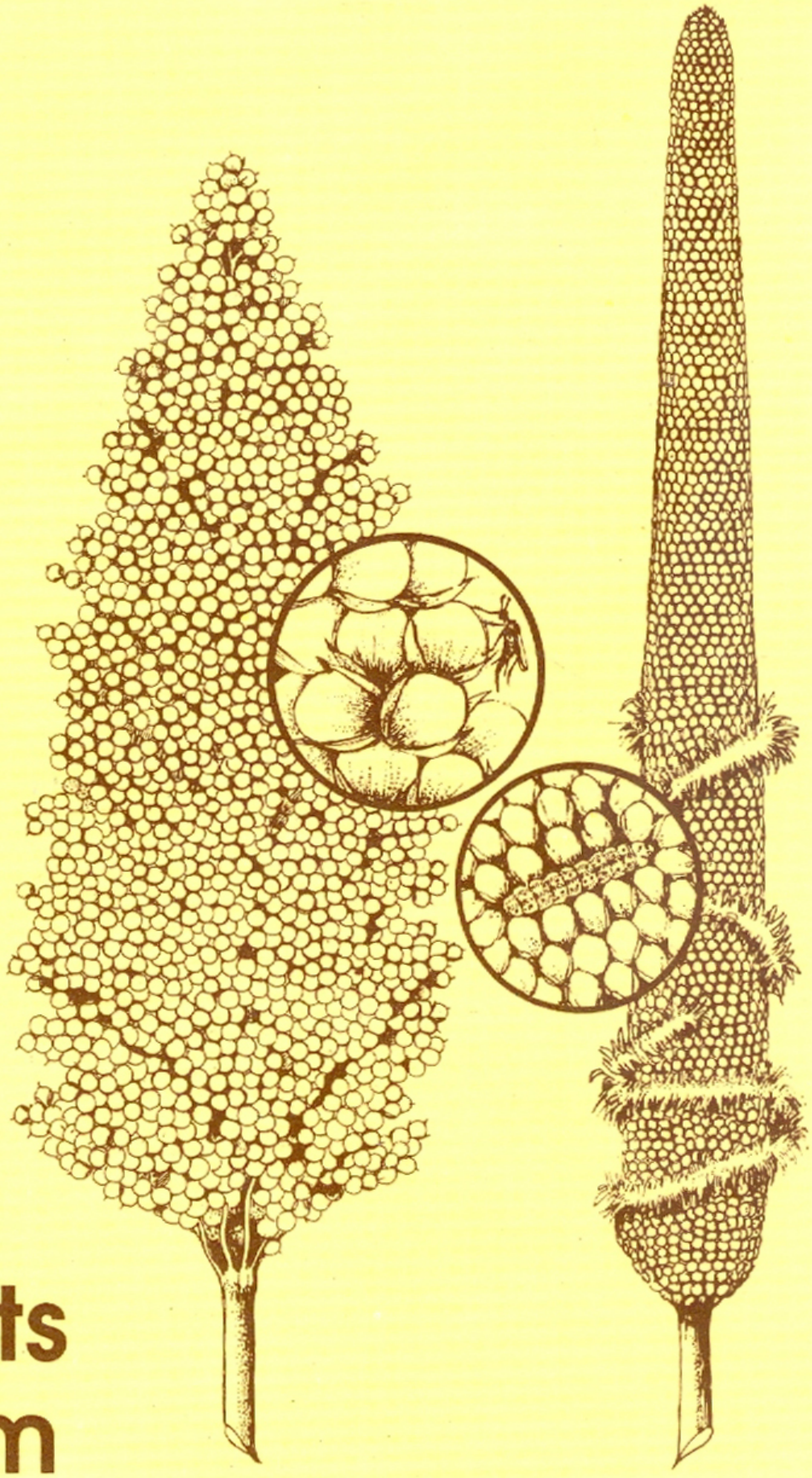

Panicle Insect Pests of Sorghum and Pearl Millet

International Crops Research Institute for the Semi-Arid Tropics

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Abstract

This workshop brought together national and international scientists from 12 countries to assess the economic importance of panicle-feeding insect pests of sorghum and pearl millet worldwide and review existing knowledge; provide concise and up-to-date information on current research on management tactics; develop research themes and priorities for their management in various cropping systems and agroecologies; and develop/strengthen linkages and enhance collaboration and partnership between international agricultural research systems, universities, and NARS, in order to achieve more effective technology transfer, resulting in increased and sustained productivity on farmers' fields.

The sessions covered bioecology and crop losses, and management strategies (including host-plant resistance, crop management and biological control, and integrated pest management). Regional reports were presented from western, eastern, and southern Africa, Asia, and the Western Hemisphere. Discussions of working groups and recommendations are included.

Presentations are reproduced in the original language of submission (English/French), followed by an extended summary in French/English as the case may be. The opening session addresses, objectives, discussions at the end of each session, general discussion session, and recommendations are in both languages.

Résumé

Insectes nuisibles des panicules de sorgho et de mil: comptes rendus d'un atelier consultatif international, 4–7 octobre 1993, Centre sahélien de l'ICRISAT, Niamey, Niger. Cet atelier a réuni des chercheurs nationaux et internationaux provenant de 12 pays en vue de déterminer l'importance économique des insectes nuisibles des panicules de sorgho et de mil à travers le monde, et de faire le point des connaissances actuelles; de fournir des données précises et mises à jour sur des études actuelles sur les stratégies de lutte; d'élaborer des thèmes et des priorités de recherche sur la lutte intégrée contre des insectes nuisibles dans divers systèmes culturaux et agroécologies; et de mettre au point/raffermir des liens de coopération et de partenariat entre des instituts nationaux et internationaux ainsi que des universités, dans le but général de réaliser un transfert plus efficace de technologie, ayant pour résultat une augmentation durable de la productivité en milieu réel.

Les sessions de l'atelier ont traité de la bioécologie et les pertes de rendement, ainsi que les stratégies de lutte (y compris la résistance variétale, la gestion des cultures et la lutte biologique, et la lutte intégrée). Des rapports régionaux ont été présentés sur l'Afrique occidentale, orientale et australe, l'Asie et l'hémisphère occidentale. L'ouvrage comprend également les discussions des groupes de travail ainsi que les recommandations.

Les présentations sont dans la langue d'origine (anglais/français), suivies par une synthèse analytique en français/anglais selon le cas. Les allocutions de la session d'ouverture, les objectifs, des discussions à la fin de chaque session, la session générale de discussion, ainsi que les recommandations sont entièrement traduits dans des deux langues.

Resumen

Los insectos nocivos de panículas de sorgo y de mijo: actas de un taller consultativo internacional, 4–7 de octubre de 1993, Centro saheliano de ICRISAT, Niamey, Niger. Este taller reunió a investigadores nacionales e internacionales procedientes de 12 países con el fin de determinar la importancia económica de los insectos nocivos de panículas de sorgo y de mijo a través del mundo así como de revisar el conocimiento existente, de proporcionar información precisa y al día sobre las estudios actuales concernientes a las estrategias de manejo, de elaborar los temas y las prioridades de investigacíon dirigida hacia el control de estos insectos nocivos en los diversos sistemas de cultivo y agroecologías, y de desarrollar/fortalecer los vínculos de cooperación y asociación entre centros internacionales y nacionales de investigación agrícola así como las universidades para poder lograr una transferencia más eficaz de tecnología cuyo resultado será un aumento durable de productividad en el campo.

Las sesiones del taller trataron de la bioecología y las pérdidas de cultivos así como las estrategias de manejo (incluso la resistencia de la planta anfitriona, el manejo de cultivos y el control biológico así como el manejo integrado de insectos nocivos). Se presentaron informes regionales sobre la Africa occidental, oriental y del sur, Asia y el hemisferio occidental. También se incluyen las discusiones sostenidas por los grupos de trabajo y las recomendaciones.

Las presentaciones incluidas vienen en la lengua original (inglés/francés), seguidas por un resumen en francés/inglés según sea el caso. Los discursos de la sesión inaugural, los objetivos, las discusiones del fin de cada sesión, la sesión general de discusión así como las recomendaciones han sido traducidos a ambas lenguas.

Panicle Insect Pests of Sorghum and Pearl Millet

Proceedings of an International Consultative Workshop
4–7 Oct 1993
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Edited by

K F Nwanze and O Youm

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
Patancheru 502 324, Andhra Pradesh, India

1995

Organizing Committee

K F Nwanze, ICRISAT
G L Teetes, Texas A&M University
H C Sharma, ICRISAT
O Youm, ICRISAT
A Ratnadass, ICRISAT/CIRAD-CA

Scientific Reviewers

K M Harris
O Youm
Belum V S Reddy
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H F W Rattunde
K Anand Kumar
N J Armes
D D Rohrbach
M L Whitaker
A Ratnadass
O Ajayi
H C Sharma
T G Shanower
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F R Bidinger
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D R Butler
K F Nwanze

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The Organizing Committee thanks the Centre Technique de Coopération Agricole et Rurale (CTA), and the Centre de Coopération en Recherche Agronomique pour le Développement/Département des Cultures Annuelles (CIRAD/CA), for sponsoring some of the Workshop participants.

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Allocution de bienvenue

C Renard[1]

Mesdames, Messieurs,

Je vous souhaite la bienvenue à ce premier Atelier consultatif international sur les insectes des panicules de mil et de sorgho. Je souhaite la bienvenue au Centre sahélien de l'ICRISAT et au Niger à ceux dont c'est la première visite.

Les insectes des panicules représentent un problème majeur pour ces deux cultures qui constituent la base de l'alimentation de plus de 250 millions de personnes parmi les plus défavorisées au monde.

Ces mêmes populations, selon les prévisions de la FAO, seront, si aucune intervention ne se réalise, les plus touchées par les déficits céréaliers que l'on prévoit pour le troisième millénaire.

A l'heure actuelle, les pertes annuelles dans la production du sorgho dues à la cécidomyie et aux punaises des panicules sont estimées à quelque 565 millions de dollars. Chez le mil, les chenilles des panicules provoquent des dégâts estimés à plus de 115 millions de dollars par an. En terme de grain, on peut estimer les pertes annuelles à quelque 5,5 millions de tonnes.

Le sorgho et le mil sont les principales cultures vivrières des zones tropicales semi-arides. Les surfaces cultivées ne font que s'accroître particulièrement en Afrique de l'Ouest, car la croissance démographique (3% par an) exige une augmentation de la production. Celle-ci se fait essentiellement par extension des cultures à des zones marginales et le repos de la terre, la jachère, appartient de plus en plus au passé. Des essais que nous menons au Centre sahélien sur les systèmes culturaux depuis plusieurs années indiquent que les insectes des panicules de mil constituent un problème majeur après 4 à 5 ans de culture même en rotation avec le niébé. Il nous semble que la pression des insectes s'accentue et l'on peut penser qu'en zone sahélienne, les paysans abandonnent les terres en raison des problèmes liés à ces pestes.

Les insectes constituent donc un obstacle majeur à la production de ces cultures et il est difficile de développer et de mettre en oeuvre des stratégies de lutte en raison de la multiplicité des espèces. Face à cette situation, la concertation entre des experts venus d'Afrique, d'Asie, d'Europe et d'Amérique vient à point nommé. La réussite de la mise en oeuvre de stratégies de lutte contre les insectes de l'épi nécessitera une collaboration étroite entre les institutions et organisations nationales, régionales et internationales. Eu égard aux thèmes qui seront traités et à la diversité des expertises, je ne doute pas que des propositions et des solutions conséquentes sortiront de vos discussions.

Une fois de plus, je souhaite la bienvenue à tous en espérant des discussions et délibérations fructueuses. J'émets également le voeu de voir les relations et les activités de collaboration entre vos institutions respectives et l'ICRISAT, se renforcer davantage.

Merci pour votre attention.

1. Directeur Exécutif, Programmes ouest-africains de l'ICRISAT, et Directeur, Centre sahélien de l'ICRISAT, B.P. 12404, Niamey, Niger. (Actuellement, Directeur Exécutif, Centre ICRISAT pour l'Asie, Patancheru 502 324, Andhra Pradesh, Inde.)

Welcome Address

C Renard[1]

Ladies and Gentlemen,

It is my pleasure to welcome you to this International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet. To those of you for whom this is a first visit to the ICRISAT Sahelian Center and to Niger, I extend a special welcome.

Panicle pests are a major problem in sorghum and pearl millet, two crops which constitute the basic diet of more than 250 million people among the most impoverished in the world.

According to FAO estimates, these people will be the most directly affected by the cereal deficits predicted in the third millennium, if timely action is not taken.

The annual losses in sorghum production due to sorghum midge and panicle-infesting bugs are currently estimated at over US$565 million, while panicle-infesting caterpillars cause a loss of over US$115 million yearly in pearl millet. In terms of grain yield, the annual losses can be estimated at around 5.5 million t.

Sorghum and pearl millet are the main food crops in the semi-arid tropics. The area under these crops is steadily increasing, especially in West Africa, since production has to meet the demand of the growing population (3% per year). This is being achieved mainly by extending cropping to marginal lands, with fallow rapidly becoming an outdated concept. Long-term trials on cropping systems at the Sahelian Center have shown that panicle-infesting pests of pearl millet are a major problem after 4–5 years of cropping, even when rotated with cowpea. Insect pressure seems to be on the increase, and we can presume that farmers are abandoning their lands due to problems associated with these pests.

Insect pests therefore constitute a major obstacle in the production of these crops, and the multiplicity of insect species makes it difficult to develop and implement management strategies. Given this situation, the concerted effort by scientists from Africa, Asia, Europe, and America could not have come at a more appropriate moment. The successful implementation of panicle pest management strategies will require close collaboration between national, regional, and international organizations and institutions. In considering the themes which will be examined and the rich diversity of disciplines involved, I am convinced that your discussions will give rise to effective solutions and proposals.

I once again extend a warm welcome to all of you, and hope that your discussions and deliberations are fruitful. I also look forward to seeing even stronger collaborative relations and activities between your respective institutions and ICRISAT.

Thank you for your attention.

1. Executive Director, ICRISAT West African Programs, and Director, ICRISAT Sahelian Center, BP 12404, Niamey, Niger. (At present, Executive Director, ICRISAT Asia Center, Patancheru 502 324, Andhra Pradesh, India.

Allocution d'ouverture

Moussa Adamou[1]

Monsieur le Directeur Exécutif du Centre sahélien de l'ICRISAT,

Messieurs les Représentants des différentes agences et institutions de coopération scientifique et technique,

Messieurs les participants à l'Atelier consultatif international sur les insectes nuisibles des panicules de sorgho et de mil,

Honorables Invités,

Mesdames, Messieurs,

Je voudrais tout d'abord vous souhaiter au nom du Directeur Général de l'INRAN, la bienvenue et un heureux séjour au Niger.

Mesdames et Messieurs, les pays du Sahel en général traversent depuis des années une crise économique et financière sans précédent. Au Niger, le secteur rural a été le plus affecté sous l'effet combiné de plusieurs contraintes abiotiques et biotiques.

Bien que sur le plan économique mondial, le sorgho et les mils sont de moindre importance comparés au blé et au riz, ces deux céréales constituent la base de l'alimentation humaine d'un grand nombre de pays d'Asie et d'Afrique dont le Niger. Près de 80% des superficies cultivées au Niger sont occupées par le mil et le sorgho.

Si au niveau des stations de recherche, les rendements sont nettement au-dessus de la tonne par hectare, en milieu paysan, ils atteignent rarement 500 kg ha^{-1}. Ces bas rendements sont liés non seulement à la faible fertilité des sols et au stress hydrique, mais aussi aux contraintes biotiques comme je le disais tantôt. Parmi ces contraintes, celles liées aux insectes sont de loin les plus importantes.

Pendant la végétation et après la récolte, le sorgho et le mil sont attaqués par une multitude d'espèces d'insectes nuisibles en provoquant une réduction notable du rendement et de sa stabilité.

Face donc à l'importance des contraintes liées aux insectes de ces deux cultures, les chercheurs de l'INRAN au même titre que ceux de la sous-région se sont attelés depuis quelques années à la recherche de méthodes de lutte dont l'intérêt est souvent conditionné par des données économiques.

Mesdames, Messieurs, votre atelier constitue un des premiers du genre sinon le premier dans la sous-région faisant intervenir des chercheurs de haut niveau et de provenances diverses concernés par les insectes du sorgho et du mil. Il se tient à la fin d'une campagne agricole dans un pays où la principale contrainte à la production est sans faute les insectes des panicules dont les plus importants sont: la mineuse de l'épi [*Heliocheilus* (*Raghuva*) *albipunctella*] sur le mil et la cécidomyie *Contarinia sorghicola* et la punaise des panicules *Eurystylus immaculatus* sur le sorgho.

Cet important atelier consultatif est le résultat d'un effort international faisant intervenir des chercheurs des programmes nationaux de recherche agricole d'Afrique et d'Asie, visant à identifier des stratégies de recherches axées sur des systèmes de lutte durables.

Qu'il me soit permis, au nom du Directeur Général de l'INRAN, de remercier très sincèrement nos partenaires de l'ICRISAT en particulier et aussi ceux de la communauté internationale en général pour cette heureuse initiative à la cause du monde rural.

Je souhaite que cet atelier soit un départ effectif d'une ère de collaboration franche tant souhaitée et de communication privilégiées entre chercheurs des programmes nationaux et ceux des institutions régionales et internationales afin d'atteindre les objectifs visés.

Je voudrais, Mesdames et Messieurs, avant de terminer, vous souhaiter plein succès dans vos travaux.

Sur ce, je déclare ouvert l'Atelier consultatif international sur les insectes nuisibles des panicules de sorgho et de mil.

Je vous remercie.

1. Représentant du Directeur Général de l'Institut National de Recherches Agronomiques du Niger (INRAN), BP 429, Niamey, Niger.

Opening Address

Moussa Adamou[1]

Executive Director of the ICRISAT Sahelian Center,

Representatives of the various agencies and institutions of scientific and technical cooperation,

Participants of the International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet,

Honorable Invitees,

Ladies and Gentlemen,

On behalf of the Director General of INRAN, I would like to first wish all of you a warm welcome and a comfortable stay in Niger.

Ladies and Gentlemen, the countries of the Sahel have been experiencing an unprecedented economic and financial crisis for several years. In Niger, the rural sector has suffered most under the combined effect of various biotic and abiotic constraints.

Although sorghum and millets are not as important as wheat and rice in the world economy, they constitute the staple human diet in many countries of Asia and Africa, as in Niger. Nearly 80% of the cropped area in Niger is under sorghum and millet.

While the yields of these crops on research stations are clearly above 1 t ha^{-1}, they seldom reach 500 kg ha^{-1} in farmers' fields. The low yields are associated not only with the low fertility of soils but also with the biotic constraints I mentioned a while ago. Insect pests are by far the most important of these constraints.

A number of species of insect pests attack sorghum and pearl millet during the vegetative period and after harvest, significantly reducing yield and yield stability.

To counter the increasing biotic stress caused by sorghum and millet pests, researchers from INRAN and other agencies in the region have, over the last few years, combined their efforts to identify control methods that often depend on economic conditions.

Ladies and Gentlemen, your workshop is one of the first of its kind—if not the first—in this region. It has brought together senior scientists of sorghum and millet pests from various parts of the world. The workshop is being held at a time when the cropping season is ending and in a country where the principal constraints to production are the panicle insect pests—earhead caterpillar *Heliocheilus* (*Raghuva*) *albipunctella* on millet, and the midge *Contarinia sorghicola* and mirid head bug *Eurystylus immaculatus* on sorghum, to name the most important.

This important consultative workshop is the result of an international effort involving African and Asian NARS scientists with the objective of identifying research strategies based on sustainable management systems.

On behalf of the Director General of INRAN, I take this opportunity to sincerely thank our partners from ICRISAT, and also those from the international scientific community for this welcome initiative for the cause of the rural sector.

I wish that this workshop heralds an era of much-desired close collaboration and communication between NARS scientists and those from regional and international institutions to realize the stated objectives.

Ladies and Gentlemen, before I close, allow me to wish you all success in your discussions and deliberations.

I now declare open the International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet.

Thank you.

1. Representative of the Director General of the Institut National de Recherches Agronomiques du Niger (INRAN), BP 429, Niamey, Niger.

Workshop Objectives

K F Nwanze[1]

In collaboration with the USAID Title XII International Sorghum/Millet Collaborative Research Support Program (INTSORMIL), the first ever workshop dedicated solely to insect pests of sorghum was held in 1984 in College Station, Texas, USA. This was followed by the International Workshop on Sorghum Stem Borers in 1987 at ICRISAT Asia Center, India. In 1989, an International *Chilo* Workshop was held at the International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya. These workshops were in response to the recognition, by the Texas A&M Workshop, of the need to focus on specific insect pests, especially where as a group they cause damage that can be thematically addressed.

A fair number of the participants to the workshops I mentioned are present here today—a good indication that entomologists are good survivors and that there is a fairly good degree of continuity in research on the crops of interest.

Panicle-feeding insects cause damage to sorghum and pearl millet at a time when plant compensation mechanisms can be of little consequence. Unlike stem borers, for instance, every degree of damage by sorghum midge, head bugs or head caterpillars can be equated with quantitative and qualitative loss in grain yield.

Apart from sorghum midge, where research has contributed to the successful development and release of high-yielding resistant sorghum cultivars in Australia, India, and USA, research efforts on mirid head bugs of sorghum, head caterpillars of sorghum and pearl millet, meloid beetles, and grasshoppers are several years behind making an impact on our ability to manage them, and contributing toward sustainable production of these crops. Countries that would suffer most from this situation are the group of less developed ones whose borders are wholly or partially within the boundaries of the semi-arid tropics.

This workshop has been convened primarily to define research strategies focusing on sustainable pest management systems that will impact on sorghum and pearl millet production. It is the result of a concerted international effort in which ICRISAT has played a major role. Consultation with scientists of other international institutions, universities and, in particular, scientists of the national agricultural research systems (NARS) in Africa and Asia, was paramount in defining the objectives of this workshop:

- Assess the economic importance of panicle-feeding insect pests of sorghum and pearl millet world-wide and review existing knowledge
- Provide concise and up-to-date information on current research on management tactics
- Develop research themes and priorities for their management in various cropping systems and agroecologies
- Develop/strengthen linkages and enhance collaboration and partnership between international agricultural research systems, universities, and NARS.

The workshop program has been arranged to provide opportunities for maximum interaction during the sessions. Presentations should be made within the time allotted, i.e., 20 min, also allowing for one or two questions of clarification. Opportunities for an in-depth discussion are provided after each set of papers have been presented. The first part of Session VI on Wednesday 6 Oct should lead us into fairly well-defined key issues for discussion in the working groups. The success of this workshop will be measured not only by how well our recommendations are formulated, or whether they are robust and transparent, but also by how well we have defined the various research opportunities and the practical implications involved in their implementation.

Ladies and Gentlemen, as Chairman of the Organizing Committee, it gives me great pleasure to welcome you to this workshop.

1. Principal Scientist (Entomology), ICRISAT Asia Center, Patancheru 502 324, Andhra Pradesh, India.

Objectifs de l'Atelier

K F Nwanze[1]

C'est en collaboration avec les Programmes américains USAID Title XII d'appui à la recherche collaborative sur le sorgho et le mil (INTSORMIL) qu'a été tenu, en 1984 à College Station, Texas, aux Etats-Unis, le tout premier atelier consacré uniquement aux insectes nuisibles du sorgho. Cette réunion était suivie par l'Atelier international sur les foreurs des tiges du sorgho en 1987 au Centre ICRISAT pour l'Asie, en Inde. En 1989, un Atelier international sur *Chilo* a eu lieu au Centre international sur la physiologie et l'écologie des insectes (ICIPE), Nairobi, au Kenya. Ces ateliers étaient tenus en réponse à la reconnaissance, dans le cadre de l'atelier de Texas A&M, du besoin de mettre l'accent sur des insectes nuisibles spécifiques, surtout dans le cas où l'ensemble du groupe de ces insectes peut causer des dégâts qui peuvent être considérés thématiquement.

Un bon nombre des participants à ces ateliers sont présents aujourd'hui parmi nous, une bonne indication que les entomologistes ont bien survécu et qu'il existe un niveau assez élevé de continuité en matière de la recherche sur les cultures considérées.

Les insectes nuisibles des panicules peuvent causer des dégâts aux cultures du sorgho et du mil au moment où les mécanismes de compensation des plantes sont peu efficaces. Contrairement aux foreurs des tiges par exemple, tout dégât causé par la cécidomyie, par les punaises des panicules ou par les chenilles des chandelles peut se traduire en des pertes quantitatives et qualitatives de rendement en grains.

Les travaux de recherche sur la cécidomyie du sorgho ont contribué à la mise au point et la vulgarisation de cultivars de sorgho résistants et à rendement élevé en Australie, en Inde et aux Etats-Unis. Cependant, les études sur les punaises des panicules du sorgho, les chenilles des chandelles, les coléoptères méloïdes et les sauteriaux ont plusieurs années de retard quant à la réalisation d'une influence sensible sur notre capacité à lutter efficacement contre ces insectes et à la contribution à la production durable de ces cultures. Les pays qui seront touchés le plus par cette situation sont le groupe des pays moins développés dont les frontières sont entièrement ou partiellement à l'intérieur des limites des zones tropicales semi-arides.

Cet atelier est convoqué essentiellement dans le but de définir les stratégies de recherche axées sur les systèmes de lutte durables qui auront un impact sur la production de sorgho et de mil. L'atelier est également le résultat d'un effort international concerté où l'ICRISAT a joué un rôle majeur. La consultation avec les chercheurs des autres institutions internationales et des universités, et en particulier avec les chercheurs des systèmes nationaux de recherche agricole (SNRA) en Afrique et en Asie, était d'importance primordiale dans la définition des objectifs de cet atelier:

- déterminer l'importance économique des insectes nuisibles des panicules de sorgho et de mil à travers le monde, et de faire le point des connaissances actuelles
- fournir des données précises et mises à jour sur des études actuelles sur les stratégies de lutte
- élaborer des thèmes et des priorités de recherche sur la lutte intégrée contre des insectes nuisibles dans divers systèmes culturaux et agroécologies
- mettre au point/raffermir des liens de coopération et de partenariat entre des instituts nationaux et internationaux ainsi que des universités.

Le programme de l'atelier a été conçu de façon à offrir des opportunités d'interaction maximale au cours des sessions. Les présentations doivent respecter le durée accordée, c'est-à-dire 20 minutes, tout en permettant une ou deux questions pour des éclaircissements. Des discussions détaillées sont prévues après la présentation de chaque ensemble de communications. La première partie de la Session VI, mercredi le 6 octobre, doit nous confronter avec des questions clés assez bien définies pour discussion au sein des groupes de travail.

Le succès de cet atelier sera mesuré non seulement par la bonne élaboration de nos recommandations, ou par la transparence ou la solidité de celles-ci, mais plutôt par la définition efficace des diverses opportunités de recherche et les implications pratiques entraînées par la mise en oeuvre des recommandations.

Mesdames et Messieurs, en tant que Président du Comité d'organisation, j'ai le grand plaisir de vous souhaiter la bienvenue à cet Atelier.

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1. Chercheur principal (Entomologie), Centre ICRISAT pour l'Asie, Patancheru 502 324, Andhra Pradesh, Inde.

World Review of Recent Research on Panicle Insect Pests of Sorghum and Pearl Millet

K M Harris[1]

Abstract

The recent development of research on the taxonomy, biology, ecology, and control of the main insect pests of sorghum and pearl millet panicles is reviewed, based on a selected bibliography of papers published during the past decade. The main targets of this research have been the sorghum midge, Contarinia sorghicola *(Coquillett), which occurs almost everywhere that sorghum is grown; the mirid head bugs* Eurystylus *and* Calocoris, *which are important on sorghum in Africa and India, respectively; the cotton bollworm,* Helicoverpa armigera *(Hübner), which attacks sorghum panicles in Africa, Asia, and Australasia, and the millet head miner,* Heliocheilus albipunctella *(de Joannis), which is an important pest of pearl millet in West Africa. Other insect pests that have also been the subjects of recent research include* Heliothis virescens *(Fabricius),* H. zea *(Boddie), and* Celama sorghiella *Riley on sorghum, and* Psalydolytta fusca *(Olivier),* P. vestita *(Dufour),* Pachnoda interrupta *(Olivier), and various grasshoppers on pearl millet.*

Research on the major pests has intensified during the past decade. Host-plant resistance has been developed and other important elements of integrated pest management (IPM) have been identified. But few IPM programs have been implemented effectively and there is a continuing need to appreciate and meet the needs of farmers, who should be the main beneficiaries of research on their crops.

Introduction

This is a general review of the most important developments in research on the insect pests of sorghum and pearl millet panicles during the past decade (1984-93), as indicated by research publications and literature reviews. Many insect species have been recorded from sorghum and pearl millet (Table 1), but relatively few of these are ranked as major pests at present. This situation could change in the future, as has already happened in the past with pests of these and other cereal crops. Minor pests, such as *Helicoverpa armigera* on sorghum or *Heliocheilus albipunctella* on pearl millet, have become major pests as varietal susceptibilities, farming practices and other factors change. The converse should also apply, with major pests relegated to the status of minor pests, but there do not seem to be many good examples of such reversals, which would indicate effective implementation of integrated pest management programs. In fact, although good research progress has been made during the past decade, it sometimes seems that the major pests of the past continue to threaten crop production while additional new pests appear.

Insect pests attacking panicles of sorghum and pearl millet are especially damaging as they affect crop development at a late stage and have direct harmful quantitative and qualitative effects on grain yields. At this late stage of crop development, the main production inputs would have already been made, which maximizes economic losses, and there is also little scope for the crop to compensate for damage done so close to harvest. There are therefore good reasons for focusing on this group of pests, although this is the first time that an international workshop has been devoted entirely to them.

The following brief reviews of work on the main groups of insect pests are based on papers published

1. 81 Linden Way, Ripley, Woking, Surrey GU23 6LP, UK.

Harris, K.M. 1995. World review of recent research on panicle insect pests of sorghum and pearl millet. Pages 7–25 *in* Panicle insect pests of sorghum and pearl millet: proceedings of an International Consultative Workshop, 4–7 Oct 1993, ICRISAT Sahelian Center, Niamey, Niger (Nwanze, K.F., and Youm, O., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

in major journals, and are intended to trace the recent development of work on each group, to identify key research papers and reviews, to summarize recent progress, and to indicate problem areas for future work.

Sorghum

The pests of sorghum have received much more attention than those of pearl millet and this greater emphasis is reflected in the preponderance of publications relating to this crop. Most research activity is still concentrated on the sorghum midge, *Contarinia sorghicola*, but work on head bugs and head caterpillars has increased.

The International Sorghum Entomology Workshop, held at Texas A&M University in Jul 1984 (ICRISAT 1985), reviewed past and current work on insect pests of sorghum and included a series of papers on panicle-feeding insects. Eight of the papers presented there reported work on the sorghum midge; two were on head bugs, and two recorded work on panicle caterpillars and pests of stored grain.

Since then, reviews and broad-based papers have been published by Sharma (1985b) on strategies for pest control in sorghum in India; by Teetes (1985b) on insect resistant sorghums in pest management; by Leuschner et al. (1985) on the role of host-plant resistance in pest management in sorghum in India; by Hassan (1987) on sorghum insect problems in Australia; by Seshu Reddy (1988) on assessments of on-farm sorghum yield losses due to insect pests; by Nwanze (1988) on the distribution and seasonal incidence of some major pests of sorghum in Burkina Faso; by Gahukar (1991) on worldwide research developments for the period 1984–89; by Nwanze et al. (1991) on the evaluation of sorghum genotypes in India for multiple insect resistance; by Seshu Reddy (1991) on insect pests of sorghum in Africa; by Sharma et al. (1992b) on techniques used to screen for resistance to insect pests; and by Merchant and Teetes (1992) on the evaluation of selected sampling methods for pests of sorghum panicles in the USA, including a beat-bucket method for head bugs and caterpillars, and *in situ* visual estimates and sticky traps for sorghum midge estimates.

Sharma (1993) reviewed in detail and discussed the role of host-plant resistance in IPM of insects on sorghum. He noted that, although adequate levels of resistance are available against only a few pests, moderate levels of resistance can be useful in suppressing pest populations since they could reduce the rate at which pest populations develop, so delaying the point at which they pass the economic threshold level. He also observed that there are other beneficial effects, including conservation of natural enemies, preservation of environmental quality, and a slowing down in the rate of development of insecticide-resistant pest populations.

Sorghum midge (*Contarinia sorghicola*)

This is the most widespread and damaging insect species attacking sorghum. It occurs almost everywhere that the crop is grown and has been the subject of much research since its first discovery in Alabama, Texas, USA, and Queensland, Australia, in the 1890s, now more than a century ago. At the International Sorghum Entomology Workshop in 1984, presented papers included a review of published sources of information for the period 1895–1983 (Harris 1985); an account of the biology, population dynamics and integrated pest management of this pest (Teetes 1985a); a report on its pest status in Burkina Faso and Mali (Bonzi and Doumbia 1985); and accounts of screening programs for resistance and the elucidation of resistance mechanisms (Kulkarni 1985, Sharma 1985a, and Rossetto 1985).

The taxonomic treatment of the sorghum midge has remained constant for the past 30 years but is about to change. Solinas (1986) proposed a new genus, *Allocontarinia*, with *Contarinia sorghicola* as type species. But this proposal cannot be accepted as there is a much earlier generic name, *Stenodiplosis* Reuter, that can be applied to the group of *Contarinia* species that develop in grass seed heads. Gagné (in press) has therefore assigned *C. sorghicola* to that genus so the correct scientific name of the sorghum midge will soon be *Stenodiplosis sorghicola* (Coquillett).

The geographic distribution of the sorghum midge is well known (CAB International 1990). It has recently been recorded as a new introduction to Puerto Rico (Segarra-Carmona and Barbosa 1988), but Harris (1964) reported dissection of larvae from sorghum inflorescences in the Kew Herbarium that had been collected in Puerto Rico in 1886—more than a century before this recent record—which demonstrates yet again how easily midge damage may be overlooked.

Since the International Sorghum Entomology Workshop in 1984, considerable progress has been made, especially in the development of host-plant resistance. Sharma (1993) reported that substantial progress has been made in identifying and utilizing resistance to midge in Australia, India, Latin America, and USA. He summarized the diverse sources of resistance that are now available and noted that ICSV 88013 and ICSV 88032 have high levels of midge resistance and yield potentials comparable with those of commercial cultivars. Resistance is being transferred to hybrid parents with improved agronomic backgrounds, and the use of host-plant resistance in the management of sorghum midge is therefore promising. In India this work has been so successful that the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has recently reported that a multipurpose grain type variety (ICSV 745), which produces good fodder in marginal environments and has strong resistance to midge, has been selected by farmers as being preferable to their traditional sorghum (ICRISAT 1993). Sharma (1993) also reviewed information on resistance mechanisms (mainly cultivar nonpreference by ovipositing females and/or antibiosis) and the inheritance of resistance (inherited quantitatively and controlled by additive genes and some cytoplasmic effects). Susceptibility to midge is positively and significantly correlated with the length of glumes, lemma, palea, anthers, and style, and the rate of grain development between the 3rd and 7th days after anthesis is negatively associated with midge damage (Sharma et al. 1990b, Sharma 1990c). A study of the factors influencing oviposition revealed that yellow, red, and white are most attractive to ovipositing females, and that panicles at half-anthesis with viable pollen and receptive stigmata suffered greater damage than panicles at pre- or post-anthesis (Sharma et al. 1990a).

Biological, ecological, physiological and other studies have continued. In Africa, Alghali (1984) studied biology, damage, and crop loss assessment in Kenya and reported that the relationship between damage and crop loss was almost perfect ($r=0.998$; $P<0.001$).

In India, in addition to the publications noted above, Patel and Jotwani (1986) studied ecological factors affecting midge damage; Mote and Ghule (1986) studied the effects of climate and parasitoids on midge, and Sharma and Vidyasagar (1992) recorded the attraction of males to sex pheromones of virgin females.

In Australia, Forrester (1987) studied larval diapause development in detail and found the temperature range 23–30°C most favorable. The rate of diapause development was linear and the period from diapause initiation to adult emergence (diapause development requirement + 2.5 week postdiapause development requirement) was predicted to be 6 months at 27°C and 7.5 months at 23°C. Forrester noted that these periods agree well with field observations in the Savanna belt of Africa and that the diapause mechanism must have evolved as an adaptation to long dry periods. It is however equally effective in temperate areas where the midge has been introduced. Also, in Australia, Modini et al. (1987) studied diurnal ovipositing activity; Franzmann and Vaschina (1989) studied oviposition in preflowering and flowering panicles; Franzmann et al. (1989) reported life table studies on susceptible and resistant varieties, and Henzell et al. (1989) reported improved host-plant resistance.

In China, Hong (1987) assessed crop loss and reported a grain loss of 1.36 g per ovipositing female and an economic injury level of 0.6 females per panicle. In Japan, Hagio and Ono (1986) described a simplified test for midge resistance and Hagio and Ono (1988) reported on resistance screening.

In the USA, Treacy et al. (1986) reported experiments on chemical control in Texas; Steward et al. (1989) evaluated six methods of sampling field populations of ovipositing midges and compared them with an absolute method, concluding that visual estimates were similar to absolute estimates when population levels were low but differed significantly at midge densities above 9.2 per panicle; Peterson et al. (1989) compared indirect resistance measures (yield loss and midges per panicle) with visual damage scores and concluded that visual rating was a more effective method of evaluation; Hanna et al. (1989) reported registration of Tift MR88; Peterson et al. (1991) reported registration of 22 midge-resistant lines; Waquil and Teetes (1990) studied compensation for midge attack in a susceptible and a resistant hybrid in Texas and concluded that there is a small compensation by surviving kernels in panicles with a low proportion of damaged spikelets, but that this does not balance the direct damage done to infested kernels; Gilstrap and Brooks (1991) monitored hymenopterous parasitoids of midge on Johnson grass in Texas, and Magallanes-Cedeno and Teetes (1991) studied the distribution of midge eggs in sorghum florets.

Finally, in Puerto Rico, Segarra-Carmona et al. (1989) assessed field susceptibility of eight hybrids; in Brazil, Palma (1988) studied female midge activity; and in Argentina, Diaz (1988) studied microhymenopterous parasitoids.

Knowledge of the midge and of its interactions with its host plants has obviously increased considerably during the past decade. Host-plant resistance is generally considered to be the main requirement for effective IPM, and subsidiary elements are well understood. But, with the exception of USA, large-scale IPM programs are yet to be fully implemented.

Head bugs (Hemiptera: Heteroptera)

Many species of hemipterous bugs have been recorded from sorghum (Table 1), but it is generally agreed that two genera, *Eurystylus* and *Calocoris*, are of major importance in Africa and Asia, respectively. A taxonomic revision of *Eurystylus* by Dr G Stonedahl, working at the International Institute of Entomology, UK, is almost complete and has shown that two distinct species are widespread in Africa on sorghum and millet. One of these is a small grayish species, *Eurystylus bellevoyei* (Reuter), which also occurs in India. The synonymy of the second species has not been finally resolved but names that have been used for it include *E. rufocunealis* Poppius, *E. oldi* Poppius, *E. immaculatus* Odhiambo, *E. maculatus* Odhiambo and *E. marginatus* Odhiambo.

In Africa, Bowden (1965) first expressed concern about the damage caused by hemipterous bugs to a compact-headed sorghum variety in Ghana, but the wider importance of this group of pests was not fully recognized until the 1980s. MacFarlane (1989) made preliminary studies of the complex of hemipterous insects in compact-headed sorghum panicles in Nigeria to provide a basis for further detailed studies. Steck et al. (1989) studied the complex of Miridae, Lygaeidae, Pyrrhocoridae, Pentatomidae, Coreidae, Rhopalidae, Reduviidae, and Anthocoridae associated with sorghum panicles in Niger, and clearly established the damaging potential of head bugs, especially *E. marginatus* which greatly outnumbered all other species. A widely grown indigenous variety of sorghum suffered about 14% yield loss, with an additional loss of at least 19% in terms of grain quality. Exotic varieties suffered even greater loss. Steck et al. (1989) discovered that *E. marginatus* oviposits directly into the sorghum grain. The endosperm adjacent to the eggs then becomes discolored and floury, and the entire grain may deteriorate, possibly due to the introduction of molds. Feeding activity is equally destructive and affects grain quality by the removal of water and nutrients, causing shrivelling, and by the action of salivary enzymes that break down the endosperm structure, producing a floury texture. The relationship between head bug density and damage was not straightforward and the relative varietal responses at the two test sites were poorly correlated, indicating that sorghum breeding programs for head bug resistance may need to be area-specific. Earlier work by Sharma (1986) in Mali also reported oviposition and feeding effects of *Eurystylus marginatus* and selection for host-plant resistance, and Sharma et al. (1992a) reported the development of a headcage technique to screen for resistance.

In India, *Calocoris angustatus* has been recognized as an important pest for much longer. Research has intensified in recent years, with particular emphasis on the development of stable resistance (Sharma and Lopez 1991, Sharma and Lopez 1992a). Screening methods have been refined (Sharma and Lopez 1992b) and resistance mechanisms have been studied (Sharma and Lopez 1990). Sharma and Lopez (1989) assessed avoidable losses and economic injury levels and reported that bug damage spoiled grain quality in terms of germination, 1000-grain mass, grain hardness, and percentage floaters, and they observed maximum avoidable losses of 88.6% in ICSV 1, 69.9% in CSH 1, and 53.9–55.0% in CSH 5. Sharma and Leuschner (1987) reported field trials of eight contact and three systemic insecticides, and an enriched neem extract, and concluded that two sprays of carbaryl applied at complete anthesis and milk stages were effective. Natarajan and Babu (1988a) described a laboratory rearing technique. Natarajan and Babu (1988b) recorded economic injury levels which varied from 7.9 nymphs, 5.4 feeding adults or 0.06 ovipositing adults with HCH treatment, to 15.1 nymphs, 10.5 feeding adults and 0.12 ovipositing adults with malathion. Natarajan and Babu (1988c) indicated damage potential on sorghum up to 31.54 g per panicle infested with three ovipositing adults during the first 3 days of panicle emergence; Natarajan et al. (1989) studied seasonal occurrence in India and concluded that in general crops sown in Feb and the first half of Mar had the highest populations and that most head bugs were present at the dough stage of development. Hiremath (1987) and Natarajan et al. (1988) reported screening trials. Mote and Jadhav (1990) recorded incidence and losses, and Hiremath (1989) surveyed *C. angustatus* and its natural enemies in Karnataka.

Head bugs seem to be of low importance in Australia since Passlow et al. (1985) and Hassan (1987) did not include them in their reviews of sorghum pests. The situation seems to be similar in North, Central, and South America (Pitre 1985, Castro 1985, Reyes 1985).

Cotton bollworm (*Helicoverpa armigera*)

This species has become an important pest of sorghum panicles in recent years. The published literature on this species is extensive, but it is mostly on crops other than sorghum. However, the development of IPM against this pest on sorghum must take into account all relevant information, regardless of crop connotations. CAB International's PEST CDROM database, covering the years 1973–91, contains 2082 references to work on this species, 93 of which refer to sorghum. A full review of their content is beyond the scope of this paper but some of the main research projects and developments of the past decade are noted below.

In 1988, van den Berg et al. published a review of natural enemies in Africa; van den Berg et al. (1990) studied parasitoid complexes on four crops (including sorghum) in Tanzania, concluding that parasitoids are strongly associated with particular crops; and Nyambo (1988) studied the significance of host plant phenology on the pest and its parasitoids, also in Tanzania. In the Sudan Gezira, Topper (1987) studied nocturnal behavior, presented a descriptive behavioral model for the first half of adult life, and discussed its use in pest management.

In India, Patel and Mittal (1986) constructed life tables based on laboratory studies on sorghum; Singh and Balan (1986) studied population densities and natural enemies on 123 plant species; Pawar et al. (1988) reported the development of a pheromone trapping system to monitor adult males; Mote and Murthy (1990) estimated avoidable grain losses on CSH 5 (665 kg ha^{-1} = 14.51%) and CSH 9 (518 kg ha^{-1} = 12.87%) hybrids, and Armes et al. (1992) studied insecticide resistance.

In Australia, Hassan (1987) reported the commercial development of a specific nuclear polyhedrosis virus; Teakle and Byrne (1988) observed the feeding behavior of larvae and reported that early instar larvae feed almost exclusively on anthers, which makes them highly susceptible to insecticides sprayed at full anthesis; Franzmann (1986) studied the effects of panicle type on infestation; Fitt and Daly (1989) noted high levels of parasitism of overwintering pupae beneath lightly sprayed pigeonpea, sorghum, and sunflower, with low insecticide resistance frequencies. They found low levels of parasitism in cotton, a heavily sprayed crop where resistance frequencies were highest. Forrester et al. (in press) developed an IPM program to manage pyrethroid and endosulfan resistance on all crops susceptible to attack by *H. armigera*.

Other panicle pests of sorghum

Few research papers on other panicle insect pests of sorghum have been published during the past decade. In USA, Goodenough et al. (1989) reported field tests of laminate and block type pheromone dispensers for the detection and monitoring of *Heliothis virescens* in Texas; Hayes (1988) studied the comparative emergence phenologies of *H. virescens* and *H. zea* on cotton and other crops (including sorghum); Kring et al. (1989) studied within-field and within-panicle distribution of *H. zea* and *Celama sorghiella* eggs in grain sorghum, Steward et al. (1990) studied egg and larval parasitoids of these two species, finding that *Trichogramma* spp appeared to be an important mortality factor, but not larval parasitism by eulophids, braconids, and tachinids.

Millet

Sharma and Davies (1988) reviewed the insect and other animal pests of pearl millet (and other millets) on a world basis. Gahukar (1989) reviewed the main insect pests of pearl millet and their management; reviews of insect pests of pearl millet in West Africa have been published by Gahukar (1984), Ndoye and Gahukar (1987), and Nwanze and Harris (1992). Ajayi and Uvah (1989) reviewed research on millet pests in Nigeria during the period 1977–87.

Millet head miner (*Heliocheilus albipunctella*)

The millet head miner became an important pest in the Sahelian region of West Africa in the 1970s. It was initially described in the genus *Raghuva*, but Matthews (1987) revised the African species of *Heliocheilus* and synonymized *Raghuva* in that genus. Gahukar et al. (1986) reviewed the status and management of this pest in the Sahel, reporting yield losses up to 85%, and Gahukar (1987) reported some sources of resistance. Nwanze and Sivakumar (1990) published a detailed account of the distribution, population dynamics, and crop loss assessment of this pest, based on field surveys and other studies in Burkina Faso, Niger, and northern Nigeria. They reported crop losses on farmers' fields up to 41%, with a mean of 20%, and gave results of population monitoring confirming that this species is univoltine and enters an obligatory diapause at the end of the growing season. Pupae carry over to the following season in soil, and soil temperature and moisture are critical in determining the survival of diapausing pupae. Gahukar (1990) described techniques for sampling eggs and young larvae on millet spikes and pupae in soil in Senegal, and discussed cultural control measures. Plowing the fields after harvest reduced populations of pupae but was considered impracticable or socially unacceptable to farmers. Bernardi et al. (1989) developed a computer simulation of *H. albipunctella* population dynamics, and Gahukar (1990) reported experiments in which a single application of a chitin inhibitor, diflubenzuron, after spike emergence gave effective control.

Meloid beetles

Gahukar et al. (1989) reported that meloid beetles have recently become key pests of food crops in Mali and Senegal, and that the abundance of the most important species, *Psalydolytta fusca* and *P. vestita*, in Sep and Oct generally coincided with sorghum and millet flowering. A colloquium convened in Ouagadougou, Burkina Faso, in March 1991 to discuss crop losses in pearl millet ranked meloid beetles as one of the major causes of loss (Nwanze and Harris 1992), but there is still little published information available on crop loss assessment, biology, and ecology. Zethner and Laurense (1988) determined damage rates in screenhouse experiments in the Gambia, reporting that a density of only one adult *P. fusca* per panicle during the susceptible period of head development caused total loss. Selander and Laurense (1987) described the triungulin larvae and recorded them from egg pods of the grasshopper, *Cataloipus fuscocoeruleipes* (Sjöstedt). Coop and Croft (1992) reported that *Psalydolytta* destroyed the surface area of millet panicles at a rate of 10.3 cm^2 day^{-1} in cage trials on farmers' fields in Mali.

Scarabaeid beetles

Grunshaw (1992) studied *Pachnoda interrupta* in northwestern Mali and described its life history, biology, and feeding habits. Yield losses to a range of beetle densities in cage experiments varied from 9 to 48%, and a regression equation was derived to provide a rough guide to economic injury levels.

Other panicle pests of millet

Virtually no research papers on other insect pests of millet panicles have been published in recent years. Coop and Croft (1992) caged five grasshopper species (and *Psalydolytta*) on millet panicles in Mali to determine relative damage rates. He reported that 35–70% of grain kernels remained when exposed to grasshoppers during the late milk and dough stages, and 10–35% when exposed during the early milk stage.

Conclusions

This review is based on published work only. It is assumed that this reflects the priorities of research programs and therefore indicates the relative importance of the major pests. That is not necessarily always the case as the number of papers published on a topic may be influenced by the activities of individual workers or organizations. Conclusions must therefore be drawn with caution, but it is apparent that the main research efforts during the past decade have been on sorghum midge, sorghum head bugs, *Helicoverpa armigera*, and *Heliocheilus albipunctella*. Much useful information is now available and there has been a notable increase in the number of review articles published on insect pests of pearl millet. Although there are exceptions, such as the increasing releases of midge-resistant varieties to farmers, a major shortcoming is still the lack of the effective use of available information in the formulation and execution of IPM programs. There is a continuing need to appreciate and meet the needs of farmers, who should be the main beneficiaries of research on their crops.

Synthèse

Le point sur les insectes nuisibles des panicules de sorgho et de mil dans le monde. Des articles scientifiques et de compte rendu sur la taxonomie, la biologie et l'écologie des principaux insectes nuisibles aux panicules de sorgho et de mil ainsi que sur les méthodes de lutte sont passés en revue. La sélection de cette documentation a été basée sur une bibliographie des articles publiés dans des revues importantes au cours des 10 dernières années (1984–93). Un bilan des connaissances actuelles sur les principaux ravageurs est dressé et les importants acquis sont soulignés afin de permettre l'identification des besoins futurs de recherche et de développement. Un tableau synoptique de tous les insectes nuisibles aux panicules de sorgho et de mil signalés est présenté avec des renseignements sur leur répartition géographique.

Les insectes nuisibles au sorgho—surtout la cécidomyie du sorgho, *Contarinia sorghicola*

(Coquillett), les punaises des panicules, tels que *Eurystylus* et *Calocoris*, ainsi que les chenilles des panicules, notamment *Helicoverpa armigera* (Hübner)—ont particulièrement attiré l'attention des chercheurs. La cécidomyie du sorgho, largement répandue dans le monde, est le plus dangereux ravageur du sorgho. Des résultats fort appréciables ont été obtenus dans la mise au point de la résistance des plantes-hôtes en Inde, aux Etats-Unis, en Australie et en Amérique latine. Des chercheurs disposent maintenant de diverses sources de résistance qu'ils incorporent dans des variétés commerciales. Des études sur la biologie, l'écologie et la physiologie de la cécidomyie se poursuivent dans plusieurs parties du monde et les connaissances acquises sur cet insecte et ses interactions avec ses plantes-hôtes sont considérables. Les punaises des panicules hémiptères, les espèces de Miridés en particulier, sont devenues d'importants ravageurs des panicules de sorgho en Inde et en Afrique. Parmi elles, *Calocoris angustatus* (Lethiery) est la plus dangereuse en Inde et on est en train d'élaborer une résistance des plantes-hôtes stable. En Afrique de l'Ouest, la recherche a porté sur la biologie, l'écologie et l'importance économique d'une espèce de *Eurystylus* qui y est dominante. Le ver de la capsule du cotonnier, *Helicoverpa armigera*, a fait l'objet d'étude poussée sur les diverses cultures qu'il attaque. En Australie, une stratégie de lutte intégrée a été mise en oeuvre afin de maîtriser efficacement les populations de ce ravageur résistantes aux insecticides sur toutes les cultures sensibles.

Par contre, les insectes nuisibles aux panicules de mil ont retenu peu d'attention. Des études ont été réalisées sur la mineuse de l'épi de mil, *Heliocheilus albipunctella* (de Joannis), en Afrique de l'Ouest où elle est devenue un ravageur-clé. Des recherches ont également porté sur les méloïdes, particulièrement *Psalydolytta fusca* (Olivier) et *P. vestita* (Dufour) et les scarabées, surtout *Pachnoda interrupta* (Olivier).

Bien qu'on possède d'importantes connaissances sur les principaux insectes ravageurs des panicules de sorgho et de mil, rares sont des programmes de lutte intégrée qui ont été élaborés et mis en oeuvre. Les paysans étant notre principal groupe cible, il faut continuer d'accorder une grande place à l'identification de leurs contraintes et des mesures à les surmonter.

Table 1. Insect pests of sorghum and pearl millet panicles.

Insect pest	Region of incidence	Crop
HEMIPTERA: HETEROPTERA (Head bugs)		
Alydidae		
Leptocorisa acuta (Thunberg)	India	Sorghum
Leptocorisa costalis (Herrich-Schaeffer)	India	Pearl millet
Mirperus jaculus (Thunberg)	Africa	Sorghum/Pearl millet
Mirperus spp	Africa	Sorghum
Riptortus spp	Africa	Sorghum
Coreidae		
Anoplocnemis curvipes (Fabricius)	Africa	Pearl millet
Cletus fuscescens Walker	Africa	Pearl millet
Fabrictilis australis (Fabricius) [= *Leptoglossus membranaceus*]	Africa	Pearl millet
Leptoglossus phyllopus (Linnaeus)	North America	Sorghum
Leptoglossus zonatus (Linnaeus)	North America	Sorghum
Cydnidae		
Aethus laticollis Wagner	India	Sorghum/Pearl millet
Lygaeidae		
Aspilocoryphus fasciativentris (Stål)	Africa	Pearl millet

Continued

Table 1. *Continued*

Insect Pest	Region of incidence	Crop
Elasmolomus sordidus Fabricius	India	Pearl millet
Dieuches armipes (Fabricius)	Africa	Pearl millet
Geocoris megacephalus Rossi	Africa	Sorghum
Graptostethus servus Fabricius	India	Pearl millet
Nysius raphanus (Howard)	North America	Sorghum
Nysius sp	Africa	Sorghum
Oxycarenus laetus Kirby	India	Pearl millet
Oxycarenus sp	Africa	Pearl millet
Peritrechus fraternus Uhler	India	Pearl millet
Pseudopachybrachius capicolus (Stål)	Africa	Sorghum
Spilostethus elegans (Wolff)	Africa	Pearl millet
Spilostethus mimus Stål	Africa	Pearl millet
Spilostethus pandurus (Scopoli)	Africa/India	Sorghum
Spilostethus rivularis Germar	Africa	Sorghum
Spilostethus spp	Africa	Sorghum/Pearl millet
Miridae		
Adelphocoris seticornis (Fabricius) [= *Adelphocoris apicalis* (Hahn)]	Africa (?)	Sorghum
Adelphocoris sp	Africa	Sorghum
Calocoris angustatus Lethierry	India	Sorghum
Calocoris norvegicus (Gmelin) [= *Megacoelum stramineum* (Walker)]	India	Pearl millet
Campylomma livida Reuter	India	Pearl millet
Campylomma nicolasi Reuter	Africa	Sorghum
Campylomma angustior Poppius	Africa	Sorghum
Campylomma subflava Odhiambo	Africa	Sorghum
Creontiades pallidus (Ramber)	Africa/India	Sorghum/Pearl millet
Eurystylus argenticeps Odhiambo	Africa	Sorghum
Eurystylus bellevoyei (Reuter)	Africa/India	Sorghum/Pearl millet
Eurystylus immaculatus Odhiambo	Africa	Sorghum
Eurystylus marginatus Odhiambo	Africa	Sorghum
Eurystylus rufocunealis Poppius	Africa	Sorghum
Lygus sp	Africa	Sorghum
Megacoelum apicale Reuter	Africa	Sorghum
Megacoelum stramineum Walker	India	Pearl millet
Megacoelum esmedorae Ballard	India	Pearl millet
Paramixia suturalis Reuter	Africa	Sorghum
Stenotus transvaalensis (Distant)	Africa	Sorghum
Taylorilygus vosseleri (Poppius)	Africa	Sorghum/Pearl millet
Tytthus parviceps (Reuter)	Africa	Sorghum
Pentatomidae		
Acrosternum heegeri Fieber	Africa	Sorghum
Agonoscelis haroldi Bergroth	Africa	Sorghum
Agonoscelis pubescens (Thunberg) [= *Agonoscelis versicolor*]	Africa	Sorghum/Pearl millet

Continued

Table 1. *Continued*

Insect pest	Region of incidence	Crop
Agonoscelis nubila Fabricius	India	Pearl millet
Agonoscelis rubrofasciatus Fabricius	Africa/India	Pearl millet
Afrius figuratus (Germar)	Africa	Pearl millet
Aspavia armigera (Fabricius)	Africa	Pearl millet
Aspongopus janus Walker	India	Pearl millet
Bagrada hilaris (Burmeister) [= *Bagrada cruciferarum*]	India	Sorghum/Pearl millet
Carbula difficilis Westwood	Africa	Pearl millet
Carbula pedalis Bergroth	Africa	Pearl millet
Carbula trisignata Germar	Africa	Pearl millet
Chlorochroa ligata (Say)	North America	Sorghum
Chlorochroa sayi (Stål)	North America	Sorghum
Diploxys floweri Distant	Africa	Sorghum
Dolycoris indicus (Stål)	Africa	Sorghum
Eridema pulchrurus Westwood	India	Pearl millet
Eusarcoris guttifer Thunberg	India	Pearl millet
Euschistus servus (Say)	North America	Sorghum
Euschistus impictiventus (Say)	North America	Sorghum
Euschistus conspersus Uhler	North America	Sorghum
Eysarcoris inconspicuus (Herrich-Schaeffer)	Africa	Sorghum
Loxa flavicollis (Drury)	Brazil	Sorghum
Menida distanti Horváth	Africa	Sorghum
Menida histrio Fabricius	India	Pearl millet
Nezara graminea Fabricius	India	Pearl millet
Nezara viridula (Linnaeus)	Cosmopolitan	Sorghum/Pearl millet
Oebalus pugnax (Fabricius)	North America	Sorghum
Oebalus mexicana (Fabricius)	North America	Sorghum
Piezodorus hybneri Gmelin	India	Pearl millet
Piezodorus rubrofasciatus Fabricius	India	Pearl millet
Piezodorus sp	Africa	Sorghum
Thyanta spp	North America	Sorghum
Pyrrhocoridae		
Dysdercus cingulatus (Fabricius)	India	Pearl millet
Dysdercus koneigii Fabricius	India	Sorghum
Dysdercus superstitiosus (Fabricius)	Africa	Sorghum/Pearl millet
Dysdercus voelkeri Schmidt	Africa	Sorghum/Pearl millet
Scutelleridae		
Alphocoris sp	Africa	Pearl millet
Calidea dregii Germar	Africa	Sorghum
Calidea nana (Herrich-Schaeffer)	Africa	Pearl millet
Calidea spp	Africa	Pearl millet
Tessaratomidae		
Tessaratoma sp	India	Pearl millet

Continued

Table 1. *Continued*

Insect pest	Region of incidence	Crop
LEPIDOPTERA (Head caterpillars)		
Cosmopterygidae		
Pyroderces sp	Africa	Sorghum
Sathrobota simplex Walshingham [= *Pyroderces simplex*]	Africa/India	Pearl millet
Gelechiidae		
Anarsia sp	India	Pearl millet
Sitotroga cerealella (Olivier)	Africa/India	Sorghum
Lymantriidae		
Euproctis scintillans Walker	India	Pearl millet
Euproctis subnotata Walker	India	Pearl millet
Euproctis xanthorrhoea (Kollar)	India	Sorghum/Pearl millet
Cynerea sp	Africa	Sorghum
Noctuidae		
Autoba silicula (Swinhoe)	India	Sorghum
Celama analis Wileman & West	India	Sorghum/Pearl millet
Celama internella Fabricius	India	Pearl millet
Celama sorghiella Riley	South America	Sorghum
Celama sp	Africa	Sorghum
Eublemma gayneri Rothschild	Africa	Sorghum/Pearl millet
Eublemma limbata [?]	India	Sorghum
Eublemma silicula Swinhoe	Africa, India	Sorghum/Pearl millet
Eublemma sp	Africa	Sorghum
Heliocheilus albipunctella (de Joannis) [= *Raghuva albipunctella*]	Africa	Pearl millet
Heliocheilus confertissima (Walker)	Africa	Pearl millet
Helicoverpa armigera (Hübner) [= *Heliothis armigera*]	Africa/Asia/ Australia	Sorghum/Pearl millet
Heliothis virescens (Fabricius)	North and Central America	Sorghum
Heliothis zea (Boddie)	North and Central America	Sorghum
Masalia nubila (Hampson)	Africa	Pearl millet
Masalia terracottoides (Rothschild)	Africa	Pearl millet
Nola spp	Africa	Pearl millet
Spodoptera frugiperda (Smith)	North and Central America	Sorghum
Timora senegalensis (Guenée)	Africa	Pearl millet
Oecophoridae		
Stathmopoda auriferella Walker	Africa	Sorghum
Stathmopoda theoris Meyrick	India	Pearl millet
Pyralidae		
Cryptoblabes adoceta Turner	Australia	Sorghum
Cryptoblabes angustipennella Hampson	India	Pearl millet

Continued

Table 1. *Continued*

Insect pest	Region of incidence	Crop
Cryptoblabes gnidiella (Millière)	India	Sorghum
Dichocrocis punctiferalis (Guenée)	India/Australia	Sorghum
Ectomyelois sp	India	Sorghum
Ephestia cautella (Walker)	India	Sorghum
Salebria mesozonella Bradley	Africa	Sorghum
Stenochroia elongella Hampson	India	Sorghum/Pearl millet
Tortricidae		
Cryptophlebia leucotreta (Meyrick)	Africa	Sorghum
Cydia sp	India	Sorghum
COLEOPTERA (Head beetles)		
Corylophidae		
Arthrolips senegalensis Matthews	Africa	Pearl millet
Lycidae		
Lycostomus praeusta Fabricius	India	Pearl millet
Meloidae		
Cyaneolytta coerulea (Pfaff) [= *Cyaneolytta acteon* Laporte]	India	Pearl millet
Cyaneolytta maculifrons Mäklin	Africa	Sorghum/Pearl millet
Cylindrothorax audouini (Haag-Rutenburg)	India	Pearl millet
Cylindrothorax dusaultii Dufour	Africa	Sorghum/Pearl millet
Cylindrothorax kulzeri Kaszab	Africa	Sorghum
Cylindrothorax melanocephalus (Fabricius)	Africa	Sorghum/Pearl millet
Cylindrothorax pictus (Laporte)	India	Pearl millet
Cylindrothorax tenuicollis (Pallas) [= *Cylindrothorax ruficollis* (Olivier)]	India	Pearl millet
Cylindrothorax westermanni (Mäklin)	Africa	Sorghum/Pearl millet
Epicauta albovittata (Gestro)	Africa	Pearl millet
Epicauta tenuicollis (Pallas)	India	Pearl millet
Epicauta tomentosa (Mäklin)	Africa	Pearl millet
Epicauta villosa Fabricius	Africa	Pearl millet
Mylabris affinis Olivier	Africa	Sorghum/Pearl millet
Mylabris argentata Fabricius	Africa	Sorghum/Pearl millet
Mylabris bifasciata (De Geer)	Africa	Pearl millet
Mylabris fimbriata Marseul	Africa	Pearl millet
Mylabris holosericea Klug	Africa	Sorghum/Pearl millet
Mylabris ligata Marseul	Africa	Pearl millet
Mylabris nigriplantis Klug	Africa	Sorghum
Mylabris nubica Marseul	Africa	Pearl millet

Continued

Table 1. *Continued*

Insect pest	Region of incidence	Crop
Mylabris pallipes Olivier	Africa	Sorghum/Pearl millet
Mylabris pustulata Thunberg	India	Sorghum/Pearl millet
Mylabris vestia Reiche	Africa	Sorghum/Pearl millet
Mylabris vicinalis Marseul	Africa	Sorghum/Pearl millet
Psalydolytta aegyptiaca (Mäklin)	Africa	Pearl millet
Psalydolytta atricollis (Pic)	India	Pearl millet
Psalydolytta cineracea Mäklin	Africa	Pearl millet
Psalydolytta fusca (Olivier) [= *Psalydolytta flavicornis* Mäklin]	Africa	Sorghum/Pearl millet
Psalydolytta rouxii (Laporte)	India	Pearl millet
Psalydolytta substrigata (Laporte)	Africa	Pearl millet
Psalydolytta theresae Pic	Africa	Sorghum/Pearl millet
Psalydolytta vestita (Dufour)	Africa	Sorghum/Pearl millet
Melyridae		
Idgia terminata Castelnau	Africa	Pearl millet
Melyris abdominalis (Fabricius)	Africa	Pearl millet
Mycetophagidae		
Typhaea stercorea (Linnaeus)	India	Pearl millet
Nitidulidae		
Carpophilus sp	Africa	Pearl millet
Meligethes heteropus Gerstaecker	Africa	Pearl millet
Scarabaeidae		
Adoretus deccanus Ohaus	India	Sorghum
Adoretus versutus Harold	India	Sorghum
Anatona stillata (Newman)	India	Pearl millet
Anomala senegalensis (Blanchard)	Africa	Pearl millet
Anomala tibialis Lansberge	Africa	Pearl millet
Anomala spp	India	Sorghum
Anthracophora crucifera (Olivier)	India	Pearl millet
Chiloloba acuta (Wiedemann)	India	Sorghum/Pearl millet
Heterorrhina elegans (Fabricius)	India	Pearl millet
Leucocelis nitidula (Olivier)	Africa	Pearl millet
Oxycetonia albopunctata (Fabricius)	India	Pearl millet
Oxycetonia versicolor (Fabricius)	India	Pearl millet
Pachnoda cordata (Olivier)	Africa	Sorghum
Pachnoda fairmairei Raffray	Africa	Pearl millet
Pachnoda interrupta (Olivier)	Africa	Sorghum/Pearl millet
Polybaphes sanguinolenta (Olivier)	Africa	Pearl millet
Protaetia alboguttata (Vigors)	India	Pearl millet
Protaetia aurichalcea (Fabricius)	India	Pearl millet
Protaetia maculata (Fabricius)	India	Pearl millet
Pseudoprotaetia burmeisteri Arrow	Africa	Sorghum/Pearl millet
Pseudoprotaetia stolata (Olivier)	India	Pearl millet
Rhabdotis sobrina (Gory and Percheron)	Africa	Pearl millet

Continued

Table 1. *Continued*

Insect pest	Region of incidence	Crop
Rhinyptia infuscata Burmeister [= *Anomala plebeja*]	Africa	Pearl millet
Rhinyptia laeviceps Arrow	India	Pearl millet
Rhinyptia meridionalis var *puncticollis* Arrow	India	Pearl millet
Schizonycha africana (Laporte)	Africa	Pearl millet
Schizonycha ruficollis (Fabricius)	India	Sorghum
Tenebrionidae		
Synallecula sp	Africa	Pearl millet
DIPTERA		
Cecidomyiidae		
Contarinia sorghicola (Coquillett)	Cosmopolitan	Sorghum
Geromyia penniseti (Felt)	Africa, India	Pearl millet
Chloropidae		
Dicraeus pennisetivora Deeming	Africa	Pearl millet
ORTHOPTERA (Locusts and grasshoppers)		
Kraussaria angulifera (Krauss)	Africa	Pearl millet
Oedaleus senegalensis (Krauss)	Africa	Pearl millet
Oedaleus nigeriensis (Uvarov)	Africa	Pearl millet
Schistocerca gregaria (Forskål)	Africa	Pearl millet
DERMAPTERA		
Forficulidae		
Forficula senegalensis Serville	Africa	Pearl millet
HYMENOPTERA		
Formicidae		
Messor barbarus Linnaeus	Africa	Pearl millet
Messor galla Emery	Africa	Pearl millet
Messor regalis Emery	Africa	Pearl millet
Monomorium areniphilum	Africa	Pearl millet
THYSANOPTERA (Thrips)		
Anaphothrips soudanensis Trybom	India	Pearl millet
Anaphothrips ramakrishna Karny	India	Pearl millet
Haplothrips tolerabilis Priesner	India	Sorghum
Taeniothrips fraegardhi Trybom	India	Sorghum

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Session 1

Regional Reports

Rapports régionaux

Panicle Insect Pests of Sorghum in West Africa

A Ratnadass[1] and O Ajayi[2]

Abstract

Although several panicle-feeding insect pests are associated with sorghum, only a few are considered to be major pests in West Africa. The sorghum midge Contarinia sorghicola, *and a complex of mirid head bugs (*Eurystylus immaculatus*) have recently become key pests. Other minor or occasional insect pest species include a range of head caterpillars and head beetles.*

Both sorghum midge and head bugs are sometimes more abundant on research stations than in farmers' fields, but the midge is an endemic and persistent constraint at some locations. Head bugs and head caterpillars are mostly associated with compact-headed improved caudatum types, and the local guinea cultivars are generally free from damage.

Methods of controlling sorghum midge include destruction of infested panicles, early and synchronized sowing, use of resistant cultivars, and chemical protection, while head bug control involves the use of resistant cultivars, appropriate cultural practices, and insecticides.

Introduction

Sorghum is the most important food crop in the savanna areas of West Africa, the largest producers being Nigeria (almost 5 million t in 1991), Burkina Faso (over 1 million t), Mali and Niger (FAO 1992). Over the last 10 years, the total sorghum production in the subregion increased due to an increase in the area cropped to this cereal, while the grain yield declined due to several factors.

Insect pests constitute an important factor limiting grain sorghum production in West Africa. Several species of insect pests attack sorghum at the different stages of its development. Recent reviews have dealt with the situation of sorghum insect pests worldwide (Young and Teetes 1977), in West Africa (Nwanze 1985), and in Africa in general (Seshu Reddy 1991). However, these papers do not deal solely with panicle pests, whose importance has increased recently particularly in West Africa.

Over 100 sorghum insect pest species have been recorded in Africa, of which more than 40 are panicle-feeding pests (Nwanze 1985, Seshu Reddy 1991). However, only a few of these are considered to be key pests in West Africa, sorghum midge (*Contarinia sorghicola*) and a complex of head bugs (*Eurystylus immaculatus*). Other, minor pests include a range of head caterpillars and head beetles. Head bugs and head caterpillars are mostly associated with compact-headed sorghum types (generally improved caudatum varieties), and the local guinea cultivars with loose panicles are usually free from these pests (Nwanze 1985).

This paper discusses the species complex and importance of the major insect pests of sorghum panicles in West Africa. Other species of minor importance are covered briefly.

Sorghum Midge

Distribution, abundance, and crop loss

The sorghum midge, *Contarinia sorghicola* (Coquillett) (Diptera: Cecidomyiidae), is probably the most widely distributed sorghum insect pest and occurs in nearly all the regions of the world where sorghum is grown. Its situation has been recently re-

1. Centre de Coopération en Recherche Agronomique pour le Développement/Département des Cultures Annuelles (CIRAD/CA), ICRISAT West African Sorghum Improvement Program (WASIP)–Mali, Samanko, BP 320, Bamako, Mali.
2. ICRISAT West African Sorghum Improvement Program (WASIP)–Nigeria, IITA Office, Sabo Bakin Zuwo Road, PMB 3491, Kano, Nigeria.

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viewed by Bonzi (1992). In West Africa, it was reported in Nigeria as early as 1929 (Harris 1961), and subsequently recorded in several French-speaking countries of West Africa (Coutin 1969). *Contarinia sorghicola* is a major pest of sorghum in the region (Libby 1968).

By feeding on the developing seed, midge larvae prevent normal grain development, which results in abortion, and partial or total destruction of the grains. Moreover, there is very little compensation for the lack of seed set in the head. Pest outbreaks are favored by staggered sowing, which results in an extension of the flowering period.

Some reports refer to high, although variable, crop loss. Harris (1961) reported a grain loss of 91 000 t in northern Nigeria in 1958. However, Nwanze (1985) mentioned that the rate of infestation in recent years was less than 5%. On the other hand, Sharma (1989) reported heavy midge damage in northern Nigeria and southern Niger in Sep-Oct 1989. An unusually widespread infestation and severe damage by the sorghum midge in the drier parts of northern Nigeria, Burkina Faso, Cameroon, and Niger was reported in 1991 (ICRISAT Sahelian Center 1992, p. 100). Infestation was as high as 100% in many farmers' fields, and almost all infested panicles were completely chaffy. In that year, only the long-duration local varieties suffered midge infestation at the Bagauda research station of ICRISAT in Nigeria, while ICRISAT's improved short-duration varieties escaped damage. Widespread midge infestation and damage were also reported by state extension agents in the Northern Sudanian Zone of Nigeria in 1992. Midge incidence is probably more frequent and widespread than is usually reported because farmers and extension agents attribute the emptiness of the panicles to other causes such as pollen wash.

Coutin (1970) reported grain losses in Senegal as high as 75–90%. Bonzi and Doumbia (1985) reported a low incidence or absence of midge in the areas of Burkina Faso located outside the 11°N and 13°N latitudes. This was confirmed by Nwanze (1988), who provided a distribution map of this pest in Burkina Faso, where it appears to be confined to the region below latitude 13°N corresponding to the 700 mm isohyet. He reported areas where midge damage resulted in losses ranging from 75 to 100%.

In Mali, infestation and damage are generally much lower in farmers' fields than in research stations. Infestation rate in farmers' fields could be up to 20% (Bonzi and Doumbia 1985). The midge was reported to occur in sorghum-growing areas in the southern and western parts of Mali, with the exception of the Sahelian region north of the Kayes-Ségou line. However, Doumbia (1989) reported a heavy midge attack in this Sahelian region, west of the country, during the 1988 rainy season.

In Chad, midge has been identified as seriously limiting grain sorghum production (D Yagoua, IRCT, Bébédjia, personal communication 1991). In Niger, there were two generations of sorghum midge in 1982, 1983, and 1984 (Maïga 1986), with peak adult populations occurring between mid-Sep and late Oct (Maïga 1980, Samir 1984). Maïga (1988) reported that damage is more severe on the long-duration local varieties, although Janjaré Red is considered to be moderately resistant (Leclerc 1962). In Cameroon, Kenga (1992) attributed grain yield losses of nearly 15% to damage by sorghum midge in farmers' fields in 1991.

The midge situation is different further south, notably in Ghana, where infestation is enhanced by the year round presence of alternative wild host plants (Bowden 1965). The same situation is found in northern Togo (Ratnadass 1991). Yehouénou (1992) also reported that the sorghum midge is an important constraint to sorghum production in Benin.

Control methods

Sorghum midge control options were recently reviewed by Bonzi (1992). They include such cultural practices as destruction of infested panicles (in crop residues, ratoons, and wild sorghums), and early synchronized regional sowings, using pure seed, to obtain uniform flowering. However, both methods are often impractical under traditional farming systems of the region.

Biological control has not been attempted, and its prospects probably are limited, since there is little evidence that natural parasitism and predation provide significant control of midge populations (Harris 1983, Bonzi 1992). Although insecticide application can provide effective protection against sorghum midge, it is neither economic nor practical in the conditions of subsistence farming in West Africa (Bonzi 1992).

As for the use of resistant cultivars in West Africa, it was reported as early as in the 1950s from the Gold Coast that 'Nunaba' varieties possessing long papery glumes were resistant to the sorghum midge (Bowden and Neve 1953, cited by Teetes 1983). Early screening trials in Senegal have indicated the existence of a number of guinea and membranaceum sorghum varieties from the region showing resistance or lower susceptibility to midge (Leclerc 1962). More recently, new resistant lines have been identified, and efforts have been made in resistance breeding notably in Mali (Doumbia et al. 1990, Ratnadass et al. 1992b).

Sorghum Mirid Head Bugs

Distribution, abundance, and crop loss

Although they have been known for quite some time in the region, it is only recently that head bugs (Heteroptera: Miridae), notably of the genus *Eurystylus* Stål, have become key pests of sorghum in West Africa. Head bug feeding and oviposition punctures on maturing sorghum grains result in severe quantitative and qualitative losses, particularly on improved compact-headed types (Doumbia and Bonzi 1985, Steck et al. 1989, Ratnadass et al. 1991, Sharma et al. 1992, Sharma et al. 1994). Head bug attack is also generally associated with greater grain mold incidence (Steck et al. 1989, Sharma et al. 1992).

Several species of panicle-feeding bugs have been reported as pests of sorghum in many parts of Africa. A list of the most common species of mirid bugs associated with sorghum panicles in six countries of West Africa is provided in Table 1.

In West Africa, the head bug complex is dominated by the genus *Eurystylus*, of which several species have been reported, notably *E. bellevoyei* Reuter from Burkina Faso (Nwanze 1985), *E. rufocunealis* (Poppius) from Nigeria (MacFarlane 1989), and *E. marginatus* Odhiambo from Niger (Steck et al. 1989) and Mali (Doumbia and Bonzi 1985, Gahukar et al. 1989a, Doumbia and Bonzi 1989).

Descamps (1954) reported *E. risbeci* Schouteden from northern Cameroon, where it was very abundant on sorghum panicles, although it was not associated with heavy damage. *Eurystylus risbeci* has also been reported as a cotton pest, notably from Farako-Bâ in Burkina Faso, a research station where sorghum is extensively grown (Nibouche 1993). Some of these reports are however likely based on incorrect identifications, and there is strong evidence that the only species actually involved, or at least the predominant one, is *Eurystylus immaculatus* Odhiambo (Sharma 1989, Ratnadass et al. 1991, Sharma et al. 1992).

Eurystylus immaculatus was also identified in Côte d'Ivoire (Ratnadass and Cissé 1990), Togo (Ratnadass 1991), and Senegal (Ratnadass 1992a), but infestation levels were much lower than those observed in Mali, Burkina Faso, Niger, and Nigeria.

In West Africa, two species of the *Campylomma* species complex on sorghum were found at Samaru (Nigeria): *C. angustior* Poppius, which was dominant, and *C. subflava* Odhiambo (MacFarlane 1989). The same situation was found at Samanko, Mali (Ratnadass, unpublished data). *Campylomma plantarum* Lindberg has also been reported from sorghum at Samaru while *C. angustior*, *C. subflava* and *C. citrinella* Odhiambo have been reported from cotton at the same location (Deeming 1981). *Campylomma unicolor* Poppius has been reported as a cotton pest at Farako-Bâ (Nibouche 1993).

In Senegal, the most abundant head bug species at Bambey in 1992 was *Creontiades pallidus* Rambur,

Table 1. Main genera and species of sorghum head bugs (Heteroptera, Miridae) reported from six countries of West Africa.

Head bug	Burkina Faso[1]	Mali	Niger	Nigeria	Senegal	Togo
Eurystylus sp	+	+	+	+	+	+
Campylomma spp	+	+	+	+	+	+
Creontiades pallidus Rambur	+	+	+	+	+	+
Megacoelum apicale Reuter	+	+	+		+	
Paramixia sp			+	+		
Taylorilygus sp			+	+		
Adelphocoris apicalis Poppius		+		+		
Tytthus parviceps Reuter			+			
Stenotus transvaalensis Distant			+			

1. + = presence of insect reported on sorghum.

Sources: Nwanze (1985), Sharma (1985), Sharma (1986), Doumbia and Bonzi (1989), MacFarlane (1989), Steck et al. (1989), Ratnadass (1991), Ratnadass (1992a), Ratnadass (1992b) while *Megacoelum apicale* Reuter was dominant at Thysse Kaymor (Ratnadass 1992a).

Sharma (1989) reported high head bug infestation (up to 250 bugs per 5 panicles) in Sep-Oct 1989 on durra and fara-fara local sorghum types of northern Nigeria and southern Niger, in comparison with local guinea types from southern Mali and Burkina Faso (where the maximum infestation was 40 head bugs per 5 panicles).

Doumbia and Teetes (1991) provided a distribution map of *E. marginatus* (*immaculatus*?) in Mali, where it was more abundant in the central-southern zones, especially around the city of Bamako. Head bugs were more abundant in research stations than in farmers' fields, and on improved caudatum varieties than on local guinea cultivars.

In southern Mali, in an on-farm test in 1992, the improved caudatum variety ICSV 1063 BF had 50 head bugs per 5 panicles, compared to less than 20 on local or improved guinea cultivars (Ratnadass et al. 1993b).

In Niger, a commonly grown indigenous sorghum variety, Mota Galmi, suffered 14% yield loss and 19% grain vitrosity reduction in field trials in which *Eurystylus* sp density averaged 80 per panicle. Among 14 other sorghum varieties grown under natural conditions, vitrosity decreased by 20% on an average (Steck et al. 1989).

In Mali and Burkina Faso, head bug infestation caused a 50% reduction in 1000-seed mass in S 34 (improved caudatum variety) and an additional 30% quantitative loss, in terms of a reduction of dehulling recovery rate. Its germination was reduced by 50%, and the proportion of low-density grains increased threefold (Ratnadass et al. 1991). Although local non-tan guinea cultivars generally did not show a marked reduction for most quantity and quality loss parameters, they showed a noticeable decrease in acceptability of *tô* color (Ratnadass et al. 1991).

At Bagauda, Nigeria, chemical control of head bugs improved grain yield by 86%, 1000-seed mass by 65%, and reduced the proportion of low-density grains by 45% in 1989 (ICRISAT Sahelian Center 1990, pp. 114-116). In 1990, a 20% decrease in grain yield, 6% reduction in 1000-seed mass, and 24% increase in proportion of low-density grains were attributed to head bug damage (ICRISAT Sahelian Center 1991, pp. 113-114). Head bug attack also significantly reduced the rate of germination (ICRISAT Sahelian Center 1992, pp. 102-103). The degree of damage was correlated with head bug population. Bug-damaged grains have also been reported to show greater severity of mold incidence (Steck et al. 1989, Sharma et al. 1992).

Control methods

Although insecticide protection with either cypermethrin (ICRISAT Sahelian Center 1991, pp. 113-114; ICRISAT Sahelian Center 1992, pp. 102-103) or diazinon (IER 1993, pp. 28-33) is effective in reducing head bug infestation and damage, it is probably not the best option for small farmers. Moreover, chemical treatment should not affect natural enemies, such as spiders, and to a lesser extent predatory bugs (e.g., *Orius* spp), as reported from Mali (Doumbia and Bonzi 1985) and northern Nigeria (MacFarlane 1989). However, the potential of biological control of head bugs has not been investigated. On the other hand, some progress on sorghum resistance to head bugs has been made in the region (Shetty et al. 1991, Doumbia 1992, Sharma et al. 1992, Ratnadass et al. 1992a, Ratnadass et al. 1993a, Ratnadass 1993, Fliedel et al. 1993, Sharma et al. 1994). Other control options include crop management practices such as date of sowing and intercropping sorghum with legume crops (ICRISAT Sahelian Center 1990, p. 117; ICRISAT Sahelian Center 1992, p. 103; ICRISAT Sahelian Center 1993, p. 52; Ratnadass 1993).

Secondary Pests

Head caterpillars

Species of lepidopterous head caterpillars (Noctuidae, Momphidae, Gelechiidae, Pyralidae, Nolidae, Stathmopodidae and Tortricidae) are widely distributed in West Africa (Descamps 1954, Nonveiller 1969). Their larvae feed on the soft sorghum grains.

Brenière (1970) mentioned *Eublemma gayneri* Rothschild and *Pyroderces hemizopa* Meyrick as the most important sorghum head caterpillars in West Africa. *Pyroderces hemizopa* was reported on sorghum panicles from northern Cameroon (Descamps 1954), while *P. simplex* (Walsingham) was reported from Senegal (Appert 1957). The sorghum head caterpillar complex was studied in Cameroon by Nonveiller (1969), who reported *Salebria mesozonella* Bradley in addition to *P. hemizopa* and *E. gayneri*. He stressed the correlation between panicle compactness and infestation by head caterpillars. From Mali, Sharma (1985) reported *Helicoverpa armigera* (Hübner) and *Pyroderces* sp, while Doumbia and Bonzi (1989) reported *E. gayneri* and *H. armigera* on sorghum panicles. The major sorghum head caterpillars at Kamboinsé (Burkina Faso) in 1986 were *H. armigera*, *E. gayneri*, *P. simplex*, and *Mythimna* sp

(Sharma 1986). Nibouche (1993) reported that in western Burkina Faso, no attack of *H. armigera* was recorded on sorghum, an observation which he linked to the loose panicles of local varieties grown in the area. Viguier (1947) reported that in Senegal and French Sudan (Mali) some stem borer caterpillars (*Eldana saccharina* Walker) and defoliators [*Mythimna loreyi* (Duponchel)] can occasionally attack the grains. *Sitotroga cerealella* (Olivier) and *Stathmopoda auriferella* Walker attack sorghum in the field and sorghum stored in the head (Prevett 1963). They were reported on sorghum panicles in northern Cameroon (Nonveiller 1969).

Head beetles

In Mali and Senegal, blister beetles (Coleoptera: Meloidae) were reported from both sorghum and millet (with greater damage on the former), although no information was provided on their actual impact (Gahukar et al. 1989b, Doumbia and Bonzi 1989). The adult beetles feed mainly on floral parts (anthers, stigmas, and petals), preventing grain formation. The main genera represented were *Mylabris* (*M. holosericea* Klug and *M. nigriplantis* Klug) and *Psalydolytta* [*P. fusca* (Olivier) and *P. vestita* (Dufour)].

Descamps (1954) and Nonveiller (1984) reported several meloid beetles from sorghum panicles in northern Cameroon that they found were responsible for only negligible loss. A small number of chafer beetles (Coleoptera, Scarabeidae, Cetoniinae), although more frequently associated with millet, were also found feeding on sorghum heads. *Pachnoda* spp [*P. cordata* (Olivier) and *P. interrupta* (Olivier)] were reported from Senegal and Mali (Risbec 1950, Appert 1957, Doumbia and Bonzi 1985 and 1989). In northern Cameroon, *P. interrupta* was occasionally abundant and reported to cause severe damage (Descamps 1954).

Other minor pests

Heteroptera other than mirids also attack sorghum, although they are more common on millet. Families represented are Coreidae [*Mirperus jaculus* (Thunberg) and *Clavigralla* (= *Acanthomia*) *tomentosicollis* (Stål)], Lygaeidae (*Spilostethus* spp and *Lygaeus* spp), Pentatomidae [Pentatominae: *Agonoscelis* spp, *Aspavia armigera* (Fabricius), *Nezara viridula* (Linnaeus) and *Acrosternum* spp; Scutellerinae: *Calidea* spp], Pyrrhocoridae (*Dysdercus voelkeri* Schmidt) and Rhopalidae (*Liorhyssus* spp and *Agrophobus* spp).

Other minor pests include earwigs (Dermaptera: Forficulidae), such as *Forficula senegalensis* Serville and *Diasperasticus erythrocephalus* Olivier in Mali, thrips (Thysanoptera), such as *Haplothrips* sp in Mali, and *Carpophilus* spp [*C. fumatus* Boheman in Mali: Doumbia and Bonzi (1989); and *C. hemipterous* (Linnaeus) in Cameroon: Nonveiller (1984)], which are secondary pests; the damage they cause to sorghum is unknown.

Earwigs are still controversial pests, since in spite of their abundance in certain areas, as in Senegal (Ratnadass 1992a), they seem to be more of a nuisance to humans than to the crop (Nwanze 1985); earwigs can also be considered as beneficiary insects, particularly as head bug predators (Sharma 1989, Ratnadass 1993).

Conclusion

Sorghum panicles are infested by a wide range of insect pests from anthesis to grain maturity, of which only a few species cause severe damage. Contrary to shoot pest damage, panicle pests can cause both quantitative and qualitative losses, which generally cannot be compensated by further plant growth and recovery. Although fragmentary data are available on pest incidence, information is lacking on the actual crop losses sustained in farmers' fields. Therefore, there is a real need for extensive monitoring and mapping of the occurrence of these pests, and a critical assessment of losses incurred, particularly as they relate to different levels and types of attack. This kind of information is a prerequisite for the definition of management strategies, especially if they involve costly inputs, like insecticides. The understanding of pest distribution and seasonal abundance could also result in recommendations in terms of cultural practices and biological control methods. The introduction of improved varieties and changes in farming practices is also likely to result in new pest problems, as is the case with head bugs, which thrive on cultivars with compact heads.

There is still scope for improvement of existing knowledge on the species complex of these insect pests. For instance, confusion persists although most *Eurystylus* species have been described by Odhiambo (1958); there might be a need for a revision of the genus.

With regard to control methods, the use of resistant cultivars holds promise, but it should be mentioned that plant characters that confer resistance to one insect could result in susceptibility to another. For example, quicker glume opening provides midge resistance in ICSV 197 by exposing the maggot to adverse biotic and abiotic factors. But it also makes the same variety highly susceptible to head bugs, by exposing the grains to bug punctures at an early stage. Also, Malisor 84-7, the only compact-headed variety identified so far with high and stable head bug resistance, can be heavily damaged by head caterpillars which are better protected from predators due to the variety's compact panicles. Further, the use of host-plant resistance alone should not be considered as a panacea, particularly when sources have a narrow genetic base. A good example is offered by the first generation of midge-resistant varieties developed by ICRISAT, derived from DJ 6514. Derivatives ICSV 197 and ICSV 745 of this cultivar have been reported to show high levels of midge damage in Kenya, and it is not known if this is the result of genotype × environment interaction or the presence of new strains of the sorghum midge (H C Sharma, ICRISAT, personal communication 1992).

The overall approach in pest control should therefore focus on the integration of different control methods, taking into account the insect pest species involved as well as the agroecosystem as a whole.

Synthèse

Les insectes paniculaires ravageurs du sorgho en Afrique de l'Ouest. Bien que bon nombre d'insectes soient associés aux panicules de sorgho, seuls quelques-uns sont considérés comme des ravageurs importants en Afrique de l'Ouest, à savoir la cécidomyie du sorgho, *Contarinia sorghicola*, et un complexe de punaises mirides, notamment du genre *Eurystylus*, qui ont été signalées dans sept pays de la région, particulièrement au Burkina Faso, au Mali, au Niger et au Nigéria, où elles sont tout récemment devenues des ravageurs-clés.

Parmi les autres espèces d'insectes paniculaires, qui sont des ravageurs soit d'importance secondaire, soit occasionnels, on compte des hétéroptères autres que les mirides, et surtout toute une gamme de chenilles de lépidoptères (appartenant à plusieurs familles), et des coléoptères (principalement méloïdes et cétoines).

La cécidomyie et les punaises sont généralement plus abondantes dans les stations de recherche que dans les champs paysans, mais la cécidomyie peut constituer une contrainte endémique et importante à la production de sorgho en certains endroits. Ainsi, ce ravageur a été responsable ces dernières années d'infestations parfois sévères et de grande ampleur sur des variétés locales de sorgho au Bénin, au Burkina Faso, au Cameroun, au Niger, au Nigéria, au Tchad et au Togo.

Les punaises et les chenilles des panicules (notamment *Helicoverpa armigera*) sont essentiellement associées aux variétés de sorgho améliorées à panicule compacte, de type caudatum (sur lesquelles les premières notamment sont responsables d'importantes pertes quantitatives et qualitatives) alors que les variétés guinea locales à panicules lâches sont généralement peu attaquées.

Une meilleure connaissance des espèces de ravageurs impliquées (notamment en ce qui concerne le complexe de punaises des panicules) serait nécessaire, ainsi que davantage de données sur la répartition et l'impact des différents ravageurs en milieu réel.

La lutte contre la cécidomyie fait appel aux pratiques culturales comme la destruction des panicules infestées, ou les semis précoces et synchronisés, à la protection chimique et à l'utilisation de variétés résistantes, dont la base génétique est pour l'instant très étroite. Les mêmes méthodes de lutte peuvent être envisagées pour les punaises. Bien que prometteuse, la résistance variétale seule ne saurait être considérée comme une panacée, notamment lorsqu'on est en présence de plusieurs groupes de ravageurs contre lesquels on ne peut envisager une résistance multiple, du fait de l'antagonisme des mécanismes de résistance impliqués.

Les stratégies de lutte devraient favoriser l'approche consistant à intégrer plusieurs méthodes de lutte, en tenant compte des espèces de ravageurs impliquées, et des autres particularités de chaque agroécosystème considéré.

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Les insectes de l'épi de mil en Afrique de l'Ouest

K Touré[1] and A Yehouénou[2]

Résumé

Le mil est une culture qui est sujette à d'importants dégâts dus aux insectes qui sont communs dans le Sahel. Parmi les insectes sévissant sur le mil, les insectes des épis occupent une place prépondérante.

*Les effets destructeurs des insectes sont presque toujours notables même en cas d'attaques faibles. Il apparait ainsi que les espèces les plus dangereuses appartiennent généralement aux ordres des Lépidoptères [*Heliocheilus albipunctella *(de Joannis)], des Diptères [*Geromyia penniseti *(Felt)] et des Coléoptères [*Psalydolytta fusca *(Olivier),* Psalydolytta vestita *(Dufour),* Pachnoda interrupta *(Olivier)]. En méthode de lutte, les insecticides comme l'endosulfan ont donné de bons résultats contre la mineuse de l'épi (*H. albipunctella*). Les variétés Souna et IBV 8001 sont résistantes à* H. albipunctella. *Le carbaryl et le carbosulfan ont réduit les populations de méloïdes du genre* Psalydolytta.

Introduction

L'agriculture en Afrique de l'Ouest est essentiellement une agriculture de subsistance de type traditionnel, fortement soumise aux aléas abiotiques et biotiques.

Dans les zones sub-sahéliennes ayant une pluviométrie comprise entre 500 et 800 mm, le mil [*Pennisetum glaucum* (L.) R. Br.] constitue la principale culture vivrière. En Afrique de l'Ouest, la culture du mil couvre à peu près 13 millions d'hectares (Nwanze 1988). Malgré cette grande surface emblavée en mil, les rendements restent très faibles en moyenne 200–400 kg ha^{-1} (Gahukar 1988, Nwanze 1985) à cause des dégâts dus aux infestations de différents ennemis dont les insectes. Les pertes dérivant des effets combinés des différents ravageurs sur cette culture à faible investissement sont variables mais généralement importantes; représentant régulièrement 50 à 80% des rendements de mil. Les très mauvaises années, ils peuvent même décimer des champs entiers causant la perte totale de la récolte. Les différents ennemis sont répartis en plusieurs groupes d'après les dégâts qu'ils occasionnent sur le mil. Il s'agit essentiellement du groupe des lépidoptères (chenilles mineuses de l'épi), du groupe des diptères (cécidomyie), du groupe des hétéroptères (piqueurs suceurs) et du groupe des coléoptères (méloïdes et Scarabaeidae).

La présente synthèse fait le point des principaux ravageurs de l'épi de mil et leur importance en l'Afrique de l'Ouest. Dans le rapport, la biologie ne sera que brièvement détaillée. Par contre on développera pour chaque insecte l'importance des dégâts et les problèmes qui sont posés à la recherche pour aboutir à la mise au point et à l'application de méthodes rationnelles de lutte qui sont des moyens d'accroissement de la productivité.

Entomofaune de l'epi de mil

Les insectes des épis se manifestant généralement plus tard pendant la campagne réduisent la production dans de graves proportions car la croissance du mil à ce stade ne dépend plus que d'un nombre réduit de facteurs. Ils attaquent directement les grains ou les tissus qui servent à la formation des grains. Le mil comme les autres plantes cultivées pour leurs fruits ou leurs graines supporte mieux au point de vue conséquence pour la récolte, les dommages faits à ses parties végétatives qu'à ses parties reproductrices.

1. Institut d'Economie Rurale (IER), Station de Recherche Agronomique de Sotuba, BP 258, Bamako, Mali.
2. Institut National Agronomique, Station de Recherches sur les Cultures Vivrières, BP 3, N'Dali, Benin.

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Les dégâts imputables aux insectes sur l'épi de mil varient selon les zones écologiques, les années, les variétés et les techniques culturales.

La mineuse de l'épi

Répartition géographique, biologie et dégâts

La mineuse de l'épi *Heliocheilus albipunctella* (de Joannis) (Lepidoptera, Noctuidae), depuis son invasion soudaine après la grande sécheresse de 1972–74, s'est révélée être l'espèce la plus importante dans le complexe des mineuses de l'épi de mil. Sa répartition géographique s'étend sur toute la zone sous-sahélienne de l'Afrique de l'Ouest (Sénégal, Gambie, Mauritanie, Mali, Niger, Burkina Faso, Nigéria, Tchad).

Les premières études sur ce ravageur ont été effectuées au Sénégal par Vercambre (1978), ensuite par Gahukar (1982, 1983 et 1984), Pierrard (1983) et Bhatnagar (1984), en Mauritanie par Magema (1984), et au Mali par Doumbia et Sidibé (1983), et Doumbia et al. (1984), et au Niger par Guevremont (1981, 1982 et 1983).

En début de saison les chrysalides diapausantes achèvent leur développement. Après l'émergence les femelles déposent des oeufs sur les pédoncules floraux. De ces oeufs sortent des larves qui se nourrissent des organes floraux et complètent leur développement à l'intérieur de l'épi. Les signes précoces de l'attaque de la mineuse se détectent par la présence des déjections blanchâtres laissées autour des fleurs. Les larves âgées creusent des galeries en forme de spirales dans le rachis. La présence de ces mines est un symptôme caractéristique d'attaque tardive. Les larves coupent les pédoncules floraux inhibant ainsi la formation des grains ou provoquant leur chute.

L'incidence de la mineuse *H. albipunctella* varie considérablement selon les années et elle dépend surtout du cycle des variétés et de la densité larvaire. Les pertes de rendement causées par les chenilles de *H. albipunctella* ont été chiffrées entre 13 et 85% en 1974–76 au Sénégal sur la variété Souna (Vercambre 1978). Au Niger, sur la variété IVSP 78 les pertes sont de l'ordre de 6% (Guevremont 1982) et 14,9% sur la variété CIVT (Nwanze 1988). Au Mali, les pertes de récolte dues à la mineuse sont estimées à plus de 50% dans les années de très forte pullulation (Doumbia et al. 1984, Doumbia et Bonzi 1985). Actuellement, au Mali, la population de *H. albipunctella* connaît une recrudescence, les pertes de rendement sont faibles (5%) voire nulles (Doumbia et al. 1989, Doumbia 1992, Touré 1993). Au Nigeria il a été enregistré à Azare des pertes de l'ordre de 5,1% (Ajayi 1988).

Méthodes de lutte

Plusieurs études ont été menées afin de développer des stratégies de lutte intégrée fiables, efficaces, pratiques, économiques et à la portée des paysans.

La lutte biologique offre de bonnes possibilités mais les informations sur le rôle des ennemis naturels de *H. albipunctella* sont insuffisantes. De 1982 à 1985 des ébauches de recherche concernant les antagonistes sont orientées sur la lutte contre la mineuse *H. albipunctella* au Sénégal. Des résultats obtenus, il ressort que le braconidae *Bracon hebetor* Say est efficace contre *H. albipunctella* (Bhatnagar 1987) et le taux de parasitisme des larves est de 64%. Au Niger, l'ectoparasite *B. hebetor* est responsable de 95% de parasitisme des larves de *H. albipunctella* (Guevremont 1983). D'autres ennemis naturels ont été recensés tels que des hyperparasites *Eurytoma* sp et *Pediobius* sp (Guevremont 1983). *Litomatix* sp parasite les larves en diapause (CNRA 1977, Vercambre 1978); *Cardiocheles* sp parasite également les larves de *H. albipunctella* mais le taux de parasitisme est faible (Bhatnagar 1984).

Il existe des insecticides efficaces mais leur utilisation n'est pas toujours profitable car le contact de l'insecticide avec la larve s'avère difficile à cause de la biologie du ravageur qui pond ses oeufs dans les fleurs, les jeunes larves qui s'abritent dans les épillets et les chenilles âgées qui quittent les panicules pour chrysalider dans le sol. La hauteur des plants des variétés traditionnelles et les modes de semis rendent très difficile, par ailleurs, le traitement avec des appareils. Les insecticides comme l'endosulfan à 525–700 g ha^{-1} de matière active (m.a.) (Gahukar 1986, Vercambre 1982), le mélange Dipterex et SIR 8514 à 1 kg m.a. ha^{-1} ont été efficaces mais il a été constaté qu'il y a eu réduction de rendement (Guevremont 1982).

Les labours profonds effectués après la récolte et en début de campagne réduisent de façon significative la population résiduelle des larves diapausantes (Vercambre 1978). Il a été remarqué que le semis des variétés à cycle court et moyen avec deux semaines de retard évite la coïncidence du pic de vol des papillons et l'épiaison du mil (Gahukar 1988). L'application de l'urée ou du superphosphate réduit la population infestante de la mineuse sur les épis (Gahukar 1992).

Il n'y a pas actuellement de méthodes de criblage normalisées disponibles. Les variétés à comparer sont testées sous conditions d'infestation naturelles. Durant ces dernières années un certain nombre de variétés se sont montrées résistantes à l'attaque des chenilles de *H. albipunctella*.

Au Sénégal les variétés Souna, 3/4 HK-78, IBV 8001 et ICMS 7819 ont été classées comme des variétés résistantes (Gahukar 1983 et 1984).

Au Burkina Faso, il a été constaté que les variétés locales sont moins attaquées par *H. albipunctella* (ICRISAT 1980).

Au Mali l'étude du comportement de sept lignées de mil a révélé que la variété Souna est résistante à l'attaque de la mineuse de l'épi (Doumbia et al. 1989).

La cécidomyie du mil

Répartition et importance des dégâts

Geromyia penniseti (Felt) (Diptera, Cecidomyiidae) est une espèce multivoltine dont les adultes émergent au moment de la floraison des variétés de mil précoces. Les oeufs sont déposés sur les soies de l'involucre ou les glumes des fleurs. A l'éclosion les larves se nourrissent de l'intérieur des fleurs provoquant leur avortement. Les larves de la dernière génération en fin de saison entrent en diapause à l'intérieur des épillets.

Geromyia penniseti est l'espèce la plus répandue et la plus abondante que l'on rencontre dans toutes les zones de culture de mil. En plus du mil, *G. penniseti* vit sur plusieurs autres adventices (Doumbia et al. 1984). L'incidence est plus importante sur les variétés à cycle long car l'étalement de la période de floraison favorise le développement de l'insecte. La larve se développe à l'intérieur de l'ovaire qu'elle dévore complètement provoquant ainsi l'avortement de l'épi. Les dégâts occasionnés par la cécidomyie sont des dégâts directs.

La présence des cécidomyies est détectée par des exsuvies nymphales accrochées à l'extrémité des glumes. Les données sur *G. penniseti* sont insuffisantes pour permettre de préciser le niveau de ses populations et des pertes occasionnées.

Méthodes de lutte

A l'heure actuelle, elles se limitent à la destruction des épis de mil et d'adventices infestés qui abritent les larves diapausantes à la fin de la saison; il faut éviter les variétés à cycle long dans les zone de très forte pullulation.

Six parasites ont été trouvés sur les larves et les pupes de *G. penniseti*: *Tetrastichus diplosidis*, *Platygaster* sp, *Aphanogmus* sp, *Eupelmus popa*, *Eupelmus* sp et *Tetrastichus* sp. Le plus important est *Tetrastichus* sp (Eulophidae) (Coutin et Harris 1968).

Les méloïdes

Répartition géographique, biologie et importance des dégâts

Au cours des dix dernières années les méloïdes sont devenus importants par la diversité des espèces et leurs dégâts; les pertes de récoltes dont ils sont responsables sont très importantes. Ils sont présents partout dans le Sahel. Parmi les espèces inventoriées sur le mil on retiendra les genres *Psalydolytta*, *Mylabris*, *Decapotoma*, *Coryna* et *Cylindrothorax*.

Les méloïdes du genre *Psalydolytta* communément appelés Cantharides [*P. vestita* (Dufour), *P. fusca* (Olivier) et *P. flavicornis* Mäklin] sont les espèces d'importance économique (Doumbia et Bonzi 1986, Selander et Laurense 1987, Magema 1987, Zethner et Laurense 1988).

Parmi les 97 espèces recensées sur les plantes cultivées et les adventices (Gahukar 1991) les plus importants numériquement en plus du genre *Psalydolytta* sont les genres *Mylabris* et *Coryna*. Ils sont polyphages, leur répartition et leur abondance dépendent de la culture et de la zone écologique.

En Gambie, les méloïdes les plus importants sur le mil sont *P. fusca* et *Mylabris holosericae* Klug (Zethner et Olivier 1984).

Au Mali les espèces les plus abondantes et dangereuses sont *P. vestita* et *P. fusca*. En plus de ces espèces on rencontre également, *Coryna argenteata* Fabricius et *Mylabris nigriplantis* Klug qui provoquent parfois des dégâts sur le mil (Doumbia 1992).

Au Sénégal les espèces dominantes sont *P. fusca* et *P. vestita*. En Mauritanie les principales espèces sont *P. vestita* et *P. fusca*.

Dans le Nord du Bénin *P. fusca* et *P. vestita* attaquent sévèrement le mil.

En Gambie, les études menées pour évaluer les dégâts par Zethner et Laurense (1988) ont montré que les dégâts sont très importants en cas d'attaque de méloïdes du genre *Psalydolytta*. Cinq méloïdes par poquet pendant la floraison provoquent 100% de perte de récolte. En Gambie, entre 1981 et 1984 les pertes de récolte enregistrées sont de 4 à 48% (Zethner et Laurense 1988). Des pertes de 100% ont été également constatées (Bridge et al. 1978).

En Mauritanie, les niveaux d'infestation par les méloïdes *Psalydolytta* spp, sont de 60% en 1983, 8,5 à 15% en 1984, 2 à 80% en 1985 et 0,5 à 50% en 1986, et ils ont occasionné des pertes de récoltes de 100% (Magema et Delhove 1985 et 1986, Magema et Beye 1987).

Au Mali les pertes sont de l'ordre de 92 à 100% sur les variétés IBV 8001, IBV 8004 et IRATP à Samé. Dans les zones de Kolokani et de Banamba en 1991 et 1992 les champs entiers ont été dévastés (100% de pertes) par *Psalydolytta* sp. Dans ces zones endémiques les paysans abandonnent la culture du mil au profit de celle du sorgho.

Au Niger les dégâts sont importants mais ils ne sont pas chiffrés (Guevremont 1982).

Au Sénégal les dégâts sont très importants surtout dans le Sud où ils peuvent atteindre 100% de pertes.

En Mauritanie en plus du genre *Psalydolytta* on rencontre *C. argenteata* et *Coryna nubica* Marseul (Magema 1987).

Les méloïdes sont également présents au Niger et au Tchad (Gahukar 1991).

En plus du mil, ils ont comme hôtes secondaires d'autres plantes cultivées telles que le sorgho, le maïs, l'arachide, le niébé, le gombo, le pois d'angole et des adventices comme *Tephrosia* sp, *Sesbania sesban*, *Acacia* sp, *Echinochloa* sp, *Dactyloctenum aegyptium* et *Pennisetum* sp (Gahukar et al. 1989, Magema 1987).

Les méloïdes se nourrissent de pollen et de stigmates ou des fleurs. La récolte est directement affectée car les grains qui ne sont pas formés. Selon Zethner et Laurense (1988) les méloïdes s'attaquent aux grains de mil au stade laiteux et ils vident le contenu.

Les méloïdes sont actifs le matin et au crépuscule, la femelle après accouplement creuse des trous dans lesquels seront déposés les oeufs. Une femelle pond en moyenne 83–135 oeufs (Doumbia et Bonzi 1986), l'incubation dure 10 à 13 jours pour les *Psalydolytta* et 15 jours pour *M. holosericae* (Doumbia et Bonzi 1986). Les larves à l'eclosion se nourrissent d'oeufs d'acridiens pour entamer leur cycle de développement qui sera interrompu pendant l'intersaison. La reprise du développement a lieu dès les premières pluies. L'abondance des méloïdes est associée généralement à la floraison des cultures.

Méthodes de lutte

La première pratique utilisée pour combattre les méloïdes est leur ramassage et leur destruction par le feu. La seconde méthode consiste à attirer les méloïdes avec les fruits du baobab (*Adansonia digitata*) et à les brûler dans le champ. Les expérimentations effectuées en Gambie ont montré que l'effet est très limité (Zethner et al. 1986).

La troisième méthode est basée sur l'utilisation du feu. Au Mali et au Bénin il a été constaté que la fumée issue du brûlage de pneus ou des cantharides ramassés ont un effet répulsif sur les méloïdes. En Gambie l'utilisation du feu durant une nuit a réduit la population de *P. fusca* de moitié (Zethner et Laurense 1988, Mbenga 1992).

Ces différentes pratiques utilisées par les paysans ne sont pas quantifiées pour connaître leur efficacité dans le contrôle des méloïdes.

Dans les pays du Sahel, les variétés de mil précoces semées en retard souffrent de l'attaque des ravageurs (Zethner et Laurense 1988). Les variétés à cycle long, par contre, sont moins attaquées car leur floraison coïncide avec le moment où la population de méloïdes décline. Les méloïdes ayant comme plantes hôtes secondaires des adventices, il est important de procéder au nettoyage des alentours du champ. Zethner et Laurense (1988) ont constaté que les variétés aristées sont moins attaquées que les variétés non aristées. Ceci n'est pas toujours vérifié car au Mali il a été constaté que même les variétés aristées ne sont pas épargnées lors de l'attaque des méloïdes (Doumbia et Bonzi 1986, Touré 1993).

La lutte chimique reste une voie essentielle, la seule utilisable à court terme, mais elle est non rentable dans le cas de la culture du mil de productivité faible. Plusieurs insecticides sont apparus efficaces dans le traitement du mil contre les méloïdes.

En Gambie il a été constaté que l'utilisation du carbaryl à 1275 g m.a. ha^{-1}, du trichlorphon à 400–1200 g m.a. ha^{-1} et du malathion à 500–750 g m.a. ha^{-1} a réduit la population de *P. fusca* de 72% sur le mil précoce (Zethner et Laurense 1988).

Au Mali, la deltaméthrine à 12 g m.a. ha^{-1}, le carbosulfan à 500 g m.a. ha^{-1} et le diazinon à 250 g m.a. ha^{-1} ont donné de très bons résultats dans la lutte contre les méloïdes (Doumbia et al. 1989). En Mauritanie, le traitement du mil avec le propoxur 2% à 12 kg ha^{-1} et le fénitrothion 2% (8 kg ha^{-1}) a réduit les pertes de rendement dues à *P. vestita* à 14% (Magema *in* Doumbia 1992).

Des parasites diptères du genre *Heliocobia* sont récoltés sur les adultes de *Mylabris holosericea* (Doumbia et Bonzi 1985).

Les Scarabaeidae

Pachnoda interrupta (Olivier) (Cetoniinae)

Lock et Mahmoud (1989), et Lock et al. (1988) ont indiqué qu'il y a une espèce de la sous-famille des Cetoniinae du genre *Pachnoda* qui est incluse dans le complexe des coléoptères ravageurs du mil. Le genre *Pachnoda* contient 130 espèces (Krikken 1984) mais l'espèce nuisible au mil au Mali est *Pachnoda interrupta* (Olivier).

Pachnoda interrupta est une espèce univoltine, les adultes passent la saison sèche dans les sols. Ils réapparaissent avec les permières pluies. Les femelles pondent les oeufs dans le sol. Une femelle pond en moyenne 24 oeufs et l'incubation dure 5 à 9 jours. Les larves passent par 3 stades. La nymphose dure environ 12 jours. Le cycle de développement de l'oeuf à la nymphose dure 45 jours. Les études ont montré que *Pachnoda interrupta*, en plus du mil, sévit sur d'autres plantes: *Mangifera indica* (Anacardiaceae), *Balanite aegyptiaca* (Zygophyllaceae), *Guiera senegalensis* (Combretaceae) et *Ziziphus mucronata* (Rhamaceae).

Au Mali des études ont montré que les dégâts causés par *Pachnoda interrupta* sont plus importants que ceux occasionnés par les sautériaux. En cas de forte pullulation, par exemple, 10 individus par épi occasionnent 50% de pertes de récolte (Lock et al. 1988). *Pachnoda interrupta* attaquant le mil au stade grains laiteux (Schmutterer 1969), les raisons de sa pullulation ne sont pas connues.

Rhinyptia infuscata Burmeister (Rutelinae)

Les adultes de *R. infuscata* sont trouvés en abondance la nuit au stade de floraison mâle sur les épis du mil dont ils dévorent les anthères. Le niveau de population varie entre 15 et 25 par chandelle. Ce déprédateur a sévi durant toute la période de floraison du mil. Ce ruteline est responsable des cas d'avortement de fleurs, mais il y a pas eu d'évaluation des dégâts. *Rhinyptia infuscata* est présent au Niger, au Mali (dans la zone de Koporo) et au Bénin il commence à prendre une importance particulière.

Les héteroptères piqueurs suceurs

Ils sont très répandus et présents partout en Afrique de l'Ouest. Ils sont la plupart du temps polyphages et piquent les grains au stade laiteux qui se rident et se couvrent de petites taches noires. La qualité des grains et les rendements sont dépréciés. Les grains attaqués sont parfois couverts de champignons. Les dégâts peuvent être très importants. Les principales familles nuisibles au mil sont les suivantes:

Les Pentatomidae. Dans cette famille les genres revêtant une importance sont: *Aspavia, Agonoscelis, Nezara* et *Diploxys*.

Les Coreidae. Les coréides qui sévissent sur le mil sont des espèces polyphages, les plus courantes sont *Acanthomia horrida* (Germar), *Mirperus jaculus* (Thunberg) et *Riptortus dentipes* F.

Les Pyrrhocoridae. Dans cette famille *Dysdercus voelkeri* Schmidt est la seule espèce qui attaque le mil. Il est présent partout où le mil est cultivé. Son impact économique sur la culture du mil n'a jamais été étudié.

Les Miridae. L'espèce *Creontiades pallidus* Rambur est la seule que l'on rencontre sur le mil.

Les acridiens

Plusieurs espèces de sautériaux et de criquets tels que *Oedaleus senegalensis* Krauss s'attaquent aux grains de mil à tous les stades de la maturation. A un stade très précoce l'épi est mangé jusqu'au fuseau. Au stade laiteux on observe des dégâts en profondeur, les glumes sont épargnées. Les pertes économiques occasionnées par les sautériaux ne sont pas déterminées. D'importants dégâts de *O. nigeriensis* sur le mil ont été remarqués en Mauritanie et au Niger (Mbaye 1992).

Autres insectes de l'epi de mil

Les chenilles de *Eublemma gayneri* Rothschild (Lepidoptera, Noctuidae) sont plus petites que celles de

H. albipunctella. Elles vivent dans l'épi. La répartition de cette espèce n'est pas connue et ses dégâts peuvent être importants mais moins caractéristiques.

Les larves se nourrissent des graines tendres et elles préfèrent les épis compacts qu'elles souillent de leurs excréments. Les épis ainsi souillés sont couverts de champignons. Les effets combinés de l'attaque des chenilles et des champignons contribuent à la dépréciation des grains.

Les chenilles de *Helicoverpa armigera* Hübner (Lepidoptera, Noctuidae) sont très proches de celles de *H. albipunctella*. Elles sont polyphages; sur le mil les chenilles s'attaquent aux fleurs, aux graines tendres qu'elles détruisent. Sur les épillets on retrouve les déjections des larves. Les dégâts peuvent être importants.

La chenille poilue *Amsacta moloneyi* (Druce) (Lepidoptera, Arctiidae) plus connue sur l'arachide et le niébé a commencé à s'attaquer à la culture du mil à la suite des longues années de sécheresse qui sont intervenues dans le Sahel. Elle s'attaque aux jeunes plants et aux épis en fin de cycle. D'importants dégâts imputables à cette espèce ont été constatés au Sénégal et dans plusieurs autres pays du Sahel (Mbaye 1992).

Forficula senegalensis Serville (Dermaptera, Forficulidae) est cosmopolite et on le rencontre dans toutes zones de culture du mil. Des oeufs pondus dans le sol ou dans les cornets sortent des larves qui restent grégaires. Les forficules se cachent dans les épis en rongeant les étamines et grattent les grains mais leur importance économique n'est pas déterminée.

Conclusion

Les insectes des épis les plus susceptibles de causer des dommages et d'affecter la productivité du mil sont surtout les Coléoptères du genre *Psalydolytta* parce qu'ils attaquent généralement les grains. A l'heure actuelle aucune variété n'est ni tolérante ni résistante à leur attaque. Seule la lutte chimique vient à bout à ce ravageur. Dans certains pays du Sahel les paysans ont dû abandonner la culture du mil à cause de ce méloïde.

La chenille mineuse de l'épi, *H. albipunctella* vient en deuxième position du point de vue des dégâts. D'autres insectes ont fait leur apparition et prennent de plus en plus le statut de sérieux ravageurs du mil tels que *R. infuscata* et *P. interrupta*.

En dehors de la chenille mineuse sur laquelle un certain nombre de travaux ont été effectués, très peu d'informations existent sur ces ravageurs. Il est donc nécessaire, voire capital que des études plus profondes soient entreprises sur la biologie et l'écologie de ces prédateurs en vue d'une meilleure compréhension de la dynamique des populations, et de la définition précise du niveau de dégâts économiques. Il est aussi important de mettre au point des méthodologies normalisées de criblage des variétés de mil tolérantes ou résistantes à ces ravageurs, d'étudier les interactions avec les ennemis naturels. Actuellement, ce dont on a surtout besoin, c'est une combinaison des différentes méthodes de lutte efficaces et peu coûteuses à mettre à la portée du paysan.

Extended summary

Panicle insect pests of pearl millet in West Africa. Pearl millet, a staple food in West Africa, is attacked by a complex of insect pests. Yields remain low, 200 to 400 kg ha^{-1} on average, due to damage by various pests, including insects. The combined effects of the different millet pests result in about 50 to 80% yield loss.

Panicle pests generally appear late in the cropping season, and directly attack grains or plant tissues involved in grain formation. They are divided into four main groups based on the damage they cause: head mining caterpillars, Dipteran species, beetles, and sucking insects.

The millet head miner (MHM) *Heliocheilus albipunctella* (de Joannis) is the most damaging species in a complex of a dozen mining caterpillars. It was responsible for yield losses ranging from 13 to 85% in 1974–76 in Senegal. It causes about 6% loss in Niger, and over 50% in Mali.

Biological control is promising, although there is a need for more information on natural enemies. The braconid microwasp *Bracon hebetor* Say is an effective parasitoid of MHM. Chemical protection with insecticides such as endosulfan are also effective, although they are generally neither economical nor practical. Deep plowing and urea or superphosphate application reduce infesting populations. Millet cultivars Souna, 3/4 HK-78, IBV 8001, and ICSM 7819 are resistant to MHM attacks.

Millet midge *Geromyia penniseti* (Felt) is the most common and abundant species of Diptera pests and is to be found across all millet-growing areas. It occurs mainly on long-duration cultivars. Destruction of the infested panicles of millet and weeds is the main method of controlling the midge.

Several beetles (Coleoptera) attack millet, the most important belonging to the genera *Psalydolytta, Pachnoda* and *Rhinyptia.*

Psalydolytta blister beetles (Meloidae) are of economic importance. In the Gambia, they cause losses of about 4 to 48%; losses can be as high as 92 to 100% in Mali, Mauritania, and Senegal. A control method consists in collecting and burning blister beetles. Long-duration cultivars are less attacked. Good results were also obtained with insecticide application, especially carbaryl (1275 g a.i. ha^{-1}) and malathion (500 g a.i. ha^{-1}).

Among scarabeid beetles, *Pachnoda interrupta* Olivier is the most damaging of chafer beetles (Cetoniinae). They can cause up to 50% loss in case of heavy infestation. *Rhinyptia infuscata* Burm. (Rutelinae) is reported to cause floret abortions, but no data on yield loss are available.

The major millet Heteropteran head bug species which cause considerable damage, belong to Pentatomidae, Coreidae, Pyrrhocoridae, and Miridae.

Other panicle insect pests of millet include different grasshopper species such as *Oedaleus senegalensis* Krauss, and locusts which attack millet grains at all stages of its development.

Lepidopteran caterpillars of *Eublemma gayneri* Rothschild, *Helicoverpa armigera* (Hübner), *Amsacta moloneyi* (Druce) feed on soft millet grain that they soil with their feces.

Forficula senegalensis Serville (Dermaptera: Forficulidae) feeds on anthers and on the surface of the grains, but its actual economic impact is unknown.

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Insect Pests of Sorghum Panicles in Eastern and Southern Africa

K Leuschner[1]

Abstract

This paper gives an overview of the panicle insect pest situation in southern and eastern Africa. Sorghum panicle insect pests were of little importance in long-duration African landrace sorghums in southern and eastern Africa, but this situation could change with the development of new high-yielding, short-duration cultivars with more compact panicles, and the changing agronomic practices. Head bugs, Helicoverpa, *and the armoured cricket have recently become important. This paper discusses pest biology, wherever known, the effect of agronomic practices on pest populations, and possibilities for control under farmers' field conditions. Some recommendations for future research are also presented.*

Introduction

Panicle insect pests of sorghum are an important group in the total insect complex attacking sorghum in Asia, the Americas, and West Africa. In eastern and southern Africa, this group of insects, mainly bollworm, head bugs, sorghum midge, and aphids, occur to a much lesser extent than they do in Asia, the Americas, and West Africa.

Very little attention has been paid to this group of insects since they were not economically important in traditional landrace sorghums grown by farmers. Moreover, entomological research in southern Africa has been mainly directed to commercial crops. Until recently, subsistence crops like sorghum have received little attention. However, the armoured cricket (*Acanthoplus speiseri*) is a pest of considerable importance in some parts of southern Africa, and panicle insects are important in the commercial farm sector in Botswana, South Africa, and Zimbabwe.

From experiences in West Africa and Asia, the change from traditional to new, high-yielding sorghum cultivars with shorter crop maturity cycles and more compact head types may, in the near future, increase panicle insect problems in eastern and southern Africa. This is already evident in some farm sectors in Botswana, Tanzania, and Zambia where improved cultivars have been used.

Sorghum Panicle Insects in Eastern and Southern Africa

From reports (Leuschner 1988, Guiragossian 1986, Sithole et al. 1987), field handbooks, and personal communication with national scientists in eastern and southern Africa, the following sorghum panicle insect species have been identified in the region (Table 1). This list is by no means exhaustive and also does not include the group of storage insects where infestation of sorghum grain begins in the field.

Relative importance of panicle insect pests in eastern and southern Africa

Efforts have been made by Sithole et al. (1987), Leuschner (1988) and Guiragossian (1986) to rate sorghum insect pests in southern and eastern Africa based on their reported importance in each country (Tables 2 and 3). This information still needs to be verified under farmers' field conditions since it was compiled mostly from research station observations.

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Table 1. Sorghum panicle insects identified in eastern and southern Africa.

Species	Common name	Countries
Acanthoplus speiseri	Armoured cricket	Malawi, Namibia, Tanzania, Zambia, Zimbabwe
Dysdercus fasciatus	Cotton stainer	Botswana, Zambia
Nezara viridula	Green stink-bug	Botswana, Malawi, Tanzania, Zimbabwe
Calidea dregii	Blue-green cotton bug	Botswana, Malawi, Tanzania
Lygaeus elegans	Red and black bug	Botswana
Eurystylus spp	Mirid bug	Botswana, Zimbabwe
Taylorilygus spp		Botswana, Ethiopia
Rhopalosiphum maidis	Corn leaf aphid	All SADC countries[1]
Melanaphis sacchari	Sugarcane aphid	Botswana, South Africa, Zambia, Zimbabwe
Contarinia sorghicola	Sorghum midge	All SADC countries
Helicoverpa armigera	Bollworm	All SADC countries
Eublemma brachygonia	Seed head caterpillar	Botswana
Astylus atromaculatus	Spotted maize beetle	Lesotho, South Africa

1. Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe.

Table 2. Relative importance of sorghum panicle insect problems in eastern African countries.[1]

	Burundi			Ethiopia			Kenya			Rwanda			Somalia			Uganda		
Insects	H[2]	I	L	H	I	L	H	I	L	H	I	L	H	I	L	H	I	L
Head bugs	6[3]	6	6	8	5	5	-	8	10	9	9	9	-	8	8	-	7	4
Aphids	5	10	10	5	5	5	-	8	3	8	8	8	-	5	5	-	5	5
Midge	10	10	10	10	6	10	-	2	8	9	9	9	-	10	2	-	10	2
Bollworm	10	8	2	5	5	5	-	8	10	9	7	6	-	-	3	-	6	5

1. Adapted from Sithole et al. 1987, Leuschner 1988, and Guiragossian 1986.
2. H = Highland (1800–2500 m), I = Intermediate (1400–1700 m), L = Lowland (0–1300 m)
3. On a scale of 1–10, where 1 = high priority for research, and 10 = low priority for research.

Table 3. Relative importance of sorghum panicle insect problems in southern African countries.[1]

Insects	Botswana	Namibia	Malawi	Mozambique	Lesotho	Zambia	Tanzania	Zimbabwe
Armoured cricket	4[2]	5	1	-	-	4	1	4
Head bugs	4	1	1	1	1	2	2	2
Aphids	4	2	4	2	3	3	3	3
Midge	1	1	2	3	-	1	2	1
Bollworm	4	1	1	1	-	2	2	3

1. Adapted from Sithole et al. 1987, Leuschner 1988, and Guiragossian 1986.
2. On a scale of 1–5, where 1 = low importance, and 5 = high importance.

Biology, Ecology, and Yield Loss

Armoured cricket

The armoured cricket is a pest of lower-altitude areas (400–800 m) of southern Africa, where there is rainfall up to 700 mm and a long, distinct, initially cool and later hot, season (7–8 months). Extended rains in Apr/May reduce egg populations in the soil and excessive rains in Jan reduce first instar nymphal populations. Cricket populations are high in cultivated areas, but low in bushland and forest areas.

Nymphs develop on the generative parts of grasses and broad-leaf weed species. The last nymphal and adult stages attack sorghum from anthesis to dough grain stage (Musonda and Leuschner 1990), during which period they feed on flowers and developing grain until physiological maturity.

The population densities of crickets vary within infested regions. Availability of food during nymphal development is an important factor. Usually weed-free fields are free of infestation as long as food is available in the surrounding areas. Flowering in sorghum coincides with the maturity of weed seeds, which are not preferred by the cricket, thus resulting in their migration into sorghum fields.

Yield losses in sorghum and pearl millet are estimated to be between 10 and 80%, depending on the population densities of crickets. Overall yield loss in Zambia and Namibia is estimated at 20% (K Leuschner, unpublished). There are few recorded natural enemies, the main ones being storks and praybirds. The potential of the armoured cricket as a major pest has been aggravated by the increase in the bushland that is being cultivated. The situation in Ovamboland in Namibia is a good example.

Head bugs

The complex of head bug species is presently of limited importance in eastern and southern Africa. Adults and nymphs suck sap from the developing grain. Nymphal development depends on the availability of immature grain with high free-water content.

Traditional landrace sorghums in eastern and southern Africa flower in 150 days or more. Anthesis occurs after the peak of the rains, and since the grain matures under declining rainfall and humidity, these conditions do not favor head bug development. Lower head bug populations are also associated with loose-panicled types (traditional landrace sorghums) (Nwanze 1985), which allow for good aeration, low humidity within the head, and easy access of natural enemies to adults and developing nymphs. However, in West Africa, traditional varieties with these plant characteristics were sometimes heavily infested and damaged (Teetes and Gilstrap 1990). Outbreaks of head bugs in southern and eastern Africa are mainly associated with newly developed compact-panicled, short-duration cultivars (120–130 days). Poor agronomic practices such as staggered sowing have also been associated with severe head bug damage.

Outbreaks have been observed on research stations such as Matopos (Zimbabwe), Kasinthula (Malawi), Dakata and Didesa (Ethiopia), and in commercial and semi-commercial production fields in Pandamatenga (Botswana), and the Kilimo/Sasakawa-Global 2000 management training plots in Tanzania. Actual yield losses caused by head bugs in eastern and southern Africa are not well defined. Over 100 adults and nymphs per panicle (several head bug species) were observed during a survey in Pandamatenga, and in Tanzania, more than 20 *Calidia* nymphs per sorghum head (Tegameo) were recorded during another survey. From research in West Africa, there is evidence that *Eurystylus* sp causes yield, germination and quality loss (Sharma et al. 1992, Teetes and Gilstrap 1990). At Pandamatenga, farmers claim that head bugs reduce yield and germination, and consequently, at least one insecticide spray is applied to the crop.

The lesson to be learned from the present situation is that head bugs are a potential threat to sorghum production, especially when new high-yielding, compact-panicled varieties are grown on a large scale, both by small and commercial farmers.

Aphids

The corn leaf aphid *Rhopalosiphum maidis* and the sugarcane aphid *Melanaphis sacchari* are mainly leaf feeders, but are known to infest sorghum heads also. Both aphids suck sap from sorghum leaves and head parts. The importance of the corn leaf aphid is questionable especially during the seedling-to-whorl stage. No clear yield reduction has been observed.

Population buildup of the sugarcane aphid begins 3 weeks after crop germination (van Rensburg 1973) and in South Africa, very high populations have been observed after the flag leaf stage. As many as 30 000 aphids per plant have been reported. The main impact on yield loss occurs from the flag leaf stage (van Rensburg 1973) and panicle infestation is probably of less importance in grain yield reduction, although it increases threshing difficulties.

Aphid densities rapidly decline 2–3 weeks after peak abundance. This has been attributed to high aphid densities, poor host conditions (van Rensburg 1973), and increased natural enemy populations. In southern Africa, the important predator species are ladybird beetles, *Cheilomenes propinqua*, *C. lunata*, *C. sulphurea*, and a syrphid fly, *Xanthogramma aegyptium* (van Rensburg 1973, Bohlen 1973, Schmutterer 1969). Several parasitoids are associated with aphid populations, but they are generally less important (van Rensburg 1973).

Drought stress conditions such as those that occur between the short and long rains in Ethiopia (Tadesse 1986) and in Jan in Zimbabwe are favorable to the sugarcane aphid. High plant density promotes low plant vigor but reduces aphid population buildup (Flattery 1982, van Rensburg 1979). Based on surveys conducted during 1989–82 in Pandamatenga (Botswana) and observations in Tanzania, Zambia, and Zimbabwe, staggered sowing leads to very high aphid populations in late Feb to Apr, which may require chemical protection against the sugarcane aphid. A similar situation was observed in the Zambezi Valley of Zambia. High populations frequently occur in research stations in Malawi (Kasinthula) and Zimbabwe (Matopos). Yield loss estimates in Botswana (Flattery 1982) and Zimbabwe (Page et al. 1985) range between 46 and 78% annually without insecticide control. No yield loss reports are available from eastern Africa. The potential increase of the sugarcane aphid is high in newly released sorghum cultivars which, in most cases, are susceptible to this insect pest.

Sorghum Midge

Sorghum midge (*Contarinia sorghicola*) is currently a minor sorghum panicle pest in eastern and southern Africa, and no severe outbreaks have been reported in farmers' fields, even on long-duration traditional landraces. Midge outbreaks have been reported from the following research stations: Kasinthula (Malawi), Chokwe (Mozambique), Matopos (Zimbabwe), Hombolo (Tanzania), Alupe (Kenya) (Ochanda 1986); Serere (Uganda) (Esele 1986); and in Sudan (Schmutterer 1969) and Ethiopia (Tadesse 1986). These midge outbreaks were associated with late sowing of improved short-duration sorghums. In Maharashtra, India, midge populations and damage increased dramatically on local landraces when farmers grew short-duration, high-yielding sorghum cultivars alongside local cultivars. Regions of potential midge outbreaks include the Caprivi area of Namibia; north Botswana; the Zambezi Valley of Zambia; coastal areas of Mozambique, Tanzania, and Kenya; the Victoria Lake districts in Tanzania and Kenya; and the southern Sudan.

Bollworm

Although *Helicoverpa* is considered an important panicle insect pest in eastern and southern Africa (Dennis 1983), it is still of low importance in small-scale farmers' fields. However, this is not the case with large- and medium-scale commercial sorghum producers who grow newly developed, high-yielding cultivars. Severe outbreaks have been observed in Botswana and Zambia (K Leuschner, unpublished) and reported from Ethiopia (Tadesse 1986) and Tanzania (Bohlen 1973). There are no documented reports on sorghum yield losses in eastern and southern Africa.

The bollworm has a wide range of host plants which include dry-season irrigated vegetables (tomato, okra, capsicum) and rainfed crops (maize, cowpea, pearl millet, sorghum, sunflower, and cotton) (Dennis 1983). This cropping pattern ensures that the insect is present all year round. In Pandamatenga, Botswana, light trap catches indicate that population buildup is slow from May until Nov, increases during Dec to Jan and peaks in Feb, Apr, and May (SADC/ICRISAT, unpublished). Sorghum sown in Dec and Jan can be heavily attacked and up to 15 larvae per head have been recorded. Staggered sowing of sorghum favors pest population buildup since panicles at the susceptible stages provide a continuous food source, as was noticed at Pandamatenga in Botswana. Denser heads harbor more larvae than do open heads (Tadesse 1986). All stages of the bollworm are attacked by natural enemies (Roome 1975). These are mainly parasitoids and include the egg parasitoid *Trichogramma* spp, and the larva parasitoid *Apanteles* sp. Levels of egg parasitism as high as 50% have been recorded in farmers' fields in Botswana. Up to 60% mortality of full grown larvae due to unidentified microbial organisms has been observed. As with head bugs, our observations indicate that *Helicoverpa* is a pest of potential economic importance in eastern and southern Africa, especially with the large-scale introduction of new cultivars.

Control

Current control methods in small-scale sorghum production

Traditional small-scale farming in eastern and southern Africa includes low-input systems with low yields (600 kg ha^{-1}), but stable production. Mostly traditional landraces are grown, and crop protection measures against sorghum insects are seldom or never practiced. Except for occasional outbreaks, due sometimes to an unusually prolonged rainy season, sorghum panicle insect pests are of low economic importance for the following reasons:

- Traditional cultivars are long-duration types (150 days to maturity) and flower and set seed late in the season under declining rainfall conditions. Such conditions are not favorable for the buildup of head bugs, aphids, midge, and bollworm. In outbreak areas in southern Africa, the armoured cricket is the only panicle pest of significance, since it is still present when traditional cultivars flower and set seed.
- Loose heads of traditional cultivars harbor fewer head bugs, aphids, midge, and bollworm (Tadesse 1986).
- Although sowing dates are staggered around the equator, farmers in Kenya and Tanzania grow photoperiod-sensitive cultivars which flower uniformly late in the rainy season in Kenya and Tanzania. In other countries where photoperiod-nonsensitive cultivars are grown, the best sowing dates are practiced, e.g., end Nov to early Jan in southern Africa, Jul in Sudan, and Oct in Somalia, which ensures that long-duration cultivars flower after the peak of the rainy season.
- In traditional farming in eastern and southern Africa, sorghum is usually intercropped with legumes. These include cowpea (Botswana), groundnut (Sudan), and pigeonpea in Kenya (Geddis 1990). It is believed that intercropping legumes with cereal crops enhances the population of natural enemies (Matteson et al. 1984).

Current control methods in commercial sorghum production

With the introduction of improved, high-yielding sorghum hybrids and varieties, plant characteristics associated with reducing panicle pest damage may have become modified. For example, the newly developed sorghum cultivars are of short duration (120–130 days) in order to avoid terminal drought. They possess compact panicles for increased yield potential and shorter glumes for ease of threshing.

Commercial farming is characterized by monocropping for ease of mechanization, but this simplifies the agroecological environment in terms of insect diversity. Under staggered sowing conditions, flowering and seed development occur over a long period during high rainfall conditions which favor population buildup of head bugs, midge, and bollworms. This situation already exists in Pandamatenga, Botswana, where farmers now need to spray up to two times against head bugs, bollworms, and the sugarcane aphid. Other examples are of the Zambezi Valley of Zambia, where a new sorghum cultivar was sprayed against the sugarcane aphid and bollworm during the 1992/93 season; sorghum and pearl millet crops in Matopos, Zimbabwe, were sprayed against bollworms, and in South Africa, sorghum is regularly sprayed against bollworms and aphids.

Suggested Research on Future Control Strategies

The following suggested areas of research on the control of sorghum panicle pests are based on research in West Africa, India, and USA:

Cultural Control

- Early sown, shorter-duration cultivars will flower and set seed at a time when head bug, bollworm, midge, and armoured cricket populations are low. Uniform sowing of similar-duration cultivars will reduce the susceptible period in sorghum. Hybrids may be excellent candidates for this type of control because they flower uniformly.
- Various intercropping systems should be studied for their value to increase insect diversity and enhance natural enemy populations.
- Field sanitation by burning, crop residue removal, and early plowing can reduce insect carry-over populations. In southern Africa, regrowth from crop stubble flower and set seed in Jan. These volunteer crops encourage the buildup of head bugs, aphids, midge, and bollworm, and could be carried over to the next major crop.

Resistance

The development of resistant cultivars holds good possibilities. Midge-resistant cultivars are already available in India and USA. For the sugarcane aphid, sources of resistance have been identified in Botswana (Manthe 1992). In the absence of sorghum genotypes with high levels of resistance against most insect pests, cultivars that support lower population levels should be encouraged. Teetes and Gilstrap (1990) reported the availability of sorghum cultivars which suffer less than 10% damage under *Eurystylus* infestation in West Africa. The development of less compact-panicled sorghums in commercial sorghum production for the reduction of bollworm, head bug, and aphid populations should receive added emphasis.

Biological control

Research on biological control should endeavor initially to identify indigenous beneficial species associated with the main panicle insect pests. Methods to augment the most effective ones should be investigated. For *Helicoverpa*, lessons should be taken from India and Australia, and if necessary, the introduction of exotic species should be considered.

Insecticides

Insecticides are currently being used against panicle pests in eastern and southern Africa. Economic threshold levels (ETLs) on which farmers should base their decision to spray are not available for any of the sorghum panicle pests. Therefore, first priority should be placed on the determination of ETLs for the major panicle insect pests. For the armoured cricket, baiting methods for control should be developed to reduce usage of insecticide.

Integrated pest management

There is a real potential danger in eastern and southern Africa that insecticides alone could be used for panicle insect pest control as soon as these become more important in small- and large-scale commercial farming. This will be very costly for the farmers and disastrous for the environment. The development of integrated pest management (IPM) systems will help to reduce this danger.

The various control options discussed above should, whenever possible, be used as components of pest management strategies. Specifically, for panicle insects that would usually attack sorghum florets and developing grain over a period of 4–5 weeks (armoured cricket, bollworm: 4–5 weeks; head bugs: 4 weeks; midge: 1 week), IPM offers a good possibility for control with minimum insecticide use. Research on the development of an IPM system for the control of the armoured cricket is being done in Namibia in the SADC/ICRISAT program. Good field hygiene after harvest and early and uniform sowing can reduce the susceptible window for attack and insect development. Resistant and less compact-headed types could help to further reduce the population.

Augmentation of natural enemies through crop diversity and intercropping systems can also contribute to stabilizing the sorghum production system.

Synthèse

Les insectes nuisibles des panicules de sorgho en Afrique orientale et australe. Les insectes nuisibles aux panicules de sorgho sont actuellement peu importants en Afrique orientale et australe où des variétés locales de sorgho sont largement cultivées par des paysans. Cependant, cette situation pourrait changer avec l'introduction à grande échelle des cultivars améliorés à haut rendement. Des enquêtes sur la dynamique des peuplements des ravageurs conduites aux stations de recherche ainsi qu'aux champs paysans commerciaux et à petite échelle indiquent que la pullulation est forte sur les nouveaux cultivars de sorgho. Les principaux insectes nuisibles associés à ce changement sont le grillon (*Acanthoplus speiseri*), les punaises des panicules, les pucerons et les vers de la capsule du cotonnier. Pour chacune de ces espèces, de brèves descriptions de la biologie, l'écologie et la relation plante-hôte associées avec le développement des populations sont présentées.

Le plus important facteur lié à l'accroissement des populations est le semis synchronisé des cultivars précoces (nouveaux) et tardifs (variétés locales). En outre, de nouveaux cultivars à forte productivité possédant des panicules compactes favorisent des pullulations des insectes paniculaires tels que les punaises, les pucerons et les vers de la capsule du cotonnier. Les pertes occasionnées par ces ravageurs sont mal connues. Des pertes de 20% de rendement en grain dû au grillon ont été signalées en Namibie et en Zambie. En Afrique du Sud et au Botswana, des dégâts causés par des pucerons sont de 46–78%.

L'infestation du ver de la capsule du cotonnier au Botswana peut atteindre jusqu'à 12 larves par plante. Tous ces dégâts ont été signalés sur les nouveaux cultivars à haut rendement.

Des mesures de lutte sont peu utilisées dans des champs paysans à petite échelle où des variétés traditionnelles sont cultivées. Ces variétés ayant un cycle long et des panicules lâches défavorisent l'attaque des insectes paniculaires. En plus, leur maturité coïncidant avec la fin de la saison des pluies et des conditions de l'humidité réduite limitent un développement important des ravageurs. La culture associée, généralement avec des légumineuses, peut entraîner un accroissement des ennemis naturels.

Par contre, dans des champs commerciaux, la monoculture des cultivars précoces et performants à panicules lâches est généralisée. Ce facteur lié aux semis échelonnés et des champs peu propres favorise un pic d'infestation. Des insecticides contre les insectes paniculaires sont souvent utilisés au Botswana et en Afrique du Sud. Dans les cas d'une sévère infestation, comme au Botswana, la culture de sorgho peut être pulvérisée jusqu'à quatre fois dont deux pulvérisations sont dirigées contre les pucerons et les vers de la capsule du cotonnier. Afin de réduire l'utilisation excessive des insecticides, la recherche doit être axée sur la mise au point des stratégies culturales améliorées et des cultivars résistants. La participation des agriculteurs dans l'évaluation des méthodes de lutte est indispensable à leur adoption. Selon notre expérience dans la région, une méthode associant la propreté des champs à un semis précoce et synchronisé des cultivars moins sensibles sert d'une base prometteuse pour la mise en place d'une stratégie de lutte intégrée.

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Insect Pests of Sorghum and Pearl Millet Panicles in Asia

B S Rana and B U Singh[1]

Abstract

In Asia, several species of midges, head bugs, head worms, and head beetles are associated with panicle damage in sorghum and pearl millet. Among them, Contarinia sorghicola *Coquillett in the Asia region;* Geromyia penniseti *Felt in southern India;* Calocoris angustatus *Lethiery in India, Myanmar, and Pakistan;* Nezara viridula *Linnaeus in Thailand;* Nysius plebejus *Distant in China;* Helicoverpa armigera *Hübner,* Euproctis subnotata *Walker and* Stenachroia elongella *in India and Thailand, assume greater importance than the others. In this paper, the distribution, economic importance, seasonal occurrence, nature of damage, and biology of important species are briefly described. The status of panicle pest spectrum has changed due to the introduction of medium-duration high-yielding cultivars to replace the long-duration traditional cultivars. The extent of avoidable grain yield losses and economic injury levels for sorghum midge and head bugs are also discussed. Cultural strategies which ensure escape from peak period of panicle pest occurrence are described. Although a few biological control agents have been identified, their effective role and establishment under field conditions remain unexplored. Chemical strategies are uneconomical and destabilize the environment. Current research efforts are focused on host-plant resistance to midge and head bug on sorghum, and to midge and head worms in pearl millet. These studies have led to the development of midge-resistant cultivars in sorghum. However, resistance to head worms in sorghum and to other panicle pests in pearl millet have not been as successful.*

Introduction

In Asia, sorghum is grown on 17.7 million ha with a total production of 17.1 t, and millets are grown on 18.4 million ha, with a total production of 14.2 t (FAO 1992). Countrywise, sorghum is grown on over 15 million ha in India, 1.6 million ha in China, and less than 0.5 million ha each in Pakistan, Thailand, Yemen, Iran, and Saudi Arabia. Bangladesh, Philippines, Sri Lanka, and Taiwan also produce sorghum. The major millet-growing countries include India (15 million ha) and China (2.23 million ha), and very little area is cropped to pearl millet in Pakistan, Nepal, and Myanmar (FAO 1992).

Economic Importance

In subsistence systems, long-duration cultivars were cultivated, which flower and mature when panicle pest populations are low. However, with the introduction of early-to-medium maturity, high-yielding varieties and hybrids, and changes in cultural practices, panicle pests have become a key limiting factor in sorghum and pearl millet production. A wide array of insect species attack sorghum and pearl millet from panicle exertion up to harvest, often with a direct effect on yields. The major panicle pests of sorghum and pearl millet are grain midges, head bugs, head worms, and head beetles (Seshu Reddy and Davies 1979, Gahukar and Jotwani 1980, Verma 1980, Srivastava 1985, Sharma and Davies 1987). The ecological distribution of economically important pests in Asia are listed in Table 1. Similar information is not available for pearl millet, although it is generally believed that infestations by panicle pests can result in severe crop damage.

In India, the estimated overall grain yield losses due to sorghum panicle pests average 4.6% (Leuschner and Sharma 1983). However, this figure varies

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Table 1. Distribution of economically important sorghum and pearl millet panicle pests in Asia.

Country	Midges	Head bugs	Head worms
Sorghum			
China		*Nysius plebejus*	
India	*Contarinia sorghicola*	*Calocoris angustatus* *Nezara viridula*	*Helicoverpa armigera* *Euproctis subnotata* *Mythimna separata*
Japan	*Contarinia sorghicola*		
Myanmar		*Calocoris angustatus*	
Pakistan	*Contarinia sorghicola*	*Calocoris angustatus*	
Philippines	*Contarinia sorghicola*		
Taiwan	*Contarinia sorghicola*		
Thailand		*Nezara viridula*	*Helicoverpa armigera* *Stenachroia elongella*
Pearl millet			
India	*Contarinia sorghicola* *Geromyia penniseti*	*Calocoris angustatus* *Nezara viridula* *Bagrada cruciferarum* *Leptocorisa acuta*	*Helicoverpa armigera* *Euproctis* spp

considerably over years. Losses due to midge and head bug in south India range from 15 to 30% for local sorghums (Ballard 1916), to 75% (Puttarudriah 1947), while in commercial cultivars, the losses range from 5.8 to 84.3% (Rao and Azam 1987) to 43–93% for head bugs alone in south India (AICSIP 1975–92, Sharma and Lopez 1989). Avoidable losses caused by head bugs were estimated at 89% for the commercial sorghum cultivar CSV 10, 70% for CSH 1, 40–55% for CSH 5, and 23–100% for CSH 9 (Leuschner and Sharma 1983). Panicle caterpillars have recently become important pests in India with grain yield losses of 18% (Rawat et al. 1970) to 34.8% in Madhya Pradesh (AICSIP 1975–92), and 44.3% in Delhi (Kishore and Jotwani 1982). *Helicoverpa armigera* Hübner alone causes 18–20% grain yield loss, corresponding to 717 kg ha^{-1} (Rawat et al. 1970). Avoidable losses of 12.83% and 14.16% have been reported in hybrids CSH 5 and CSH 9, which correspond to 518 and 665 kg ha^{-1} (Mote et al. 1986, Mote and Murty 1990). Data on economic injury levels (EILs) are available for midge and head bug (Table 2). Although this information is primarily for India, it shows that there are differences in EILs for different cultivars.

Panicle Pests

Grain midges

The sorghum midge, *Contarinia sorghicola* Coquillett is an economically important pest in India, China, Japan, Pakistan, and the Philippines. It was reported from India as early as 1914 (Fletcher 1914), and from the Philippines in 1918 (Felt 1919). Among the pearl millet midges, *Geromyia penniseti* Felt described by Felt (1920) is potentially an important pest on long-duration millets grown in southern India (Coutin and Harris 1968). The seasonal incidence of sorghum midge in India differs according to climatic conditions (Patel and Jotwani 1986), but generally appears in August, with population peaks in mid or late September, coinciding with the flowering of local photoperiod-sensitive cultivars (AICSIP 1965–92). In Tamil Nadu, four peaks of infestation occur in April, June, August, and October (AICSIP 1980–92, Natarajan and Chelliah 1985). Certain wild and uncultivated grasses, Sudangrass, Broom corn, pearl millet, sweet sorghum, *Sorghum almum* Parodi, and *Sorghum halepense* serve as alternate hosts. No detailed studies have been

Table 2. Economic injury levels (EILs) for sorghum midge and head bug in sorghum.

Pest	Insecticide	Economic injury level (per panicle)	Genotype	Country	Reference
Midge	BHC or endosulfan	0.7–2.7 adults (× 1.0)	CSH 5	India	
Midge		0.6 ovipositing adults		China	Shie-Cheng Hong (1987)
Head bug	Hexachlorocyclohexane	7.4 nymphs	CSH 5	India	Natarajan and Sundara Babu (1988a)
Head bug	Hexachlorocyclohexane	5.4 feedbug adults	CSH 5	India	Natarajan and Sundara Babu (1988a)
Head bug	Hexachlorocyclohexane	0.06 ovipositing adults	CSH 5	India	Natarajan and Sundara Babu (1988a)
Head bug	Malathion	15.1 nymphs	CSH 5	India	Natarajan and Sundara Babu (1988a)
Head bug	Malathion	10.5 feeding adults	CSH 5	India	Natarajan and Sundara Babu (1988a)
Head bug	Malathion	0.12 ovipositing adults	CSH 5	India	Natarajan and Sundara Babu (1988a)
Head bug	Methyl-S-demeton	1.3–1.4 bugs	CSH 1	India	Sharma and Lopez (1989)
Head bug	Methyl-S-demeton	0.2–0.4 bugs	CSH 5	India	Sharma and Lopez (1989)
		0.4–0.6 bugs	CSH 5	India	Sharma and Lopez (1989)
Head bug	Methyl-S-demeton	0.2–0.9 bugs	CSH 11	India	Sharma and Lopez (1993)
Head bug	Methyl-S-demeton	0.8–4.2 bugs	IS 9692	India	Sharma and Lopez (1993)
Head bug	Methyl-S-demeton	10–50 bugs	IS 17610	India	Sharma and Lopez (1993)
Head bug	Methyl-S-demeton	0.5–1.3 bugs	IS 21443	India	Sharma and Lopez (1993)

reported on the seasonal abundance of the pearl millet midge.

There are similarities in the biology of midges and their damage to sorghum and pearl millet. Damage is caused by larval feeding on the contents of the developing ovary leading to grain abortion. Glumes of infested florets retain their flat shape. The period of susceptibility varies from 5 to 8 days for individual panicles (from preflowering to complete flowering) to several weeks in fields depending on the variability in flowering. Under severe infestations, the entire panicle becomes blasted.

During the rainy season, the life cycle takes 2 weeks allowing 4–5 overlapping generations. But higher temperatures at flowering reduce population buildup (Patel and Jotwani 1986). At crop maturity, sorghum midge populations decline rapidly due to larval parasitization, and a good proportion of larvae also undergo facultative diapause.

Until the 1960s, the sorghum midge was a minor pest but gradually attained major pest status causing grain damage of 15.1% in 1966 and 19.8% in 1967 in Maharashtra (AICSIP 1965–68, Jotwani 1982). The first report of an epidemic outbreak came from Maharashtra in 1970 where high-yielding, short-duration cultivars had been introduced and resulted in 40–60% grain loss on local sorghums.

The primary component of midge control is identification of resistance sources, determining the components of resistance, and their potential use as resistance donors in improved high-yielding cultivars. Numerous germplasm accessions and elite breeding lines have been evaluated and resistant sources have been identified and utilized in AICSIP and ICRISAT programs (AICSIP 1969–92, Singh 1987, Agrawal and Abraham 1985). Among the identified resistant sources, the genotypes AF 28, DJ 6514, TAM 2566, SGIRL MR-1, ICSV 197, and DSV 3 (ICSV 745) have shown stability of resistance across different geographical locations (Rao et al. 1978, AICSIP 1980–92, Agrawal and Abraham 1985, Table 3). In Japan, the stability of resistance was not consistent in SGIRL MR-1 and TAM 2566 (Hagio et al. 1985). These resistant sources showed the presence of ovipositional antixenosis and antibiosis components and recorded low grain damage (Natarajan and Chelliah 1986). Sharma (1985) reported that the interaction of componental characters such as short and compact

Table 3. Promising sources of resistance to panicle pests of sorghum and pearl millet.

	Panicle pests		
Crop	Midge	Head bug	Head worms
Sorghum	AF 28	IS 2761	Chencholam
	DJ 6514	IS 9392	IS 2177C
	DSV 3 (ICSV 745)	IS 17610	IS 12537C
	ICSV 197	IS 17618	
	SGIRL MR-1	IS 17645	
	TAM 2566	IS 21444	
Pearl millet	HIB 111		HIB 111
	N 74		N 74
	PHB 12		PHB 12
	PHB 37		PHB 37

glumes, initial faster rate of ovary development and tannin content in the ripening grain contributed to the expression of resistance. Among the identified resistant sources, DJ 6514 was released in 1978 and DSV 3 in 1993 by the University of Agricultural Sciences, Dharwad, India, for cultivation in midge-endemic areas of Karnataka and parts of Tamil Nadu. In pearl millet, a high degree of multiple resistance to midge and head worms has been reported in four experimental hybrids, HIB 111, N 74, PHB 12, and PHB 37 (Prem Kishore 1991).

Under field conditions, three important larval parasitoids have been reported from India (AICSIP 1980–92) and the Philippines (Barrion and Litsinger 1982). Among them, *Tetrastichus diplosidis* Crawford is predominant during June-August, *Eupelmus popa* Girault appeared from August to November, and *Aprostocetus gala* Walker suppressed midge populations considerably from November to January. The former two parasites had a potential impact in lowering the sorghum midge populations, especially in western Maharashtra. As a supplement, Garg and Taley (1977) suggested using phosalone or endosulfan against midge to prevent their deleterious effect on parasitoid populations. Effective control of sorghum midge has also been achieved with the application of carbaryl, endosulfan, malathion and phosalone first at 90% panicle emergence and the second 4–5 days later.

Limited information is available on predators which include spiders, ants, anthocorids, mirids, mites, lacewings, and coccinellids. Among them, an anthocorid (*Orius maxidentex* Ghauri), and sorghum head bug (*Calocoris angustatus* Lethiery) were found predating on ovipositing midges of sorghum and pearl millet in India (Hiremath and Thontadarya 1983). The biology of *O. maxidentex* revealed that each bug consumes 16–24 midges during its life span of 22–42 days (Thontadarya and Rao 1987).

Head bugs

Several hemipterous bugs suck the sap of developing grain, causing serious losses to sorghum and pearl millet (Table 1). Among them, *Calocoris angustatus* is distributed widely in southern India (Ballard 1916, Cherian et al. 1941, Hiremath and Thontadarya 1984, Natarajan et al. 1989, Sharma and Lopez 1990). It has also become a serious pest in Maharashtra (Mote and Kadam 1984), and is reported to be spreading northwards. Its occurrence is higher on sorghum grown on Vertisols than that grown on Alfisols (Sharma and Lopez 1990). The seasonal abundance of sorghum head bug reaches peak levels from mid-September to October in Andhra Pradesh, Karnataka, and Tamil Nadu. In Karnataka, it occurs throughout the year except from March to May (Hiremath and Thontadarya 1984), but in Tamil Nadu, severe infestations occur in Apr and Jul sowings than in sorghum sown in early Jun or Sep. Higher populations have been recorded on ratoon crops than on the main crops in all sowings (Natarajan et al. 1989).

The sorghum head bug feeds primarily on the developing grain. The extent of damage depends on the bug population per panicle, duration of infestation, and panicle development stage. Infestation during early grain development results in more severe damage than at the hard dough stage. Both adults and nymphs cause reduction in mass, quality, and 30–100% loss in the germination of seeds (Cherian et al. 1941, Mote and Jadhav 1990). The dry matter production of seedlings from infested seed (45.4 mg) was significantly lower than that from healthy seeds (86.2 mg) (Natarajan and Sundara Babu 1988b). Moreover, the damaged grain show red-brown feeding punctures and are predisposed to mold infections.

The biology of *C. angustatus* was first described by Ballard (1916), and detailed investigations followed subsequently in other southern Indian States (Cherian et al. 1941, Natarajan and Sundara Babu 1987, Sharma and Lopez 1990, Hiremath and Viraktamath 1992). Adults are attracted at the pre-anthesis stage, and eggs are laid between the glumes of a floret. Among the five nymphal stages, the fourth instar consumes the maximum food from the developing grain (Natarajan and Sundara Babu 1988a), while adults consume thrice the quantity consumed by fourth instar nymphs. Two to three overlapping generations may occur on the same crop. *Calocoris angustatus* also feeds on pearl millet and maize foliage and inflorescence, both during the rainy and postrainy seasons, and in summer, it survives on the sorghum crop (Sharma and Lopez 1990).

Few sources of resistance with consistently low panicle damage rating have been identified (AICSIP 1983–92, Table 3). Resistant genotypes have long glumes and cover the grain over a period of 20 days after flowering, compared with 6–8 days in the susceptible controls CSH 1, CSH 5, and CSH 9 (Sharma and Lopez 1992). This may possibly restrict the effective feeding period of bugs on the exposed grain. In general, it has been observed that loose-panicled genotypes harbor greater bug numbers (Balasubramaniam et al. 1979).

About 23 species of natural enemies comprising of 4 predators, 16 predatory spiders, 1 parasitic mite, and 1 fungal pathogen have been identified (Hiremath and Thontadarya 1983). Also, cannibalism (2–5%) has been reported under field conditions (Hiremath et al. 1984). Application of carbaryl or malathion is highly effective (AICSIP 1980–92, David et al. 1969) in the control of *C. angustatus*. Demeton-S-methyl, a systemic insecticide, is also very effective against *C. angustatus* and other panicle-infesting bugs such as *Campylomma* sp and *Eurystylus bellevoyei* Reuter (Sharma and Leuschner 1987).

The southern green stink bug (*Nezara viridula* Linnaeus) preferentially infests developing sorghum grain from the milk stage, and the smaller false chinch bug (*Nysius plebejus* Distant) infests sorghum from the soft dough stage, causing unfilled and shriveled spotted grains. Grain quality is also affected. Infestation continues till the grain ripening stage followed by a decline in population. There are several generations of southern green stink bug in a year. On pearl millet, *Leptocorisa acuta* Thunberg and *Bagrada cruciferarum* Kirkaldy occasionally feed on the developing grain, and the infested grains become yellowish-brown and shriveled.

Head worms

Several lepidopteran species of head worms feed on developing sorghum grain, and are assuming major status in areas where compact-panicled sorghum and pearl millet cultivars have been introduced. Among them, *Helicoverpa armigera* feeds predominantly on sorghum in Thailand, and on pearl millet in India. Other important panicle caterpillars include hairy caterpillars and webworms in India and Thailand (Table 1).

Being a cosmopolitan and polyphagous pest, *H. armigera* has a range of 41 host-plant species (Singh and Balan 1986). Early larval instars feed on the anthers, while late stadia destroy the ovaries of maturing grain. The frass and webs produced by the larvae help in retaining dew and raindrops over longer periods, thus promoting mold growth and loss in grain quality. Non-uniform crop growth is favorable for the increased incidence of *H. armigera*, and since the newly released sorghum and pearl millet cultivars flower early, and grain ripening occurs under high humidity conditions, pest development and infestation are greatly favored.

The oriental armyworm, *Mythimna separata* Walker occurs sporadically in northern India, causing both panicle and foliar damage. It is also now established in the southern state of Karnataka (AICSIP 1975–92).

Patel et al. (1986) reported a few sources of resistance to *H. armigera* in sorghum such as IS 2177C, IS 12537C, and Chencholam. However, in pearl millet, it was found that genotypes with a thick cover of anthers are susceptible to *H. armigera* (Sharma 1987), the presence of long awns on the spike and lack of covering by the flag leaf are associated with reduced oviposition and feeding by *Pyroderces simplex* Walsingham (Sandhu et al. 1977). Cannibalism of *H. armigera* larvae is an important population-limiting factor, and coupled with natural enemies, is often sufficient to keep this pest below economic threshold levels. Several active parasitoids have been reported from Thailand on eggs (*Trichogramma confusum* Viggiani and *T. bactrae* Nagaraja), and larvae (*Carcelia* sp nr *rutilla* Rondani, *Tachina sorbillans* Wiedemann and *Eriborus argentiopilosus* Cameron) (Meksongsee and Chawanapong 1985), and from India on larvae (*Apanteles* sp, *Bracon* sp, *Microbracon hebetor* Say, *Campoletis chlorideae* Uchida and *Euplectrus euplexiae* Roh.) (Singh and Balan 1986). Among them, *C. chlorideae* was found to be potentially promising in southwest India (Pawar et al. 1986 1989). Further, spraying of an entomogenous nematode, *Steinernema feltiae* Filipjev suspension on sorghum panicles during grain formation stage showed promising results in controlling *H. armigera* and *M. separata* (AICSIP 1989). A poison bait consisting of a mixture of monocrotophos (250 mL), wheat bran (50 kg), and jaggery (4 kg), diluted in 6–8 L of water, when stored for 2 days and applied at 50 kg ha^{-1} on sorghum panicles effectively killed 98% of larvae and and 70% of adults (Hiremath et al. 1990).

Pheromones in a dry-white funnel trap placed just above the crop canopy was effective in reducing moth populations (Pawar et al. 1988). A single spray of carbaryl, chlorpyriphos (Mote and Kadam 1984), and endosulfan at 100% flowering also effectively controlled *H. armigera* and increased sorghum grain yields (Mote and Murty 1990).

Though considered to be a minor pest, *Euproctis subnotata* Walker feeding on maturing sorghum grain is common in Andhra Pradesh, Karnataka, and Maharashtra. *Eublemma siliculana* Swinhoe has been reported on pearl millet in these states as well as in northern and central India. Occasionally, infestations of *Eublemma gayneri* Rothschild and *Pyroderces simplex* Walsingham also attain serious levels on pearl millet. In northern India, the larval parasitism of *M. separata* by *Apanteles* sp ranged between 41.2% in September to 0.6% in February (Ram Singh et al. 1987). Effective control on sorghum was also achieved within 24 h after the application of malathion or chlorpyriphos, followed by BHC and carbaryl dusts (Kishore and Jotwani 1982, Mittal et al. 1978, Mote and Kadam 1984).

Panicle webworms primarily occur in the humid regions of northern India and Thailand. Among them, *Stenachroia elongella*, *Cryptoblabes gnidiella* Millière, *Celama analis* Wileman and West, and *Dichocrosis punctiferalis* Guenee assume greater importance than the others on sorghum and cause significant grain yield losses. They feed primarily on the inflorescence and subsequently on the starchy contents of the developing seed of sorghum and pearl millet. The neonate larva begin feeding within a single seed, but as it becomes larger, a protective webbing is produced which binds the panicle together and protects the larvae from predators. There may be up to six generations annually. The incidence of webworms can be effectively controlled by spraying endosulfan or monocrotophos (Srivastava and Singh 1976).

Panicle beetles

The distribution and relative importance of panicle beetles is not well known. Heavy infestation of head beetles at flowering on sorghum and pearl millet can cause considerable damage. Adults devour the pollen and stigma, and are responsible for grain abortion and panicle sterility. Peak population buildup varies with location and year, but they occur most frequently in September. Among them, *Mylabris pustulata* Thunberg and *Chiloba acuta* Wiedemann on sorghum in Uttar Pradesh, and *Oxycetonia versicolor* Fabricius on pearl millet in Rajasthan assume greater importance than the others. Adults feed on the flowers and cause poor seed set.

Integrated Pest Management

The Indian experience of the introduction of high-yielding short-duration sorghum cultivars to replace long-duration local cultivars is an important lesson in the context of integrated pest management (IPM). Panicle pests were not known to be a serious problem with long-duration traditional cultivars. But mixed sowing of short- and long-duration cultivars led to increased susceptibility of the locals to midge. With a better knowledge of the bioecology of sorghum midge which followed the development of short-duration cultivars, early and synchronous sowing over large areas, and the introduction of cultivars with similar flowering duration have resulted in effective IPM of midge. However, late sowing in dry areas where irrigation facilities are available may continue to favor increased susceptibility to major panicle and shoot pests. Selection of short-duration shoot pest-resistant cultivars for late sowing so as to synchronize their flowering with early-sown medium-duration cultivars would ensure escape from midge infestation. Further, some cultural practices such as destruction of chaffy panicles and their residues, and removal of alternate hosts which minimize infestation should be considered in IPM.

Future Outlook

Knowledge of the factors influencing panicle pest biology should facilitate the development of strategies to reduce their potential impact on pearl millet and sorghum production. Knowledge about the influence of biotic and abiotic factors on the life cycle of many panicle-feeding insect pests is still incomplete. Of special interest is the integration of various components of resistance to individual pests, and cross resistance to major pests by crops that are high-yielding, have early maturity, and have seed and panicle characteristics which influence the host-plant interaction to midges, head bugs, and lepidopterous larval feeding species. Since many of the lepidopterous caterpillars are occasional pests, low levels of resistance, coupled with cultural and biological components could provide effective control. In addition, factors influencing the behavior of key natural enemies over a wider host range and increased efficacy on panicle pests in relation to different ecological niches need to be investigated. There is also a basic need to exploit the potential and economic value of botanical insecticides such as neem and its components, which may act as deterrents and/or antifeedants.

Development of effective cultural management practices and identification of potential insecticides effective against a wide spectrum of panicle pest species on sorghum and pearl millet, but less toxic to natural enemies need to be explored. There is clearly a need to develop an effective IPM, with approaches under particular geographic locations or situations to transform subsistence agriculture into a more productive system.

Synthèse

Les insectes nuisibles des panicules de sorgho et de mil en Asie. En Asie, le sorgho est cultivé sur près de 17,7 millions d'hectares (production totale de 17,1 millions de tonnes) et le mil sur 18,4 millions d'hectares (production totale de 14,2 millions de tonnes). Avec l'introduction des variétés et des hybrides performants à cycle précoce et intermédiaire et des changements dans des pratiques culturales, des insectes paniculaires telles que les cécidomyies, les punaises, les chenilles et les cantharides sont devenues d'importantes contraintes à la production du sorgho et du mil.

En Inde, les pertes de rendement en grain causées par les insectes paniculaires de sorgho s'élèvent à 4,6% en moyenne (Leuschner et Sharma 1983). Des cécidomyies (*Contarinia sorghicola* chez le sorgho et *Geromyia penniseti* chez le mil) apparaissent en général en août et la pointe d'activité a lieu en septembre/octobre. Les larves provoquent des dégâts en se nourrissant des ovaires en formation et entraînent ainsi l'avortement de toute la panicule. Au cours de la saison des pluies, le cycle biologique dure deux semaines et on peut dénombrer 4 à 5 générations chevauchantes. La résistance des plantes tient une grande place dans la lutte contre la cécidomyie. Parmi les sources de résistance identifiées chez le sorgho, AF 28, DJ 6514, TAM 2566, SGIRL MR-1, ICSV 197 et DSV 3 ont manifesté une résistance durable à travers différentes régions. Chez le mil, quatre hybrides expérimentaux—HIB 111, N 74, PHB 12 et PHB 37—se sont distingués par leur résistance multiple élevée aux cécidomyies et aux chenilles des panicules (Prem Kishore 1991). Des parasitoïdes larvaires tels que *Tetrastichus diplosidis* Crawford, *Eupelmus popa* Girault et *Aprostocetus gala* Walker réduisent les populations de la cécidomyie du sorgho. Mais, les informations sur les prédateurs sont insuffisantes.

Parmi les punaises hémiptères, *Calocoris angustatus* Lethiery est responsable d'infestations sévères sur les panicules de sorgho et de mil. Le ravageur suce la sève du grain en formation. La densité de peuplement la plus élevée de ce ravageur est atteinte de la mi-septembre jusqu'au mois d'octobre dans les états indiens d'Andhra Pradesh, de Karnataka et de Tamil Nadu. L'infestation a pour effet la diminution du poids, de la qualité et du pouvoir germinatif des grains et les prédispose aux moisissures. Il peut y avoir deux ou trois générations chevauchantes sur la même culture. Quelques génotypes ayant de longues glumes qui couvrent les grains pour 20 jours après la floraison ont des dégâts faibles sur des panicules. Ce caractère limite la période d'alimentation des punaises sur les grains exposés (Sharma et Lopez 1992). Environ 23 espèces d'ennemis naturels dont 4 prédateurs, 16 araignées prédatrices, un insecte parasite et un pathogène fongique s'attaquent à ce ravageur (Hiremath et Thontadarya 1983). Des applications de carbaryl, de malathion ou de l'insecticide systémique déméton-*S*-méthyl se sont avérées efficaces contre les punaises des panicules. Plusieurs espèces lépidoptères de chenilles des panicules, surtout *Helicoverpa armigera*, sont devenues des ravageurs-clé dans des régions où des sorghos et des mils à panicules compactes ont été introduites. Des lignées de sorgho IS 2177-C, IS 12537-C et Chencholam ont manifesté une résistance modérée à cet important ravageur. Le cannibalisme des larves ainsi que des parasitoïdes affectant des oeufs et des larves permettent de limiter la population de cette espèce. Des appâtages à poison avec du monocrotophos et des phéromones placées au-dessus de la canopie végétale sont d'autres mesures de lutte. Des cantharides (*Mylabris pustulata* Thunberg, *Chiloba acuta* Wiedemann, *Oxycetonia versicolor* Fabricius) se nourrissent des fleurs et empêchent la formation des grains. Cependant, la distribution et l'importance relative de ces espèces sont peu connues.

Bien que la résistance des plantes ait particulièrement retenu l'attention, une meilleurs connaissance de la bioécologie de la cécidomyie du sorgho, des semis précoces et synchroniques à grande échelle et l'introduction des cultivars à maturité uniforme permettront de maîtriser ce ravageur. Les méthodes culturales de lutte comprenant la destruction des résidus de culture et l'élimination des plantes-hôtes secondaires réduiraient la possibilité de l'infestation initiale et la pullulation. Le potentiel et la valeur économique des insecticides botaniques tels que le neem et ses composantes qui serviraient de préventifs doivent être exploités.

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Caterpillar Pests of Sorghum Panicles in the Western Hemisphere

H N Pitre[1]

Abstract

Panicle-feeding caterpillar pests on sorghum in the Americas are discussed, with emphasis on geographic and seasonal occurrence, aspects of biology, behavior, and ecology in relation to population dynamics. The impact of pest populations on yield, control tactics, insect pest management (IPM) strategies, and sustainability of IPM systems are discussed.

Introduction

Sorghum is grown on small subsistence farms, and over large monoculture areas in the Americas. In many areas of Central and South America, local, multipurpose sorghum is intercropped with maize; in North America, grain sorghum hybrids are grown in monoculture. Most of the insects that attack maize also attack sorghum.

Insects of economic importance to sorghum have been reviewed by Teetes (1976), Young and Teetes (1977), Teetes et al. (1979), and Pitre (1985). Most of these are occasional pests; some are secondary pests. Few of the sorghum pests are key pests in the Americas (Teetes 1976, Pitre 1985). However, insect pest problems and pesticide use on sorghum have intensified with the introduction of sorghum hybrids in the 1950s (Young and Teetes 1977).

Geographic distribution, pest status, crop damage and economic threshold levels for a number of insects attacking sorghum were discussed by Young and Teetes (1977). In this paper the lepidopterous caterpillars that attack sorghum panicles in the Americas are addressed. Aspects of the life cycle, ecology, behavior, and population dynamics are considered. Some specific crop plant-insect relationships that are known to influence insect biology and pest suppression strategies are also discussed.

Distribution of Panicle Caterpillars

Insect pest problems on sorghum in Brazil (Viana 1985), Central America (Reyes 1985), Mexico (Castro 1985), and USA (Pitre 1985) were discussed at the International Sorghum Entomology Workshop held at Texas A&M University in 1984. The sorghum webworm (SWW), *Celama sorghiella* Riley, fall armyworm (FAW), *Spodoptera frugiperda* J.E. Smith, and corn earworm (CEW), *Helicoverpa zea* Boddie, were recognized as the principal lepidopterous caterpillars attacking sorghum panicles in these regions. These pests can occur in mixed populations, thus causing extensive damage to the sorghum crop.

The FAW, CEW, and SWW appear to be widely distributed throughout the Americas, but as Young and Teetes (1977) point out, some insect pests on sorghum are identified more closely with specific geographical areas than others. The CEW appears to be more of a pest on sorghum in western USA, while the SWW, FAW, and CEW can be of economic importance in eastern USA (Pitre 1985). Viana (1985) reported that the Christmas berry webworm, *Cryptoblabes gnidiella* Millière and the Indian meal moth, *Plodia interpunctella* Hübner are secondary pests on grain sorghum panicles in Brazil. The armyworm,

1. Department of Entomology, Mississippi State University, Mississippi State, MS 39762, USA.

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Pseudaletia unipuncta Haworth is a pest in Mexico (Castro 1985). Some indication of sorghum yield losses attributed to the major sorghum pests may be obtained from papers presented at the above workshop.

Major Pests

Fall armyworm (*Spodoptera frugiperda*)

The FAW is reported to have its origin in the tropical-subtropical Western Hemisphere (Luginbill 1928). In Central and South America, its distribution extends from Mexico, southward to northern Argentina and northern Chile (Andrews 1980). It has no diapause mechanism, thus it does not overwinter in temperate North America, instead migrating northward from overwintering sites. Females lay eggs in clusters (average 140 per mass, Vickery 1929). The eggs are covered with a dense layer of gray body scales and are generally laid on the underside of plant leaves, but when insect density is extremely high, eggs are laid on almost any surface, plant or otherwise. On sorghum they are laid on panicles at the flowering stage. Newly hatched larvae (neonates) feed in a group, but soon begin to move away from the mass apparently due to competition. The larvae spin threads and descend from upper to lower locations on the plant in order to disperse. They may be carried by the wind for some distance. The descent by the larvae appears to be adaptive for dispersal, limiting competition.

Larvae are characterized by a dark head capsule. The body can vary in color, but most larvae are dark brown to greenish, with wide, pale stripes on the sides. They develop through six instars, the first three consuming less than 5% of the total foliage required for larval development to pupae. Larvae that are present on the plant when the panicle emerges are carried upward, where they feed on the reproductive stages. Since moths lay eggs on the panicle mostly during preflowering and flowering stages, larvae at all stages of development can be found infesting the panicle. Larvae feeding in the panicle cause extensive damage to the grain: thresholds are 2 larvae less than 1.27 cm or 1 larva greater than 1.27 cm per panicle (Young and Teetes 1977, Teetes and Wiseman 1979).

Larvae drop to the ground at maturity and pupate in the soil (about 2.5–7.5 cm below the surface). Moths emerge from the soil and virgin females emit a sex pheromone and initiate calling from the upper plant structures. Successfully mated moths begin laying eggs thereafter.

Corn earworm (*Helicoverpa zea*)

The CEW is similar to the FAW in its attack on the sorghum plant. Although both insects attack sorghum at the whorl stage, the CEW may not show the same degree of foliage feeding preference as FAW. The two insects cause similar feeding damage to the panicle.

The CEW moth is generally brown but can be light olive green to dark reddish brown (Wiseman 1985). The front wings have a brown spot, roughly in the middle of the upper wing. Moths are active in the evening, initiating feeding and oviposition. This behavior generally begins one hour after sundown under normal weather conditions (Lingren et al. 1982). Eggs are white and are laid singly (average 1000 per female). Moths show some preference for the flowering stages of sorghum. On emergence, larvae are creamy-white with a black head capsule but may turn red, brown, gray or cream with stripes as they develop. They consume the developing seed and although cannibalism has some influence on infestation levels, this behavior appears to be limited in the panicle. A single larva damages an average of 166 grains (Buckley and Burkhardt 1962). Larvae generally develop through six instars, and at maturity drop to the ground to pupate in the soil. The life cycle may be 20 to 30 days. There can be several generations a year, depending on the geographical location. Threshold levels are the same as for FAW.

Sorghum webworm (*Celama sorghiella*)

The SWW is a pest on sorghum mainly during wet growing seasons (Reinhard 1937), when environmental conditions are favorable for rapid increase of the population.

The SWW moth is small and whitish, with tufts of scales on its front wings. The white eggs have a pale greenish to yellow tinge, change to a straw color, and are deposited on the panicle during pollination or soon after. A moth may deposit 100–300 eggs singly on the glumes, flowers, or grain. The larvae have a woolly, pale greenish appearance at first, but change to creamy brown or yellowish brown. They are somewhat flattened with longitudinal brown or reddish stripes and have long hairs on their slender body (about 1.27 cm at maturity). The larvae feed on the developing grain, causing round holes in the kernels; they may consume the whole grain. A single larva may feed on as many as 12 grains per day (Randolph et al. 1960). They form a webbing within the panicle and develop through five instars. Pupation occurs within the panicle. Pupae are enclosed in a white, silken cocoon. The life cycle may range from 18 to 30 days depending upon the temperature (Reinhard 1938). They overwinter as larvae on food plants and there may be up to six generations per year.

Compact-headed sorghum provides a favorable microenvironment in the panicle for SWW to develop large infestations and cause extensive damage to the crop. Infestations greater than 100 larvae per panicle have been observed by the author on compact-headed sorghum. The SWW can be found feeding on grain at the hard dough stage, whereas this may not be generally characteristic of FAW or CEW. The amount of damage by two SWW to sorghum panicles may be compared to that of one CEW. An established threshold for SWW is five larvae per panicle (Young and Teetes 1977).

Migration

Movement of insect pests from source areas into areas not previously infested is a key factor in outbreaks of some pests, such as the FAW. Favorable conditions allowing the pest to build up to high populations in the source area and certain weather patterns (atmospheric trajectories) have been associated with the initiation of long range movement of adults in southern USA (Westbrook and Sparks 1986). Movement from one region to another or from crop to crop can be an important factor in the population dynamics of an insect pest. Knowledge of pest movement, time of initial infestation, infestation levels, and pest population dynamics are critical to developing management recommendations, such as sowing date and timely application of insecticides against insect pests like FAW (Hogg et al. 1982). The CEW shows both short-range dispersal and long-range migration behavior. Sorghum webworm moths move from field to field, but do not appear to move long distances (Reinhard 1938).

Investigations to determine the relationship of FAW in different geographical regions have shown little commonality among the test insects. Biological comparisons between the fall armyworm from areas in Central and North America did not reveal relationships between insects collected in the distinct geographical regions (Castro and Pitre 1988). No relationships were observed among FAW from North and Central America, or the Caribbean when evaluated using insecticide bioassay tests (Pitre 1988). Sex pheromone studies with strains from Central and North America indicated dissimilar calling rhythms between insects from different regions (Ramaswamy et al. 1988). Further studies are needed to provide information on source areas of this migratory insect pest.

Sampling Methods

Frequent monitoring of the sorghum crop for pest infestation is essential to establish pest suppression tactics and reduce reliance on insecticides. Sampling to determine infestation levels can be time consuming and may be less than adequate for making pest management decisions if not done properly. However, since economic thresholds for sorghum panicle-feeding caterpillars are based on density of larvae in size classes, sampling procedures are not difficult. Caterpillars can be dislodged from panicles by shaking the panicle over a container, identifying and counting the insects, and recording the infestation level (Merchant and Teetes 1992).

The duration of crop sampling for insect pests depends on the insect species and the developmental stage(s) of the crop attacked. Sampling for panicle-feeding FAW, CEW, and SWW should extend from shortly before flowering through the hard dough stage.

Kring et al. (1989) determined that SWW and CEW have no oviposition preference for any particular portion (upper, middle, or lower) or flowering stage (1/2, 2/3, or full bloom) of the sorghum panicle. This information is useful in establishing accurate sampling techniques to determine relative estimates of pest infestations.

Indicator fields of corn and bermuda grass were used as an early warning of potential FAW infestation (Hunt 1980). However, Barfield et al. (1980) indicate that polyphagy and mobility of FAW make prediction of infestations difficult.

Pest Suppression

Although pest suppression measures are not required for insect pests (e.g., sorghum midge) during the flowering period, lepidopterous caterpillars can establish high infestations in the panicles. The success of suppression measures often depends upon sampling efficiency to detect pest infestation levels at critical stages of panicle development. However, some pests like the FAW and CEW are difficult to control due in part to the large number of host plants available during the crop-growing season. The FAW is reported to have numerous host plants (68 genera reported by Tietz, 1972), many of which are grasses. The insects, developing on host plants throughout the agroecosystem, are attracted to sorghum at various stages of plant development. The FAW may infest sorghum panicles throughout grain development. Consequently, insecticides, because of their low cost and fast action, are relied upon for control of pest caterpillars. The length of residual efficacy of particular insecticides will determine the number of spray applications that may be required to protect the panicles during grain development.

Cultural Practices

Early sowing and good tillage practices (e.g., grass-free fields) have been reported to minimize FAW infestations (Luginbill 1928). Fall armyworms are reported to cause more damage to the second sowing (Aug) of sorghum in Nicaragua and El Salvador in Central America than to the first sowing (May-Jun) (Sequeira et al. 1976). Early sowings escape damage by the high populations of FAW and SWW that build up during the growing season (Reinhard 1938). This management practice does not increase the farmer's costs.

Tillage, involving plowing the stubble after harvest to destroy immatures preparing to overwinter, is recommended for suppression of SWW. Recently the effects of different weed control practices on FAW infestations have been investigated (Carballo et al. 1980, Castro et al. 1989, Portillo et al. 1991). Infestations of FAW were higher in plots without weeds than those with weeds (Portillo et al. 1991). The grass weeds served as an additional source of food for the FAW, giving some relief to the crop plants.

Biological Control

Many naturally occurring beneficial organisms, including predators, parasitoids (Ashley 1979), entomopathogens (Gardner and Fuxa 1980, Gardner et al. 1984) attack the complex of lepidopterous caterpillars (FAW, CEW, and SWW) feeding on the sorghum panicle. The role of insect predators and parasitoids, as well as microbial agents in suppressing these pest populations below threshold levels must consider the reproductive rate of the beneficial organism within the microenvironment of the panicle in the specific cropping system, as well as the impact of the pest feeding damage on the panicle, insecticide use patterns, and impact (e.g., decimation of predators and parasitoids), and cost effectiveness of the pest suppression tactics (Bell 1982, Kring et al. 1989).

Host-Plant Resistance

Host-plant resistance in crops has long been recognized as a viable component in integrated insect pest management (Wiseman and Morrison 1981). This insect suppression tactic is compatible with other pest management tactics for use in integrated pest management (IPM) systems. However, information on agronomically acceptable sorghum types with suitable levels of resistance to panicle-feeding caterpillars for use by the farmer has been slow in developing. Nevertheless, open-headed sorghum types are recommended for use where FAW, CEW, and SWW are constraints to sorghum production (Young and Teetes 1977, Teetes and Wiseman 1979, Wiseman and Morrison 1981, Wiseman 1985). Biological and chemical measures can be more efficient on open-headed than on compact-headed sorghum.

The use of resistant genotypes is an alternative to the use of insecticides for pest suppression because of the low cash value of the crop. The occasional pest status of panicle-feeding caterpillars may allow the use of sorghum types with low levels of resistance in an integrated pest management system.

Research on sorghum host-plant resistance to insect pests over the past two decades was reviewed by Wiseman (1985). Host-plant resistance to panicle feeding insects in sorghum is discussed in detail in another paper in this workshop.

Insecticide Sprays

Application of insecticide for suppression of pests on grain sorghum, including ground, aerial, and irrigation techniques was discussed by Young (1979) and Gardner et al. (1981). FAW control using chemicals was reviewed by Pitre (1986).

Chemicals applied through the center pivot irrigation system (Young 1980) is an advancement in application technology. This approach is less expensive than applying insecticide using ground equipment (Young 1981).

Insecticides might be expected to be more effective when applied to open-headed than compact-headed sorghum types, as the insecticide should have greater penetration into the open-headed sorghum panicle. This could be especially significant when applying the insecticide in low volume from an airplane.

Integrated Pest Management

Kendricks (1978) emphasized that information on insect biology and population dynamics, and plant phenology are keys to successful application of IPM practices. Knowledge of certain sorghum plant-insect pest relationships for FAW, CEW, and SWW have been addressed here, and are basic to the successful implementation of pest suppression tactics in IPM systems designed for panicle-feeding insect pests. The pest suppression tactics must be cost-effective and profitable to the farmer (Lathan 1976) and should be sustainable. Although early sowing of compact-headed sorghum and insecticide sprays have been routinely recommended, other measures should be considered for suppression of the complex of caterpillars attacking sorghum panicles.

Synthèse

Les chenilles des panicules de sorgho dans l'hémisphère occidentale. En Amérique centrale et du Sud, des agriculteurs de subsistance cultivent parfois des sorghos polyvalents en association avec le maïs, tandis qu'en Amérique du Nord, des sorghos hybrides sont cultivés en monoculture. Bien que la plupart des insectes nuisibles au sorgho soient d'importance secondaire ou occasionnelle, quelques-uns sont des ravageurs importants. Le ver à soie du sorgho (*Celama sorghiella* Riley), la chenille légionnaire (*Spodoptera frugiperda* J.E. Smith) et le ver américain de la capsule du cotonnier (*Helicoverpa zea* Boddie) sont les principales chenilles lépidoptères qui affectent les panicules de sorgho dans les Amériques et sont susceptibles de provoquer de sérieux dégâts, bien qu'elles n'y soient considérées comme des ravageurs-clé.

Comme aucune diapause n'a été signalée pour la chenille légionnaire, elle n'hiverne pas en Amérique du Nord tempérée. Elle migre vers le nord à partir des régions favorables à son hivernage. Les papillons déposent des oeufs sur les panicules et les larves causent de graves dommages au grain. Le seuil a été déterminé à 2 petites larves (moins de 1,27 cm) ou 1 grande larve (plus de 1,27 cm) par panicule. Le ver américain de la capsule du cotonnier préfère de pondre aux stades floraux et les larves provoquent autant de dégâts que celles de la chenille légionnaire. Ce ravageur peut entrer en diapause et a des capacités de disperser sur de courtes et de longues distances. Le seuil déterminé est le même que pour la chenille légionnaire. Le ver à soie du sorgho s'attaque au sorgho au cours des saisons humides de croissance. Il peut causer des dégâts importants sur les panicules et une larve peut consommer jusqu'à 12 grains par jour. Le ver à soie du sorgho, tout comme la chenille légionnaire et le ver américain de la capsule du cotonnier, hiverne sous la forme de pupe. Mais, l'hivernage a lieu dans la panicule et non pas dans le sol. Un seuil de cinq larves par panicule a été établi.

Une bonne connaissance des déplacements de l'insecte à travers des régions ou des cultures, l'époque de l'infestation initiale, les taux d'infestation et la dynamique des peuplements est indispensable à la formulation des recommandations des mesures de lutte telles que la date de semis et l'application des insecticides en temps opportun.

Il importe de conduire souvent des échantillonnages des cultures pour déterminer le taux d'infestation afin de mettre au point des stratégies de lutte et de réduire le recours systématique aux insecticides. Ces mesures auront pour effet de minimiser des effets néfastes sur l'environnement, d'abaisser le coût de production et d'éviter la résistance aux insecticides. L'échantillonnage de ces ravageurs doit être fait juste avant la floraison jusqu'au stade pâteux dûr. On peut déplacer les chenilles à partir des panicules de sorgho en secouant la panicule au-dessus d'un récipient.

Si des insecticides ne sont pas appliqués pendant la floraison (par exemple, dans la lutte contre la cécidomyie du sorgho), les infestations des chenilles pourraient devenir sévères sur les panicules. Alors, on est obligé d'employer des insecticides pour les maîtriser. Les méthodes de lutte préconisées comprennent le semis précoce, la destruction des larves et des pupes et l'élimination des plantes-hôtes secondaires au moyen de labour, la préservation des insectes auxiliaires, la résistance des plantes (par exemple, le sorgho à panicules compactes) et l'usage raisonné des insecticides. Ces stratégies doivent être à la fois efficaces, économiques et n'auront pas d'impact négatif sur l'environnement.

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Summary of Discussion

Session 1

Concerns over current research emphasis on head bugs underpin the need for a rigorous assessment of on-farm pest situations, since it has been reported that this pest is a problem only on research stations and not on farmers' fields. However, valid and disturbing concerns were raised on the potential danger if the focus in breeding for high-yielding compact-panicled sorghums was pursued in West Africa. The products of research should be farmer-oriented.

The overall effectiveness of chemical insecticides remains questionable. If properly employed, chemical insecticides can be effective and economical under high-input agriculture. However, their misuse and consequent effect on human health and the environment are a major concern. Particular attention should be given to naturally occurring plant-derived pesticides such as neem extracts.

Farmers have evolved individual and collective cultural management practices which research should take into consideration. Although some farmers' technologies (often referred to as 'cultural practices') may appear unscientific, they constitute simple but effective alternative management tactics that are of particular relevance to low income earners. A systematic attempt should be made to inventory these technologies, and evaluate and incorporate them into pest management systems.

Synthèse de discussion

Session 1

L'attention donnée à la recherche sur les punaises des panicules souligne la nécessité de faire une analyse rigoureuse de la situation de ces ravageurs sur les stations de recherche puisqu'il est signalé qu'ils y posent un problème et non pas en champs paysans. Les participants se sont inquiétés, avec raison, au danger potentiel si la sélection pour des sorghos performants à panicules compactes est poursuivie en Afrique de l'Ouest. Les produits de la recherche devront être destinés aux paysans.

L'efficacité globale des insecticides chimiques est remise en question. Dans les conditions de l'agriculture intensive à intrants élevés, des insecticides chimiques peuvent être efficaces et économiques, pourvu qu'ils soient utilisés judicieusement. Cependant, une utilisation excessive et irraisonnée des produits phytosanitaires et leur effet sur la santé humaine ainsi que sur l'environnement continuent d'être des soucis majeurs. L'attention doit se porter tout particulièrement sur l'exploitation des biopesticides tel que l'extrait de neem.

Au fil des ans, des agriculteurs ont élaboré des pratiques culturales individuelles et collectives que les chercheurs doivent prendre en compte. Bien que certaines de ces pratiques paysannes semblent non scientifiques, elles représentent des méthodes de substitution simples et efficaces qui sont d'intérêt particulier aux agriculteurs à faible revenu. On doit s'efforcer d'inventorier systématiquement ces technologies et les incorporer après leur évaluation dans les stratégies de lutte contre les insectes nuisibles.

Session 2

Bioecology and Crop Losses

Bioécologie et pertes de rendement

Biology and Population Dynamics of Sorghum Head Bug *Calocoris angustatus* in India

I G Hiremath[1]

Abstract

The head bug Calocoris angustatus *is a key pest of sorghum in parts of India. Nymphs and adults suck the juice from milk grain and reduce the quality and quantity of grain. The duration of egg and nymphal stages is 4.2–11.0 and 9.5–12.5 days. Adult longevity is 11.2–17.2 days (male) and 12.2–23.5 days (female). The insect completes 16 generations in a year. Temperature adversely affects the nymphal period ($r = -0.97$) and adult longevity ($r = -0.98$) but not survival of nymphs ($r = -0.29$). The optimum temperature for development ranges from 25° to 30°C. Fecundity varies from 65 to 276 eggs. Cannibalistic and predatory behavior of the head bug and its preference for various hosts is discussed.*

The sorghum head bug is active throughout the year except for a few weeks in summer, although the computed seasonal indices are higher in Aug (190–230), Sep (220–240), and Oct (230–250) during the rainy season, and in Jan (200–220) during the postrainy season which coincides with the milk stage of the crop. Among abiotic factors, temperature exerts negative pressure ($r = -0.35$) whereas relative humidity favors population buildup ($r = 0.45$). Late sowing (15 Jul–15 Aug) also favors population buildup. Biotic factors that reduce population levels include spiders, reduviid bugs, ants, mantids, erythraeid mites, and an entomogenous fungus, Cephalosporium *sp. Their role in the population dynamics of this insect pest is discussed.*

Introduction

The head bug, *Calocoris angustatus* Lethiery, is one of the major insect pests of sorghum in India (Sheshu Reddy and Davies 1979, Hiremath 1981), and has become a key limiting factor in sorghum production (Sharma and Lopez 1990). Young and Teetes (1977) also categorized this bug as a key pest of sorghum in southern India. Although the pest is confined primarily to India, its occurrence has been reported from Kenya and Rwanda in eastern Africa (Sheshu Reddy and Omolo 1985). The nymphs and adults suck the juice from developing grains, and continual feeding at the milk stage causes the grain to shrivel, reducing both yield and quality. Leuschner and Sharma (1983) recorded losses as high as 43.9% compared with 43.2% and 28% due to midge and head caterpillars.

Systematics

The genus *Calocoris* Fieber belongs to the tribe Mirini, subfamily Mirinae of the family Miridae. *Calocoris angustatus* was first described by Lethiery (1893) from the former state of Madras (now Tamil Nadu). In India, this bug has many local names: *navai puchi* (Tamil), *patcha purugu* (Telugu), *aaru kalin chitte* and *tene tigane* (Kannada), and jowar earhead bug or sorghum earhead bug (English).

Distribution

The head bug is essentially a pest of sorghum in southern India (Lethiery 1893, Fletcher 1914, Ballard 1916, Puttarudriah 1947, Thimmaiah et al.

1. Department of Agrobiology, Seoul National University, Suwon 441 744, South Korea.

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1972, Mani and Venugopal 1976). It has also been reported from Andhra Pradesh (Paul 1976) and Rajasthan (Anonymous 1979). However, the distribution and status of the bug in India during the last 10 years (1983–92) indicate its severe occurrence in Maharashtra, Andhra Pradesh, and Tamil Nadu (Table 1). Its occurrence in New Delhi (1984/85), Rajasthan (1984/85), Gujarat (1985/86), and Madhya Pradesh (1992/93) is also worthy of note (Fig. 1).

The economic threshold level (ETL) of the bug on sorghum varies from four (Hiremath 1981) to 15 bugs panicle^{-1} (Natarajan and Sundarbabu 1988). However, incidence as high as 200 bugs panicle^{-1} has been reported (Table 1), especially on a late-sown crop. This is particularly the case in Karnataka and Maharashtra, where the distribution of the southwest monsoon is very erratic and could become a limiting factor for sowing sorghum.

Biology

The biology of this bug was first discussed by Ballard in 1916. Subsequent studies in India by Cherian et al. (1941), Natarajan and Edwards (1959), Hiremath (1981), Natarajan and Sundarbabu (1987), Sharma and Lopez (1990), and Hiremath and Viraktamath (1992) are well documented. These have also been reviewed and summarized by Ayyar (1963), Pant and Kalode (1964), Pradhan (1969), Heinrichs (1972), Nayar et al. (1976), and Young and Teetes (1977).

The female adult bug lays 2–10 eggs inside the floral glumes or in the middle of the floret. Nearly 97% of the eggs are laid in sessile (fertile) spikelets, and the rest in pedicellate (unfertile) spikelets. Fecundity depends greatly on the season, variety, host, etc., and varies from 65 to 276 eggs per female. The incubation period also varies from 4.2 to 11.0 days depending on the location and climatic conditions. The egg is cigar-shaped, tapering towards the posterior end, with an operculum at the anterior end. Freshly laid eggs are light blue to hyaline but change to orange-red before hatching. Unfertilized eggs remain blue or hyaline and ultimately shrivel after 8 days.

Nymphs displace the operculum to emerge from the egg shell. Five nymphal instars have been observed and the total nymphal period varies from 9.5 to 12.5 days. Nymphs in their first two instars are red in color and 1–2 mm in length. Wing pads appear during the third instar; sex determination can also be done at this stage.

Adult longevity at Coimbatore is much lower than at Dharwad and Hyderabad, probably due to weather parameters. Females outnumber males by 200%. The males are green yellow with dark markings and are 5.0–5.1 mm long, whereas females are stouter and paler and measure 5.6–5.8 mm. The pre-oviposition period varies from 1.2 to 3.0 days with an average of 2.1 days. An oviposition period of 7.2–15.0 days has been recorded at Dharwad.

Continuous rearing of bugs on caged sorghum panicles in the field resulted in 16 generations at Dharwad, when the eggs laid on the first day by a pair of experimental bugs were used to rear subsequent generations. A period of 19.3 days was required for one generation during summer (Apr–May), and 30.1 days in winter (Dec-Jan). A significant negative ($r = -0.92$) relationship has been recorded between the generation period and minimum temperature.

Among several weather parameters, temperature exerts negative pressure on the biology of head bugs (Table 2). Temperatures varying between 25 and 30°C are optimum for the survival of nymphs (80–87%), nymphal development (9.3–13.4 days), and adult longevity (19.9–28.4 days). High temperatures adversely affect nymphal period ($r = -0.97$) and adult longevity ($r = -0.98$), but not the survival of nymphs ($r = -0.29$)

Cannibalistic and Predatory Behavior

Under field conditions, adult males and females are known to probe in the third and fourth abdominal sternites and suck the haemolymph of adults of both sexes. As a result, the body color of the dead bug changes to pale. The proportion of dead bugs due to cannibalism ranges from 2 to 5% in both field and laboratory conditions under high population density. Head bugs have also been observed to predate on the sorghum midge, *Contarinia sorghicola* Coq. Both nymphs and adults extend their proboscis and puncture the abdomen of ovipositing midges on sorghum panicles. Feeding lasts for 2–3 minutes during which the abdominal contents of the midge fly are completely sucked out (Hiremath et al. 1984).

Host Preference

Head bugs are known to attack 16 plant species (Hiremath 1981). Among six important host plants studied [grain sorghum, fodder sorghum, finger millet, pearl millet, small millet, and *hariyali* (*Cynodon dactylon*, Bermuda grass)] grain sorghum was the

Table 1. Pest status of the sorghum head bug in India between 1983 and 1993.

Year	Location	State	Incidence	Number of bugs panicle^{-1}	Pest status[1]
1983/84	Rahuri	Maharashtra	Very high	30–120	+ + + +
	Surat	Gujarat	High	3.1 on a 0–9 scale[2]	+ + +
	Palem	Andhra Pradesh	High	4.0 on a 0–9 scale	+ + +
	ICRISAT Asia Center	Andhra Pradesh	High	40	+ + +
1984/85	Dharwad	Karnataka	High	30–40	+ + +
	Mysore	Karnataka	High	30–35	+ + +
	New Delhi	New Delhi	High	–	+ + +
	Udaipur	Rajasthan	High	–	+ + +
	ICRISAT	Andhra Pradesh	High	8–45	+ + +
1985/86	Rahuri	Maharashtra	High	–	+ + +
	Jalagaon	Maharashtra	High	–	+ + +
	Coimbatore	Tamil Nadu	High	–	+ + +
	Surat	Gujarat	High	–	+ + +
	ICRISAT	Andhra Pradesh	Medium	5–25	+ +
1986/87	Parbhani	Maharastra	High	37–40	+ + +
	Jalagaon	Maharashtra	High	25	+ + +
	Dhule	Maharashtra	High	25	+ + +
	Rahuri	Maharashtra	High	25	+ + +
	Dharwad	Karnataka	High	25–35	+ + +
	ICRISAT	Andhra Pradesh	Medium	5–25	+ +
1987/88	Parbhani	Maharashtra	Very high	100–130	+ + + +
	Rahuri	Maharashtra	High	12–38	+ + +
	Dhule	Maharashtra	High	12–38	+ + +
	Dharwad	Karnataka	Very high	100–150	+ + + +
	Palem	Andhra Pradesh	Very high	60–100	+ + + +
	Coimbatore	Tamil Nadu	High	32–35	+ + +
	Surat	Gujarat	Medium	–	+ +
1988/89	Dharwad	Karnataka	Very high	110	+ + + +
	Coimbatore	Tamil Nadu	High	–	+ + +
1989/90	Dharwad	Karnataka	Very high	158	+ + + +
	Bijapur	Karnataka	Low	2–10	+
	Coimbatore	Tamil Nadu	Medium	17	+ +
	Parbhani	Rajasthan	Very high	100% damage (late season crop)	+ + + +
1990/91	Udaipur	Rajasthan	Low	5–8	+
	Dharwad	Karnataka	Very high	72–93	+ + + +
	Indore	Madhya Pradesh	Medium	–	+ +
1991/92	Dharwad	Karnataka	Very high	50–126	+ + + +
	Coimbatore	Tamil Nadu	High	–	+ + +
	Parbhani	Maharashtra	High	–	+ + +
1992/93	Dharwad	Karnataka	Very high	150–200	+ + + +
	Parbhani	Maharashtra	High	22–33	+ + +
	Coimbatore	Tamil Nadu	High	50	+ + +
	Salem	Tamil Nadu	High	50	+ + +
	Dharapuri	Tamil Nadu	High	50	+ + +
	Indore	Madhya Pradesh	Low	6	+

1. + = minor, ++ = less severe, +++ = severe, ++++ = very severe.
2. Damage severity scored on a 0–9 scale, where 0 = no damage, and 9 = very high damage.

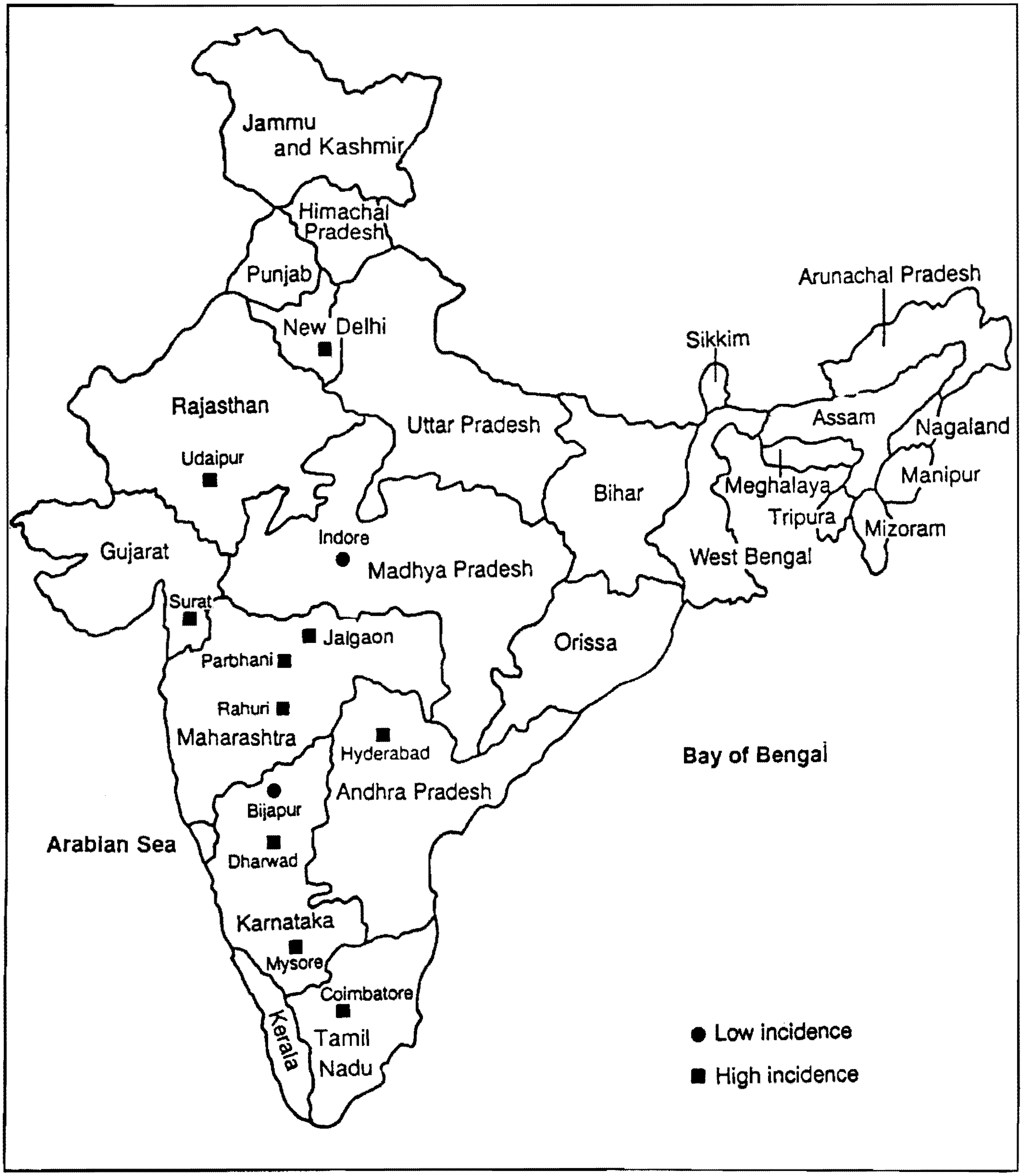

Figure 1. Sorghum head bug distribution in India.

Table 2. Effect of constant temperature on the nymphal period, nymphal survival, and adult longevity of the sorghum head bug, *Calocoris angustatus* Lethiery.

Temperature	Nymphal period (days)[1]	Survival of nymphs (%)[2]	Adult longevity (days)
20°C	4.34 (17.85)[3]	22.5 (15)	43.15
25°C	3.78 (13.45)	64.33 (80)	28.45
30°C	3.20 (9.3)	69.53 (87.5)	19.9
35°C	2.94 (7.65)	35.48 (35)	8.95
40°C	1 (0)	1 (0)	2.25
SEM	±0.05	±0.74	±0.76
CD at 1%	0.22	16.15	3.28
r	-0.9758	-0.2949	-0.988

1. = $\sqrt{x+1}$ values.
2. = Arcsin $\sqrt{\text{percentage}}$ values.
3. Figures in parentheses are original values.

most preferred and resulted in the highest survival (92%), adult weight, and size (Hiremath 1986). Similarly, oviposition occurred only on sorghum panicles. Compact-panicled sorghum genotypes are most preferred by bugs. DBR-1 (from Dharwad) with an open-type panicle is resistant to head bugs.

Seasonal incidence

Systematic studies on the seasonal incidence of head bugs in sorghum (CSH 1) sown at 10-day intervals throughout the year revealed that this pest can occur all the year round except for a few weeks in summer (Fig. 2). The most preferred panicle stage was milk grain. Hiremath and Thontadarya (1984) reported high populations of bugs on sorghum during Aug (18–27 bugs panicle^{-1}), Sep (26–48), Oct (26–66), and Jan (16–23). The corresponding seasonal indices computed through time series analysis (Croxton and Cowden 1964) were 230, 222, 264, and 215, respectively. However, the range of indices in recent years varied from 190–230 during Aug, 220–240 during Sep, 230–250 during Oct, and 200–220 during Jan, which coincided with the milk stage of the crop during the rainy and postrainy seasons at Dharwad. The findings of Sharma and Lopez (1990, 1992) also reveal the presence of large numbers of bugs from Aug

Table 3. Incidence of head bug in relation to time of sowing.

Time of sowing	Number of bugs panicle^{-1}				
	Dharwad				Parbhani
	1987	1988	1989	Mean	1989
1 Jun	-	-	-	-	43.9
15 Jun	10.2	5.7	15.2	12.9	124.4
1 Jul	10.6	7.6	62.6	34.4	22.3
15 Jul	106.5	59.5	110.7	94.3	29.5
1 Aug	110.7	72.6	125.1	103.4	49
15 Aug	112	96.3	129.3	113.4	33.6
1 Sep	96	89	89.4	82.6	-
15 Sep	62	22.6	86	57.2	-
1 Oct	58	18.6	1.9	29.6	-
15 Oct	15	20.8	0.6	16.4	-
1 Nov	89.2	59.2	5.2	43.1	-
SEM	±4.2	±2.9	±5.3	-	-
CD at 5%	11.9	9	15.6	-	-

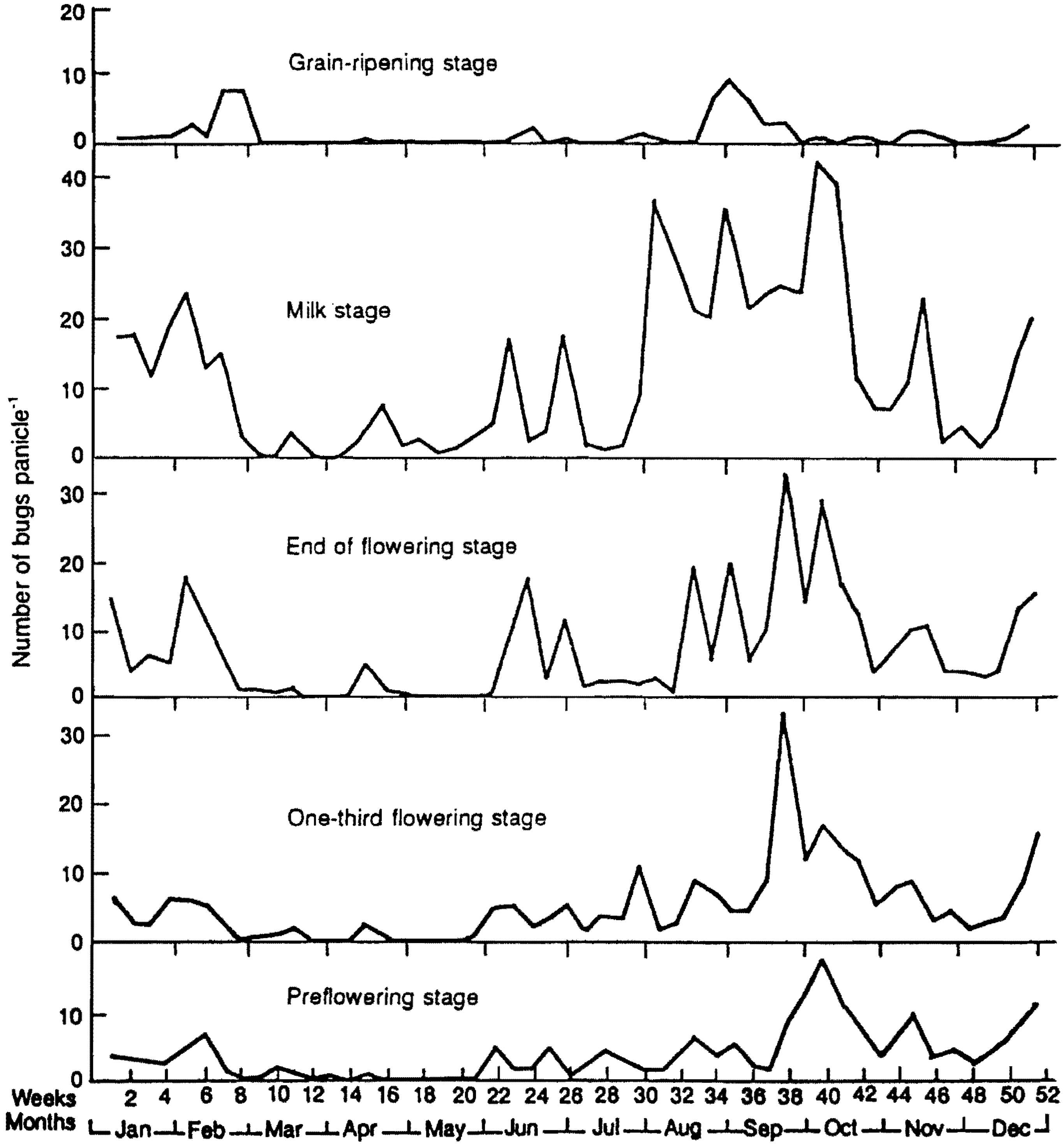

Figure 2. Sorghum head bug incidence at different stages of the sorghum panicle (CSH 1), Dharwad, Karnataka, India, 1978.

to Nov and low numbers between Nov and Apr in studies conducted between 1982 and 1986 at Patancheru, near Hyderabad.

The seasonal incidence of the bug in relation to the date of sowing at Parbhani during the rainy season of 1989 (Anonymous 1990) indicated up to 124.4 insects panicle^{-1} during the last week of Sep on the crop sown on 15 Jun (Table 3). The decline in maximum temperature (<30°C) and increase in relative humidity (RH) (>80%) 2 weeks prior to observation might be responsible for this peak. Similarly, studies at Dharwad between 1987 and 1989 showed high populations varying from 94.3 to 113.4 bugs panicle^{-1} on the crop sown from 15 Jul to 15 Aug. Variations in peak incidence may be attributed to changes in the rainfall pattern and sowing dates. Considering the bug population density, sowing of sorghum should be completed before 15 Mar in Tamil Nadu (Ayyar 1963), by the beginning of Apr in southern Karnataka (Puttarudriah 1947) and during Jun in northern Karnataka (Hiremath and Thontadarya 1984). At Coimbatore, the main crop sown in Apr is more prone to bug attack than the ratoon crop (Natarajan et al. 1989). Detailed studies are needed at other locations where the bug is found to be a limiting factor in sorghum production.

Abiotic Factors

Temperature exerts a negative and RH a positive effect on bug population. The bug population declines sharply in summer (Apr–May) since the maximum and minimum temperatures increase above 32°C and 20°C, and maximum and minimum RH fall below 70% and 30%. Normally, intermittent rains increase the RH and lower the temperature, producing a favorable effect on bug population. Increase in maximum and minimum temperatures above 32°C and 18°C, and RH less than 30% adversely affect bug populations (Sharma and Lopez 1990). Moisture deficiency and wind speed are normally negatively associated with bug population. Dubey et al. (1988) analyzed the field data for bug incidence at Dharwad (1974–80) and Coimbatore (1955–67) and arrived at the following multiple linear regression equations to estimate infestation:

$$1)\quad Y = -914.4685 + 27.976\,X_1 + 7.333\,X_2 - 0.038\,X_3 - 0.868\,X_4 + 1.053\,X_5$$

$$2)\quad Y = -81.0650 - 1.947\,X_1 - 1.270\,X_2 + 0.57\,X_3 - 0.016\,X_4 + 0.559\,X_5 + 0.173\,X_6$$

where Y is the estimated value of percentage incidence of head bugs on sorghum; X_1, X_2, X_3, X_4, X_6 are the weekly means of maximum temperature, minimum temperature, RH-1, RH-2, and sunshine hours, and X_5 is the weekly total of rainfall in the standard weeks of highest correlation coefficients.

Equations 1 and 2 correspond to Dharwad and Coimbatore. The optimum value of maximum temperature at Dharwad is 28°C in the third week of Nov, and at Coimbatore, 31°C during the second week of Aug. Morning RH and rainfall are positively correlated with bug numbers at both locations. Infestation decreases suddenly when the minimum temperature increases beyond 17–18°C. Bright sunshine at Coimbatore for more than 8 h in Dec increases the activity of the bugs, resulting in more grain damage. Similar observations have also been made by Sharma and Lopez (1990).

Biotic Factors

Biotic factors such as parasitoids, predators, and pathogens play an important role in bug population. A pathogen similar to 'pebrine' in silkworm (Ballard 1916), reduviid bugs *Geocoris tricolor* (F.) and *Reduviolus* sp (Nayar et al. 1976), and an unidentified parasite (Anonymous 1978) were the only biotic fauna reported on the bugs till a systematic survey was undertaken in sorghum-growing tracts in Karnataka (Hiremath 1989). This survey revealed the occurrence of 24 natural enemies (Table 4). The population of insect predators and erythraeid mites was usually much lower than that of spiders.

Table 4. Occurrence of *Calocoris angustatus* and its natural enemies in Karnataka in different seasons during 1977–80.

	Population 10 panicles^{-1}		
	Rainy season (17)[1]	Postrainy season (17)	Summer (14)
Calocoris angustatus	24.7	10.5	8.7
Camponotus sp	0.63	0.44	0.93
Reduviolus fuscipes	0.1	0.06	0.17
Geocoris tricolor	0.09	0.08	0.01
Erythraeid mites	0.2	0.77	0.33
Spiders	1.72	1.3	1.3

1. Figures in parentheses represent number of surveys.

A maximum of 6.5 spiders per 10 panicles were observed at Mysore, although the corresponding figures for the whole of Karnataka were 1.72, 1.30, and 1.30 during the rainy, postrainy, and summer seasons. Among 16 species of spiders, *Neoscana rumpfi* (Threll), *N. achine, Clubiona* sp, *Chiracanthium* sp, *Plexippus paykulli* (Aud.), *Rhena* sp, *Marpissa* sp, and *Thomisus dhakuriensis* Tikar were relatively more abundant. *Neoscana achine, T. dhakuriensis, N. rumpfi, Chiracanthium* sp and *T. shillongensis* have the potential to consume more than four bugs per day. An entomogenous fungus, *Cephalosporium* sp, was also observed to infect bugs both in the field and in the laboratory. Infection resulted in the death of the bug within 2 days.

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Synthèse

La biologie et la dynamique des populations de la punaise des panicules de sorgho en Inde. La punaise des panicules, *Calocoris angustatus*, est un important ennemi du sorgho en Inde. Des larves et des adultes sucent la sève des grains en formation. En se nourrissant des grains au stade laiteux, le ravageur réduit le poids de la récolte et en déprécie la qualité. Leuschner et Sharma (1983) ont signalé des pertes de 43,9% dues à la punaise des panicules contre 43,2% dues à la cécidomyie et 28% dues à la chenille des panicules. Bien que la punaise soit largement répandue dans plusieurs parties du nord et du sud de l'Inde, des infestations sévères ont eu lieu dans les états indiens de Maharashtra, d'Andhra Pradesh et de Tamil Nadu au cours de la dernière décennie. La distribution aléatoire de la mousson du sud-ouest qui détermine le semis du sorgho est un important facteur de l'incidence élevée des punaises des panicules.

La femelle adulte pond des oeufs dans les glumes florales ou entre les anthères des fleurs du sorgho. En générale, la fécondité varie de 65 à 276 oeufs par femelle. Les oeufs sont en forme de cigare avec un opercule à la partie antérieure. La période d'incubation se situe entre 4,2 et 11 jours en fonction de la région et des conditions climatiques. Cinq stades larvaires de 9,5 à 12,5 jours ont été observés. Les femelles sont légèrement plus grandes que les mâles et les surpassent en nombre jusqu'à 200%. Une génération peut s'accomplir en 19,3 jours en été et 30,1 jours en hiver et on a observé 16 générations par an. Des températures de 25–30°C sont optimales pour le développement nymphal ainsi que la longévité des adultes. Des températures élevées affectent la période nymphale ($r = -0{,}97$) et la longévité des adultes ($r = -0{,}29$) mais non pas la survie nymphale (–0,29).

Le cannibalisme (2–5%) a lieu sous des pressions élevées de population. Des femelles en oviposition de *Contarinia sorghicola* Coquillett sont attaquées par des prédateurs.

La punaise des panicules infeste 16 espèces végétales (Hiremath 1981), surtout le sorgho à grain. Le ravageur est actif toute l'année sauf quelques semaines en été. La densité de peuplement est la plus élevée entre les mois d'août et de novembre (Hiremath et Thontadarya 1984, Sharma et Lopez 1990, 1992) et varie en fonction des régions. Des enquêtes sur le ravageur sont indispensables dans les régions où la punaise est une importante contrainte à la production du sorgho.

La température a un effet négatif ($r = -0{,}35$) tandis que l'humidité relative (RH) a un effet positif sur la population du ravageur. Des températures audessus de 32°C et audessous de 18°C et une RH de <30% sont préjudiciables à ce ravageur (Sharma et Lopez 1990). Une enquête systématique conduite par Hiremath (1989) sur des ennemis naturels associés à la punaise des panicules dans les régions sorghicoles de Karnataka ont révélé la présence de 24 espèces dont les araignées présentent une importance particulière. Parmi les 16 araignées repérées, *Neoscana rumpfi* (Threll), *N. achine, Clubiona* sp, *Chiracanthium* sp, *Plexippus paykulli* (Aud.) *Rhena* sp, *Marpissa* sp et *Thomisus dhakuriensis* Tikar ont été relativement plus abondantes. Un champignon entomogène *Cephalosporium* sp aussi affecte la punaise et la tue en 2 jours.

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Bioecology of Sorghum Head Bug *Eurystylus immaculatus*, and Crop Losses in West Africa

A Ratnadass[1], Y O Doumbia[2], and O Ajayi[3]

Abstract

The life cycle (pre-oviposition, egg incubation, and nymphal development periods) and other biological parameters (nymphal survival, sex ratio, adult longevity, female fecundity, and hatching rate) of the sorghum head bug Eurystylus immaculatus, *were determined in the laboratory at Samanko, Mali, in 1991/92 and 1993, and at Bagauda, Nigeria, in 1992/93. Head bug population dynamics surveys conducted at Sotuba, Mali, showed two peaks of infestation, in late Sep and late Oct both in 1989 and 1990. At Samanko, there were four head bug generations in 1991, and three in 1992. In 1989 at Bagauda, the highest* E. immaculatus *population occurred at the soft dough stage. The contributions of head bug feeding and egg-laying punctures in the overall damage to sorghum grains, were studied in 1991 at Farako-Bâ, Burkina Faso. At Sotuba, correlation between bug damage and grain mold infection was low in 1990, and very high in 1991; this was due to differences in humidity levels. Bug attack alone accounted for most of the overall damage to sorghum. Using cypermethrin protection at Bagauda, avoidable sorghum grain yield losses due to head bugs were 83% in 1989 and 21% in 1990, the difference being due to differences in infestation levels. The economic injury level was 2.52* E. immaculatus *per panicle in 1989 and 0.97 in 1990.*

Introduction

Head bugs (Heteroptera, Miridae) have recently become key pests of sorghum in western Africa. Their feeding and oviposition punctures on developing grains result in severe quantitative and qualitative losses, including higher grain mold incidence, particularly on improved compact-panicled types (Doumbia and Bonzi 1985, Steck et al. 1989, Ratnadass et al. 1991, Sharma et al. 1992, Sharma et al. 1994). However, opinions differ on the relative effects of the two types of punctures on overall damage (Sharma 1986, Steck et al. 1989).

The head bug complex is dominated by the genus *Eurystylus* Stål, of which several species have been reported, notably *E. rufocunealis* (Poppius) from Nigeria (MacFarlane 1989), *E. bellevoyei* Reuter from Burkina Faso (Nwanze 1985), and *E. marginatus* Odhiambo from Mali (Doumbia and Bonzi 1985) and Niger (Steck et al. 1989). It is, however, likely that only one species is actually involved, or at least largely dominant. Earlier papers referring to *E. marginatus* are probably based on *E. immaculatus* Odhiambo (Sharma 1989). Some information on *E. immaculatus* bioecology and damage to sorghum is available from earlier reports (MacFarlane 1989, Steck et al. 1989, Sharma 1989, Doumbia 1992a,b).

However, in order to further improve our knowledge of this head bug, in view of its increasing importance, the studies reported here were conducted, as a prelude to its management, during 1989–93 in Mali, Nigeria, and Burkina Faso, by ICRISAT's West African Sorghum Improvement Program (WASIP) and the Institut d'Economie Rurale (IER), the Malian national

1. Centre de Coopération en Recherche Agronomique pour le Développement/Département des Cultures Annuelles (CIRAD/CA), ICRISAT West African Sorghum Improvement Program (WASIP)–Mali, Samanko, BP 320, Bamako, Mali.

2 Institut d'Economie Rurale (IER), Station de Recherche Agronomique de Sotuba, BP 438, Sotuba, Mali.

3. ICRISAT West African Sorghum Improvement Program (WASIP)–Nigeria, IITA Office, Sabo Bakin Zuwo Road, PMB 3491, Kano, Nigeria.

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agricultural research system (NARS). Some of these studies have been partly reported elsewhere (Doumbia and Teetes 1991, ICRISAT 1991, 1992, 1993, INTSORMIL 1991).

Biology of *Eurystylus immaculatus*

Laboratory studies on the biology of *Eurystylus immaculatus* were carried out between Nov 1991 and Mar 1992, and between Jan and Apr 1993 at Samanko, Mali, and between Oct 1992 and Jan 1993 at Bagauda, Nigeria (ICRISAT Sahelian Center 1992, p. 112, and 1993, p. 52, Mallé 1993). Insect cultures were started from field-collected insects. For bug oviposition and feeding studies, panicles at the milk stage were used. This involved various head bug susceptible caudatum sorghum cultivars at Samanko, and only one cultivar, ICSV 247, at Bagauda.

At Samanko, one pair of newly emerged adults was confined on fresh sorghum rachis with four to six sprigs, held in an upright position in a glass vial filled with water. This was then held in a 1.25-L transparent plastic container with mesh-covered perforations to provide aeration. Sorghum rachis were changed daily, and observed under the microscope for egg counts and hatching records. Freshly emerged first instar nymphs were transferred individually to 0.25 L plastic containers, where sorghum sprigs, with the base wrapped in wet cotton wool covered with Parafilm®, were provided as food. The sprigs were changed every second day; containers were checked daily to record molting and nymphal mortality.

At Bagauda, adult females, assumed to have mated in the field, were confined to sorghum sprigs, using transparent plastic cages. The bases of the sprigs were wrapped in cotton wool and kept in water. Grains were examined daily at 0900 and those with eggs were removed and placed individually on a moistened filter paper in petri dishes. They were checked twice daily at 0900 and 1400. First instar nymphs were transferred carefully onto new sprigs in the cages and monitored until they died as nymphs or developed into adults. Sprigs were replaced with fresh ones every other day. One male and one female adult, emerging from these sprigs, were paired on a fresh sprig inside a cage and records were kept of the following: pre-oviposition period, number of eggs laid per female, duration of egg and nymphal stages, and adult longevity. Three pairs were successfully studied in this way. Results showed that eggs were laid inside sorghum grains at the milk stage, on the portion exposed outside the glumes. Eggs were detectable by their protruding tip (operculum).

At Samanko, the number of eggs laid in a single grain varied from 1 to 7. Hatching took place after an incubation period of 4–6 days in 1991/92. There were five nymphal instars. Total nymphal period was 6–11 days. Detailed results on nymphal instar development periods are presented in Table 1. In 1991, nymphal survival until adult was 80.8 ±4.7%. In both study periods, sex ratio was 1:1. Pre-oviposition period was 2–3 days in 1992, and 3.0 ±1.7 days in 1993. In 1992, maximum longevity observed for a mated female was 18 days, during which 181 live nymphs were produced. In 1993, mean adult longevity was 13.5 ±7.3 days for mated males (maximum 26 days), and 7.6 ±3.5 days for mated females (maximum 11 days). Mean number of live progeny for five mated females was 80.4 ±56.3.

Table 1. Duration of nymphal development of *Eurystylus immaculatus* on maturing caudatum sorghum grains under laboratory conditions at Samanko, Mali, 1991–93.

Dates	Sex	Number of observations	Duration of nymphal instars (days) I	II	III	IV	V	Total period
Nov 91–Mar 92	M	12	2.1 ±0.3	1.4 ±0.5	1.5 ±0.5	1.9 ±0.5	2.3 ±0.6	9.2 ±0.6
	F	15	2.3 ±0.6	1.3 ±0.5	1.6 ±0.5	1.5 ±0.5	2.5 ±0.5	9.2 ±0.6
Jan–Apr 93	M	13	1.7 ±0.5	1.2 ±0.4	1.2 ±0.4	1.6 ±0.5	2.2 ±0.4	7.9 ±0.5
	F	14	1.8 ±0.4	1.2 ±0.4	1.1 ±0.3	1.3 ±0.5	2.3 ±0.6	7.7 ±0.6

Laboratory conditions: Nov 1991–Mar 1992: temperature 25 ±2°C, relative humidity 80 ±10%, natural photoperiod: daylength 11 h 15 min to 12 h 05 min.

Jan–Apr 1993: temperature 27 ±1°C, relative humidity 67 ±10%, natural photoperiod: daylength 11 h 20 min to 12 h 20 min.

At Bagauda, the mean pre-oviposition period was 3.67 ±0.58 days; the eggs hatched in 6.84 ±1.29 days, with peak hatching in 6 days; the nymphal period (5 instars) lasted for 8.07 ±0.26 days; the maximum adult longevity observed was 40 days; the number of eggs laid per female was 667 with a hatching percentage of 24–61%.

Population Dynamics of *E. immaculatus* on Sorghum

A study was carried out at Bagauda in 1989 to determine the population density of *E. immaculatus* in relation to the phenology of the sorghum plant (ICRISAT Sahelian Center 1990, pp. 114–115). Five panicles of ICSV 247 were randomly sampled at five stages of grain development, in a randomized complete block design (RCBD) with three replications. Each head was first covered with a polythene bag and then excised at the peduncle. The bag and its contents were kept in a deep freezer for 5 min to immobilize the insects, which were then sorted and counted in the laboratory.

The number of *E. immaculatus* increased from pre-anthesis (0.7 bugs per five panicles) through the other stages (2.0 bugs at half-anthesis, 8.7 at complete anthesis, and 12.0 at milk stage), and peaked at the dough stage (53.3 bugs per five panicles) (ICRISAT Sahelian Center 1990, pp. 114–115).

Head bug adult and nymphal population dynamics were studied in 1989/90 at Sotuba (Doumbia and Teetes 1991). Ten samples of five panicles each were chosen randomly, on an assortment of sorghum cultivars, all sown on the same date, and covering a range of maturity cycles. Sampling was done as described above, once every 10 days. After all the rainfed sorghum had been harvested, panicles from ratoons and off-season sorghum plants were sampled.

The first *Eurystylus* adults were observed in mid-Sep in 1989, and a week earlier in 1990. Head bug population dynamics showed two peaks of infestation each year, in late Sep and late Oct. The second peak in 1990 was much lower than the first peak of the same year, and lower than the second peak in 1989, and this was attributed to differences in weather conditions, notably rainfall pattern (Doumbia and Teetes 1991).

In both surveys, the last adult bugs were recorded on sorghum panicles in off-season plots, in Jan and Feb (Doumbia and Teetes 1991).

During the 1991 and 1992 rainy seasons, head bug population dynamics was studied at Samanko, on sorghum cultivar ICSV 197, sown on eight different dates (DOS) at weekly intervals, from mid-Jun to early Jul, in a RCBD with six replications per DOS. Twice a week, from flowering to grain maturity, three panicles per plot were sampled as described above. Mirid eggs were counted under the microscope on 100 grains, randomly selected from the top, the middle, and the bottom of the panicle.

The first three DOS in 1991, and the last three DOS in 1992, suffered from poor plant stand and staggered flowering, and therefore were not taken into account. In 1991, when they were first sampled on 9 Oct, panicles of DOS 4 and DOS 5 were already at the milk stage, and bug adult populations were at their highest (Fig. 1a). For each DOS, there was only one peak of adult population, at the milk stage, followed 5–17 days later by a peak in nymphal population, at the dough stage (Fig. 1b). Numbers of mirid eggs per 100 grains recorded on the last four DOS ranged from 2.17 ±0.71 on DOS 5 to 4.83 ±1.66 on DOS 8. *Eurystylus immaculatus* was the dominant species, responsible for most of the oviposition observed during the survey period.

On DOS 1 in 1992, the first *E. immaculatus* adults were observed on 11 Sep, at the complete anthesis stage (Fig. 2a). This colonization by first generation adults continued over a period of more than 2 weeks. The first nymphs were observed for DOS 1 on 17 Sep, at the milk stage, and their population peaked on 24 Sep, at the soft dough stage (Fig. 2b). This was followed by a peak in adult infestation on 5 Oct, at the hard dough stage, which coincided with a second peak in nymphal infestation. Adults of the second generation left the panicles of DOS 1 on which they had developed and moved onto panicles of other later maturing DOS as the panicles developed through vulnerable stages.

In both years, there was a peak in adult populations at the milk stage of sorghum panicles, corresponding to maximum attractiveness. It is probably then that maximum oviposition took place, which resulted in a peak in nymphal population at the dough stage. In all cases, only one generation developed on a particular panicle. The population trend in the two years showed some differences, which may be related to the difference in the rainfall patterns (Figs. 1c and 2c). As a consequence, there were probably four succeeding generations in 1991, as compared to only three in 1992: the last peaks in adult and nymphal populations that were observed in early Nov in 1991, did not occur in 1992.

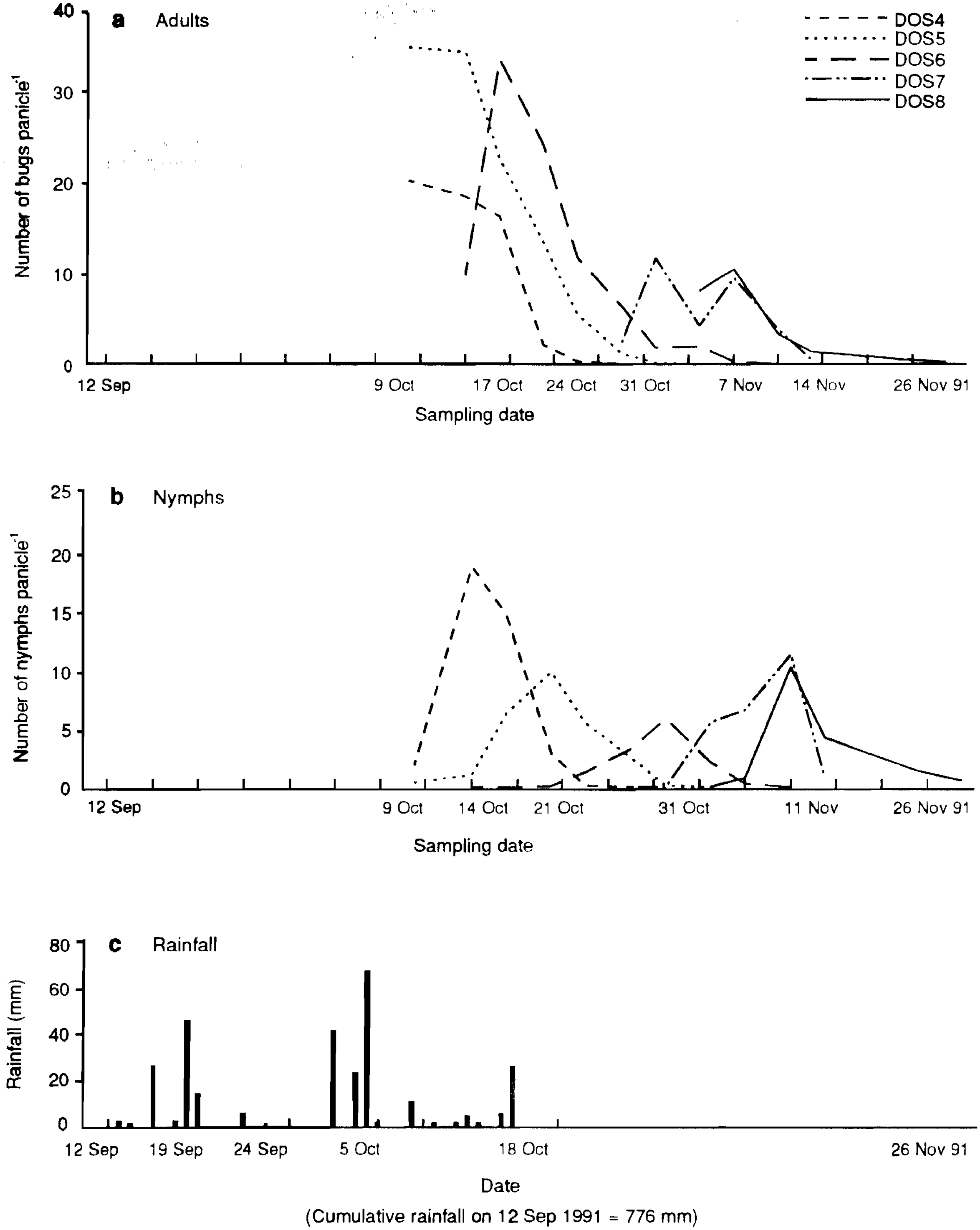

Figure 1. Seasonal population fluctuation of *Eurystylus immaculatus* on sorghum variety ICSV 197 at WASIP, Samanko, Mali, rainy season 1991.

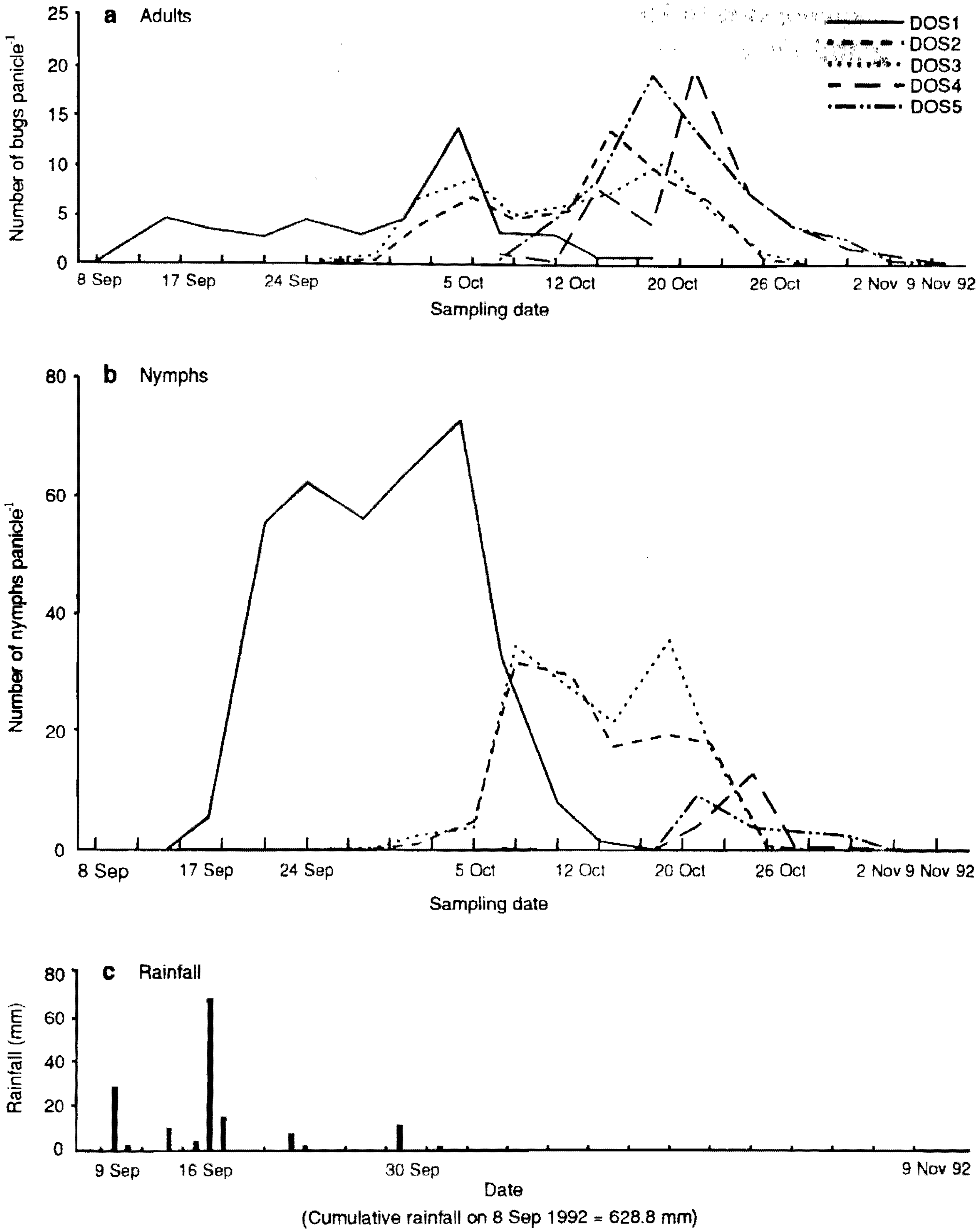

Figure 2. Seasonal population fluctuation of *Eurystylus immaculatus* on sorghum variety ICSV 197 at WASIP, Samanko, Mali, rainy season 1992.

Grain Damage Due to Head Bug Feeding and Oviposition

In a trial conducted at the research station of the Institut d'Etudes et de Recherches Agricoles (INERA) at Farako-Bâ, Burkina Faso, during the 1991 rainy season, sorghum panicles were artificially infested with adult bugs at complete anthesis, using the head cage technique (Sharma et al. 1992). At maturity, grains of the panicles of four varieties (ISIAP Dorado, S 34, Malisor 84-7, and Gnofing) were divided into three categories: undamaged; damaged with feeding punctures only; damaged with both feeding and oviposition punctures. There were no cases in which grains showed only oviposition punctures. On each fraction, the following grain quality measures were taken: 1000-grain mass, proportion of light grains, grain vitrosity, and germination rate (Ratnadass et al. 1991).

Results show that a combination of egg-laying and feeding is more destructive to the grain than feeding alone (Fig. 3). However, oviposition plus feeding, compared with feeding alone, did not result in a marked reduction of 1000-grain mass (notably in local cultivar Gnofing and head bug resistant cultivar Malisor 84-7), whereas it resulted in a distinct loss of vitrosity of all four cultivars, an increase in the proportion of low-density grains (except in Gnofing), and lower germination (except in Malisor 84-7).

Interaction Between Bug Damage and Grain Mold Infection

An experiment was conducted in 1990 and 1991 at Sotuba, to determine the relationship between head bug damage to sorghum grain and the degree of infection by grain molds. The sorghum cultivar used was ICSV 1002. There were four treatments, in a RCBD with four replications: protection of panicles by application of a fungicide (benomyl); protection using a plastic bag; protection with a plastic bag plus fungicide; and control (natural infestation without any protection). Fungicide was applied three times. Bug abundance was determined from a sample of five randomly selected panicles per plot, 14 days after anthesis. At grain maturity, bug damage was visually scored on a 1–5 rating scale (Doumbia and Teetes 1991), and grain mold infection on a 1–5 scale (where 1 = no grain mold, and 5 = >50% of the grains moldy). Thousand-grain mass and grain yield were also determined after harvest (INTSORMIL 1992, pp. 28 and 199).

Results are presented in Table 2. Levels of bug infestation were much higher in 1991 (mean 150 bugs per 5 panicles) than in 1990 (33 bugs per 5 panicles). Differences in the number of bugs per 5 panicles between fungicide-protected (21 and 213 in 1990 and 1991) and unprotected panicles (37 and 130) were not apparent. Fungicide application only slightly affected bug damage, whereas in both years, grain mold infection was greater on unprotected than on fungicide-protected panicles (Table 2). On the other hand, panicles protected from bugs alone with a plastic bag had no more pathogen infection than panicles protected either by fungicide alone, or both by fungicide and plastic bag. In 1990, neither head bug nor grain mold damage resulted in any loss in 1000-grain mass or grain yield (INTSORMIL 1992, pp. 28 and 199), whereas in 1991, head bug damage resulted in a sig-

Table 2. Head bug damage and grain mold infection, and their effect on 1000-grain mass and grain yield of sorghum cultivar ICSV 1002 at Sotuba, Mali, rainy seasons 1990 and 1991.[1]

	Head bug damage[2]		Grain mold infection[3]		1000-grain mass (g)		Grain yield (t ha^{-1})	
Treatment	1990	1991	1990	1991	1990	1991	1990	1991
Fungicide protection	2.5	3.9	1.9	2	21.1	25.7	1.41	2.23
Plastic bag protection	1	1	1.1	2.1	22.3	33.7	1.83	2.57
Fungicide + plastic bag	1	1	1.1	2	22	36.7	1.71	2.54
Control	2.9	4.6	2.7	3.5	20.7	25.4	1.6	1.71
SE	±0.1	±0.07	±0.16	±0.31	±1.78	±0.73	±0.37	±0.1
Mean	1.8	2.6	1.7	2.5	21.5	30.4	1.64	2.26
CV (%)	11	6	19	25	17	5	30	6

1. Randomized complete block design with 4 replications. Plot size 15 m^2.
2. Damage visually scored on a 1–5 scale, where 1 = <10%, and 5 = >60% grains showing head bug damage.
3. Infection visually scored on a 1–5 scale, where 1 = <10%, and 5 = >50% grains moldy.

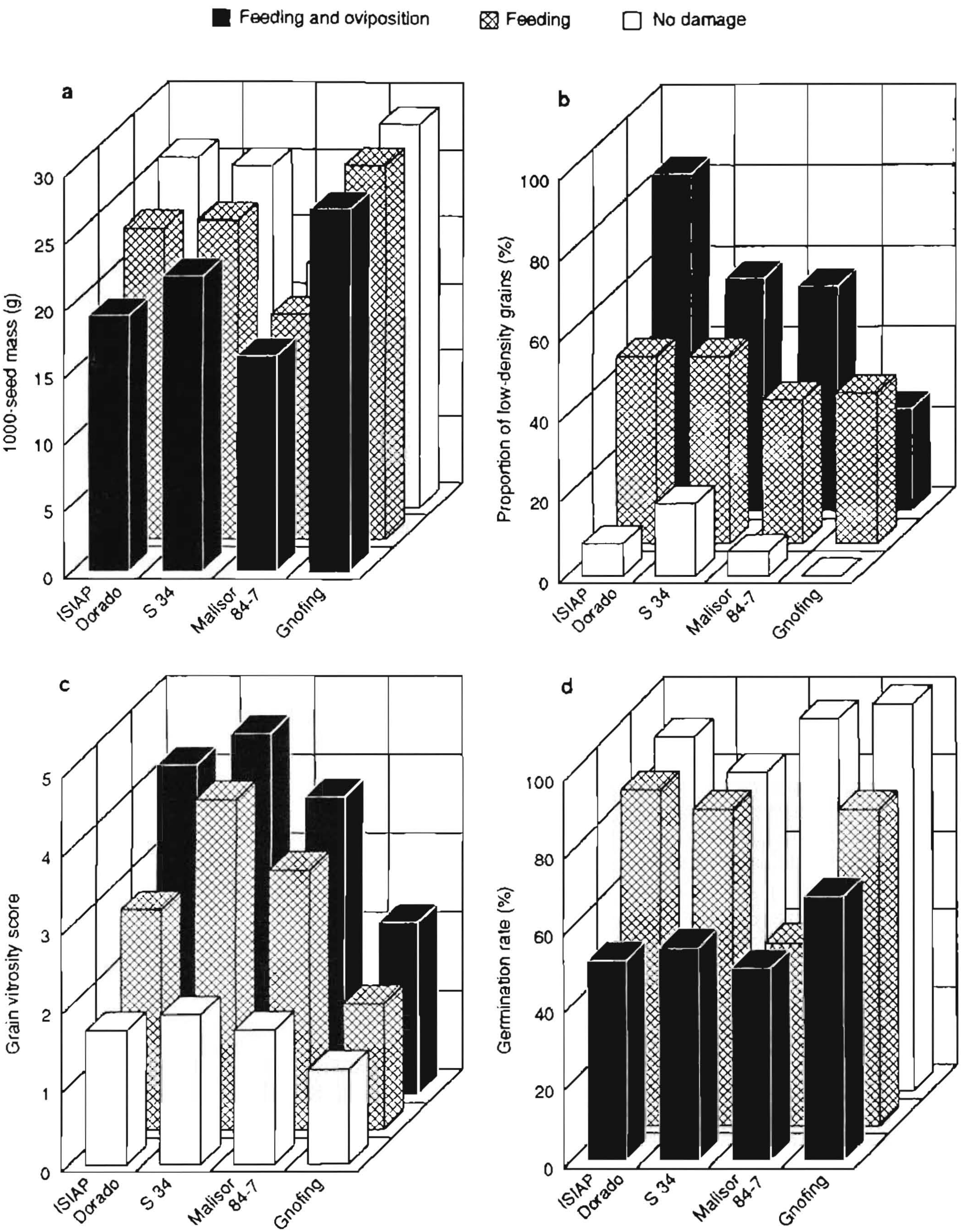

Figure 3. Effect of head bug feeding and oviposition punctures on grain quality of four sorghum cultivars at INERA, Farako-Bâ, Burkina Faso, rainy season 1991.

nificant reduction of both quantitative loss parameters, and mold damage in a reduction of only grain yield. Head bugs caused much more loss than did grain mold.

In 1991, correlation coefficients of bug damage to 1000-grain weight and to grain yield were −0.934 and −0.842, both highly significant ($P<0.001$). The correlation coefficient of bug damage to pathogen infection (grain mold rating) was not significant in 1990 ($r = 0.313$), while it was significant in 1991 ($r = 0.653$; $P<0.01$). These differences were attributed to variations in humidity levels.

Grain Yield Loss and Economic Threshold Levels

Studies were conducted in 1989/90 at Bagauda to estimate the avoidable losses due to head bugs, and to obtain an estimate of economic injury levels (ICRISAT Sahelian Center 1990, pp. 114–116, and 1991, pp. 113–114). Four concentrations of cypermethrin EC were sprayed at half-anthesis of sorghum cultivar ICSV 247, to create different levels of head bug infestation. In 1989, head bug populations were estimated on five randomly selected panicles 24 h before and after spraying. The insecticide application was repeated the following day to achieve a gradient of head bug infestation at the complete-anthesis stage. In 1990, the same concentrations of cypermethrin were sprayed three times at weekly intervals, beginning from half-anthesis. In each year, head bug populations were estimated as above on five randomly selected panicles 24 h before and after spraying. The economic injury level was calculated using the method of Michels and Burkhardt (1981).

In both years, 0.02% cypermethrin gave the best control of *E. immaculatus*. For example, in 1989, it reduced the population of bugs from 39 per five panicles before the first spray to 4 after the second spray when there were 48 on the control panicles (Table 3); spraying with 0.02% cypermethrin improved grain yield by 83% and grain mass by 65% while reducing the proportion of floaters by 59% compared to the control (ICRISAT Sahelian Center 1990, pp. 114–116). In 1990, this treatment increased grain yield by 21% and grain mass by 5%, while the proportion of floaters was reduced by 25% (ICRISAT Sahelian Center 1991, pp. 113–114). The differences between the two years were because bug populations decreased from 1989 to 1990. The economic threshold level was 2.52 bugs per panicle in 1989 and 0.97 in 1990.

Discussion

This is the first detailed report on the life history of *E. immaculatus*. Egg incubation and total nymphal

Table 3. Effect of cypermethrin on *E. immaculatus* numbers on sorghum (ICSV 247) at Bagauda, Nigeria, rainy season 1989.[1]

Cypermethrin concentration (%)	Number of headbugs[2] Before spray	After first spray	After second spray	10 days after second spray	Grain yield (t ha^{-1})	1000-grain mass (g)	Floaters (%)
0.001	36(6.0)[3]	46(6.7)	8(5.7)	33(1.1)	3.7	29.0	70.5(8.40)
0.005	34(5.7)	19(4.2)	7(4.6)	22(1.1)	4.0	27.9	54.3(7.37)
0.01	49(6.9)	18(4.2)	7(3.6)	13(1.2)	4.8	32.7	42.8(6.54)
0.02	39(6.2)	16(3.7)	4(3.1)	10(1.2)	5.3	35.7	31.0(5.57)
Nontreated control	40(6.3)	38(5.7)	48(6.1)	39(1.1)	2.9	21.7	76.2(8.73)
SE	(0.65)	(1.05)	(0.51)	(0.45)	0.35	0.66	(0.032)
Mean	40(6.2)	27(4.9)	5(4.6)	23(1.1)	4.1	29.4	55.0(7.32)
CV (%)	(18)	(37)	(16)	(9)	15	4	(1)

1. Randomized complete block design with 3 replications.
2. Counted per 5 randomly selected panicles.
3. Figures in parentheses are square-root values.

periods of this species were slightly longer than those reported from India by Sharma and Lopez (1990) for *E. bellevoyei* (7 and 7.3 ±0.07 days), and shorter than those reported for *Calocoris angustatus* Lethiery by the same authors (7–8 and 9.3 ±0.16 days). They were also much shorter than those reported for *C. angustatus* by Hiremath and Viraktamath (1992) (5.6–11.0 and 10.0–17.0 days). However, there was some variation between data from Samanko and Bagauda, which could be due to differences in weather conditions and sorghum cultivars used. However, data from both locations indicate that the total life cycle is 2–3 weeks. On the other hand, data on female fecundity and egg fertility were highly variable, and information on mortality of different stages is lacking. There is therefore a need for further studies, in view of the establishment of the life table of this pest.

Data obtained at Bagauda on sorghum phenology, as it relates to head bug infestation, enable a more precise determination of the best time to attempt control measures, i.e., before the peak population is reached. In a similar study conducted in Mali in 1984/85, Doumbia (1992a) reported that both adult and nymph populations were higher at maturity than at the milk stage. However, sampling was not carried out, either at the dough stage in that study, or at the maturity stage in the work reported here. Observations by Sharma et al. (1992), on the effect on head bug numbers of the stage of panicle development at the time of infestation, also support the results of both studies.

In studies conducted in 1983/84 in northern Nigeria, MacFarlane (1989) reported that only one generation of head bugs could be completed on a particular panicle. In 1986 in Niger, Steck et al. (1989) reported three generations of head bugs on an assortment of sorghum varieties at Tarna, with a first population density peak in early Sep. The adult and nymphal curves obtained at Samanko in 1991 and 1992, show a bimodal pattern, as at Sotuba, with peaks in late Sep/early Oct, and late Oct/early Nov. First generation colonizing adults presumably moved from an alternate host plant, unknown so far, on which they had undergone diapause at some stage of their development (Steck et al. 1989). In other observations at Samanko in both 1991 and 1992, the first adults of *E. immaculatus* were observed in late Aug on early flowering sorghum panicles and the last adults were collected in early Dec on late-flowering panicles, notably from ratoons. *Eurystylus immaculatus* was seldom observed on sorghum grown in the off-season, and never beyond Feb.

Data from Samanko on the number of generations observed in the field, are consistent with those of laboratory studies on the life-cycle, although the latter were carried out during the off-season. However, staggered flowering situations as achieved in our studies favor head bug population buildup, and are not commonly found in farmers' fields. Numbers of eggs recorded, although low, in view of female fecundity, are consistent with the number of offspring (as number of grains per panicle is above 3000 in ICSV 197). Comparisons between nymph and adult population peaks, suggest that nymphal survival is much lower in the wild than in the laboratory. This high mortality can be due to adverse weather conditions, or to control by natural enemies. First peaks in nymphal populations that occurred in Sep, were thus higher, probably because of higher humidity. On the other hand, Doumbia and Bonzi (1985) in Mali, and MacFarlane (1989) in Nigeria, stressed the importance of spiders, and to a lesser extent predatory bugs, notably the anthocorid *Orius* spp [which were also collected in large numbers by Steck et al. (1989) in Niger], while Sharma (1989) mentioned earwigs (Dermaptera, Forficulidae) as potential predators of head bugs.

Results from Farako-Bâ support observations by Steck et al. (1989), that feeding activity is as destructive as oviposition, in contrast to those by Sharma (1986), that the main head bug damage is due to oviposition. The proportion of grains directly affected by egg-laying rarely exceeds 5%, whereas most grains are generally affected by feeding (over 50% at the third level on the 1–9 scale used for visually scoring head bug damage) (Ratnadass et al. 1993). The effects of head bug feeding are the physical removal of nutrients and water (leading to shrivelled grains and weight loss) and the action of salivary enzymes [which results in the break down of endosperm texture, leading to floury texture (or loss of vitrosity)]. Following oviposition, the endosperm adjacent to the egg frequently becomes discolored and floury, and may deteriorate completely, due to the introduction of molds, which also results in a reduction of the germination rate (Steck et al. 1989, INTSORMIL 1992, pp. 172–177).

Although Steck et al. (1989) and Sharma et al. (1992) had reported earlier that bug-damaged grains showed greater severity of mold incidence, data obtained at Sotuba are the first to clearly demonstrate the strong relationship between head bugs and grain molds.

Results from Bagauda clearly show that severe reductions in grain mass, total grain yield, and quality can be caused by *E. immaculatus*, but that the magnitude of losses increases with an increase in levels of infestation. This underscores its importance as a pest of sorghum. The economic threshold levels calculated for *Calocoris angustatus* were 9.7 nymphs, 5.4 feeding adults, or 0.06 ovipositing adults when HCH was used; 15.1 nymphs, 10.5 feeding adults, and 0.12 ovipositing adults when malathion was used (Natarajan and Sundara Babu 1988); 1.3–1.4 insects per panicle for CSH 1, 0.4 for ICSV 1 and 0.2–0.6 for CSH 5 (Sharma and Lopez 1989). Studies on *C. angustatus* demonstrate the variability of the economic injury levels depending on crop variety and plant growth stage (Sharma and Lopez 1989 and 1993), and the insecticide used (Natarajan and Sundara Babu 1988). The results presented here for *E. immaculatus* should be considered against that background.

Acknowledgments

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Synthèse

Bioécologie de la punaise miride des panicules* Eurystylus immaculatus *en Afrique de l'Ouest et dégâts occasionnés au sorgho. La biologie de la punaise miride des panicules de sorgho (*Eurystylus immaculatus*) a été étudiée au laboratoire pour la première fois, à Samanko (Mali) en 1991/92 et 1993, et à Bagauda (Nigéria) en 1992/93.

La durée d'incubation des oeufs a été de 4–6 jours à Samanko, et de 6.8 ±1.3 1 à Bagauda. A Samanko, la mortalité larvaire était inférieure à 20%, et le sex ratio de 1:1. La descendance moyenne par femelle y était de 80±56 larves, comparé à 667 oeufs pondus par femelle à Bagauda, avec un taux d'éclosion de 24 à 61%.

La dynamique des populations de punaises a été suivie à Sotuba (Mali) en 1989 et 1990, sur des variétés de sorgho couvrant une large gamme de cycles, et à Samanko, en 1991 et 1992, dans un essai où une même variété (ICSV 197) était semée en six dates différentes.

Les quatres années, on a observé deux principaux pics d'infestation, l'un en septembre, l'autre en octobre. A Samanko, ces pics ont correspondu à quatre générations de punaises en 1991, et trois en 1992, du fait de différences climatiques entre les deux années. Les deux années, il y eu un pic d'infestation par les adultes au stade laiteux, et un pic des populations de larves au stade pâteux, chaque panicule n'autorisant le développement que d'une seule génération.

Dans un essai conduit à Bagauda en 1989, et visant à déterminer le niveau de population de *E. immaculatus* en relation avec la phénologie de la panicule de sorgho (variété ICSV 247), la population la plus élevée a été relevée au stade pâteux du grain.

La part des piqûres d'alimentation d'une part, et d'oviposition d'autre part, dans le dégât global occasionné aux grains par les punaises, a été étudié à Farako-Bâ (Burkina Faso) sur quatre variétés de sorgho. Bien que les grains ayant subi les deux types de piqûres soient plus dégradés que ceux ayant subi seulement les piqûres d'alimentation, la différence n'était très nette que pour la vitrosité, et peu marquée pour le poids de 1000 grains.

La relation entre les dégâts des punaises et ceux des moisissures des grains a été étudiée à Sotuba (Mali) en 1990 et 1991. La corrélation entre les deux dégâts a été faible en 1990, et très élevée en 1991, du fait de différences climatiques entre les deux années. En 1991, les punaises étaient responsables de l'essentiel des dégâts, leur attaque réduisant de façon significative le poids de 1000 grains et le rendement.

Dans un essai conduit en 1989/90 à Bagauda, où les panicules de la variété de sorgho ICSV 247 étaient protégées des punaises par traitement insecticide à la cyperméthrine, les pertes évitables de rendement en grain dues aux punaises et les seuils économiques de nuisibilité ont été respectivement de 83% et 2.5 punaises par panicule en 1989, et de 21% et 1.0 punaise par panicule en 1990.

Ces résultats et leurs implications sont discutés à la lumière d'études antérieures, et dans l'optique de la lutte contre ces ravageurs.

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Population Monitoring and Crop Loss Assessment in Integrated Pest Management of Panicle Pests of Sorghum and Pearl Millet

N D Jago[1]

Abstract

The main panicle pests of pearl millet recorded during a Natural Resources Institute, (UK), project in North West Mali (1985–91) are listed. The importance of operational crop loss assessment, crop damage, and pest monitoring is emphasized as a means of interpreting pest dynamics, detecting population trends, and forecasting ahead of the next season. Some pearl millet varieties show pseudo-resistance to grasshoppers, panicle-feeding beetles, and other pests. Sorghum varieties, however, combine this factor with intrinsic chemical defenses, making it possible to reduce pest damage to pearl millet by intercropping the two cereals. The importance of rainfall records is explained. Rainfall data may indicate when it is uneconomic to apply chemical insecticides for certain pests such as the millet head miner caterpillar. The difficulties inherent in monitoring concealed and overt damage to millet are discussed. Proposals are made for practical IPM interventions against panicle pests. Long-term research into genetic engineering in pearl millet is tentatively proposed as the most effective way of improving IPM of panicle and foliage pests.

Introduction

Crop loss assessment (CLA) plays a key role in any pest control measure and it is the first justification for inputs into IPM practice. Unfortunately millet CLA is in its infancy. Bullen (1966) made a pioneer attempt to assess crop losses due to locusts and grasshoppers. Deeming (1978) refers to surveys of millet in Nigeria, where crop losses of 7–51% due to *Heliocheilus albipunctella* were recorded. Dively (1984, 1985) was the first to focus on crop loss due to grasshopper attack on pearl millet and to formulate a CLA methodology suitable for farmer-level surveys. Our own work and that of such others as Nwanze and Sivakumar (1990) have followed. Such assessments need to be made over several years and over a large area. They are not yet universally part of routine operations by extension services or crop protection agencies.

The Natural Resources Institute (NRI) of the Overseas Development Administration (ODA) Mali Millet Pest Control Project (Le Projet Pilote Britannique) operated in North West Mali in close collaboration with the Service de la Protection des Végétaux, Mali, from 1985 to 1991. Various pest control measures were attempted (Jago et al. 1993). Studies were made of the financial and socioeconomic structures of the farming community, the effectiveness of control measures, and the economic viability of pest management practices set against the cyclical market value of small grain cereals. Volunteer or 'pilot' farmers eventually reached a total of 328 in 1990 (Table 1). The northern low-rainfall zone (300 mm mean annual rainfall) was represented by village clusters centered upon Dilli and Nara, the southern low-rainfall zone (500 mm) being represented by three village clusters centered upon Mourdiah with a subsidiary group at Fallou. The term 'pilot farmers' is widely accepted in Mali as referring to farmers in a pilot agricultural development scheme which predicates a larger program of adoption and dissemination.

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Table 1. Numbers of volunteer pilot farmers offering paired subplots, NRI Mali Millet Pest Project, North West Mali, 1985–90.

Geographical zones		1985	1986	1987	1988	1989	1990
Northern	Dilli		20	40	62	68	68
	Dilli		20	40	62	68	68
	Nara		20	43	60	69	69
Southern	Mourdiah (with 3 subsectors)	4	40	84	140	151	159
	Fallou					30	32
Total		4	80	167	262	318	328

Methodology

Pilot farmers offered paired 0.5 ha plots (one control, one treatment plot). The project focused on pearl millet, *Pennisetum glaucum*, since this was the predominant crop and was subject to greater crop loss than sorghum, *Sorghum bicolor* (L.) Moench. Two main varieties of pearl millet were grown, the short-duration 70-day Souna variety and the long-duration 120-day Sanyo variety. While the latter was invariably grown in monoculture, the former was often intercropped with sorghum. Field layout in the intercrop was studied to determine the benefits to be gained against pest attack. The plant density and the number of plants per hole (locally called 'pockets', and referred to as such here), was found to differ consistently in the high- and low-rainfall zones. Insect pests were monitored in the paired plots roughly once every 5 days, while mobile adult stages were monitored every night at light traps (Jago 1993b). There was a major trap at each of the four bases, Dilli, Nara, Mourdiah, and Fallou. Each was located next to the millet crop. For practical reasons, traps were only operated between 1830 and 2030. Graphs of pest levels provided below represent insects counted at light. Although weeds affect the panicle indirectly and weeding schedules play a major part in the IPM of pests such as grasshoppers, they will not be covered here. Likewise, although *Coniesta ignefusalis* (Hampson) (Lepidoptera, Pyralidae), the millet stem borer, has an indirect effect on the millet panicle, it is omitted here. Crop loss monitoring took place mainly during late Jun and Jul (to estimate loss of seedlings and area requiring resowing) and from Sep to Nov (to estimate panicle damage from emergence to harvest). Crop loss assessment methods are delineated in Jago (1993c).

Results and Discussion

Major insect pest species

The main pests of millet panicles in the region during 1985–90 were:

- The millet head miner, *Heliocheilus albipunctella* de Joannis (Lepidoptera, Noctuidae).
- Six major grasshopper species (Orthoptera, Acrididae): *Oedaleus senegalensis* Krauss, *Kraussaria angulifera* Krauss, *Hieroglyphus daganensis* Krauss, *Cataloipus cymbiferus* Krauss, *Diabolocatantops axillaris* Thunberg, and *Kraussella amabile* Krauss.
- Two major genera of flower-feeding beetles (Coleoptera): *Pachnoda interrupta* Olivier (Scarabaeidae), chafer beetles, and three species of *Psalydolytta* (Meloidae), blister or oil beetles often referred to as 'cantharides' in francophone West Africa.

Pachnoda interrupta and *K. amabile* are diurnally active and not attracted to light. Their populations were in the fields during daylight.

Pest population, crop damage, and crop loss survey of pests in IPM of millet

Suggestions for frequency of sampling to monitor panicle insect pests have been given by Jago (1993b). Daytime sampling every 3 or 4 days may be sufficient during the hopper stages of grasshopper pests, but daily observation may be required during periods of adult migration. Daytime sampling of *Pachnoda* beetles on panicles will indicate local population build-up quite accurately, but meloids are also active at night and many of these insects hide among the foliage during the daytime. Day counts of meloids on the panicles are, on their own, likely to lead to underestimation of numbers, though peak numbers of *Psalydolytta* spp at light traps correspond to peak incursion into fields. With some pests such as *C. ignefusalis* there is a good correspondence between peaks of the adult insects at light and incidence of association with the host plants in the field (e.g., oviposition) (Harris 1962, Gahukar 1990). *Heliocheilus albipunctella* (millet head miner) adults are sexually active in the fields well before they start appearing in large numbers at light (Fig. 1). Grasshopper light-trap data must also be carefully interpreted. Grasshopper maturing eggs never come to light, hence a large proportion of the insects capable of causing major crop damage are not represented in the night sample. *Pachnoda* species never come to light. Table 2 shows crop losses due to the major pest groups.

Trends in pest complex attacking pearl millet at different stages

Pest damage and pest numbers varied considerably from year to year (Table 3). The heavy early-season crop loss (category A) in 1985 and 1986, for example, was caused mainly by *O. senegalensis* and occurred following years when the Inter-Tropical Wind Convergence Zone (ITCZ) had moved southward prematurely in early Sep. This carried large populations of immature, late-season adults deeply southward. Their dense egg fields, located at 12–13°N latitude (south of the Project area) produced a highly successful first generation on the next rains (1986 hopper density 5 m^{-2} over 100 000 ha). By late Jun they were adult, and following the Launois model (Launois 1979), added their eggs to the local egg fields at Mourdiah. This hatching coincided with the germination of pearl millet, hence the enormous loss in sowing area (calculated at 25% over a cultivated area of 325 km^2). The enormous mid-season (foliage) and late-season (panicle) damage (category B) caused by an upsurge of grasshoppers in 1989 (all species except *O. senegalensis*) followed the well-distributed rains of 1988 (Table 4). The years 1988 and 1989 were notable for the absence of an end-of-season southward descent by *O. senegalensis*, the ITCZ remaining strongly northwards till late in the year. The more favorable rains of 1988–90 were associated with serious mid-season attacks by *P. interrupta*, while 1989 (the year of major grasshopper numbers) was followed by a year of massive meloid beetle (*Psalydolytta* spp) attack (see Table 2 for crop losses). The great instability of the component populations of the panicle pest complex means that a standard prophylactic approach to IPM from year to year is not effective. IPM tactics must adapt flexibly each year to different pest levels.

Trends in pest population levels and attack on millet panicles

During the project, the percentage of millet panicles attacked by *H. albipunctella* declined (Table 5). From 1988 onwards the northern Nara and Dilli subzones maintained higher levels of *H. albipunctella* infestation than the southern zone. The causes of these

Table 2. Millet grain loss due to major pest groups in nontreated plots, North West Mali, 1990.

Zone	Mean grain loss (kg ha^{-1}) Grasshoppers and *Pachnoda*	*Psalydolytta* or drought sterility	Birds	Fungi	Millet head miner	Total grain loss (kg ha^{-1})	Potential yield (kg ha^{-1})	Estimated grain loss (%)
South								
Mourdiah 1	51	195	26	8	52	332	714	47
Mourdiah 2	41	161	28	1	46	277	461	61
Mourdiah 3	120	304	17	0	88	529	847	63
Fallou	22	43	2	1	62	130	216	60
North								
Nara	51	26	17	9	31	134	440	31
Dilli	37	51	16	1	93	198	404	49

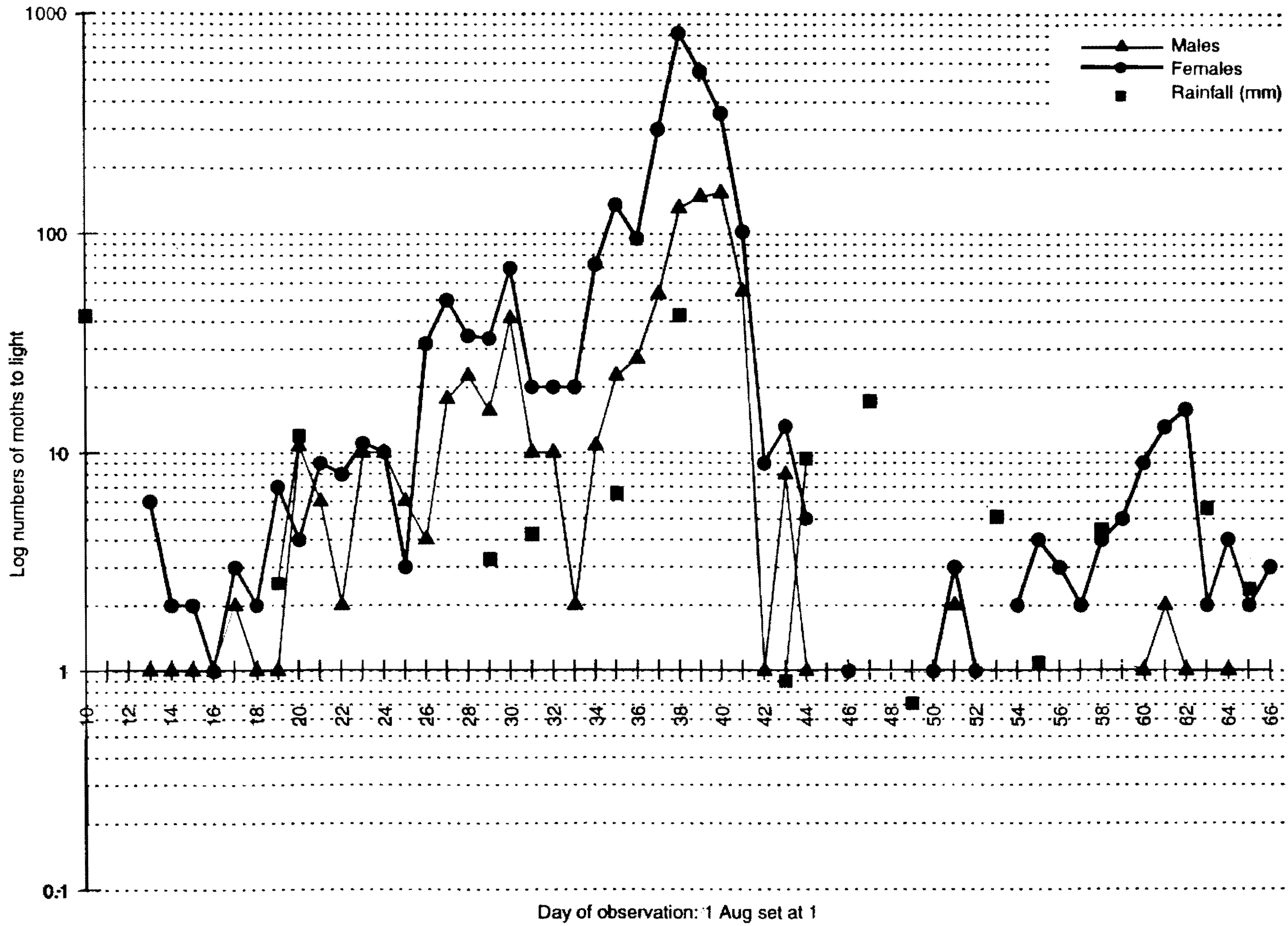

Figure 1. Light trap counts of *Heliocheilus albipunctella* in Mourdiah, North West Mali, 1985.

Table 3. Schematic representation of damage[1] by major pests of pearl millet in Nara circle, North West Mali, 1985–91.

Year	Northern Zone[2] A	B	C	D	E	F	Southern Zone[3] A	B	C	D	E	F[4]
1985	2	0	3	0	0	2	0	2	3	0	0	0
1986	2	2	3	0	0	2	3	0	3	0	0	0
1987	2	2	3	0	0	2	0	0	3	0	0	0
1988	2	0	3	0	2	0	0	0	2	0	2	0
1989	2	3	2	0	2	3	2	3	1	0	2	3
1990	0	2	2	2	2	2	2	2	0	2	1	2
1991	0	0	1	2	0	0	0	0	0	0	0	1

1. Damage level on a scale of 0–3, where 0 = nil, and 3 = severe.
2. Mean annual rainfall 300 mm; latitude 15°N.
3. Mean annual rainfall 500 mm; latitude 14°30' N.
4. Key to damage types:
   A = Germinating plants destroyed by grasshopper instars;
   B = Mid-season defoliation by acridid grasshoppers and young adults;
   C = Larvae of millet head miner; mines causing grain loss;
   D = Sterilization of florets by meloid beetles (*Psalydolytta* spp);
   E = Young grains destroyed by chafer beetles (*Pachnoda interrupta*);
   F = Ripening grain destroyed by adult grasshoppers end-of-season.

Table 4. Mean monthly rainfall (mm), 1984–91, and 25-year mean for Mourdiah base, North West Mali.

Year	May	Jun	Jul	Aug	Sep	Oct	Nov
1984	–	16.7	155.9	76.4	27.4	63	15
1985	–	20.7	133	124.4	77.2	–	–
1986	4.4	38.3	164.7	40	133.5	12.3	–
1987	–	65	102	92	95	52	–
1988	–	61	171.8	232.7	138.6	4	–
1989	7.9	73.1	177.7	307.2	60.2	10.5	–
1990	–	32.9	247.6	68.8	92.1	11.8	–
1991	–	51.9	115.5	117.1	88.3	10	–
Mean	16.5	62	151	194	92	24	3

trends are unknown. They do not relate in any simple fashion to rainfall. Predator and parasite pressures may be a major factor.

The sudden upsurge of *Psalydolytta* blister beetles in 1990, however, was probably the result of a superabundance of grasshopper host egg-pods in 1989. One of its favored hosts, *Cataloipus cymbiferus*, was particularly common in 1989. Likewise, the importance of *P. interrupta* in 1988 and 1989 was associated with favorable Aug rains and high levels of animal manure on which the larvae feed (Grunshaw 1992).

Consistent monitoring of panicle pests and associated crop loss in the Sahel, will be required to provide the data necessary to understand pest population dynamics. Lack of such data is inhibiting the development of predictive models to feed into IPM strategies.

Close inspection of the seasonal pearl millet phenology (Fig. 2) shows that the apparent resistance of pearl millet varieties to panicle pests is due to the timing of the vulnerable crop stages rather than to plant resistance. In the case of *H. albipunctella*, the maximum female flight activity coincides (Fig. 1)

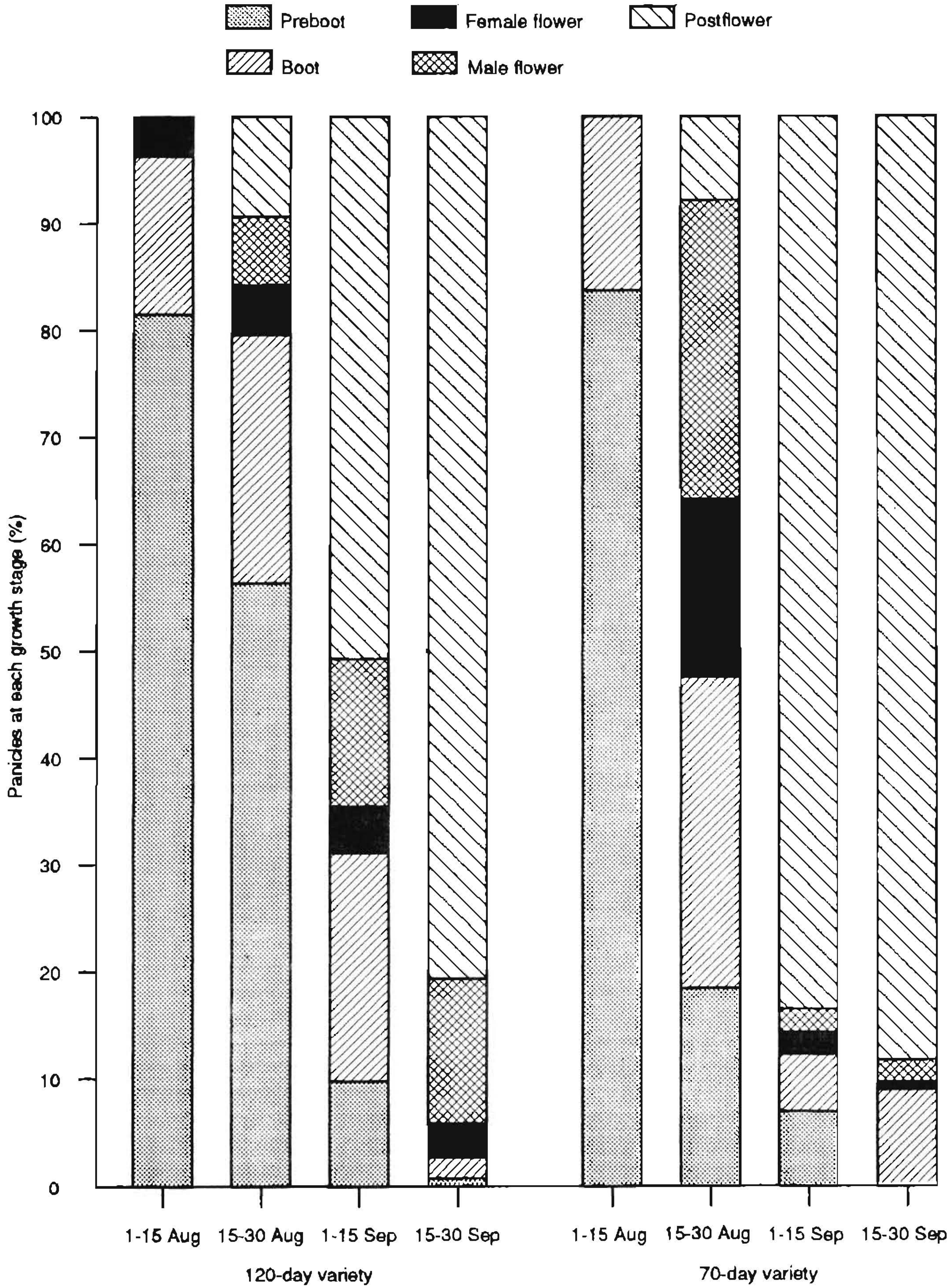

Figure 2. Whole-plot pearl millet phenology, Mourdiah, North West Mali, 1985.

Table 5. Mean percentage of panicles attacked by *Heliocheilus albipunctella*, North West Mali, 1987–90.

Zone	1990	1989	1988	1987
South				
Mourdiah 1	14.3	46.6	53.1	57.2
Mourdiah 2	11.7	64.6	52.0	59.9
Mourdiah 3	19.5	56.9	42.8	80.3
Fallou	25.7	49.7	–[1]	–
North				
Nara	25.9	77.0	64.5	60.2
Dilli	45.5	70.3	63.0	70.0

1. – = no data.

with the major flush of female flowering in the 70-day variety, whereas in the 120-day variety, the female flowering occurs over an extended period both before and after the moths are active. The female moths lay selectively on the emerging panicles prior to male anthesis (Vercambre 1982). Observations were made in 1985 on 100 marked pockets in each of 8 pairs of treated (cypermethrin ULV 3 g a.i. L^{-1}) against millet head miner larvae) and untreated 0.5 ha plots on four pilot farms at Mourdiah. The three principal panicles in each pocket were followed from tiller stage to harvest. A careful analysis of those of the 70-day variety infested by *H. albipunctella* at harvest, showed that they had reached panicle emergence in the period of peak flight by the pest. Fewer of these stages were available to *H. albipunctella* at this critical time, in adjacent fields of the long-duration millet.

IPM in millet may be made more effective by the introduction of millet varieties that flower outside the periods of maximum pest activity. Alternatively, those like the Souna millet which are very vulnerable at mid-season could be more effectively protected by minimal use of ULV pesticide if their flowering period were synchronous and greatly shortened. Due to economic constraints, the NRI project applied only one ULV treatment at the point when 50% of the millet panicles were at anthesis or older. This time of application was chosen because it seemed to correspond to the moment when as many as possible of the newly emerged and vulnerable panicles would be protected. Even so, this would represent only about 10% of this category of panicles at the time of treatment. Since 3 g a.i. L^{-1} of cypermethrin has an active persistence of only 5–7 days, only a fraction of the emergent panicles will be protected. This partly explains the limited success of ULV pesticide against this pest.

During the project (1985–91), the rainfall was characterized by its late start and early cessation (compare with mean monthly long-term values, Table 4). The 'normal' rainfall pattern gives a peak of rainfall in Aug. In rain-deficit years, Jul rainfall (1984–87 and 1990) exceeded that of Aug (1988, 1989). In years with an Aug rains failure, short-duration millet is badly stressed and may produce many sterile panicles due to terminal drought. Under such circumstances, providing late-season rain is adequate; long-duration millet actually produces a better crop.

Another major consequence of near-normal Aug rains was dramatically demonstrated in 1988 (Table 4), which followed a series of years with low Aug rains. Fortunately crop loss due to grasshopper attack was very low. The mean grain mass per panicle throughout the region in 1988 was double that in 1987 (Table 6). Factors such as sowing density were statistically the same in 1988 as in 1987, though the range of stem density ha^{-1} was very wide (1987, 5 880–55 323; 1988, 3 552–60 991 stems $plot^{-1}$). Likewise, the intensity of *H. albipunctella* attack (percentage of panicles attacked per plot) remained the same statistically or fell only slightly. The doubled grain mass in 1988 meant that the enlarged grains sealed the mines caused by the millet head miner. Consequently ULV treatment was less effective in 1988 (percentage reduction in damage much less in the Mourdiah sectors in 1988) and the reduction in grain loss so small that the treatment was uneconomical in the Mourdiah region.

The conclusion must be that in the 500 mm mean annual rainfall belt, in years with Aug rains higher than those of Jul, the use of ULV pesticide directed solely against *H. albipunctella* will be uneconomical. Minimal use of ULV treatments in IPM strategies against this pest will be more economically viable, whatever the rainfall pattern, in the 300 mm mean annual rainfall belt.

Conclusions

Some high-yielding sorghum varieties are said to be clearly resistant to foliage pests and the form of both flowers and panicles made them less prone to damage by sorghum midge, birds, and meloids (J F Scheuring, ICRISAT, personal communication). The use of sorghum intercropping and as part of the layout of

Table 6. Millet yield, sowing characteristics, and head miner attack, North West Mali, 1987 and 1988.

		Project zone				
Observations	Year	Mourdiah 2	Mourdiah 2	Mourdiah 3	Dilli	Nara
Sample size 1987:1988	1988	29:44	25:46	30:37	40:59	43:57
Mean stem density 0.5 ha^{-1}	1987	20755 ± 3068	27589 ± 3423	29063 ± 3099	16110 ± 2162	28438 ± 3684
	1988	27050 ± 1312	29812 ± 1283	25292 ± 1430	13542 ± 1133	18784 ± 1152
Mean yield[2] (kg ha^{-1})	1987	349 ± 88.7	471.2 ± 114.3	529.8 ± 118.8	306.8 ± 56.4	347 ± 60.2
	1988	921.1 ± 54.5	942.1 ± 52.6	770.7 ± 58.8	310.1 ± 49.1	460.2 ± 47.4
Average grain mass panicle^{-1} (g)	1987	6.9 ± 0.6	6.6 ± 0.4	7.5 ± 0.9	5.4 ± 0.5	9.5 ± 0.9
	1988	17.7 ± 1.2	17.2 ± 1.1	16.1 ± 1.2	11.9 ± 1	16 ± 1
Mean percentage attack[2]	1987	80.3 ± 4.8	57.2 ± 7.3	59.9 ± 4.1	70 ± 4.3	60.2 ± 6.3
	1988	53.1 ± 3.1	52 ± 1.9	42.8 ± 3.4	63 ± 2.5	64.5 ± 2.5
Mean percentage damage reduction[3]	1987	33.7	39.3	52.4	29.8	31.1
	1988	19	20	22.9	29.1	27.3
Mean percentage yield improvement[3]	1987	45.4	16.7	26.3	46.8	69.4
	1988	3.3[4]	12.5[4]	12.7[4]	49	30.2

1. Standard error of mean (SEM)
2. For untreated plots.
3. After insecticide treatment.
4. Statistically no improvement.

field margins to deter entry by grasshopper pests in North West Mali was noted (Jago 1993b).

There is a tendency to monitor the most obvious and direct panicle damage such as that due to mining beneath or destruction of florets, or damage to ripening grains. Some panicle damage is indirect, however, and more difficult to observe. Examples include that caused by *Coniesta ignefusalis* which not only eliminates whole panicles by destruction of the growing point (deadheart) (Nwanze 1989), but also causes loss of grain mass in panicles on stems containing the larvae. The latter case is similar to grain mass loss due to inadequate water supply. NRI Project studies have shown that grain mass loss in millet panicles with infested stems is of the order of 3 to 8 g. Field trials in 1990 showed that 13 and 44 deadhearts in 60 millet pockets probably represent a loss of 4 and 8 panicles respectively at harvest.

Practical methods must be devised to monitor indirect crop losses effectively; such as those caused by foliage pests (grasshoppers, lepidopterous larvae) which restrict nutrients to the panicle. Legg and Togola (1993) showed that 50% of the lower leaves of pearl millet could be destroyed without detectable effect on the millet head. Survey of key pests is seldom carried out routinely by government services or farmers. Normally, monitoring begins in response to an explosion of the pests or even later, when damage has occurred. Since assessments involve redirection of time and manpower to collect data, they must provide clear benefits. The main benefits will be:

- To obtain an early warning of peak numbers of the most vulnerable stages of a pest, e.g., eggs of the millet head miner, hatchlings of grasshoppers;
- To time an application to give maximum protection to the millet or sorghum crop. This will require monitoring of the vulnerable crop stages, so that the maximum numbers of panicles are protected against pests whose numbers in the crop are reaching economic thresholds. The more pests are targeted by a single treatment, the more economically effective it is likely to be. Timing of application will be at least as critical when biological control is attempted;
- To indicate when available methods of intervention are inappropriate. This may often occur if a pest upsurge is so great that treatment with biological control agents or chemicals is likely to be ineffective. The sensible response will then be to guard stocks and recommend other tactics to reduce crop loss, such as premature harvest;
- To enable farmers and local government to estimate pest risk within the short term and to a lesser extent for the following season. This will improve the value of advisory and early warning services. It will also put logistical deployment of limited resources on a sounder technical basis and reduce political pressures on overextended extension and plant protection services;
- To build up a database on pest/cultivar association. This will enable correlations to be clarified, cause and effect confirmed, and economic thresholds for interventions to be more accurately determined;
- To enable farmers and local government to collect the data required to demonstrate the economic efficacy of a particular set of interventions. This will be measured in the final analysis by the degree to which the methods invested have reduced the shortfall in cereal self-sufficiency. The cost of interventions must relate to the local value of the cereal crop. This has been a factor inhibiting adoption of pesticide methodology by the farmers.

Interventions likely to be effective against panicle insect pests include:

- Better field layout designed to inhibit entry of pests, e.g., grasshoppers in the hopper stage;
- Good weeding practice, reducing plant competition, but also reducing the shelter for pests like grasshoppers and meloids;
- Tightly controlled pesticide application, including dust formulations used as barriers or for dusting young seedlings (latter very effective with Mouskouari sorghums), and ULV liquid pesticides, including insect growth regulators (IGRs) and the classical nerve toxins such as pyrethroids;
- Deterrent compounds and antifeedants (including neem extract);
- Pest trapping techniques, including light traps and pheromone traps;
- Biological control, including fungal pathogens, viral pathogens, and protozoan parasites.

Of the interventions listed, the first three have been most consistently used by the better farmers. Control of pesticide application and the use of deterrent compounds have been shown to be effective where attacks are of moderate intensity. Used unwisely in the face of very heavy infestations, they will be ineffective.

Insect growth regulators have shown extraordinary promise in recent trials against grasshoppers (Sissoko and Dobson, personal communication), but the high cost of the application equipment and active ingredient for use against millet and sorghum pests is worrying. For reasons not yet fully understood, they show remarkable persistence and with careful formulation can be targeted at specific grasshopper or coleopterous pests. Used in baits they will be most effective against geophilous grasshopper pests, rather than foliage-inhabiting species. Their environmental impact has also to be assessed.

The use of azadirachtin from crude aqueous neem extracts produced locally at village level warrants further trials (Passerini and Hill 1993). Again, neem extract is likely to be effective only when pest populations are moderate. A useful feature that it has in common with pyrethroids, is their deterrent and antifeedant effect. This may be a key factor against meloids, which are particularly sensitive to deterrent odors.

Biological control agents have had a mixed reception. *Nosema locustae* seems to have been effective with nonmigratory orthopteran pests in USA. The fungal and viral pathogens are still at the trials stage and some have worked well under laboratory conditions. The practicality of applying them under village conditions must not be underestimated. Cost has not yet been carefully considered in such techniques.

Synthèse

La surveillance des populations et l'évaluation des pertes de rendement dans la lutte intégrée contre les insectes nuisibles des panicules de sorgho et de mil. Des enquêtes sur les pertes de rendement du mil dues aux insectes paniculaires ont été réalisées au cours de plusieurs années par l'Institut des ressources naturelles (Royaume-Uni) dans le cadre de son Projet du Mali (1985–90). Des variations de l'incidence des ravageurs (Tableau 3) ont montré que la mise au point des modèles prédictifs ne serait pas possible sans la surveillance préalable de la dynamique des peuplements dans une région donnée du Sahel au cours de plusieurs années. Vu ces larges variations dans l'incidence des ravageurs, il n'était pas possible de recommander des mesures prophylactiques habituelles de lutte. Il importait d'abord de collecter des données (l'incidence des ravageurs de l'année courante par rapport à celle de l'année précédente, la pluviométrie mensuelle de l'année courante, etc.), afin d'élaborer des stratégies susceptibles d'être ajustées d'une année à l'autre. Des données socio-économiques jouent aussi un grand rôle dans la prise des décisions sur les mesures de lutte raisonnées.

Le Projet a couvert une série d'années à pluviométrie faible en août et 2 années à pluviométrie d'août près de la moyenne (Tableau 4). Ceci a permis au Projet de faire des corrélations entre l'incidence des ravageurs et la pluviométrie. En outre, il était facile de classifier selon la pluviométrie les villages qui ont fait l'objet d'étude en deux groupes: (1) zone à pluviométrie très faible (pluviométrie annuelle moyenne de 300 mm), (2) zone à pluviométrie modérée (pluviométrie annuelle moyenne de 500 mm). On a tiré des conclusions sur les contrastes qui existaient dans les façons culturales des deux zones (densité de poquets par hectare et densité de plantes par poquet) (Tableau 6), le potentiel de la récolte et la viabilité économique des mesures de lutte intégrée contre les insectes paniculaires pour des années ayant des pluviométries d'août différentes.

Les principaux insectes nuisibles aux panicules de mil repérés ont été:

- La mineuse de l'épi de mil, *Heliocheilus albipunctella* de Joannis (Lepidoptera: Noctuidae) dont l'importance a diminué au cours de la durée du projet (Tableau 5). La résistance apparente des variétés de mil à cycle long (120 jours) à cette espèce s'est avérée fausse (pseudo résistance); elle est due au fait que la ponte et les stades vulnérables de la panicule n'ont pas coïncidé (Figures 1 et 2).
- Six principales espèces de sauteriaux ravageurs, dont cinq espèces sont migratrices. Il y a eu de fortes pullulations de sauteriaux en 1988 et 1989 (des années à pluviométrie plus élevée en août).
- Des cantharides (*Psalydolytta* spp) ont eu d'énormes accroissements de la densité de peuplement à la suite de l'explosion de la population des sauteriaux de 1989.
- Des cétoines (*Pachnoda interrupta* Olivier) ont eu de fortes recrudescences durant les années 1988 et 1989 à cause des pluies plus élevées.

La surveillance des populations de *H. albipunctella* à l'aide des pièges lumineux serait utile pour déterminer, selon le nombre des ravageurs observés dans le champ, l'application des insecticides par des pulvérisateurs à ultra-bas volume. Cependant, ces mesures n'étaient efficaces que les années où la pluviométrie d'août était plus faible que celle de juillet.

La poursuite de la surveillance des insectes paniculaires et des pertes de rendements revêt donc une grande importance dans la planification et la prise de décisions sur la nécessité de recourir aux insecticides dans le cadre de la lutte intégrée. Six avantages résultant de l'adoption régulière de ces mesures sont soulignés.

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Bioecology of scarab beetle *Rhinyptia infuscata* and millet head miner *Heliocheilus albipunctella*

O Youm[1]

Abstract

The scarab beetle Rhinyptia infuscata *Burmeister (Coleoptera: Scarabaeidae) and the millet head miner* Heliocheilus albipunctella *de Joannis (Lepidoptera: Noctuidae) are important panicle pests of pearl millet. Studies were conducted to better understand pest bioecologies and behavior as prerequisites to the development of improved control techniques. The scarab beetle is distributed in a large area in Niger and causes substantial damage to millet in most survey areas. Results showed that feeding and mating activities of the scarab beetle are more pronounced between 2000 and 2400, with peak activity around 2300. Larval behavior of the millet head miner with regard to migration was also studied. Results showed that larval migration occurred mostly between 2400 and 0600. The relevance of these findings to the management of these key millet pests is discussed.*

Introduction

Pearl millet, *Pennisetum glaucum* (L.) R. Br., is a major cereal food crop in the Sahelian zones of West Africa. Its production is constrained by a number of biotic and abiotic factors. Insect pests represent a significant proportion of the overall reduction in millet grain production. The number of insect pests associated with pearl millet is variable. In a recent review on insect pests of pearl millet in West Africa, the number of species known to attack millet varied from 81 to over 150 species depending on the country and location (Nwanze and Harris 1992). Despite the list of many species reported as pests or potential pests, the number of species classified as major pests of economic importance is apparently less than a dozen (Nwanze and Harris 1992). The definite pest status of many insects associated with pearl millet has not been determined, and that information, in addition to a description of insect bioecology, is crucial for the development of sound integrated management strategies. Knowledge of insect bioecology and damage identification is a first step, and the quantification of losses from insect damage contributes to the determination of pest status.

The millet head miner *Heliocheilus albipunctella* de Joannis (Lepidoptera: Noctuidae), is a major insect pest of pearl millet. The confusion on its taxonomic status was recently cleared (Matthews 1987) and the insect accounts for 95–98% of *Heliocheilus* species collected from light traps in Senegal (Vercambre 1978, N'doye 1979) and in Niger (Guevremont 1982) [in Nwanze and Harris 1992]. Damage to millet heads caused by the developing head miner larvae is very typical and is characterized by the presence of spiral mines developed by larvae during feeding (Vercambre 1978). In mines caused by full grown larvae, there is a typical presence of white fecal pellets. Damage due to young larvae results from their feeding in the florets (floral glumes) initially, and this type of damage is not easy to detect unless the developing panicle is very carefully examined. The damage due to late instars can be easily detected because they feed on the base of the flowers or florets which fall out, leaving the mines open. The early phase of this damage can be detected by the uneven surface of the millet head as the developing larvae push florets/seed from the rachis (Vercambre 1978).

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1. ICRISAT Sahelian Center, BP 12404, Niamey, Niger.

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Youm, O. 1995. Bioecology of scarab beetle *Rhinyptia infuscata* and millet head miner *Heliocheilus albipunctella*. Pages 115–124 *in* Panicle insect pests of sorghum and pearl millet: proceedings of an International Consultative Workshop, 4–7 Oct 1993, ICRISAT Sahelian Center, Niamey, Niger (Nwanze, K.F., and Youm, O., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

In contrast, the bioecology of the scarab beetle *Rhinyptia infuscata* Burmeister (Coleoptera: Scarabaeidae), until recently, was poorly documented due to the nocturnal feeding habits of this insect. *Rhinyptia infuscata* has been reported to attack millet in Niger (Guevremont 1981), and Senegal (Gahukar and Pierrard 1983). Although *R. infuscata* has been reported to attack sorghum and millet (Gahukar and Pierrard 1983) or as an occasional pest of pearl millet (N'doye and Gahukar 1987), it was not until recently that its pest status was recognized. Lukefahr and Mamalo (1989) reported this insect as a serious pest of pearl millet, with population densities as high as 500 000 adults ha^{-1}. The damage due to *R. infuscata* is more difficult to describe due to its nocturnal feeding habits and similarities with the damage caused by other panicle-feeding insects. The beetle is reported to feed on the stigmas of millet, resulting in empty spikelets (ICRISAT 1990, p. 57). Gahukar and Pierrard (1983) reported that *R. infuscata* feeds on flowers, often resulting in empty glumes.

Although the biology of the millet head miner is described in more detail than that of the scarab, information is lacking on both adult and larval movements. These two aspects are important in the development of sound IPM strategies. Reports on *R. infuscata* feeding and damage were mainly based on observations made at the research station level, and information was lacking on its importance in farmers' fields. Therefore, the objectives of the studies reported here are (a) to develop a better understanding of scarab bioecology, feeding behavior, distribution, and importance in farmers' fields; (b) to determine movements of mature head miner larvae from millet to the soil, and the mechanisms involved.

Materials and Methods

Fields surveys: distribution and importance of *R. infuscata*

Surveys were conducted in farmers' fields in Niger along 5–6 transects in 1991 and 1992 including Niamey-Say, Niamey-Makalondi, Niamey-Tillabéry, Niamey-Filingué, Niamey-Birni, and Birni-Dosso-Gaya. The Birni-Dosso-Gaya transect was only sampled in 1992. Along each transect, millet heads in farmers' fields at three to six sites were sampled for adults of *R. infuscata*. Sampling usually started around 1900 and ended around 0600 the following morning. For sampling of adult beetles, millet plants were illuminated by a rechargeable 4.8 volt battery-powered light source. Sample size varied from 100 to 300 heads per site and each site was sampled twice. Sampling was done in 1991 from 21 Aug to 7 Sep at 19 sites, and in 1992, from 8 Aug to 19 Sep at 27 sites. Adult numbers were recorded against time of sampling in order to obtain the period of peak activity under natural farmers' field conditions.

Millet head miner: larval migration

Studies on the larval migration of the millet head miner were conducted at Sadoré in Sep 1990, Aug-Sep 1991, and Sep 1992 during the growing seasons, in millet plots previously infested with this insect. Experimental plots were sown with the variety 3/4 HK after the first normal rain. Normal cultural practices such as weeding, thinning, and fertilizer were applied. At the milk stage, heads were examined for larval infestation. To collect migrating larvae, 50 × 50 × 15 cm box-type traps made from Styrofoam® were securely attached around millet stems. All openings around the stem were closed to prevent larvae from escaping. The bottom of each trap was then covered with a film of non-drying sticky insect glue (Agrisense BCS Ltd., UK). Hourly observations were made and the number of larvae trapped were recorded against time of observation to obtain peak migration time. The position of the trapped larvae relative to the stem was also measured to determine the migration pattern. Daily rainfall and hourly temperature and relative humidity were recorded.

An additional experiment was conducted in 1992 to study the role of environmental factors such as light in the migration of mature larvae of the head miner. Whole plant hills with infested millet heads were carefully uprooted and placed in large plastic buckets. Box-type traps as described above were placed around the stems. Plants were divided into two groups. One group was illuminated with diffused light (100 W) at night and left in the shade during the day, while the other group was kept in complete darkness at night and under partial darkness during the day. A third set of traps were secured around infested millet plants in the field under natural conditions as described earlier. Temperature and humidity were recorded. Hourly observations of trapped larvae were recorded.

Results and Discussion

Distribution and importance of *R. infuscata* in farmers' fields

Population densities of *R. infuscata* at different locations are shown in Tables 1 and 2. In 1991, population densities of the *Rhinyptia* beetle were high at most locations along the five survey transects. The greatest mean number of beetles head^{-1} (21.2) occurred in Lontuabery on the Niamey-Say transect and the lowest densities head^{-1} (3.5) occurred at Lanfogou along the Niamey-Makalondi transect (Table 1). Except for Lanfogou, the mean number of beetles at each location was > 5 head^{-1} at all 19 sites. In 1992, the overall population densities were slightly lower than in 1991. The greatest mean densities of beetles head^{-1} occurred in Tombobaley (14.2) and Kahe (13.4) along the Birni-Dosso-Gaya and Niamey-Say transects (Table 2). In 1991, *R. infuscata* was collected from all 19 locations sampled, whereas in 1991, this was the case in only 19 of the 27 locations. The Birni-Dosso-Gaya transect, where no beetles were recovered in 50% of the locations, was sampled only in 1992 and sampling was done about 3 weeks earlier than at other locations. It is possible that *R. infuscata* peak emergence could have occurred before or after the samples were taken.

Our results represent the first quantified large-scale sampling and population assessment in farmers' fields in Niger. In Senegal, Gahukar and Pierrard (1983) recorded population densities of 0.8 beetles head^{-1} in 40–60% of farmers' millet fields during small-scale surveys, and a mean of 1.4 and 15 beetles head^{-1} in 1980 and 1981 on the research station. In Niger, mean population densities ranging from 5 to 25 beetles head^{-1} have been reported (Guevremont 1981, 1983). During the 1989 rainy season, population densities of *R. infuscata* were estimated at 800 000 adults ha^{-1} with an estimated grain yield loss of 42% (ICRISAT Sahelian Center 1990). These differences in density may reflect differences in sampling dates and emphasize the need for a more comprehensive survey during the cropping season. The relationship between population densities in farmers' fields and yield losses is a logical follow-up to determine the pest

Table 1. Surveys on distribution and infestation by *Rhinyptia infuscata* in farmers' millet fields in Niger, rainy season 1991.

Sampling transect	Location	Number of heads sampled	Mean ± SE head^{-1}
Niamey-Say	Lelehi	200	5.7 ± 0.3
	Kahe	300	13.4 ± 0.4
	Lontuabery	200	21.2 ± 0.9
Niamey-Makalondi	Gorouwa	300	16.4 ± 0.4
	Kabadie	199	14.6 ± 0.5
	Gnaktire	200	6.5 ± 0.3
	Lanfogou	100	3.5 ± 0.3
Niamey-Tillabéry	Bangawi	299	8.8 ± 0.2
	Zamakourma	200	6.3 ± 0.2
	Lossa	200	6.4 ± 0.3
	Dia-Dia	100	10.8 ± 0.5
Niamey-Filingué	Hamdallaye	300	5.9 ± 0.3
	Wankama	199	6.7 ± 0.4
	Agarous	199	5.9 ± 0.4
	Balleyara	100	8.7 ± 0.3
Niamey-Birni N'Gaouré	Kokoarey	304	5.7 ± 0.3
	Tioubi	198	7.9 ± 0.4
	Goumibi	201	5.4 ± 0.3
	Birni N'Gaouré	100	7.1 ± 0.3

Table 2. Surveys on distribution and infestation by *Rhinyptia infuscata* in farmers' millet fields in Niger, rainy season 1992.

Sampling transect	Location	Number of heads sampled	Mean ± SE head⁻¹
Niamey-Say	Lelehi	200	5.8 ± 0.4
	Kahe	200	13.4 ± 0.9
	Lontuabery	200	9.4 ± 0.5
Niamey-Makalondi	Gorouwa	200	0.0 ± 0.0
	Kabadie	199	2.9 ± 0.2
	Gnaktire	200	0.0 ± 0.0
	Lanfogou	200	0.0 ± 0.0
Niamey-Tillabéry	Bangawi	200	3.5 ± 0.2
	Zamakourma	199	3.9 ± 0.3
	Lossa	199	1.3 ± 0.1
	Dia-Dia	199	9.0 ± 0.6
Niamey-Filingué	Hamdallaye	200	5.9 ± 0.5
	Wankama	199	4.3 ± 0.3
	Agarous	200	8.8 ± 0.6
	Balleyara	196	1.9 ± 0.1
Niamey-Birni N'Gaouré	Kokoarey	198	3.0 ± 0.2
	Tioubi	199	7.0 ± 0.3
	Goumibi	200	7.7 ± 0.5
	Birni N'gaouré	200	0.0 ± 0.0
Birni-Dosso-Gaya	Tombobaley	200	14.2 ± 0.9
	Tombo-Kaina	300	10.4 ± 0.4
	Dosso-Kigoudou-K.	300	5.9 ± 0.4
	Guitodo	200	0.0 ± 0.0
	Bella-2	200	0.0 ± 0.0
	Malgorou	200	0.0 ± 0.0
	Koté-Koté	200	1.0 ± 0.1
	Gaya	200	0.0 ± 0.0

status of *R. infuscata* across a wider range of locations and climatic conditions.

Peak nocturnal activities of *R. infuscata* were determined from recorded observations in farmers' millet fields. In 1991, it was observed between 2200 and 2400, with the lowest activity occurring between 0400 and 0600 (Fig. 1a). Trends were similar in 1992 (Fig. 1b). These results are in agreement with previous reports by Lukefahr and Mamalo (1989) and Gahukar and Pierrard (1983). These results and current studies suggest that control measures that target adults would be most effective if applied between 2000 and 2400, and primarily around 2300 when most adults would have emerged from the soil to feed on millet heads.

Millet head miner: larval migration

Head miner larval migration was more intense between midnight and 0600 with peak activity during 0400–0500 (Fig. 2a, b, and c). Peak activities also coincided with the time of lowest ambient temperature and highest relative humidity. There are no previous reports on the migration of the head miner. Continuous exposure to light or partial darkness did not affect the pattern of migration (Fig. 3). However, atmospheric moisture and rainfall may be important factors. Most mature larval migration occurred following a heavy rain in 1990 (Fig. 4a), but the pattern was less clear in 1991 and 1992 (Figs. 4b and c). Therefore, it is possible that larvae not only migrate

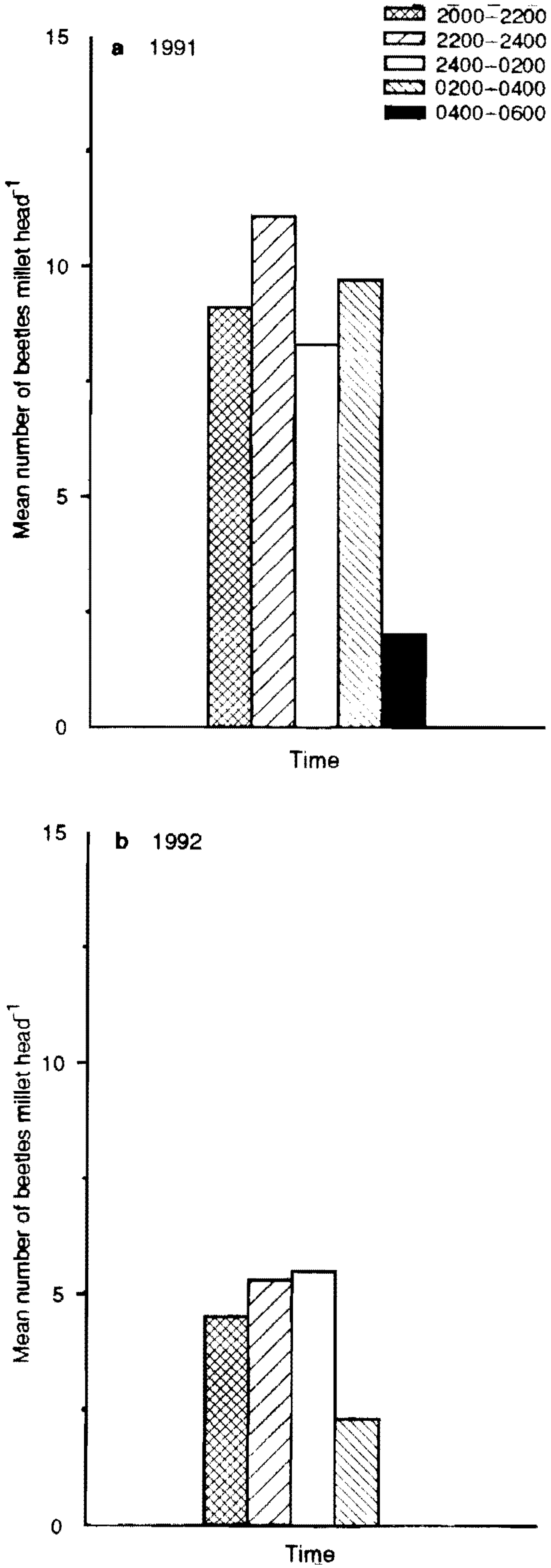

Figure 1. Peak nocturnal activity of *Rhinyptia infuscata* in farmers' fields in 1991 and 1992, Niger.

during the early morning hours but also following substantial rains so that on reaching the soil, they can penetrate without much difficulty for subsequent pupation. The synchronization of larval migration with high humidity, low temperature, and rains provides a clue to the factors involved in head miner larval movement.

The results from the study on head miner larval migration pattern from the millet head to the soil were inconclusive. Large and mature prepupal larvae appear to randomly drop down from millet heads. The distance from locations where larvae were trapped to the millet stem ranged from 1 to 24 cm in 1990 and 1 to 19 cm in 1992 (Fig. 5a and b). However, the majority were found between 3 and 10 cm. It appears that mature larvae do not necessarily crawl from millet heads and along millet stems or use a silken thread as observed with small larvae (Youm, unpublished). Vercambre (1978) indicated that sixth instars dislodge themselves from millet heads and drop to the soil. It is possible that during the migration process, millet leaves serve to break their fall.

Conclusions

Surveys conducted in farmers' fields have shown that *R. infuscata* occurs in large areas in all survey transects in western Niger in Tillabery and Dosso. Peak beetle feeding and mating behavior occurred between 2000 and 2400. Migration of mature *H. albipunctella* larvae occurs throughout the day, peaking between midnight and 0600. Larval migration from head to soil is a random process, as larvae do not necessarily move along millet heads or stems to the soil. Studies indicate that moisture, rainfall, and temperature are likely important factors that influence migration. Using this information supplemented with more detailed studies on head miner biology, models can be developed to predict time of migration to the soil and the time to apply appropriate control measures. As a contribution to IPM, the present studies show that control measures against *R. infuscata* can be applied most effectively between 2000 and 2400.

Future studies should (a) provide more comprehensive regional surveys during the cropping season to gain information on the distribution and importance of *R. infuscata* in a wider range of locations and climatic conditions, (b) determine the relationship between beetle densities and yield losses in farmers' fields, (c) design more in-depth studies to determine the role of moisture/rainfall and light on the migratory pattern of the head miner.

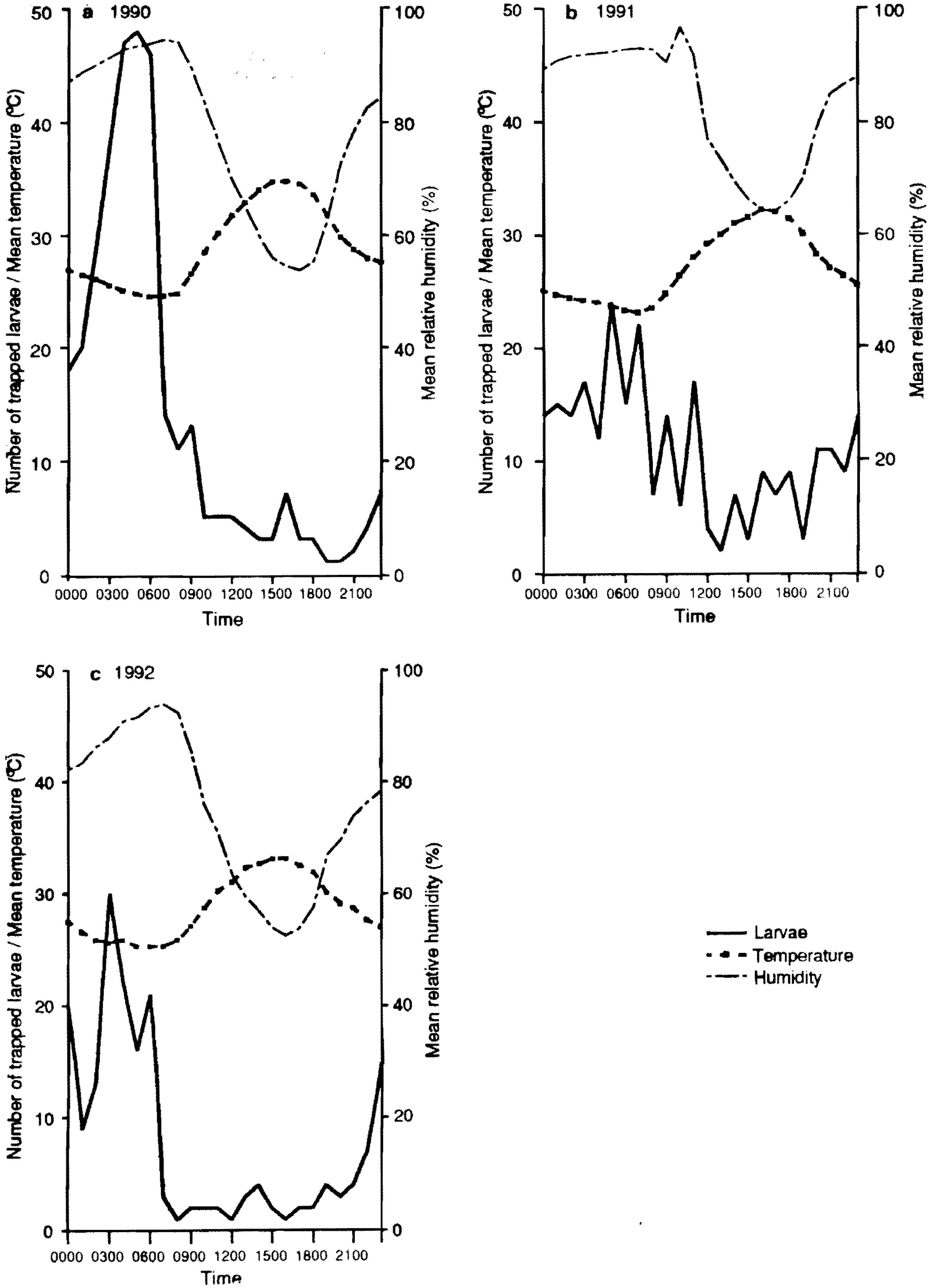

Figure 2. Hourly migration of millet head miner, Sadoré, Niger, 1990–92.

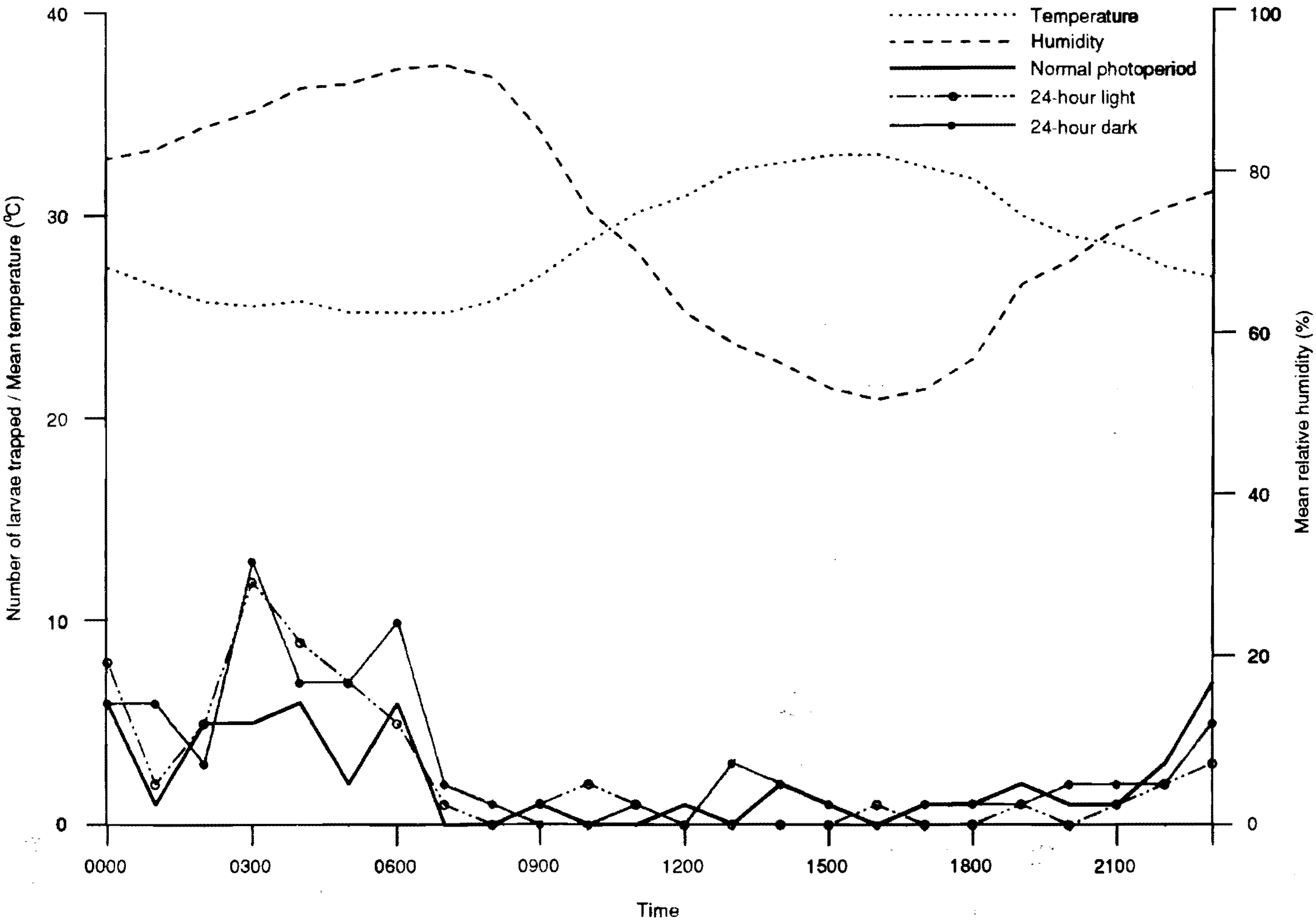

Figure 3. Migration of millet head miner under different light regimes, Sadoré, Niger, 1992.

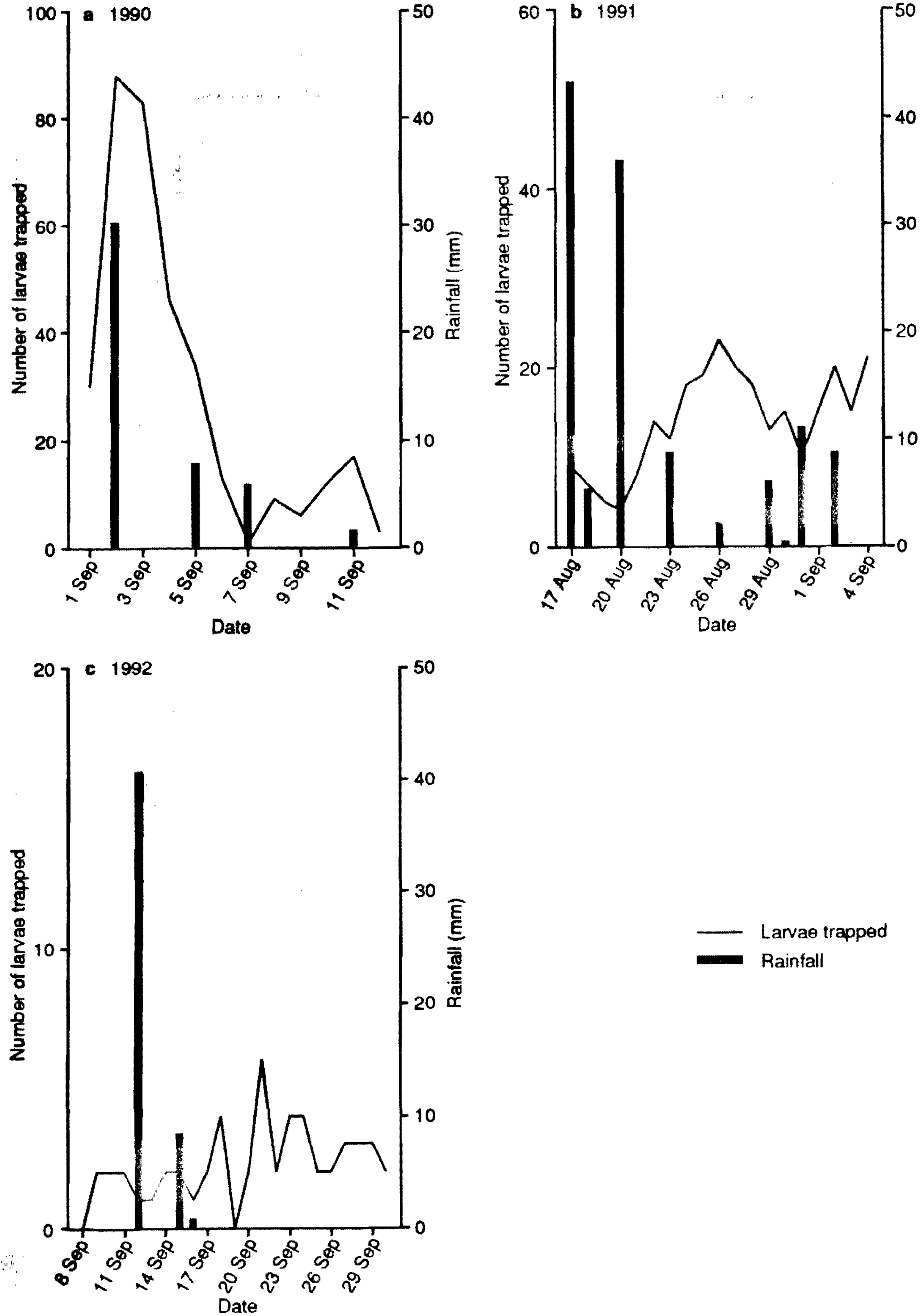

Figure 4. Migration of millet head miner in relation to rainfall, Sadoré, Niger, 1990–92.

***La bioécologie du scarabée* Rhinyptia infuscata *et de la mineuse de l'épi* Heliocheilus albipunctella.** Le petit mil [*Pennisetum glaucum* (L.) R. Br.] est une importante culture céréalière de soudure dans les zones sahéliennes de l'Afrique de l'Ouest et sa production est réduite par de nombreuses contraintes tant biotiques qu'abiotiques. Le nombre d'insectes recensés sur le mil varie de 81 à 150 espèces, dépendant du pays et de la localité. Cependant, l'importance économique de la majorité des insectes reste encore à déterminer. Le scarabée *Rhinyptia infuscata* Burmeister (Coleoptera: Scarabaeidae) et la mineuse de l'épi *Heliocheilus albipunctella* de Joannis (Lepidoptera: Noctuidae) sont d'importants ravageurs des épis du mil. Des études ont été menées en vue de mieux cerner la bioécologie et le comportement de ces deux ravageurs et améliorer les techniques de lutte. Pour le scarabée, des échantillonnages ont été menés en 1991 et 1992 sur six axes dont Niamey-Say, Niamey-Makalondi, Niamey-Tillabery, Niamey-Filingué, Niamey-Birni, Birni-Dosso-Gaya. Utilisant de simples pièges à colle, la migration larvaire de la mineuse de l'épi et les mécanismes régissant cette migration ont été étudiés. Les résultats ont montré que la période d'intenses dégâts et d'accouplement du scarabée se situe entre 2000 et 2400 h avec une pointe d'activité aux environs de 2300 h. L'aire de répartition du scarabée est étendue au Niger, avec des dégâts substantiels sur le mil dans la plupart des zones échantillonnées. En 1991, la plus importante densité de scarabée par épi (21,2) était relevée à Lontuabery sur l'axe Niamey-Say, et la moins importante (3,5) à Lanfogou sur l'axe Niamey-Makalondi. Les densités de population du scarabée étaient moins élevées en 1992. La plus importante densité par épi était de 14,2 à Tombobaley sur l'axe Birni-Dosso-Gaya, et 13,4 à Kahe sur l'axe Niamey-Say.

Le comportement larvaire de la mineuse de l'épi par rapport à la migration a également été étudié. Les résultats ont montré que la migration larvaire était plus importante entre 2400 et 0600 h. Cette période correspondait à une température ambiante moins élevée et une humidité relative plus prononcée. En 1990, une forte migration larvaire a coïncidé avec une forte pluie. Cette relation entre la pluviométrie et la migration larvaire était moins claire en 1991 et 1992. L'utilisation de la lumière diffuse continue ou l'obscurité totale ou partielle n'avait pas d'effet sur la migration larvaire. Ceci montre la nécessité de mener des études beaucoup plus approfondies afin de déterminer les

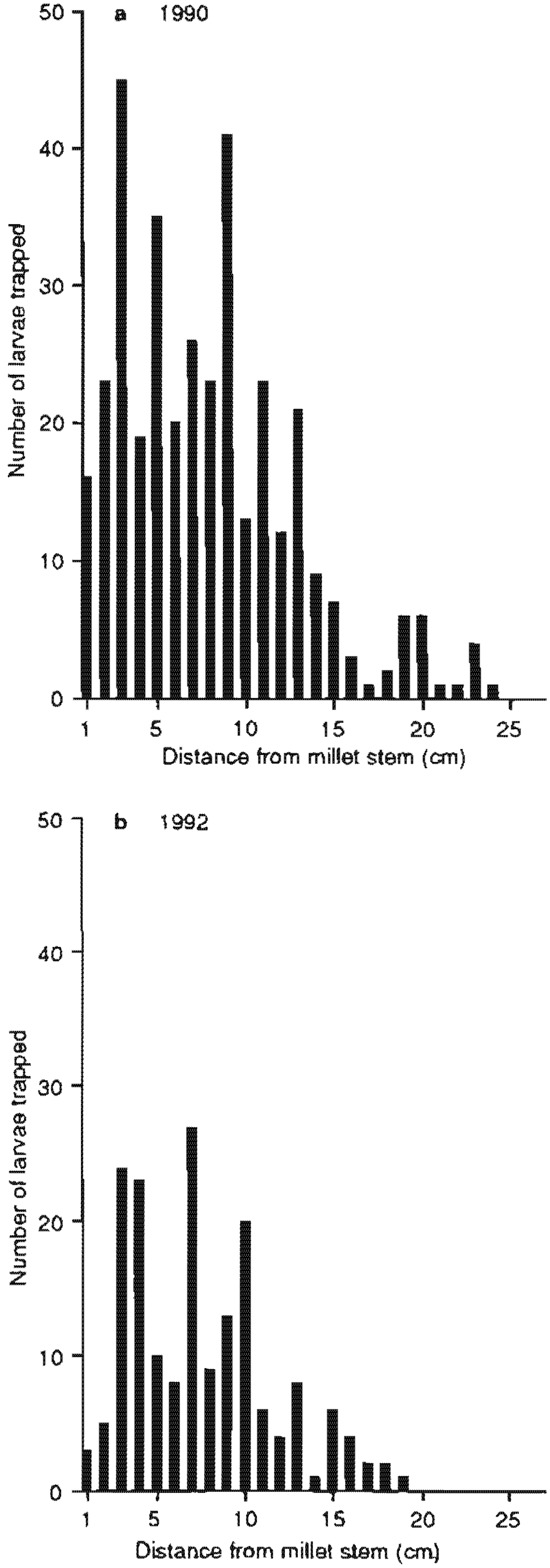

Figure 5. Migration pattern of millet head miner in 1990 and 1992, Sadoré, Niger.

facteurs-clef régissant le temps de migration de la mineuse de l'épi.

Les études sur les mécanismes de la migration larvaire étaient moins conclusives. Les larves âgées apparemment tombent par hasard au sol à partir de l'épi et n'utilisent pas nécessairement la tige lors de la chute. Cependant, les feuilles de mil pourraient éventuellement réduire l'effet de la chute. Le lieu de chute des larves par rapport à la tige était de 1 à 24 cm en 1990, et de 1 à 19 cm en 1992. Pour les deux années, cette distance était de 3 à 10 cm pour la majorité des larves piégées.

Compte tenu de ces études, des recherches plus approfondies doivent être menées afin de déterminer (a) la distribution et l'importance du scarabée sur de grandes zones géographiques et diverses conditions climatiques, (b) la relation entre les densités du scarabée et les pertes de rendement du mil en champs paysans, et (c) le rôle de l'humidité, la pluviométrie, et la lumière sur la migration larvaire de la mineuse de l'épi.

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Yield Loss Assessment and Economic Injury Levels for Panicle-Feeding Insects of Sorghum

H C Sharma[1] and G L Teetes[2]

Abstract

Economically important panicle-infesting insect pests of sorghum include the sorghum midge, Contarinia sorghicola *(Coquillett); head bugs such as* Calocoris angustatus *(Lethiery),* Eurystylus immaculatus *Odhiambo, and* Oebalus pugnax *(Fabricius); and caterpillars such as* Helicoverpa zea *(Boddie) and* H. armigera *(Hübner). Annual monetary losses due to sorghum panicle-feeding insects have been estimated at US$ 535 million in the semi-arid tropics (SAT), US$ 250 in the USA, and US$ 80 million in Australia.*

Economic injury levels (EILs) for the sorghum midge are 0.4–6, 2–15, and >50 midges panicle^{-1} on susceptible, moderately resistant, and highly resistant cultivars. EILs for the sorghum head bugs, C. angustatus *and* E. immaculatus *are 0.5–1 and 0.97–2.52 bugs panicle^{-1}. EILs for head bugs are 2 to 3 times greater on resistant cultivars than on susceptible commercial cultivars. They range from 2 to 12 bugs panicle^{-1} for* O. pugnax, *2 to 9 for* Nezara viridula *(Linneaus), 2 to 10 for* Leptoglossus phyllopus *(Linneaus), and 2 to 10 for* Chlorochroa ligata *(Say). EILs for* H. zea *larvae are 0.2–2.5 panicle^{-1}. Plant resistance has a profound influence on EILs depending on the nature of damage and resistance mechanism(s). The relevance of EILs for decision making in integrated pest management for sorghum has been discussed.*

Introduction

Approximately 150 insect species have been reported to infest sorghum in different parts of the world (Jotwani et al. 1980). The major insect pests include the shoot fly, *Atherigona soccata* (Rondani); stem borers, *Chilo partellus* (Swinhoe), *Busseola fusca* (Fuller), and *Eldana saccharina* (Walker); armyworms, *Mythimna separata* (Walker), *Spodoptera frugiperda* (J.E. Smith), and *S. exempta* (Walker); aphids, *Schizaphis graminum* (Rondani), *Sipha flava* (Forbes), and *Melanaphis sacchari* (Zehntner); the chinch bug, *Blissus leucopterus leucopterus* (Say); the sorghum midge, *Contarinia sorghicola* (Coquillett); head bugs, *Calocoris angustatus* (Lethiery), *Eurystylus immaculatus* Odhiambo, *Nezara viridula* (Linneaus), *Oebalus pugnax* (Fabricius), and head caterpillars, *Heliothis* and *Helicoverpa* (Sharma 1993).

Yield Loss Assessment

Assessments of sorghum grain yield losses due to insect pests are scarce and difficult to obtain. Monetary losses caused by insects can be measured in two ways: actual loss in yield due to insect pest damage, or losses due to the costs involved in controlling insect pests, usually the expenses associated with insecticide use. Insecticides do not increase yield, but only protect the potential yield of the crop. Insecticide use is considered to be justified when the yield is of equal or greater value than the cost of the insecticide and its application. Unwarranted insecticide use is not a production cost, but a loss in profit.

Annual losses due primarily to panicle-infesting insect pests differ in intensity on a regional basis. They have been estimated to be US$ 550 million in the semi-arid tropics (SAT), US$ 250 million in USA, and

1. ICRISAT Asia Center, Patancheru 502 324, Andhra Pradesh, India.
2. Department of Entomology, Texas A&M University, College Station, Texas 77843-2475, USA.

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Sharma, H.C., and Teetes, G.L. 1995. Yield loss assessment and economic injury levels for panicle-feeding insects of sorghum. Pages 125–134 *in* Panicle insect pests of sorghum and pearl millet: proceedings of an International Consultative Workshop, 4–7 Oct 1993, ICRISAT Sahelian Center, Niamey, Niger (Nwanze, K.F., and Youm, O., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

US$ 80 million in Australia (ICRISAT 1992). In India, 4–84% of sorghum grain is lost to panicle-feeding insect pests. Annual grain yield losses at the minimum level of 4.6% are equivalent to US$ 100 million (Leuschner and Sharma 1983). In Tamil Nadu, India, sorghum midge and earhead bug cause an estimated crop loss of 30% valued at US$ 100 million (H.C. Sharma, unpublished). The incidence and extent of losses reported from different parts of the world are discussed below.

Sorghum midge

The sorghum midge is the most ubiquitous and serious insect pest of sorghum worldwide. Annually, it destroys about 10–15% of the world sorghum crop. Sorghum sown early in a growing season usually escapes infestation, while late-sown sorghum is severely damaged.

In Texas, USA, losses due to sorghum midge vary over seasons and locations, but commonly exceed US$ 28 million each year. In comparison, control of the greenbug, *Schizaphis graminum* (Rondani), costs about US$ 21 million. In the SAT, sorghum midge occasionally becomes epidemic, especially when sowing is staggered in a given area or when cultivars with different durations are sown together. Inadequate and uneven rainfall can delay sowing, or make resowing necessary. Landrace varieties most often flower uniformly, while high-yielding, early flowering cultivars often do not. Sorghum sown and flowering later than normal is exposed to sorghum midge for a longer period of time, and can suffer severe damage. Severe midge infestations were recorded between 1965 and 1975 in India when sorghum hybrids were first introduced. During the 1991/92 season, severe midge infestations occurred in Nigeria and Niger, in West Africa (K.F. Nwanze, ICRISAT, personal communication). Sorghum midge is especially abundant in the Gambella region in Ethiopia, Busia region in Kenya, Illonga in Tanzania, Yemen, and in the states of Karnataka, Maharashtra, and Tamil Nadu in India. Nearly 30% of sorghum grain valued at US$ 7 million was damaged by the midge in western Kenya in 1990 (H.C. Sharma, unpublished). The pest damages almost 25% of sorghum grain in southern Africa (Leuschner and Pande 1992). In the Americas, Australia, and South Africa, midge damage is often extensive, and the crop is usually sprayed with insecticides at flowering to maintain the grain yield potential.

Hallman et al. (1984) determined that for a susceptible sorghum hybrid, 1.5 g of grain (42–48 kernels) were destroyed by the progeny produced by one female per panicle. Each insect infesting resistant sorghum destroyed 0.32 g of grain (9 kernels). Grain loss is therefore much higher in susceptible cultivars than in resistant ones at the same level of insect density.

Head bugs

Grain losses of 18–57% due to *Calocoris angustatus* have been recorded in Karnataka, India (Kulkarni and Bhuti 1983). Under experimental conditions, *C. angustatus* can cause 55–88% grain loss in commercial cultivars (Table 1), and 8–30% in bug-resistant cultivars (Sharma and Lopez 1989, 1993). In Maharashtra, India, loss of grain ranged from 23 to 100% depending on the abundance of head bugs (Mote and Jadhav 1990). Panicle-feeding bugs in Texas cause grain losses worth US$ 1.9 million per year (Cronholm et al. 1993).

In West Africa, *Eurystylus immaculatus* has become a serious pest of sorghum. It is one of the most important constraints to the introduction of high-yielding cultivars, which suffer more than 80% loss in grain yield. Steck et al. (1989) observed that the local cultivar, Mota Gami, suffered 14% loss in yield under natural infestation in Niger. The proportion of light-weight grain (damaged by *E. immaculatus*) is greater in panicles infested at the complete-anthesis stage (42%) than those infested at the dough stage (17%) (Sharma 1986, Sharma et al. 1992).

Table 1. Avoidable losses caused by head bugs in three cultivars, ICRISAT Asia Center, rainy seasons 1985–87.

Cultivar	Grain yield (t ha^{-1})		Avoidable losses (%)
	Protected[1]	Unprotected	
CSH 1 (1985)	1.677	0.505	69.89
ICSV 1 (1985)	2.599	0.296	88.61
CSH 5 (1986)	2.903	1.339	53.88
CSH 5 (1987)	2.388	1.075	54.98

1. Plots sprayed with carbaryl (0.05%) at flowering, complete-anthesis, milk, and dough stages.

Head bug damage decreases grain hardness, 1000-grain mass, and seed germination (Sharma 1986, Steck et al. 1989, Sharma et al. 1992). Under cage screening, the percentage of light-weight grain varied from 40.3% in IS 14334 to 75.8% in 83F6-111. Head bug damaged light-weight grain is unfit for human consumption (Sharma et al. 1994). Bugs not only reduce the grain yield, but also spoil the quality of the grain, and render it unfit for human consumption (Sharma and Lopez 1989, Sharma et al. 1992). An increase in bug damage rating by 1 (on a 1–5 scale) is equivalent to a loss of 12.6 g of grain per panicle, 4.4 g in 1000-grain mass, and 15.5% in seed germination. A 1-g decrease in 1000-grain mass results in 15.5% less seed germination. Bug-damaged grain is of poor nutritional quality, has greater amounts of tannins, and results in poor seedling establishment and vigor (Natarajan and Sundara Babu 1988a, Sharma et al. In press). Thus, while evaluating bug damage and computing EILs, loss of grain quality also should be considered.

Head caterpillars

Rawat et al. (1970) estimated 18–20% grain loss due to caterpillars infesting panicles of sorghum hybrid CSH 1 in Madhya Pradesh, India. The caterpillars, *H. armigera*, *Dichocrocis punctiferalis* (Walker), *Cryptoblabes gnidiella* (Milliere), *Euproctis xanthorrhoea* (Coll.), *Ephestia cautella* (Walker), and *Sitotroga cereallela* (Oliver) have been reported to cause grain losses of 44.4% at New Delhi (Kishore and Jotwani 1982). Sorghum hybrids CSH 9 and CSH 5 suffered grain yield losses of 14.5 and 12.9% in Maharashtra (Mote and Murty 1990), and 21.9–51.8% in Gujarat (Patel and Mittal 1986). In southern Africa, *H. armigera* causes 10–20% loss in grain yield annually (Leuschner and Pande 1992).

For each additional *H. armigera* larva per panicle, grain damage increased by 4.9%, and grain yield decreased by 3 g panicle^{-1} (Mote and Murty 1989). With a 1% increase in grain damage, grain yield decreased by 0.78 g panicle^{-1} (Mote and Murty 1989). Wilson (1976) reported that each *H. armigera* larva reduced grain yield by 5.4 g on RS 610 sorghum and 8.4 g on Pickett. In Queensland, Twine and Kay (1982) recorded a loss of 1.6 g of grain larva^{-1} panicle^{-1}. One larva caused grain losses of 22.1, 20.5, and 15.6% when released at the half-anthesis, milk, and dough stages, respectively (Mote and Murty 1989).

Kinzer and Henderson (1968) found that one *H. zea* larva per panicle decreased grain yield by 3.9 g at harvest. Infestations by 1–16 larvae of varying sizes per panicle damaged 10–60% of the grain (Burkhardt and Breithaupt 1955, DePew 1957). Based on artificial infestation, a regression equation has been developed to predict the number of grains a known number of larvae would destroy (Buckley and Burkhardt 1962). Sorghum grain losses caused by corn earworms can be estimated by using the equation: $Y = 71 + 102X$, where X = number of larvae per panicle (Teetes and Wiseman 1979).

Economic Injury Levels (EILs)

The EIL is defined as the insect pest abundance, or amount of damage that results in economic yield loss. EIL is an objective and a determinable value. In contrast, the economic threshold level (ETL), is subjective. ETL is the insect abundance level at which remedial control is required to prevent an insect pest that is increasing in abundance from reaching the EIL (Stern 1973). In most cases, the economic threshold, action threshold, or treatment threshold is lower than the economic injury level to allow time for curative action. If insect pest abundance does not increase, the economic injury and threshold levels are the same. Currently, synthetic insecticides are almost always the curative action. EILs are a dynamic phenomenon, and they vary with the cultivar grown, cost of control, expected value of the crop, productivity potential, and socioeconomic factors.

The methodology used in determining EILs is important to adjusting crop management recommendations. Assessment of the EIL requires determination of the relationship between yield loss and insect pest abundance, or level of damage. This includes: 1) observations of natural insect pest infestations which are then related to yield loss, 2) modifying insect pest abundances and relating them to yield loss, 3) using artificial infestation levels and relating insect pest abundance to yield loss, and 4) simulating damage by mechanical means and computer modeling.

Factors that need to be considered in determining density-to-damage relationships include: 1) time of injury with respect to plant growth, 2) part of the plant injured, 3) type of injury (direct or indirect), 4) intensity of the injury, and 5) environmental effects on the plant's ability to withstand injury. Adding an insect-resistant cultivar to this agenda doubles the amount of work. Information available on EILs for panicle-feeding insects of sorghum is discussed below.

Table 2. Economic injury levels for sorghum midge susceptible and resistant hybrids, College Station, Texas, USA, 1984.

Control cost (US$) ha⁻¹	Market value of crop (US$) ha⁻¹										
	250	300	350	400	450	500	550	600	650	700	750
						Susceptible hybrids					
7.5	1.2[1]	1.0	0.9	0.8	0.7	0.6	0.6	0.5	0.5	0.4	0.4
10	1.6	1.3	1.1	1.0	0.9	0.8	0.7	0.7	0.6	0.6	0.5
12.5	2.0	1.7	1.4	1.3	1.1	1.0	0.9	0.8	0.8	0.7	0.7
15	2.4	2.0	1.8	1.5	1.3	1.2	1.1	1.0	0.9	0.9	0.8
17.5	2.7	2.3	2.0	1.8	1.6	1.4	1.3	1.2	1.1	1.0	0.9
20	3.0	2.7	2.3	2.0	1.8	1.6	1.5	1.3	1.2	1.1	1.1
						Resistant hybrids					
7.5	6[1]	5	5	4	4	3	3	3	3	2	2
10	8	7	6	5	5	4	4	4	3	3	3
12.5	10	9	7	7	6	5	5	4	4	4	4
15	12	10	9	8	7	6	6	5	5	5	4
17.5	14	12	10	9	8	7	7	6	6	5	5
20	15	14	12	10	9	8	8	7	6	6	6

1. Number of ovipositing sorghum midges panicle⁻¹.

Sorghum midge

EILs for sorghum midge have been estimated to be 0.6 adult sorghum midges panicle⁻¹ in Taiwan (Hong 1987), 0.4–3.0 panicle⁻¹ in Texas (Cronholm et al. 1993), 1.0 in India and Argentina (Limonti and Villata 1980, Karanjkar and Chandurwar 1978), 2–3 in Mississippi (Pitre et al. 1975), and more than 6 midges panicle⁻¹ in Australia (Passlow 1973). ETLs for the midge on resistant sorghum hybrids in Texas have been estimated to be 2–15 midges panicle⁻¹ depending on the expected value of the crop and the cost of insecticide (Hallman et al. 1984; Table 2).

Head bugs

EILs for panicle-feeding bugs differ by cultivar and the stage of panicle development when infestation occurs (Hall and Teetes 1982a,b; Natarajan and Sundara Babu 1988b, Sharma and Lopez 1989, 1993). EILs for *C. angustatus* at the half-anthesis stage vary between 0.2 and 1.4 adults panicle⁻¹ on commercial cultivars (Table 3). At the milk stage, when maximum bug abundance and damage occur, EILs vary from 2.3 to 2.4 bugs panicle⁻¹ (Sharma and Lopez 1993). Natarajan and Sundara Babu (1988b) reported EILs for *C. angustatus* to be 0.06–0.12 adults at the half-

Table 3. Economic injury levels (EILs)[1] for *Calocoris angustatus*, ICRISAT Asia Center, rainy season 1985–87.

		Loss in grain yield (t ha⁻¹)				
Cultivar	Year	One insect per panicle	Following natural increase	EIL (one insect across stages)	EIL (based on natural increase)	EIL (Norton 1976)
CSH 1	1985	0.022	0.077	4.5	1.3	1.4
ICSV 1	1985	0.209	0.251	0.5	0.4	0.4
CSH 5	1986	0.154	0.548	0.6	0.4	0.5
CSH 5	1987	0.286	0.232	0.4	0.2	0.2

1. Number of adult bugs panicle⁻¹ at the half-anthesis stage.

anthesis stage and 5.4–10.5 adults at the milk stage, or 7.9–15.0 nymphs at the milk **stage**. For ***E. immaculatus***, EILs have been estimated to be 0.97–2.52 bugs panicle^{-1} at the milk stage (O. Ajayi, ICRISAT, personal communication).

Hall and Teetes (1982a) studied the insect density-to-yield loss relationships for four species of panicle-feeding bugs: *Oebalus pugnax*, *Chlorochroa ligata*, *Leptoglossus phyllopus*, and *Nezara viridula*. Largest reductions in grain yield occurred when panicles were infested at the milk-to-maturity stage of grain development. Percentage yield reductions increased quadratically with an increase in bug abundance. At the milk stage, the EILs were 2–6 bugs panicle^{-1} for *N. viridula*, *C. ligata*, and *L. phyllosus*, and 3–8 for *O. pugnax* (Hall et al. 1983; Table 4).

Head caterpillars

Insect density-to-damage relationships for sorghum head caterpillars have been computed in Australia (Wilson 1976, Twine and Kay 1982), India (Mote and Murty 1989), and USA (Kinzer and Henderson 1968; Teetes and Wiseman 1976). These relationships can be used to determine EILs for different cultivars and regions. Cronholm et al. (1993) reported EILs for a range of production levels and control costs for the corn earworm in sorghum (Table 5). For example, when the value of the crop is US$ 650, the EIL is 1 larvae panicle^{-1}.

Effect of Plant Resistance on Economic Injury Levels

One of the first and most important adjustments to crop management recommendations that must be made relates to economic threshold or action threshold in relation to host-plant resistance. This approach is in concert with the integrated pest management approach and adds to the security the farmers demand. In some cases, there are several different resistant cultivars of a crop that have different resistance levels. However, general or common resistance levels usually occur for which relative differences between resistant and susceptible cultivars can be determined. Experimental and empirical data are very valuable in determining the level of resistance of a cultivar.

Because the term 'resistance' conveys different expectations to different people and farmers desire no additional risk, the use of EILs to define the level of resistance of a newly released crop cultivar is critical. Insect-resistant cultivars decrease insect pest abundance or delay the time required by the insect pest to attain the EIL, or increase the EIL, depending on the mechanism of resistance and the criterion on which the EIL is based (Teetes 1985, Sharma 1993). If the EIL is based on damage, then the EIL will be the same for an insect-resistant cultivar as it would be for a susceptible cultivar (Fig. 1a) (Sharma 1993). If the

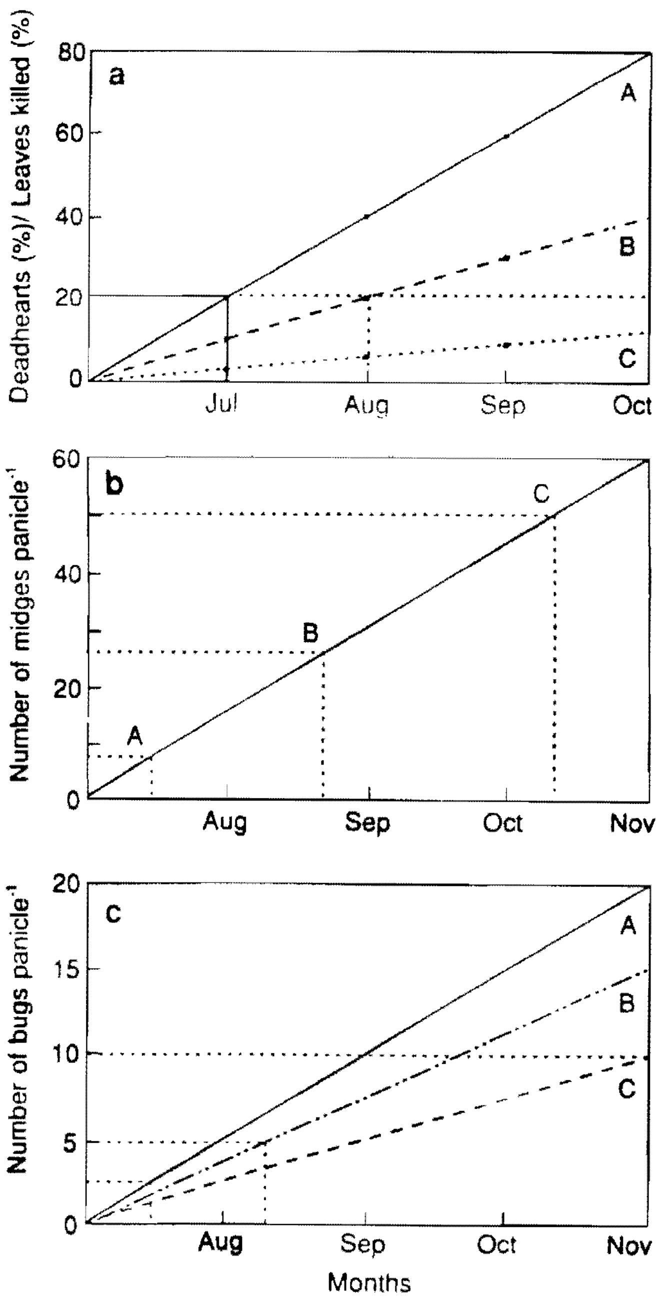

Figure 1. Effect of plant resistance on economic injury level (EIL). EIL based on a) damage, b) non-damaging adult stage, and c) damaging adults on genotypes with nonpreference and antibiosis mechanisms of resistance. A, B, and C are susceptible, moderately resistant, and resistant genotypes.

Table 4. Economic injury levels for rice stink bug, southern green stink bug, Conchuela stink bug, and leaf-footed bug, College Station, Texas, USA, 1984.

Control cost	Market value (US$) of crop ha^{-1}												
(US$) ha^{-1}	250	275	300	325	350	375	400	425	450	475	500	525	550
							Rice stink bug						
5	4[1]	4	4	4	3	3	3	3	3	3	3	3	3
7.5	5	5	4	4	4	4	4	4	4	4	4	3	3
10	5	5	5	5	5	5	4	4	4	4	4	4	4
12.5	6	6	6	5	5	5	5	5	5	5	4	4	4
15	7	6	6	6	6	6	5	5	5	5	5	5	5
17.5	7	7	7	6	6	6	6	6	5	5	5	5	5
20	8	7	7	7	6	6	6	6	6	6	6	5	5
22.5	8	8	7	7	7	7	6	6	6	6	6	5	5
25	8	8	8	7	7	7	7	7	6	6	6	6	6
							Southern green stink bug						
5	3	3	3	3	3	3	2	2	2	2	2	2	2
7.5	4	3	3	3	3	3	3	3	3	3	3	3	3
10	4	4	4	4	3	3	3	3	3	3	3	3	3
12.5	4	4	4	4	4	4	4	4	3	3	3	3	3
15	5	5	4	4	4	4	4	4	4	4	4	3	3
17.5	5	5	5	5	5	4	4	4	4	4	4	4	4
20	5	5	5	5	5	5	4	4	4	4	4	4	4
22.5	6	6	5	5	5	5	5	5	4	4	4	4	4
25	6	6	6	5	5	5	5	5	5	5	4	4	4
							Conchuela stink bug						
5	3	3	3	3	3	2	2	2	2	2	2	2	2
7.5	3	3	3	3	3	3	3	3	3	2	3	3	2
10	4	4	4	3	3	3	3	3	3	3	3	3	3
12.5	4	4	4	4	4	4	3	3	3	3	3	3	3
15	5	4	4	4	4	4	4	4	4	4	3	3	3
17.5	5	5	5	4	4	4	4	4	4	4	4	4	4
20	5	5	5	5	5	4	4	4	4	4	4	4	4
22.5	6	5	5	5	5	5	5	4	4	4	4	4	4
25	6	6	5	5	5	5	5	5	4	4	4	4	4
							Leaf-footed bug						
5	3	3	3	3	3	3	3	2	2	2	2	2	2
7.5	4	4	3	3	3	3	3	3	3	3	3	3	3
10	4	4	4	4	4	3	3	3	3	3	3	3	3
12.5	5	4	4	4	4	4	4	4	4	3	3	3	3
15	5	5	5	4	4	4	4	4	4	4	3	4	4
17.5	5	5	5	5	5	4	4	4	4	4	4	4	4
20	6	5	5	5	5	5	5	4	4	4	4	4	4
22.5	6	6	5	5	5	5	5	5	5	4	4	4	4
25	6	6	6	6	5	5	5	5	5	5	5	4	4

1. Number of bugs panicle^{-1}.

Table 5. Economic injury levels[1] for corn earworm larvae in sorghum, College Station, Texas, USA, 1979.

Control cost	Crop value (US$) of crop ha⁻¹								
(US$) ha⁻¹	250	300	350	400	450	500	550	600	650
5	0.5	0.4	0.3	0.3	0.3	0.2	0.2	0.2	0.2
7.5	0.8	0.6	0.5	0.5	0.4	0.4	0.3	0.3	0.3
10	1.0	0.8	0.7	0.6	0.6	0.5	0.3	0.3	0.3
12.5	1.2	1.0	0.9	0.8	0.7	0.6	0.6	0.5	0.5
15	1.5	1.2	1.1	0.9	0.8	0.8	0.7	0.6	0.6
17.5	1.7	1.4	1.2	1.1	1.0	0.9	0.8	0.7	0.7
20	2.0	1.7	1.4	1.2	1.1	1.0	0.9	0.8	0.8
22.5	2.2	1.9	1.6	1.4	1.2	1.1	1.0	0.9	0.9
25	2.5	2.1	1.8	1.6	1.4	1.2	1.1	0.9	1.0

1. Number of larvae panicle⁻¹.

EIL is based on the number of insects at a nondamaging stage of the insect (e.g., number of adult sorghum midges per panicle or number of adult insects caught in pheromone or light traps), the EIL will increase with an increase in the level of plant resistance. In the case of sorghum midge, the EIL is 0.4–3.0 adult midges panicle⁻¹ of susceptible sorghum, 2–15 midges panicle⁻¹ for a moderately resistant cultivar, and >50 midges panicle⁻¹ for a highly resistant cultivar (Fig. 1b). If the EIL is based on adults which also cause damage (e.g., panicle-feeding bugs), and the mechanism of resistance is antibiosis (which decreases the rate of increase in insect abundance), then the time taken by the insect to attain the EIL will be lengthened by the resistant cultivar (Fig. 1c).

For sorghum midge, the EIL increases with an increase in the level of resistance to this insect. Hallman et al. (1984) studied sorghum midge density-to-plant damage relationships for resistant and susceptible hybrids. EILs for midge-resistant sorghum hybrids are five times higher than for susceptible hybrids (Cronholm et al. 1993; Table 2). Sharma et al. (1993) estimated EILs for two midge-resistant experimental cultivars (ICSV 197 and ICSV 745) and four commercial cultivars (CSH 1, CSH 5, ICSV 1 and ICSV 112). There was a linear relationship between midge abundance and percentage grain loss for the susceptible cultivars CSH 1, CSH 5, and ICSV 112. However, with an increase in midge abundance, there was only a marginal increase in damage for the resistant cultivars. Damage to ICSV 1 moderately increased with an increase in midge abundance. Insect density-to-damage relationships were better correlated when cultivars were infested 4–5 times with a range of insect densities (5–80 midges panicle⁻¹ day⁻¹) than with a single infestation. EILs using 40 midges panicle⁻¹ and across four infestations were 0.2–0.3 midges panicle⁻¹ for ICSV 1, ICSV 112, and CSH 1, compared with 4.4 midges for ICSV 745 and 88.1 midges for ICSV 197 (Table 6).

Table 6. Economic injury levels[1] for sorghum midge for different number of infestations and four insect densities on five sorghum genotypes, ICRISAT Asia Center, postrainy season 1989/90.

	Number of infestations				Infestation levels			
Cultivar	1	2	3	4	5	10	20	40
ICSV 197	3.1	1.6	2.0	33.3	333.3	2.9	12.5	100.0
ICSV 745	20.0	7.7	4.8	25.0	12.2	2.2	3.3	6.7
ICSV 1	0.8	0.6	0.3	0.2	2.2	2.3	0.6	0.2
ICSV 112	0.6	0.4	0.2	0.2	2.9	0.8	0.6	0.2
CSH 1	0.3	0.3	0.3	0.1	0.5	0.5	0.3	0.2

1. Number of midges panicle⁻¹.

EILs for *C. angustatus* have been determined to be 0.2–0.9 bugs panicle^{-1} on CSH 11, a highly susceptible sorghum; 0.8–4.2 bugs on IS 9692, a susceptible sorghum; 0.5 to 1.3 bugs on IS 21443, a moderately resistant sorghum; and 10–15 bugs on IS 17610, a bug-resistant sorghum. Based on multiple regression, the EILs varied from 0.04 to 0.30 bugs panicle^{-1} of CSH 11, 0.9 to 6.6 bugs on IS 9692, 0.3 to 5.1 bugs on IS 21443, and 2.7 bugs on IS 17610 at the half-anthesis stage (Sharma and Lopez 1993).

Future Research Needs

- Survey the major sorghum-growing areas in the SAT to estimate insect-associated losses in farmers' fields and determine research priorities
- Establish EILs for economically important insect pests of currently grown and newly developed cultivars
- Determine insect density-to-yield loss relationships for important panicle-feeding insect pests of sorghum
- Assess the effects of natural enemies and crop combinations on panicle-feeding insect pests of sorghum and on EILs

Synthèse

L'évaluation des pertes de rendement et des seuils économiques de nuisibilité des insectes paniculaires du sorgho. A peu près 150 ravageurs s'attaquent au sorgho dans les différentes parties du monde. La cécidomyie du sorgho, *Contarinia sorghicola* Coquillett; les punaises des panicules, *Calocoris angustatus* (Lethiery), *Eurystylus immaculatus* Odhiambo, *Nezara viridula* (L.), *Oebalus pugnax* (Fabricius); et les chenilles des panicules, *Heliothis* et *Helicoverpa* sont les plus importants insectes nuisibles au sorgho à grain dans le monde.

Le niveau des pertes annuelles dues aux insectes paniculaires varie en fonction des régions. Des pertes ont été estimées à 550 millions de dollars dans les tropiques semi-arides, 250 millions de dollars aux Etats-Unis et 80 millions de dollars en Australie.

Les seuils économiques établis pour la cécidomyie du sorgho sont de 0,6 adulte par panicule au Taïwan, 0,4 à 3 à Texas, 1 en Inde et en Argentine, 2 à 3 à Mississippi et plus de 6 en Australie.

Des seuils pour des punaises des panicules varient selon des cultivars et des stades de développement paniculaire lorsque l'infestation a lieu. En ce qui concerne *C. angustatus*, au stade de demi-anthèse, les seuils se situent entre 0,2 et 1,4 adultes par panicule des cultivars commerciaux et entre 2,3 et 2,4 au stade laiteux lorsque la densité de peuplement de l'insecte est la plus élevée et les dégâts sont les plus sévères. Au stade laiteux, les seuils ont été estimés à 0,97 à 2,52 punaises par panicule pour *E. immaculatus*, 2 à 6 punaises pour *N. viridula*, *C. ligata*, et *L. phyllosus*, et 3 à 8 punaises pour *O. pugnax*. Le seuil pour *Helicoverpa* est d'une larve par panicule.

L'une des plus importantes modifications qu'on doit faire aux recommandations sur la gestion culturale concerne le seuil économique ou le seuil d'intervention par rapport à la résistance des plantes. Des cultivars résistants réduisent l'abondance des insectes ravageurs ou retardent le temps nécessaire par le ravageur pour atteindre le seuil économique de nuisibilité ou bien augmentent le seuil en fonction du mécanisme de résistance et du critère sur lequel le seuil est basé. Si le seuil est basé sur la sévérité des dégâts, alors il serait le même tant pour des cultivars résistants que sensibles. Par contre, si le seuil est basé sur le nombre d'insectes au stade non nuisible du ravageur (par exemple, le nombre de cécidomyies adultes par panicule ou le nombre d'adultes attrapés dans des pièges lumineux ou à phéromones), il augmenterait avec le niveau de la résistance des plantes. En revanche, si le seuil est basé sur le nombre d'adultes nuisibles (par exemple, les punaises des panicules) et le mécanisme de résistance est l'antibiose (qui réduit le taux d'augmentation de l'abondance des ravageurs), alors le temps nécessaire par le ravageur pour atteindre le seuil économique de nuisibilité serait prolongé par les cultivars résistants. Le seuil pour des sorghos hybride résistants à la cécidomyie est cinq fois plus élevé que pour des hybrides sensibles. Les seuils à 40 cécidomyies par panicule, et à travers quatre infestations sont de 0,2 à 0,3 cécidomyies par panicule pour ICSV 1, ICSV 112 et CSH 1 contre 4,4 pour ICSV 745 et 88,1 pour ICSV 197. Les seuils pour *C. angustatus* ont été déterminés à 0,2 à 0,9 punaises par panicule chez CSH 11, un sorgho très sensible; 0,8 à 4,2 punaises chez IS 9692, un sorgho sensible; 0,5 à 1,3 punaises chez IS 21443, un sorgho à résistance modérée; et 10 à 15 punaises chez IS 17610, un sorgho résistant.

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Panicle Insect Pest Damage and Yield Loss in Pearl Millet

S Krall[1], O Youm[2], and S A Kogo[3]

Abstract

*It is often difficult to identify panicle pest damage and estimate yield losses due to the presence of multiple pests and other biotic and abiotic factors. In addition, the technology used to assess insect-related crop losses in pearl millet [*Pennisetum glaucum *(L.) R. Brown] is limited. This paper provides a description of the basic principles for identifying pest damage and covers the techniques available for evaluating losses resulting from such damage. Examples of crop loss assessment methods are given, with estimates of losses from selected pearl millet insect pests.*

Introduction

Biologically intensive integrated pest management has received wide support as being an environmentally friendly approach to crop protection. Besides an accurate identification of the causative pest, other prerequisites for integrated crop protection measures include detailed information on the extent of damage and the resulting yield losses. This information is available for a number of important crops (e.g., cotton), but is inadequate or completely lacking for many basic food crops. Pearl millet [*Pennisetum glaucum* (L.) R. Brown)] is a major food crop in Sahelian West Africa and is attacked by several insect pests. One hundred and sixty-one species were reported in Nigeria (Ajayi 1987), 84 in Niger (Guevremont 1982), and 81 in Senegal (Ndoye 1979). Knowledge of pest biology is available for only a few important species (Anonymous 1988, Gahukar 1989, Jago 1993a, Krall and Dorow 1993, Matthews and Jago 1993, Ndoye 1989, Sharma and Davies 1988). Many pearl millet insect pests, especially the panicle-feeding species, have not been studied adequately, and information on their pest status is often not available. Wewetzer et al. (1993) have reviewed the methods for the assessment of crop losses. Although advantages and drawbacks vary from one method to another, the overall merit of developing such methods remains crucial. Much work has been conducted on basic insect biology and on crop damage caused by a few insects, but relatively little on pearl millet pests. In this paper, an overview of the current state of knowledge is presented, and areas in which further research is needed are highlighted and discussed.

Damage Caused by Panicle Insect Pests

Pantenius and Krall (1993) listed 15 insect species in six genera as the major pests (in addition to other diseases and birds) of pearl millet (Table 1). The importance of these pests varies from region to region, as well as within a particular country.

Millet head miner

The millet head miner (*Heliocheilus albipunctella* de Joannis) is widely distributed and is one of the most serious pests of pearl millet (Nwanze and Sivakumar 1990, Nwanze 1991, Bal 1992). The larvae mine into the panicle in a spiral path, and depending on larval and panicle stage, they destroy either the florets or the grain. In certain cases the damage can be serious.

1. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Postfach 5180, 65 726 Eschborn, Germany.
2. ICRISAT Sahelian Center, BP 12404, Niamey, Niger.
3. Direction de la Protection des Végétaux, BP 323, Niamey, Niger.

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Table 1. Pests and diseases of pearl millet (adapted from Pantenius and Krall 1993).

Insects	
Lepidoptera	
Spodoptera spp (1)[1]	
Coniesta ignefusalis (Hampson) (2)	
Heliocheilus albipunctella de Joannis (3)	
Coleoptera	
Lema planifrons Weise (1)	
Pseudocalaspsis setulosa Lefèvre (3)	
Rhinyptia infuscata Burmeister (3)	
Pachnoda interrupta (Olivier) (3)	
Mylabris (= *Decapotoma*) *affinis* (Olivier) (3)	
Psalydolytta spp (3)	
Cylindrothorax spp (3)	
Diptera	
Geromyia penniseti (Felt.) (3)	
Orthoptera	
Oedaleus senegalensis (Krauss) (1,3)	
Heteroptera	
Dysdercus völkeri Schmidt (3)	
Spilostethus spp (3)	
Dermaptera	
Forficula senegalensis Serville (3)	
Birds	
Quelea quelea L. (3)	
Passer luteus Lichtenstein (3)	
Diseases	
Tolyposporium penicillariae Bref. (3)	
Sclerospora graminicola (Sacc.) (1,3)	
Claviceps fusiformis Loveless (3)	

1. (1) = damage to leaves, (2) = damage to stems, and (3) = damage to panicles.

Pachnoda interrupta

The life cycle of the beetle *Pachnoda interrupta* (Olivier) is well adapted to pearl millet and the appearance of adults is closely associated with the different stages of grain development. Grain damage can be severe if feeding occurs during the milky and dough stage, in which case the grain is completely destroyed and shriveled. Damage to mature grain is usually superficial. These beetles are widely distributed, but are rarely observed in large numbers. Consequently, their pest status is often not considered important. Apart from *P. interrupta*, other cetonid beetles are associated with panicle damage of pearl millet, but are not considered to be serious pests (Grunshaw 1992).

Blister beetles

The species complex of blister beetles [*Psalydolytta* spp, *Cylindrothorax* spp, *Mylabris* (= *Decapotoma*) *affinis*] that feed on pearl millet panicles as adults, is quite heterogeneous and varies with region (Doumbia 1992). For example, while *Psalydolytta fusca* (Olivier) is designated as a major pest in Mali and Gambia (Coop and Croft 1992, Zethner and Laurense 1988), and *P. vestita* (Dufour) is often reported as an important pest in Mali and Senegal (Doumbia 1992) these two species are of negligible importance in Niger (Krall and Dorow 1993). The pest status of *Cylindrothorax dussaulti* (Dufour) and *C. westermanni* Maklin, which occur locally in Niger, have been poorly investigated. Observations in field cage trials in Niger in 1992 and 1993 showed their feeding preference for stamens (S Krall, unpublished). However, since pearl millet is cross-pollinated, the consumption of all the stamens on a panicle has not been associated with yield loss and the presence of several individuals on a panicle did not affect grain formation. Serious damage, however, could arise when these insects are present during the very early stages of panicle development. This is rarely the case in farmers' fields due to the differential development of panicles and because these insects are often localized. *Mylabris* (= *Decapotoma*) *affinis* (Olivier) is more widely distributed, prefers to feed on stamens like *C. dussaulti* and *C. westermanni*, and is unlikely to be a serious pest.

Rhinyptia infuscata

Adult *Rhinyptia infuscata* Burmeister beetles are nocturnal, with a peak in activity between 2200 and 2400 (ICRISAT 1992). Studies at the ICRISAT Sahelian Center and at other locations in Niger, have shown that these insects feed on both florets and stamens, resulting in the formation of empty spikelets. Farmers recognize these beetles as serious pests and often set night fires to lure them to be burned. Their precise status as pests, however, remains uncertain.

The local occurrence of this species is quite variable and in some regions, epidemics may result in severe damage and crop loss.

Pseudocolaspsis setulosa

The beetle *Pseudocolaspsis setulosa* Lefèvre has not been adequately studied. Adult activity begins at dusk and continues through the night, when the insects feed on the flowers and can be found locally in large numbers on the panicles. Adults are only a few millimeters long. Their damage is assumed to be of minimal importance.

Millet grain midge

The larvae of this tiny midge [*Geromyia penniseti* (Felt)] develop inside the flowers. When the adults emerge, the white exuviae remain on the panicle and can be seen hanging on the shriveled spikelets. The extent of the damage caused by *G. penniseti* is still unknown and is also difficult to determine (Coutin and Harris 1968).

Grasshoppers and locusts

Various species of grasshoppers (both adults and nymphs) can damage millet panicles. When an attack occurs during flowering or early seed development, the panicles can be severely damaged, depending on the density of grasshoppers. With fully mature grain, only a part of the grain is eaten away. The more common species include *Oedaleus senegalensis* (Krauss) and *Oedaleus nigeriensis* (Uvarov) (Nwanze and Harris 1992). Grasshoppers are certainly more serious during early vegetative growth than at the grain development stage. Nonetheless, they are major pests, as they occur widely in most countries (Coop and Croft 1993). The desert locust, *Schistocerca gregaria* (Forskal), and the African migratory locust, *Locusta migratoria* (L.), often occur in swarms, devouring all vegetation (Nwanze and Harris 1992). Concerted international efforts are often required for their control.

Head bugs

Adult bugs and their larvae, primarily *Dysdercus völkeri* Schmidt and *Spilostethus* spp, are regarded as important pests. Field observations in Niger have shown that the most widely prevalent species, *D. völkeri*, attacks newly exserted panicles and feeds on the young, tender florets. Such florets dry out and can later be recognized as light brown patches between undamaged grains. Feeding continues into the milk and dough stages. Damage is greatest at the milk stage. Other species of head bugs occurring on pearl millet are not known to cause any significant damage to grain.

Earwigs

Earwigs (*Forficula senegalensis* Serville) sometimes appear in high densities on pearl millet panicles, but their incidence is often localized and highly aseasonal. Nymphs and adults feed on all parts of the spikelet and are primarily active in the evening and at night. The damage they cause to grain is negligible.

Crop Loss Assessment Techniques

Most of the information provided here on the assessment of panicle and crop yield losses is derived from practical field work in West Africa. There are several approaches for estimating damage and yield losses. One method involves the caging of individual panicles (Grunshaw 1992, Coop and Croft 1992), or whole plant stands (S Krall, unpublished) into which a known number of insects are introduced. Apart from providing direct quantitative information on pest damage, this method can also be used to study pest activity. However, field trials and extensive surveys are necessary to obtain data on the extent of crop damage and yield losses. Nwanze (1988) classified crop loss assessment methods as follows:

- incidence ratio
- visual score paired analysis
- damage density loss ratio
- quantitative assessment (insecticide trials).

Cage Experiments

Single panicles

Grasshoppers and blister beetles. In experiments by Coop and Croft (1992) in Mali, five grasshopper species [*Hieroglyphus daganensis* Krauss, *Kraussaria angulifera* (Krauss), *Kraussella amabile* (Krauss), *Cataloipus cymbiferus* (Krauss), and *Oedaleus* *senegalensis* (Krauss)] and two blister beetle species (*Psalydolytta pilipes* Maklin and *P. fusca*) were introduced into plastic gauze cages containing individual panicles and allowed to feed for 4 days. Each treatment included 12 individually caged panicles. For grasshopper treatments, two females of each species were used per panicle, except for *C. cymbiferus* (one female per cage due to cannibalism). Beetle treatments were based on a ratio of 1.24:1 female:male. There were 12 repetitions for each species. Dead insects were routinely replaced in each cage. After 4 days, the damaged surface area of the panicle was measured and related to the number and dry weight of the insects introduced into the cages.

Pachnoda interrupta. In Mali, *P. interrupta* was investigated by introducing different densities in cages which enclosed individual panicles. The number of insects per panicle was 0 (in the controls), 1, 2, 3, 5, and 10. The duration of the experiment was from 7 to 9 days. The number of replications was 30. The losses were calculated from the yield of the infested panicles relative to that of uninfested ones. Here the surface area of the panicles was included in the calculation of losses (Grunshaw 1992).

Dysdercus völkeri. In Burkina Faso experiments were carried out with *D. völkeri* in a project sponsored by the Canadian International Development Agency (CIDA), but no concrete data are available (Anonymous 1991).

Whole plants

Flower-feeding insects. In Niger, in the framework of a GTZ project, experiments were undertaken (S Krall, unpublished) to determine the damage potential of different insect species including *D. völkeri*, *Spilostethus* spp, *F. senegalensis*, *P. setulosa*, *R. infuscata*, *M. affinis*, *Cylindrothorax* spp, and *P. interrupta*. The pest species was introduced on 1–2 plant stands enclosed in cages (1.3 × 1.3 × 2 m). Observations were made primarily on the behavior of the insects, as well as on their damage potential and feeding pattern. Losses here were only estimated semi-quantitatively.

Rhinyptia infuscata. Experiments were carried out in 3 × 3 × 9 m cages to determine losses due to this insect. Six different adult populations were maintained in cages for 15 consecutive days in Aug to simulate damage under natural conditions. At harvest, plants were divided in five groups: 0, 1–25%, 25–50%, 51–75%, and 76–100% damage. This method was compared with an open field assessment of yield loss due to *Rhinyptia* beetles. In this case 400 panicles were collected from the field at harvest and classified into five groups as described above. Losses in grain yield based on level of damage were recorded. The losses from the harvested panicles were determined (ICRISAT 1990).

Paired Plant or Plot Analysis

The paired plot analysis (comparing treated plants/plots with untreated controls) is the oldest and most frequently used applied experimental method. In some cases, the extent of damage by different insects was also determined, with the control kept more or less damage-free by very frequent spraying with pesticide (more than once week^{-1}) or by enclosing the individual panicles before damage could occur. The pests most frequently investigated with this method were *C. ignefusalis* and *H. albipunctella* (Bal 1992).

In Senegal, Guinea Bissau, and Gambia, experiments were carried out in 1980–82 in which plots were kept pest free and compared with untreated ones (Settle 1981, 1982, 1983). In this way the total damage attributable to pests was determined.

Surveys and Field Studies

Crop loss estimation in Niger

In Niger, a method to assess crop losses using the damage pattern of different insect species has been developed. The damaged area on the panicles was estimated for each pest (insects, birds, diseases) with the help of damage rating keys. Later, on the basis of standard values in cm^2-weight per panicle surface, these were recalculated as yield loss. Since 1989, wide scale investigations have been carried out in Niger using this method; about 300 fields have been studied during the past 2 years (Pantenius and Krall 1993).

Millet head miner

Assessment of crop loss due to the millet head miner (*Heliocheilus albipunctella*) was conducted in 1987 at Sadoré (ICRISAT Sahelian Center). The method consisted of randomly sampling 1000 panicles which were stored in paper bags. The number of larvae which had completed their development were counted and recorded. Panicles were then weighed and threshed. Yield losses resulting from different levels of panicle infestation were estimated.

Crop loss assessment in Mali

In Mali, a 5-year project was carried out to establish an approach for integrated pest management for pearl millet. It began with insecticide experiments but was then expanded to include observations on individual pests as well as socioeconomic studies (Jago et al. 1993).

Adjusted length method

Based on the work of Settle and Dively in West Africa from 1981–84, the adjusted length method was developed (Dively and Coop 1993). Pearl millet panicles were evaluated with respect to various kinds of damage, and the damaged area was measured by hypothetically projecting the affected area onto an enclosing cylinder. Yield loss was also calculated on the basis of damaged area. Since this method is very similar to that of Pantenius and Krall (1993), a direct comparison of the methods was undertaken in Mali (Sidibé 1992).

Results and Discussion

Cage experiments

a) Single panicles

Grasshoppers and blister beetles. Results showed that the two species of *Psalydolytta* were potentially more damaging than the grasshopper species. They consumed 10.3 cm^2 of pearl millet panicle day^{-1} compared with 1.3–4.3 cm^2 day^{-1} by the grasshopper species (Coop and Craft 1992).

Pachnoda interrupta. For *P. interrupta* investigated by Grunshaw (1992) in Mali, losses ranged from 9.7% for an infestation level of one insect $panicle^{-1}$ to 48.7% (10 individuals $panicle^{-1}$). A regression curve for the damage threshold at various millet prices based on known levels of beetle densities was presented.

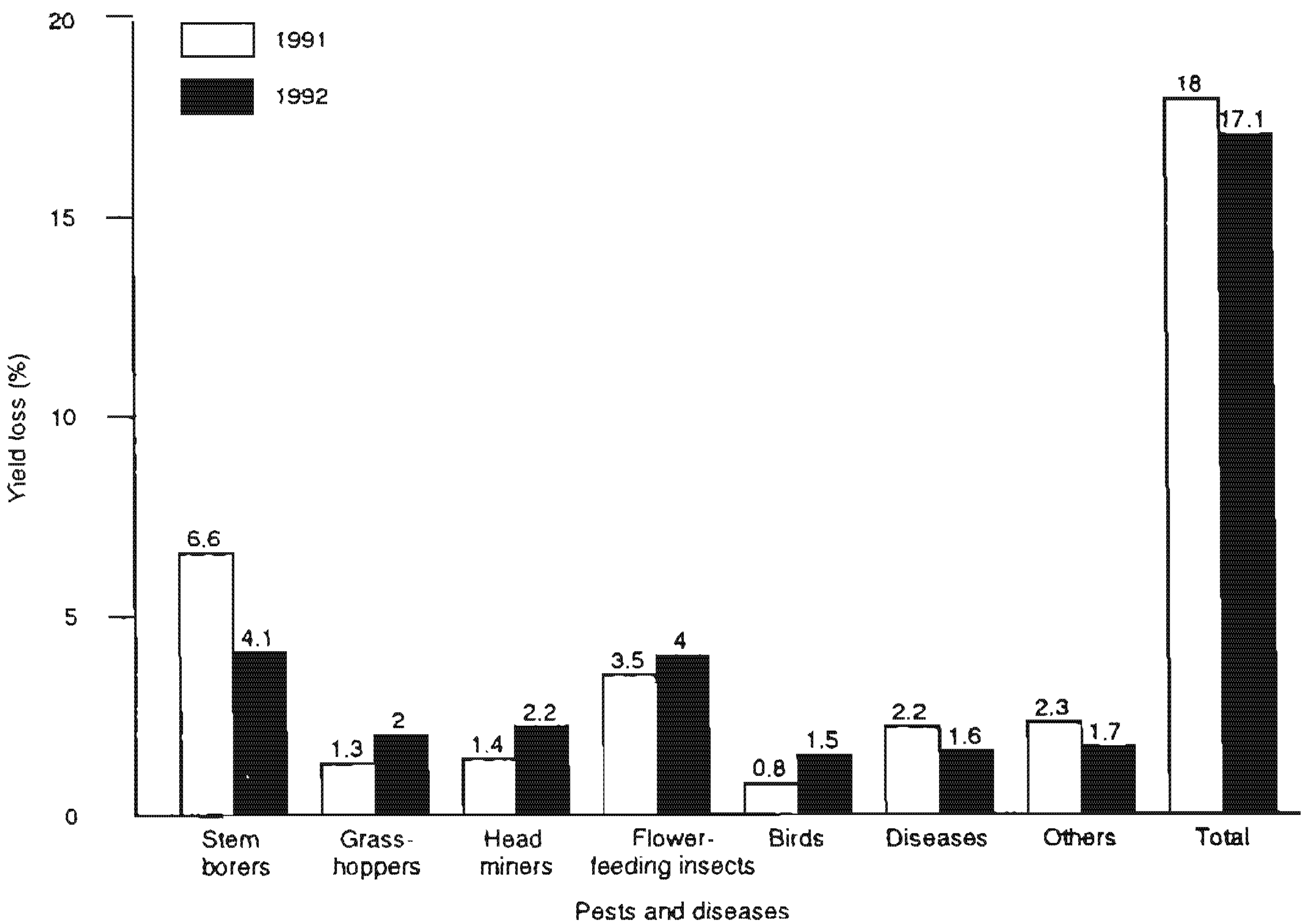

Figure 1. Pearl millet yield losses due to different pests and diseases, rainy seasons 1991 and 1992, Niger.

b) Whole plants

Flower-feeding insects in Niger. Krall (unpublished) studied the pest status of the insect species listed above and the damage potential and feeding pattern. Yield losses due to flower-feeding insects were 3.5 in 1991 and 4% in 1992 (Fig. 1).

Potential yield losses due to *R. infuscata* are shown in Table 2. Yield losses in the cage studies were lower than in the field samples, but in both cases, major losses occurred with 21 and 54% in cages and field experiments, respectively, at damage levels greater than 25%. Mean yield losses on the field samples ranged from 37 to 57%.

Field studies on the use of insecticides in pearl millet in Mali

Investigations in Mali showed that insecticide treatments were economically beneficial only in dry years, if at all, and only with inexpensive or subsidized products; instead, integrated pest management has been recommended for millet. Generally speaking, insecticide treatment cannot be recommended at the level of the individual small farmer in the Sahel zone (Matthews and Jago 1993).

Adjusted length method

Results of investigations carried out between 1983 and 1990 (Dively and Coop 1993) are summarized in Figure 2. The adjusted length method and the GTZ method have their own advantages and disadvantages, but both are suitable for large-scale use (Sidibé 1992).

Crop loss estimation in Niger

Pantenius and Krall (1993) continuously recorded data on the level of damage by individual pests. Both the methodology as well as the training of the field observers have been constantly improved. As representative data, the yield losses measured for the years 1991 and 1992 are presented in Figure 1. Based on a country-wide survey, results showed some variability in pest incidence. In comparison with Table 2, losses seem to be much lower and suggest that more accurate information on losses can be secured when better and improved methods are developed.

Table 2. Reported losses in pearl millet yields due to *Heliocheilus albipunctella* and *Rhinyptia infuscata*.

Loss (percentage of grain mass)	Location	Author
Heliocheilus albipunctella		
13–35	Senegal	Vercambre 1978 (in Bernardi et al. 1989)
29–82	Senegal	Gahukar 1982, 1983 (in Bernardi et al. 1989)
8–41	Niger	Nwanze 1988
3.5–44.8[1]	Niger	ICRISAT Sahelian Center 1988
8–47	Niger	ICRISAT Sahelian Center 1990
15	Niger	Brenière 1974 (in Nwanze 1988)
3–82 and 15–20	Senegal	Gahukar et al. 1986 (in Nwanze 1988)
16–85	Burkina Faso Gambia, Mali Senegal	Anonymous 1990 (Sahel PV Info 1990)
0.8–14.9	Niger	Nwanze and Sivakumar 1990
7–20	Senegal	Bal 1992
Rhinyptia infuscata		
38–97[2] (field, ranges) (37–57, field means)	Niger	ICRISAT 1990
1–70 (cages, ranges from main stems)	Niger	ICRISAT 1990

1. 1–2 larvae caused 3.5% grain yield loss, 3–4 larvae caused 20.7%, 5 larvae caused 34.5%, and >5 larvae caused 44.8% grain yield loss.
2. Damage of 1–25% resulted in 38% grain yield loss, 26–50% resulted in 64% grain yield loss, 51–75% resulted in 80%, and 76–100% damage resulted in 97% yield loss.

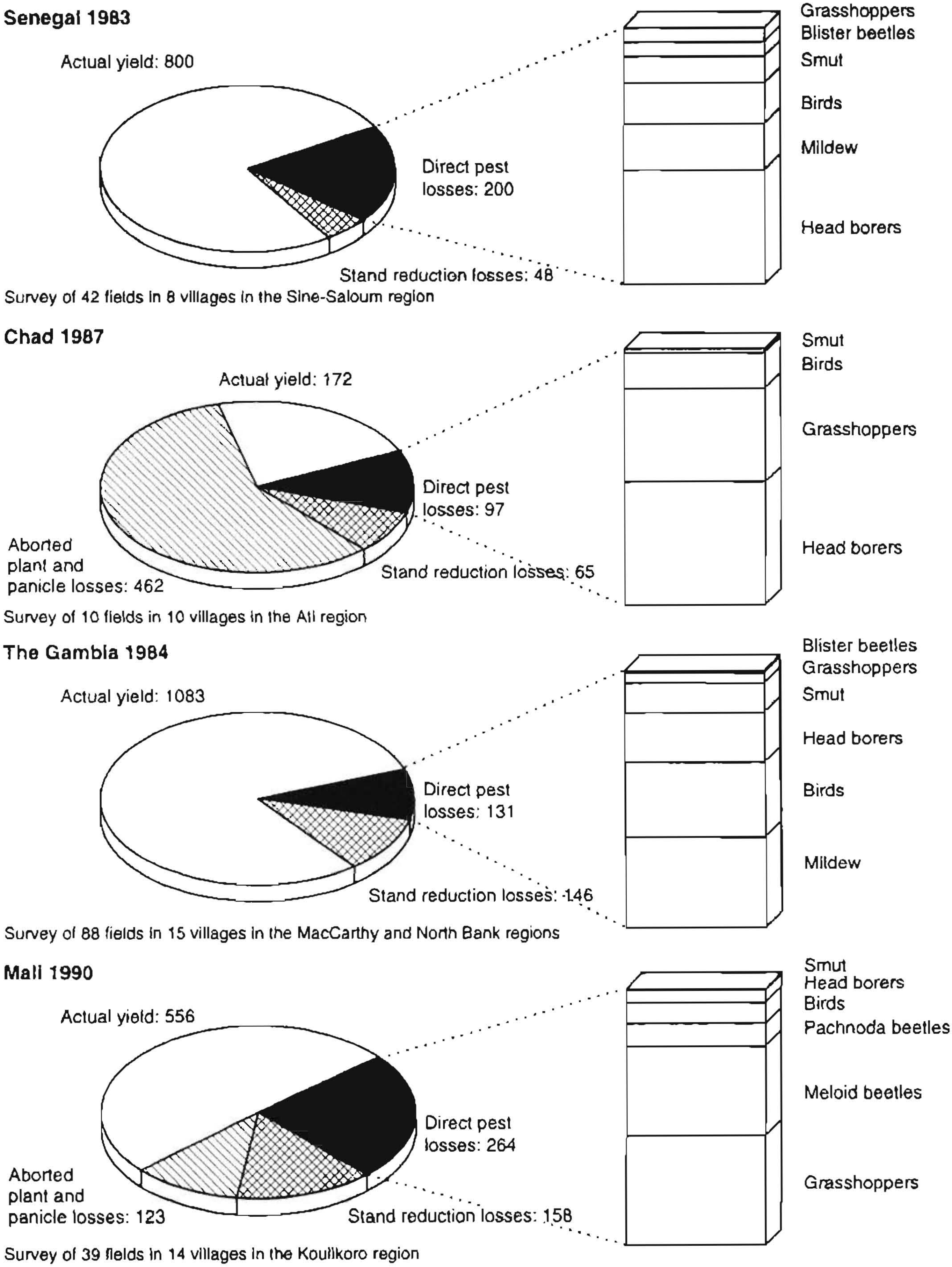

Figure 2. Yield loss profiles from loss assessment surveys in West Africa (Yield and losses are in kg ha^{-1}. Source: Dively and Coop 1993).

Investigations on the millet head miner

The head miner is considered one of the most serious pests of pearl millet, and has been extensively studied. A summary of these results on *Heliocheilus albipunctella* is given in Table 2. It is obvious that high variability exists here in both results and methodologies. For example, results on yield loss estimation due to millet head miner was 3.5% for 1–2 larvae panicle^{-1}, 20.7 for 3–4 larvae panicle^{-1}, 34.5% for 5 larvae panicle^{-1}, and 44.8% for >5 larvae panicle^{-1} (ICRISAT Sahelian Center 1988). Estimation of losses due to the millet head miner was based a variety of methods. Results (Table 2) call for simple standardized methods so that data can be compared across regions and locations.

Advantages and limitations of techniques

Experiments on individual panicles alter natural conditions so much that reliable conclusions about the behavior of the pest in the field are difficult to make. Since the introduced insects cannot behave according to their biology, their feeding behavior can be disturbed. In addition, the test insect on an isolated panicle has no choice but to feed, and feed on that panicle. Nevertheless, these experiments do provide interesting results in some cases.

Experiments with cages in which at least one plant stand is present are more accurate than those involving individual panicles, because the climatic conditions are almost identical inside and outside the cage and panicles in different developmental stages are available. However, a purely quantitative evaluation is already made impossible by the fact that standard conditions are not involved. Moreover, in such cages undesirable pests can be present but remain unnoticed at the start of the trial. Field-cage studies are, however, well suited for detailed observations and photography or filming of individual pests and semiquantitative evaluations.

Experiments based on paired plot analysis have a number of disadvantages (Settle 1983): (a) distinction between different pests is not possible, (b) loss estimation is inexact, since all insect species are not completely controlled (e.g., stem borers), (d) errors occur, e.g., when insecticides drift onto the untreated plots, (e) there is possibly an influence of the insecticide on plant growth, (f) fungal diseases are not prevented, since only insecticides are applied, (g) the procedure is very expensive, time-consuming, and laborious. In addition, it has been found that even weekly insecticide treatments are sometimes insufficient to keep the control plots pest-free (Settle 1981).

Field studies or surveys such as those in Mali and Niger, can lose precision when conducted on a large scale. However, they become more interesting due to greater representation as country-wide studies. In this case one is dealing with a number of factors. For example, accurate observations require scientifically trained personnel, which is almost always a resource of limited availability. Thus one can only evaluate a small number of samples. In country-wide surveys as in Niger, reliance is made on ordinary field observers. Accordingly, the level of accuracy can depend on the person, but the advantage is that the number of fields evaluated is large.

Implications and Recommendations for Future Research

Techniques for investigating losses due to panicle pests are available in principle but need to be refined and in some cases standardized. For some pests, investigations are very difficult and remain completely lacking (e.g., *G. penniseti*). Programs which are economical and can be carried out region- or even country-wide have been developed and conducted in Niger and Mali. However, they must be tested under different conditions and in different countries before they can be regarded as standard methods. Most importantly, identification of pests remains critical. Accurate description of pest damage and estimation of the resulting losses is paramount. Future studies should (a) develop methodologies for accurate pest and damage identification, (b) provide efficient and rapid standardized methods for pearl millet yield loss assessment, and (c) compare and further refine existing crop loss estimation techniques. Finally, training on techniques in field surveys and yield loss assessment remains a high priority.

Synthèse

Dégâts et pertes de rendements causés par les insectes des panicules du mil (**Pennisetum glaucum*****).*** Le mil, *Pennisetum glaucum* (L.) R. Br., une importante culture de soudure dans la zone sahélienne de l'Afrique de l'Ouest, est attaqué par plusieurs insectes nuisibles. Au Nigéria, 161 espèces ont été recensées (Ajayi 1987), au Niger 84 (Guevremont 1982) et au Sénégal 81 (Ndoye 1979). La majorité des insectes attaquant le mil, en particulier ceux qui se nourrissent des panicules, ont été insuffisamment étudiés dans bon nombre de cas. Par conséquent, l'information sur certains de ces insectes n'est pas suffisante pour déterminer leur importance économique.

Un bon nombre de méthodes d'estimation des pertes de rendement a fait l'objet d'une récente revue critique (Wewetzer et al. 1993). Bien que les avantages et les inconvénients varient d'une méthode à l'autre, il est évident que le développement de telles méthodes revêt une importance primordiale.

L'objet de cette communication est de donner un aperçu général sur l'état des connaissances concernant l'identification des dégâts et les pertes de rendements causés par les insectes nuisibles aux panicules de mil. Cette communication décrit les dégâts causés par la mineuse de l'épi (*Heliocheilus albipunctella* de Joannis), *Pachnoda interrupta* (Olivier), les méloïdes [*Psalydolytta* spp; *Cylindrothorax* spp, *Mylabris* (=*Decapotoma*) affinis (Olivier)], *Rhinyptia infuscata* Burmeister, le moucheron du mil, les sauteriaux, les punaises des épis, et les forficules. Les dégâts causés par ces insectes sont sévères pour certains (exemple la mineuse de l'épi) et négligeables pour d'autres (exemple *Pseudocolaspsis setulosa* Lefèvre).

Les techniques d'estimation des pertes peuvent se faire par les méthodes de mise en cage, (des panicules individuelles, ou des plantes entières); par la méthode d'échantillonnage des plantes dans les champs, par comparaison de plantes ou de parcelles protégées avec celles non protégées. Bien que ces techniques ne soient pas toujours parfaites, elles permettent néanmoins de déterminer les pertes de rendements causées par certains insectes de panicules. Par exemple, les pertes dues à *P. interrupta* étaient passées de 9,7% avec un niveau d'infestation d'un insecte par panicule à 48,7% si le niveau d'infestation est de 10 insectes par épi. Les dégâts causés par les insectes floricoles étaient de 3,5 à 4% selon la saison.

Pour la mineuse de l'épi, les pertes étaient de 3,5% avec un niveau d'infestation de 1–2 larves par panicule, 20,7% pour 3–4 larves, 34,5% pour 5 larves par panicule, et 46,8% pour >5 larves par panicule. D'après les résultats présentés dans cette communication, il ressort une variabilité aussi bien au niveau des résultats que des méthodologies d'estimation des pertes.

Ces techniques comportent aussi bien des avantages que des inconvénients. Les essais de mise en cage des panicules modifient les conditions naturelles si bien que les conclusions sur le comportement de l'insecte au champ deviennent difficiles du fait d'une éventuelle perturbation de leur comportement dans ce microenvironnement. Par contre, les essais menés en cages contenant les plantes entières semblent convenir le mieux. Cependant, dans de telles situations d'autres insectes pourraient déjà être dans les cages avant les expériences, et de ce fait peuvent influencer les résultats.

Les inconvénients des méthodes comparant les parcelles protégées (par insecticide) et non protégées pour estimer les pertes sont multiples. On peut citer entre autres (a) la difficulté de distinguer les différents ravageurs, (b) la difficulté de maîtriser tous les insectes présents dans les parcelles, (c) les erreurs dues à la dérive des insecticides sur les parcelles non traitées. En plus, c'est une procédure coûteuse qui requiert beaucoup de temps et d'efforts.

A la suite de cette revue sur l'état des connaissances sur les méthodologies concernant l'évaluation des pertes, les recommandations suivantes en découlent: (a) les techniques disponibles sur l'estimation des pertes nécessitent une amélioration et une standardisation; (b) ces techniques doivent être évaluées dans différents pays, sous plusieurs environnements; (c) des efforts sur l'identification fiable des ravageurs et leurs dégâts doivent être renforcés; (d) de nouvelles méthodes standardisées, efficaces et rapides d'estimation de pertes doivent être mises au point; e) et enfin la formation dans les techniques d'enquêtes et d'estimation des pertes de rendement reste un domaine prioritaire.

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Summary of Discussion

Session 2

Good knowledge of the ***bioecology*** of a pest species is essential when developing crop loss assessment techniques. The bioecology of *Calocoris angustatus* and *Contarinia sorghicola* has been studied extensively. However, much remains to be known about the *Eurystylus* complex in West Africa, *Rhinyptia infuscata*, *Heliocheilus albipunctella*, and various panicle-feeding beetles especially meloids and *Pachnoda interrupta*.

Yield loss assessment is necessary to determine the importance of each insect as a pest. Assessing losses due to pests of panicles is much easier than assessing losses due to pests that attack at an earlier stage of crop development, such as stem borers. Losses caused by the following insects have been measured and documented: *Contarinia sorghicola*, *Calocoris angustatus*, and *Eurystylus immaculatus*. Knowledge of crop losses due to the following insects is incomplete and simple procedures are needed: *Eurystylus* spp, *Heliocheilus albipunctella, Rhinyptia infuscata*, and various panicle-feeding beetles (meloids and *Pachnoda interrupta*).

Economic injury levels (EILs) are useful as a rough guide for taking important decisions on pest management actions. EILs have been documented for *Calocoris angustatus*, *Contarinia sorghicola*, and *Eurystylus immaculatus*. Work needs to be done to establish EILs for *Eurystylus* spp, *Heliocheilus albipunctella*, *Rhinyptia infuscata*, and various panicle-feeding beetles (meloids and *Pachnoda interrupta*).

Integrated pest management (IPM) models need to be developed based on available knowledge of bioecology, crop losses, EILs, and socioeconomic factors. In particular, there should be more interaction between entomologists and farmers who often have good perceptions of the relative importance of pests, but are not always correct in their interpretation of field observations. Also, monitoring of pest incidence, rainfall patterns and other environmental factors would enhance IPM. Examples: (a) *Pachnoda interrupta*—influence of animal manure and rainfall pattern; (b) grasshopper egg-pod survey—monitoring of grasshopper adults and presence of parasitoids at the larval stage to forecast likely damage by the grasshopper.

Synthèse de discussion

Session 2

La mise au point des techniques fiables d'évaluation des pertes de rendement occasionnées par les ravageurs n'est pas possible sans une bonne connaissance de leur ***bioécologie***. La bioécologie de *Calocoris angustatus* et de *Contarinia sorghicola* est bien connue tandis qu'il reste beaucoup à savoir à propos du complexe de *Eurystylus* en Afrique de l'Ouest, de *Rhinyptia infuscata*, de *Heliocheilus albipunctella* et de diverses cantharides des panicules, surtout les méloïdes et *Pachnoda interrupta*.

L'évaluation des pertes de rendement est nécessaire pour déterminer l'importance de chaque insecte en tant que ravageur. Il est plus facile d'évaluer les pertes dues aux insectes paniculaires que celles dues aux ravageurs qui s'attaquent à un stade plus tôt de développement de la plante, tels que les borers des tiges. Des pertes causées par *Contarinia sorghicola*, *Calocoris angustatus* et *Eurystylus immaculatus* ont été évaluées et enregistrées. Il faut combler le manque de connaissances des pertes dues à *Eurystylus* spp, *Heliocheilus albipunctella*, *Rhinyptia infuscata*, et diverses cantharides des panicules (les méloïdes et *Pachnoda interrupta*) à l'aide des méthodes d'évaluation simples.

Des ***seuils économiques de nuisibilité*** servent de guide dans la prise des décisions sur les méthodes de lutte à utiliser contre les insectes nuisibles. Des seuils économiques ont été établis pour *Calocoris angustatus*, *Contarinia sorghicola* et *Eurystylus immaculatus* mais non pas pour *Eurystylus* spp, *Heliocheilus albipunctella*, *Rhinyptia infuscata*, et diverses cantharides des panicules (les méloïdes et *Pachnoda interrupta*).

Des ***modèles de lutte intégrée contre les ravageurs*** devront être mis au point sur la base des connaissances de la bioécologie, des pertes de rendement, des seuils économiques de nuisibilité et des facteurs socio-économiques. Il importe tout particulièrement d'avoir davantage d'interactions entre les entomologistes et les paysans qui sont souvent bien informés sur l'importance relative des ravageurs, mais n'arrivent pas toujours à tirer des conclusions correctes à partir des observations en milieu réel. En plus, la surveillance de la dynamique des peuplements des ravageurs, des régimes de pluies et d'autres facteurs climatiques permettrait d'augmenter l'efficacité de la lutte intégrée contre les insectes nuisibles. Parmi les cas où la surveillance serait utile sont: (a) *Pachnoda interrupta*—l'influence de l'engrais animal et des régimes de pluies; (b) des sauteriaux—la présence des adultes et des parasitoïdes au stade larvaire afin de prévoir les dégâts causés par des sauteriaux.

Session 3

Host-plant Resistance

Résistance variétale

Breeding for Resistance to Sorghum Midge in USA

G C Peterson[1]

Abstract

Sorghum midge, Contarinia sorghicola, *is a major insect pest of grain sorghum in the southern USA. The insect is especially damaging in late-sown sorghum or in fields with delayed anthesis. The Texas Agricultural Experiment Station/Texas A&M University sorghum improvement program has identified converted exotic genotypes resistant to sorghum midge, and released many improved resistant germplasm lines. The commonly used source of resistance has been TAM 2566 (SC175-9), and the highest level of resistance found is in Tx2782 (resistance source from AF28). The first midge-resistant hybrids were characterized by resistance lower than in either parent and relatively low yield potential. Hybrids are currently being evaluated with sorghum midge resistance at least equal to the mean of either parent and excellent yield potential. Recent efforts have been directed toward developing A-lines (females) with improved resistance and yield potential in hybrid combination.*

Introduction

The sorghum midge [*Contarinia sorghicola* (Coquillett)] is probably the most cosmopolitan insect pest of sorghum. In USA, it was first reported as a pest in Texas in 1908 (Herrick 1909). Resistance sources have been reported from several countries (Johnson et al. 1973, Jotwani et al. 1971, Parodi et al. 1974, Peterson et al. 1989, Santos and Carmo 1974, Wiseman et al. 1973, Wuensche et al. 1981).

The midge is a key insect pest of sorghum throughout the southern sorghum-producing region of USA. The insect is usually most devastating in sorghum which has been delayed in sowing. Increasing in population density in early spring on Johnson grass, *Sorghum halepense*, midges then move into flowering sorghum. The second and third generations usually have the highest population density. Numbers of adult midges then decrease in succeeding generations late in the year.

The Texas Agricultural Experiment Station (TAES) sorghum improvement program has conducted research on developing midge-resistant sorghum genotypes for over 20 years. Activities of the breeding program include screening and evaluation of introduced genotypes for resistance, development and selection of breeding populations and random-mating populations, and testing of lines in hybrid combination. Several sources of resistance have been identified from the converted exotic sorghum collection. Many germplasm lines have been released as a result of the research. Principal emphasis is being shifted to the development of improved A-lines (females) in A1 cytoplasm.

Germplasm

The development of sorghums resistant to sorghum midge, or other biotic or abiotic stresses, is contingent upon usable resistance sources in acceptable agronomic form. Because sorghum is an introduction to the temperate USA, many of the 20 000–30 000 accessions in the World Sorghum Collection from tropical, short-day regions of the world are too tall, too late, or otherwise unadapted to the climatic zone of USA. American sorghum workers therefore dealt with a restricted germplasm base until a method was developed to make new germplasm available in a usable form.

The sorghum conversion program, initiated in 1963, was established to enhance the available germplasm base (Stephens et al. 1967) of sorghum in USA. The cooperative project is operated by TAES/Texas

1. Texas Agricultural Experiment Station, Route 3, Box 219, Lubbock, Texas 79401-9757, USA.

Peterson, G.C. 1995. Breeding for resistance to sorghum midge in USA. Pages 149–157 *in* Panicle insect pests of sorghum and pearl millet: proceedings of an International Consultative Workshop, 4–7 Oct 1993, ICRISAT Sahelian Center, Niamey, Niger (Nwanze, K.F., and Youm, O., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

A&M University and the United States Department of Agriculture (USDA), Science and Education Administration, Agricultural Research Service. Since the initial release in 1969, 533 converted exotic sorghum genotypes have been released from the program.

The conversion program has been the primary source of 'tropically adapted' germplasm containing many desirable traits (resistance to insects, pathogens and grain molds, drought tolerance, grain quality, improved yield potential and adaptation) used in sorghum improvement in USA and many other areas of the world. It has provided all the sources of resistance to sorghum midge used in USA except for AF-28. Continued germplasm exchange is vital to improvement programs throughout the world. As long as germplasm is allowed to move freely between programs and countries, all scientists have equal access to potentially useful germplasm. Greater progress can then be made in breeding objectives, and production constraints more efficiently addressed. Frequently, usable traits will not be identified until later. For example, the midge resistance of TAM 2566 (SC175-9), a partially converted zera zera type sorghum from Ethiopia was discovered by accident and resulted in initiation of the breeding program for midge resistance. If germplasm exchange is not reciprocal or impossible due to government regulation then little incentive to cooperate exists, with the result that our ultimate clientele, the consumer, has a more expensive and lower quality food supply.

Cooperative Research

Progress in the development of the TAES sorghum midge resistance program has been substantially enhanced through cooperative research between breeders and entomologists. While responsibilities vary, it is important to have substantial interaction and exchange between scientists. Scientists view the nurseries together as a team, with the entomologist usually concerned primarily with insect resistance and the breeder with agronomic traits. Germplasm selection, crosses for breeding populations or hybrids, studies, and graduate student training are all discussed while viewing breeding material. The result is a well-integrated program where the scientists involved know what each is doing. Multi- and interdisciplinary research also provides excellent training opportunities for graduate students and visiting scientists. The TAES sorghum improvement program is a cooperative effort involving scientists from several disciplines. This type of cooperative effort has resulted in more improvement in midge resistance than if the scientists had little or no interaction.

Sources of Resistance

Lack of temperately adapted germplasm hindered the identification of resistance sources and development of elite resistant germplasm, until lines from the sorghum conversion program were available. Also, breeding nurseries were sown at a time designed to escape midge damage, or were sprayed with insecticides to control midges if they became a problem. Independent observations in 1969 by scientists at TAES, Lubbock, Texas, USA, and the USDA Federal Experiment Station in Mayaguez, Puerto Rico, suggested a differential response to sorghum midge damage by lines in the sorghum conversion program.

Subsequent evaluation of lines from the conversion program over the last 20 years resulted in the identification of several resistance sources (Table 1). In 1973, initial evaluation of 60 converted exotic sorghum genotypes for resistance to sorghum midge was conducted at Lubbock (Johnson et al. 1973). IS12666C, a partially converted zera zera from Ethiopia, was subsequently released as TAM 2566. This has been the major source of resistance used in the TAES sorghum midge resistance program. During 1975–79, 211 lines were evaluated for sorghum midge resistance in more than one year and location (Wuensche et al. 1981). Of this group, 11 lines were identified as possessing useful resistance. Two hundred and fourteen converted lines were screened for resistance during 1983–85 (Peterson et al. 1989). Of this group, IS3390C (SC572-14) and IS12572C (SC62-14) appeared to possess the best resistance. IS12572C, classified as a caudatum-nigricans-conspicuum, has a different plant phenotype than other midge-resistant lines, with a loose panicle and glumes which do not tightly clasp the seed. Additionally, the resistance is expressed at approximately the same level regardless of the midge population density. However, no advanced elite lines have been produced from either line. During 1991/92, 55 lines were evaluated for resistance and 5 lines appeared to contain usable resistance. IS6919C (SC846-14) is a tan plant, white-seeded genotype which is a B-line in A1 cytoplasm. Identification of a tan plant B-line in A1 cytoplasm are two potentially useful traits in TAES' breeding program. Heterosis has been restricted due to the presence of the same resistance source in both parents of a hybrid. This line gives us the opportunity to develop potentially unique resistance sources in

Table 1. Resistant converted exotic lines identified in Texas, USA.

IS number[1]	SC number[2]	Group[3]	Year identified[4]
IS12666C	SC175-9	39(1): Zerazera	1973
IS2579C	SC423-14E	39(1): Zerazera	1973
IS2508C	SC414-14E	38: Caudatum-Kafir	1973
IS12608C	SC108-14E	39(1): Zerazera	1973
IS2549C	SC228-14E	39(1): Zerazera	1976–79
IS2862C	SC655-14E	24: Caffrorum-Birdproof	1976–79
IS3071C	SC237-14E	31(1): Dobbs	1976–79
IS63920	SC490-14E	46(1): Nandyal	1976–79
IS7064C	SC420-14E	38: Caudatum-Kafir	1976–79
IS7142C	SC564-14E	33: Caudatum	1976–79
IS8231C	SC645-14E	23: Caffrorum-Darso	1976–79
IS8233C	SC643-14E	23: Caffrorum-Darso	1976–79
IS8263C	SC328-14E	31(1): Dobbs	1976–79
IS8337C	SC574-14E	39: Caudatum-Nigricans	1976–79
IS12593C	SC84-14E	47: Durra-Nigricans	1976–79
IS8232C	SC642-14E	23: Caffrorum-Darso	1983–85
IS8237C	SC644-14E	23: Caffrorum-Darso	1983–85
IS8112C	SC725-14E	33: Caudatum	1983–85
IS2740C	SC708-14E	33: Caudatum	1983–85
IS3390C	SC572-14E	38: Caudatum-Kafir	1983–85
IS7132	SC693-14E	31(1): Dobbs	1983–85
IS2685C	SC692-14E	31(1): Dobbs	1983–85
IS957C	SC810-14E	40: Caudatum-Durra	1983–85
IS7193C	SC694-14E	31(1): Dobbs	1983–85
IS2144C	SC741-14E	34: Caudatum-Kaura	1983–85
IS12572C	SC62-14E	39(3): Caudatum-Nigricans	1983–85
IS8179C	SC752-14E	38: Caudatum-Kafir	1991/92
IS6919C	SC846-14E	41: Durra	1991/92
IS2655C	SC113-14E	39: Caudatum-Nigricans	1991/92
IS3693C	SC632-14E	22: Caffrorum	1991/92
IS17211C	SC1072-14E	22: Caffrorum	1991/92

1. IS = India sorghum number. The C following the number indicates the converted version.
2. SC = Sorghum Conversion number. The underlined number denotes the stage of conversion. E = line in exotic cytoplasm.
3. Based on the classification of Murty et al. (1967).
4. Lines were evaluated in at least one of the years indicated

R- and B-line germplasm. In 1992/93, an additional 70 converted lines were screened for resistance with none of the lines being resistant.

Another resistance source currently utilized is AF28, an introduction from Brazil. AF28 contains the highest level of presently identified resistance. This excellent resistance is expressed in the derivative line Tx2782. Unfortunately, Tx2782 has serious agronomic deficiencies (tight head, seed size, height, etc.) which limit its usefulness as a parent in either breeding materials or hybrids. These traits have been very difficult to select against while maintaining the resistance level, with only a few advanced elite lines having been produced as derivatives of Tx2782.

Screening Techniques

Due to the biology of sorghum midge, techniques to artificially rear the insect have not been developed. It has thus not been possible to utilize greenhouse screening. Naturally occurring infestations in field plants have to be used. The unreliability and/or fluctuations of midge density levels and maturity variation of the test plants are inherent problems associated with field screening.

Damaging midge infestations are best achieved by delayed sowing, multiple sowings of the same test materials, and/or earlier sowings of susceptible sorghums in which damaging levels of midge are obtained by the time the test plants reach flowering. As a variation of the latter technique, a mixture of susceptible hybrids ('midge spreader') of different maturities are sown around the nursery and at regular intervals (every 25–30 rows) within the nursery. This increases midge density and allows for relative comparisons of maturity and damage ratings. For comparison, an adequate number of resistant and susceptible controls should be sown at regular intervals. These controls should represent a range of maturities, and should include the earliest and latest maturing lines adapted to the area in which the test is grown. This is especially important since the number of midges fluctuate on a daily and weekly basis. In the TAES breeding program, controls are selected to represent a range of maturities. Susceptible controls are Tx3042 (early), and Tx623, Tx430, and Tx378 (medium-medium late); resistant controls are TAM 2566 and Tx2782 (resistance sources), Tx2755 and Tx2801 (B-line), and Tx2767, MB108B, Tx2878, Tx2880, and Tx2882 (R-line). Tx2782 will consistently express a higher level of resistance over environments and is our 'best' resistant control.

Midge damage is rated as a percentage of 'blasted' or aborted grain on a 1–9 rating scale, where 1 = 1–10% blasted grain panicle^{-1}, 2 = 11–20% blasted grain, and 9 = 81% blasted grain panicle^{-1}. Plants cannot generally be rated sooner than 20 days after anthesis. Individual heads in a row are rated and a mean damage rating calculated, or the entire row is rated by visual observation.

Breeding nurseries are sown at three locations in Texas to evaluate germplasm for resistance to sorghum midge. Plots at each location are sown 3–4 weeks later than normal sorghum in the region. The Corpus Christi nursery, sown in early Apr, is usually subjected to high population density at anthesis. Germplasm selected for resistance at this location generally possesses an excellent level of resistance to sorghum midge anywhere in the world. Additional traits selected for in this nursery include adaptation, preflowering drought tolerance, and resistance to some foliar stresses (insecticide phytotoxicity, diseases including zonate leaf spot, caused by *Gloeocercospora sorghi*). The College Station nursery, sown in late Apr/early May, enables germplasm evaluation under moderate population density. Environmental conditions are usually not as stressful as at Corpus Christi. These two locations enable material to be evaluated and selected under two midge density levels and two environments. The Lubbock midge nursery, sown in the last week of Jun, provides data on performance of the material in a temperate environment, as well as seed increase and crossing based on data obtained at the other locations. A winter nursery in Puerto Rico is used to grow all F_1s and increase lines or hybrids. Following harvest in Puerto Rico, the F_2s are then sown at College Station. Using this system, TAES scientists are able to, in a single year, evaluate lines and breeding material, make crosses based on the evaluation, grow F_1s, and sow F_2s in a field environment where midges are present.

Breeding Methodology

Development of improved midge-resistant germplasm is difficult since all known resistance sources are inherited as a recessive quantitative trait (horizontal resistance). It is difficult to maintain a high level of resistance in segregating breeding progeny, the progeny frequently exhibiting a lower resistance level than the resistant parent. To further complicate the problem, resistance has to be in both parents of a hybrid. Also, it is possible to cross two resistant lines (in either breeding germplasm or as a hybrid) and produce a susceptible population. Thus as many combinations as possible need to be evaluated in the breeding program with advanced lines evaluated on specific testers consistently.

Most of the research in the program has been in pedigree or modified pedigree breeding systems. Lines with superior resistance are crossed with nonresistant agronomically elite lines that contain favorable traits including improved yield potential, wider adaptation, and resistance to diseases. Crosses of resistant × susceptible parents will produce susceptible F_1 plants. The F_1s should be grown in an area free from midge, usually in an off-season nursery. Segregating generations beginning with large F_2 populations are grown in areas of high midge density. Although selection in this generation may be done without the midge, the presence of midge will enable the elimination of susceptible plants or populations.

Random-mating populations can also be used to develop genotypes with high levels of sorghum midge resistance. With this breeding procedure, resistant lines and elite germplasm are random-mated, facilitated by using a genetic male-sterile gene (usually *ms3*). Following initial random-mating, the population is selected for increased levels of sorghum midge resistance by selecting S_1s (fertile heads) under midge pressure for resistance and agronomic traits, compositing equal amounts of seed from the selections, and growing the bulk at locations without midge pressure to obtain genetic recombination by selection of half-sibs (sterile-heads). Equal amounts of seed from the male-sterile selections are bulked to constitute a new population. The cycle is repeated as many times as required to accomplish the program objectives. Material can be selected at any cycle to produce a homozygous line through pedigree breeding. To enhance the potential for heterosis and utilization in hybrids, separate B-line (female) and R-line (male) populations should be used.

Released Germplasm

A number of midge-resistant lines have been released, primarily by TAES. The first midge-resistant line released, TAM 2566, is a derivative of SC175-9 (Johnson et al. 1982a). In 1979, Tx2754 through Tx2781 were released with the resistance primarily tracing back to SC175-9 (Johnson et al. 1982c). ISR1, released in 1979 (Johnson et al. 1982b), and Tx2782, released in 1981 (Peterson et al. 1983), contain resistance derived from AF28. The first group of released lines to use resistance other than SC175-9 were Tx2801 through Tx2815, released in 1983 (Peterson et al. 1985). In 1989, lines designated Tx2869 through Tx2890 were released (Peterson et al. 1991). Resistance in these lines is derived from either TAM 2566 (SC175-9), Tx2782 (AF28), or SC423-14. Five germplasms, SGIRL-MR-1 (Wiseman et al. 1973), SGIRL-MR-2 (Wiseman et al. 1984), SGIRL-MR-3 and SGIRL-MR-4 (Wiseman et al. 1988) and Tift MR88 (Hanna et al. 1989) have been developed and released by the USDA-ARS and the Georgia Agricultural Experiment Station. Two random-mating populations, TP8R (R-line) and TP23B (B-line) have been developed by TAES although only TP8R has been released.

In commercial industry, a limited amount of breeding for hybrids resistant to sorghum midge is being done. Most of the research has been conducted by DeKalb Plant Genetics, USA, and in the last 3 years DeKalb has expanded its research in this area. As in the TAES program, DeKalb is testing hybrids with excellent resistance and yield when midge is present and yield equal to susceptible hybrids when the pest is absent.

Sorghum Midge Resistant Lines and Hybrids

Several lines released by TAES can produce hybrids that yield well under midge infestation. Tx2767, Tx2880, and Tx2882 are used as restorer lines (R-lines) to evaluate new females in hybrid combination for midge resistance and yield potential. The lines can produce hybrids with excellent resistance and combining ability under severe sorghum midge infestation. Some hybrids in certain environments and years can produce grain yield equal or superior to that of susceptible hybrids in the absence of midge. ATx2755 can produce hybrids with excellent midge resistance although the yield is not as good as needed. Development of new females has received considerable emphasis in the TAES program recently.

Results of the 1993 Texas Midge Line Test are presented in Table 2. The midge damage rating was significantly higher at Corpus Christi than at College Station indicating the presence of more adult midges at anthesis. Thus ratings from Corpus Christi represent resistance under high population density while the College Station ratings represent performance under more moderate population density. The susceptible controls were significantly more damaged than all entries except the resistant control Tx2801. Two lines currently being used as R-line testers, Tx2880 and Tx2882, exhibited resistance not significantly different from that of Tx2782. Three experimental R-lines (MR114-90M11, MR112B-92M4, and MR127- 92M5) had resistance equal to that of the most resistant controls. Their resistance was significantly better than that of Tx2767, one of the first resistant elite R-lines. These lines have been selected for further evaluation, testing, and crossing in the breeding program. Several experimental B-lines exhibited resistance equal to or better than Tx2755, the most resistant B-line control. Most of the lines were judged to be more desirable than Tx2755 based on general appearance. Several of the lines are currently being tested in hybrid combinations, and results from the yield trials will be used together with data from this test to select lines for further testing.

Results of the 1993 Texas Midge Hybrid Test are presented in Table 3. Midge infestation at Corpus Christi was significantly higher than at College Station. Susceptible controls are ATx399 × Tx430, ATx2752 × Tx430, and ATx3042 × Tx2737; resistant controls are ATx2755 × Tx2880, ATx2755 × Tx2767, ATx2801 × Tx2767, and ATx2801 × Tx2872. A resistant × susceptible control is ATx2755 × Tx430. Grain yield of the resistant controls in nearly all compari-

Table 2. Midge damage rating and desirability of selected entries in the 1993 Texas Midge Line Test.

Pedigree	Midge damage rating[1]			Desirability[2]		
	$\bar{x}$[3]	CC[4]	CS[5]	$\bar{x}$	CC	CS
Tx3042	8.5	8.0	9.0	3.2	3.3	3.1
Tx623	8.0	8.7	7.3	2.6	2.5	2.7
Tx430	7.8	9.0	6.7	2.4	2.4	2.5
Tx378	7.2	8.7	5.7	3.0	2.8	3.2
Tx2801	6.3	9.0	3.7	2.5	2.5	2.5
TAM 2566	5.5	5.0	6.0	3.1	3.1	3.2
MB104-B91NF6	4.3	5.7	3.0	2.7	2.6	2.8
MB110-B92NF3	3.8	5.7	2.0	2.5	2.5	2.5
MB104-B92NF7	3.8	4.0	3.7	2.7	2.6	2.7
MB104-B92NF8	3.8	5.0	2.7	2.7	2.5	2.8
MB104-B92NF9	3.7	4.0	3.3	2.6	2.5	2.6
MB104-B93NF1	3.7	5.0	2.3	2.5	2.4	2.6
Tx2878	3.2	5.3	1.0	2.5	2.5	2.5
MR114-90M11	3.2	4.0	2.3	2.6	2.6	2.5
MR112B-92M4	3.2	4.0	2.3	2.6	2.6	2.7
Tx2882	3.0	4.7	1.3	2.4	2.4	2.3
MR127-92M5	3.0	5.0	1.0	2.5	2.4	2.5
Tx2782	2.8	3.3	2.3	3.1	3.2	3.1
Tx2880	2.5	3.6	1.3	2.6	2.5	2.7
MR112B-92M2	2.5	4.0	1.0	2.7	2.6	2.7
$\bar{x}$	4.4	2.9	6.0	2.6	2.7	2.6
$LSD_{0.05}$	1.1	0.2	1.0	0.2	1.1	0.3

1. Rated on a 1–9 scale, where 1 = 0–10% blasted grain panicle^{-1}, 2 = 11–20% blasted grain panicle^{-1}, and 9 = >81% blasted grain panicle^{-1}.
2. Rated on a 1–5 scale, where 1 = most desirable, 5 = least desirable.
3. Mean midge damage rating or desirability rating over two locations, 1993.
4. CC = Corpus Christi.
5. CS = College Station.

sons was significantly higher than grain yield of the susceptible controls at each location and across locations. At Corpus Christi, the grain yield of ATx2755 × Tx430 was not significantly different from that of the susceptible control. This confirmed previous observations that resistant hybrids could only be produced using two resistant parents. However, at College Station, grain yield of this hybrid was greater than that of the susceptible controls indicating that a hybrid heterozygous for resistance can express some resistance under low to moderate density. Grain yield of experimental hybrids was significantly greater than that of susceptible hybrids, and greater than that of resistant hybrids although the differences were not significant in all comparisons.

An important comparison is ATx2755 × Tx2767, the first midge-resistant hybrid, versus the experimental hybrids with new A-lines (designated AMB). In nearly all comparisons, grain yield of the new hybrids was greater than grain yield of this control, with many comparisons being significant. Analysis and interpretation of the data led to the conclusion that progress is being achieved in developing A-lines (females) with improved characteristics.

Future Research Needs

There are at a minimum three areas of research which are being emphasized for the future. First,

Table 3. Grain yield and midge damage rating of selected hybrids in the 1993 Texas Midge Hybrid Test.

Hybrid	Grain yield[1]			Midge damage rating[2]		
	$\bar{x}$[3]	CC[4]	CS[5]	$\bar{x}$	CC	CS
ATx2755 × MR127-92M5	4818.7	3419.0	6218.4	3.2	3.7	2.7
ATx2755 × Tx2880	4394.7	2380.3	6409.1	3.7	5.0	2.3
A91NF8(MB104) × Tx2767	4333.8	1663.3	7004.1	3.8	6.0	1.7
A92NF8(MB104) × Tx2882	4262.1	2809.1	5715.1	3.3	4.3	2.3
A92NF3(MB110) × Tx2880	4255.8	2299.6	6212.0	3.0	4.7	1.3
A92NF8(MB104) × Tx2880	4206.3	2642.0	5770.6	3.5	4.7	2.3
A91NF6(MB104) × Tx2767	4041.3	1938.3	6144.2	3.5	5.0	2.0
A92NF7(MB104) × Tx2880	4018.3	2243.7	5793.0	3.7	5.3	2.0
A91NF8(MB104) × Tx2882	3803.4	2049.4	5557.3	3.5	5.0	2.0
ATx2755 × MR112-92M1	3734.8	1984.4	5485.1	4.0	6.0	2.0
A92NF3(MB110) × Tx2882	3721.4	1698.8	5744.1	3.7	5.3	2.0
A91NF6(MB104) × Tx2880	3696.5	2309.5	5083.6	3.5	4.3	2.7
ATx2755 × MR112B-92M4	3645.5	2681.5	4609.6	3.5	4.0	3.0
A91NF8(MB104) × Tx2880	3624.6	2126.8	5122.4	3.8	5.0	2.7
A92NF6(MB104) × Tx2880	3613.9	1935.0	5292.8	4.2	5.7	2.7
ATx2755 × Tx2767	2992.9	542.4	5443.5	4.8	7.7	2.0
ATx2801 × Tx2767	2390.2	164.6	4615.8	5.7	8.7	2.7
ATx399 × RTx430	1243.2	592.6	1893.7	8.3	8.3	8.3
ATx2755 × RTx430	1238.0	84.8	2391.1	7.6	9.0	5.5
ATx2752 × RTx430	599.0	163.8	1251.9	8.2	9.0	7.0
ATx3042 × Tx2737	302.8	242.8	362.8	9.0	9.0	9.0
$\bar{x}$	2958	142.8	4499	4.7	6.2	3.1
$LSD_{0.05}$	1147	842	1727	1.4	1.6	1.3

1. Grain yield (kg ha^{-1}).
2. Rated on 1–9 scale, where 1 = 0–10% blasted grain panicle^{-1}, 2 = 11–20% blasted grain panicle^{-1}, and 9 = >81% blasted grain panicle^{-1}.
3. Mean grain yield or midge damage rating over two locations, 1993.
4. CC = Corpus Christi.
5. CS = College Station.

A-lines (females) with improved performance are critical to success in developing midge-resistant hybrids. Traits needed specifically in new A-lines include improved yield potential in the presence/absence of the pest, resistance which is expressed in hybrid combination, and improved seed set in hybrid production. Potentially superior females were identified in 1993 which could partially alleviate these problems, but significantly more progress needs to be made. Second, parental lines with improved agronomic traits need to be developed. This is especially important for B-line material. Improved traits include better yield potential or combining ability in hybrid combination, better adaptation, larger seed size on resistant lines and hybrids, and better foliar traits such as disease resistance and resistance to the phytotoxic reaction of insecticides ('insecticide burn'). Many crosses have been made to incorporate other superior traits into the germplasm pool, and this material is in the early segregating generations. Third, the level of sorghum midge resistance should be improved and additional useful sources of resistance identified. To increase the level of midge resistance over that currently available, different sources of resistance need to be combined into the same genotype, especially if they are to be used in each parent of a hybrid.

Resistance sources are being crossed with elite adapted resistant lines which previously have been developed in the resistance breeding program. This will eventually enable the selection of types with more than one resistance source in a good agronomic background. Techniques need to be developed which will enable the identification of different resistance sources in a single genotype. Information is needed on the nature of the resistance sources, levels of resistance, and corresponding morphological differences. We need to know the genetics of the sources of resistance (number of genes controlling resistance, etc.) and how the plant is able to resist the insect. We also need to know how flowering differs between resistant and susceptible lines, and what characteristics cause the sorghum midge not to prefer resistant lines.

A new research activity has been initiated which will incorporate biotechnology into the breeding program. Populations are being produced for analysis by restriction fragment length polymorphisms (RFLPs). Using probes to identify exact molecular markers for resistance, this activity will eventually alleviate some of the problems in identifying genotypes with multiple sources of resistance and will facilitate studies on the inheritance of resistance. This research will also enable exotic sorghum genotypes to be evaluated before conversion to identify those which have the most favorable combination of genes for resistance to sorghum midge.

Synthèse

La sélection pour la résistance à la cécidomyie du sorgho aux Etats-Unis. La cécidomyie du sorgho, *Contarinia sorghicola*, est un important insecte paniculaire du sorgho dans le sud des Etats-Unis. Le ravageur est particulièrement dangereux sur les sorghos semés tard ou dans les champs où l'anthèse est retardée.

Des sorghos résistants à la cécidomyie ont pu être mis au point aux Etats-Unis à la suite de l'identification des ressources génétiques résistantes au Programme de conversion du sorgho. L'évaluation de 533 génotypes exotiques convertis de sorgho au cours des deux dernières décennies a débouché sur l'identification de plusieurs sources de résistance dont les meilleures sont TAM 2566 (SC 175-9), IS 2579 C (SC 423-14), IS 3390 C (SC 572-14), IS 12572 C (SC 62-14) et IS 6919 C (SC 846-14). Bien que d'autres sources de résistance soient identifiées, elles sont moins utilisées. Une introduction du Brésil, AF 28, a été remarquée pour sa résistance et Tx 2782 (lignée issue de AF 28) présente une excellente résistance. La source de résistance la plus couramment utilisée est TAM 2566 (SC 175-9).

Plusieurs lignées résistantes à la cécidomyie dont TAM 2566, Tx 2782, Tx 2755, Tx 2767, Tx 2880 et Tx 2882 ont été vulgarisées. La plupart de ces lignées qui ont confirmé leur haut niveau de résistance dans des conditions de densité élevée de cécidomyies à l'anthèse, proviennent de la Station de recherche agricole de Texas. Elles ont été retenues afin d'améliorer davantage leur niveau de résistance à la cécidomyie. En plus Tx 2767, Tx 2880 et Tx 2882 sont susceptibles de produire des hybrides à résistance élevée à la cécidomyie du sorgho.

Les premiers hybrides résistants à la cécidomyie du sorgho ont été caractérisés par une résistance plus faible que celle des parents et un faible potentiel de rendement. Un effort particulier a été fait récemment sur l'élaboration des lignées A (femelles) pourvues de résistance et de potentiel de rendement améliorés qui sont exprimés dans la combinaison hybride. L'évaluation des hybrides ayant une résistance à la cécidomyie au moins égale à la moyenne des deux parents et un excellent potentiel de rendement est en cours. Les sélectionneurs poursuivent également des travaux sur l'amélioration des caractéristiques agronomiques, de l'adaptation et de la résistance aux maladies des ressources génétiques résistantes à la cécidomyie du sorgho.

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Breeding for resistance to sorghum midge at ICRISAT Asia Center

Belum V S Reddy, H C Sharma, and J W Stenhouse[1]

Abstract

Sorghum bicolor *is grown widely in the semi-arid tropics primarily for food. The sorghum midge,* Contarinia sorghicola, *is one of the major pests that attack developing sorghum ovules causing chaffy sterile florets. Breeding for host-plant resistance to midge is considered an integral part of achieving and maintaining higher yield levels.*

In this paper, we summarize work related to screening techniques, identification of stable source lines and mechanisms and inheritance of resistance, and breeding methods for improving restorers and female lines for resistance, grain yield, and other agronomic traits. To a large extent, we have achieved the transfer of resistance into high-yielding backgrounds. However, pedigree analysis shows that the improved lines have mostly received resistance genes from a single parent (DJ 6514). The need to diversify resistance sources used in breeding programs is emphasized.

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is grown widely in the semi-arid tropics for food, feed, fodder, and forage. Although India and Africa represent the major sorghum-growing areas, grain yield levels are very low compared with those in the developed world.

Although hybrid sorghums have become popular with farmers both in the developed world (e.g., USA) and some developing countries (e.g., India), their high grain yield potential generally renders them susceptible to insect pests. Because insect pests are a major factor in sustainable agriculture in the semi-arid tropics where modern agricultural inputs are not easily accessible, breeding for host-plant resistance which involves no additional cost to farmers, is an important aspect of the crop improvement strategy at ICRISAT Asia Center (IAC). The insect pest species targeted are shoot fly (*Atherigona soccata*), stem borer (*Chilo partellus*), midge (*Contarinia sorghicola*), and head bug (*Calocoris angustatus*).

In this paper we report the efforts and progress made in developing restorers and seed parents resistant to midge and the performance of the resulting hybrids for grain yield and midge resistance.

Screening Techniques

Efficiency in screening improves heritability estimates, and hence the success of breeding programs. A two-stage screening procedure is followed at ICRISAT. The first involves an infector-row method for field screening in hot-spot locations and seasons to evaluate early segregating generations. In the second method, a no-choice artificial infestation is used for screening advanced lines. This involves the no-choice head cage technique which was developed at IAC (Sharma et al. 1992).

Identification of Resistance Sources

Significant progress has been made in the identification of resistance sources at IAC in India using the

1. ICRISAT Asia Center, Patancheru 502 324, Andhra Pradesh, India.

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above techniques. Similar progress has been reported in programs in Australia, Latin America, and USA. Several cultivars (31 landraces, 48 varieties, and 4 hybrids) were identified in these different programs (Sharma 1993). The work at IAC further showed that DJ 6514, TAM 2566, and IS 12666C had repeatable levels of resistance to midge even under the no-choice head cage technique (Sharma et al. 1988 a,b).

Mechanisms of Resistance

An understanding of resistance mechanisms can enhance progress in a breeding program since component traits can often be fixed more readily than the resistance trait itself because of less complex inheritance. Resistance sources differ in their levels and types of resistance mechanisms but nonpreference appears to be predominant. The varieties TAM 2566, IS 12666C, DJ 6514, AF 28, and IS 15107 were not preferred by the midge, while S-GIRL-MR-1 was susceptible under no-choice conditions. A combination of more than one resistance mechanism is sometimes involved. For example, TAM 2566, could have antibiosis (possibly due to tannins) in addition to nonpreference, as indicated by the prolonged (by 5–8 days) life cycle of the insect on this host (Sharma 1993).

Our research further showed that several morphological traits are known to contribute to resistance. These include short floral parts (glumes, lemma, palea, anther, style) and rapid grain development.

Genetics of Resistance

The inheritance of resistance also varies, depending on the parental source material. Resistance appears to be controlled by recessive genes—at least two in AF 28, and one in Tift MR 88. In quantitative studies by Kukadia et al. (1985), it was shown that resistance is controlled by additive gene effects. Studies at ICRISAT have indicated the possibility of cytoplasmic effects in midge resistance. For example, midge damage (chaffy florets) and adult emergence were significantly lower on midge-resistant B-lines (PM 7061 and PM 7068) than the corresponding A-lines, while the reverse was true for midge-susceptible genotypes (296B and ICSB 42). When infected without pollination, no significant differences were observed among the A-lines of susceptible and resistant genotypes. Sources of pollen did not influence midge emergence on the highly resistant A-line, PM 7061A. Genotype × pollination treatments were significant for differences in midge damage and midge emergence (H.C. Sharma et al., unpublished 1993).

It was also noted that the general combining ability (GCA) effects were greater than specific combining ability (SCA) effects for midge damage. However, the SCA effects were greater than GCA effects for nonpreference by midge flies. Further, substantial differences were observed in GCA and SCA effects between natural infestation and head cage testing and over seasons (H.C. Sharma et al., unpublished 1993).

Breeding Resistant Restorers and Varieties

Breeding has involved improvement of high-yielding inbred lines for resistance for direct use as varieties, or as restorers in developing midge-resistant hybrids. Taking advantage of hot spot locations and the infector-row technique, over 7800 germplasm lines were screened between 1980 and 1984 (ICRISAT 1982, 1983, 1984, and 1985). This work led to the identification of DJ 6514, TAM 2566, and IS 12666C as the most stable midge-resistant lines.

The breeding program at IAC involved crossing resistant lines in single crosses with improved lines, screening the F_2 and subsequent generations under the infector-row technique in hot spot seasons or locations, and selecting high-yielding lines with resistance. Further evaluation of the resulting advanced lines was carried out in replicated preliminary and advanced (multilocational) trials, and finally in no-choice head cage trials to confirm resistance.

Phase I (1973–83)

Resistant source lines were initially crossed with high-yielding lines. Ten lines (SC 423, IS 2508C, IS 2579C, IS 2816C, IS 3574C, IS 12573C, AF 28, S-GIRL-MR-1, TAM 428, and TAM 2566) originated from USA and one (DJ 6514) from India. Most of the lines (221) selected from a nursery of 1254 progenies in the 1980 postrainy season, were derivatives from crosses involving DJ 6514, IS 12573C, TAM 2566, AF 28, and S-GIRL-MR-1 (ICRISAT 1982). By 1982, a breeding line (PM 7348—a derivative of the resistant line, IS 12573C) was identified as less susceptible to midge from multilocational trials. Also, 145 advanced generation lines were selected for further testing (ICRISAT 1982). During the 1983 evaluation, PM 11344 (ICSV 197)—a derivative of the resistant parental line, DJ 6514—was identified as the most promising variety. It was entered in the All India Coordinated Sorghum Improvement Project (AICSIP) in India and its yield performance in relation to the controls is given in Table 1.

Phase II (1983–93)

PM 7348 and PM 11344 were further crossed with high-yielding lines, and the resulting populations were screened. This program yielded the following promising lines ICSVs 743, 745, 88032, 88013, 89057, 89058, 91006, 91017, and 91008. The best entries were ICSV 743 and ICSV 745 and their grain yield performance is given in Table 2. ICSV 743 and ICSV 745 were also tested for 3 years on farmers fields in the state of Karnataka in India (ICRISAT 1992), and ICSV 745 was officially released in 1993 as a variety for cultivation in that state. Further, the midge-resistant varieties, ICSV 88013 and ICSV 88032, were tested in the advanced trials in AICSIP, and ICSV 88032 was retained for further testing in the Indian Program. Their performance for grain yield in various trials is given in Table 3. The performance of other midge-resistant lines (ICSV 89057 and ICSV 89058) in various trials is given in Table 4.

Population improvement

In addition to the pedigree approach mentioned above, a population with the ms_3 gene is being developed. After incorporating 20 resistant source lines into the US/R-C_3 population, mass selection coupled

Table 1. Performance of the midge-resistant variety, ICSV 197 developed in Phase I of the sorghum midge resistance breeding program. ICRISAT Asia Center.

Trial/ Year	Variety/ Control	Grain yield ($t\ ha^{-1}$)	Time to 50% flowering[1] (days)	Plant height[1] (m)
PVT[2] 1984 (AICSIP)[3]	ICSV 197	3.6	77	2.4
	Controls			
	ICSV 1	3.8	68	2.1
	CSH 5	3.9	69	2.3
	Mean	3.1	71	1.8
	SE	±0.35	±0.92	±0.07
PVT-1-1985 (AICSIP)	ICSV 197	3.2	76	2.2
	Controls			
	CSV 11	3.3	70	1.7
	CSH 5	3.6	69	1.7
	Mean	2.9	74	1.8
	SE	±0.36	±2.14	±0.08
PVT-1-1986 (AICSIP)	ICSV 197	2.8	73	2.1
	Controls			
	CSV 10	3.2	73	1.9
	CSV 11	3.6	71	1.7
	Mean	3.3	73	1.7
	SE	±0.33	±1.73	±0.07

1. Based on 9, 10, and 9 locations in 1984, 1985, and 1986.
2. Preliminary Varietal Trial.
3. All India Coordinated Sorghum Improvement Project.

Table 2. Performance of the midge-resistant varieties ICSV 743 and ICSV 745 developed in Phase II of the sorghum midge resistance breeding program, ICRISAT Asia Center.

Trial/ Year	Variety/ Control	Grain yield ($t\ ha^{-1}$)	Time to 50% flowering[1] (days)	Plant height[1] (m)
PVT[2]-2-1987	ICSV 743	4.9	71	2.6
	ICSV 745	5.2	71	2.2
	Controls			
	CSH 5	4.0	68	1.9
	SPH 221	5.5	66	1.9
	Mean	3.0	74	2.1
	SE	±0.23	±0.5	±0.04
AVT-MM[2]-1988	ICSV 743	3.8	72	2.8
	ICSV 745	3.5	69	2.2
	Controls			
	ICSV 112	3.8	71	2.1
	ICSH 110	4.5	67	2.2
	Mean	3.6	70	-
	SE	±0.1	±0.3	-
AVT-1990 (AICSIP)[3]	ICSV 745	2.8	73	1.9
	Controls			
	ICSV 112	3.1	74	1.8
	CSH 5	2.8	71	1.8
	Mean	2.9	72	2.0
	SE	±0.13	±0.58	±0.04

1. Based on 5 locations in PVT-2-1987, 7 in AVT-MM-1988, and 34 in AVT-1990 (AICSIP).
2. PVT = Preliminary Varietal Trial; AVT-MM = Advanced Varietal Trial-Medium Maturity.
3. All India Coordinated Sorghum Improvement Project.

with recombination is being employed to further advance the population. This population is now in the third selection cycle.

Restorer collection

Most of the improved lines and varieties behaved as restorers on the A_1 male-sterile cytoplasm. The pedigrees (Table 5) showed that to a large extent DJ 6514 alone contributed to these final selections thus indicating narrow genetic variability.

ICRISAT's A_1 cytoplasm restorer collection (360 lines) was also screened for midge resistance using the infector-row technique (ICRISAT 1991) and the following restorers selected: ICSRs 70, 114, 146, 154 (ICSV 197), 155, 89054, 89067, 89068, 89069, 90010, 90011, 90015, 90016, 91002, 91003, 91014, 91015, 91027 (ICSV 745), and 91030. Since these were all derived from IS 12611C, DJ 6514 or IS 12573C, the narrow genetic base is again indicated.

Pedigree breeding efforts at IAC are therefore aimed at bringing the diversified resistance sources into the elite materials. The following sources are included: Malisor 84-7, IS 8671, IS 15107, IS 18563, IS 21871, IS 21881, IS 22806, and IS 26789.

Breeding Resistant Female Parents

Female parents of sorghum hybrids are cytoplasmic-genetic male-sterile lines. The female-parent develop-

Table 3. Performance of the other midge-resistant varieties developed in Phase II of the sorghum midge resistance breeding program, ICRISAT Asia Center.

Trial/ Year	Variety/ Control	Grain yield (t ha^{-1})	Time to 50% flowering[1] (days)	Plant height[1] (m)
IVT[2]-1-1990 (AICSIP)[3]	ICSV 88013	2.9	68	2.1
	ICSV 88032	3.1	68	2.0
	Controls			
	CSV 10	2.6	74	2.2
	ICSV 112	2.8	76	1.9
	Mean	2.5	74	2.2
	SE	±0.37	±1.73	±0.15
AVT[2]-1991 (AICSIP)	ICSV 88013	3.6	67	1.9
	ICSV 88032	3.4	67	1.9
	Controls			
	CSV 13	3.7	73	1.7
	CSH 5	3.3	69	1.8
	Mean	3.3	70	2.0
	SE	±0.43	-	-
PVT[2]-1-1988	ICSV 88013	4.0	66	2.1
	Controls			
	ICSH 153	5.1	67	2.2
	ICSV 112	4.2	72	2.0
	Mean	3.0	-	-
	SE	±0.1	-	-
PVT-2-1988	ICSV 88032	3.6	66	2.1
	Controls			
	ICSV 197	4.2	75	2.6
	ICSV 112	4.0	71	2.0
	Mean	2.4	73	-
	SE	±0.2	±0.7	-

1. Based on 8 locations for IVT-1-1990, 38 in AVT-1991, 7 each for PVT-1-1988 and PVT-2-1988.
2. IVT = Initial Varietal Trial; PVT = Preliminary Varietal Trial; AVT = Advanced Varietal Trial.
3. All India Coordinated Sorghum Improvement Project.

ment program can be described in two parts—before 1990, and current (1990-93).

Initial phase (before 1990)

At IAC, male steriles were based on A_1 or milo cytoplasms discovered by Stephens and Holland in 1954. The emphasis was to develop male-sterile lines with high yield potential and white grain, and no systematic effort was made to incorporate resistance. Primarily, the A_1 male-sterile cytoplasm was exploited. The selected inbred lines of high-yielding R-line × B-line crosses or selected derivatives of B-populations with sterility maintaining ability were converted into male-

Table 4. Performance of the midge-resistant varieties ICSV 89057 and ICSV 89058 developed in Phase II of the sorghum midge resistance breeding program, ICRISAT Asia Center.

Trial/ Year	Variety/ Control	Grain yield (t ha^{-1})	Time to 50% flowering[1] (days)	Plant height[1] (m)
PVT[2]-1989 (Rainy)	ICSV 89057	3.1	75	2.6
	ICSV 89058	3.0	77	1.9
	Controls			
	CSV 13	2.9	80	2.0
	Mean	2.2	78	2.1
	SE	±0.18	±0.7	±0.05
MIR[2]-1989 (Postrainy)	ICSV 89057	3.2	69	1.7
	ICSV 89058	3.1	70	1.4
	Controls			
	ICSV 745	2.8	81	1.7
	Mean	2.4	77	1.7
	SE	±0.23	±1.4	±0.04
PVT-1990	ICSV 89057	5.2	61	2.0
	ICSV 89058	4.4	70	2.0
	Controls			
	ICSV 112	4.6	69	1.7
	ICSV 745	3.6	70	2.1
	Mean	4.0	67	2.0
	SE	±0.3	±0.7	±0.07
AVT[2]-1990	ICSV 89057	4.3	64	2.1
	ICSV 89058	4.2	70	1.9
	Controls			
	ICSV 1	4.7	66	1.8
	ICSV 112	4.7	69	1.8
	Mean	4.2	68	1.8
	SE	±0.2	±0.4	±0.03

1. Based on one location in each season/year.
2. PVT = Preliminary Varietal Trial; MIR = Multiple Insect Resistance Trial; AVT = Advanced Varietal Trial.

sterile lines by backcrossing, using CK 60A or 2077A (which contained A_1 cytoplasm) as the female line, and the inbred/derivative as recurrent parent. This program yielded 108 male-sterile lines (ICRISAT 1992).

Current phase (1990–93)

The program primarily aimed to diversify the male-sterile lines for cytoplasms and nuclear genome and to improve them for resistance. It consisted in screening available A_1 cytoplasm male-sterile lines for resistance; converting promising midge-resistant lines into male steriles involving alternative male-sterile cytoplasm; and breeding high-yielding; midge-resistant A_1 cytoplasm male-sterile lines.

Screening available A_1 cytoplasm male-sterile lines. The available male-sterile lines mentioned above

Table 5. Improved midge-resistant lines, their resistance source and behavior on various male-sterile cytoplasms, ICRISAT Asia Center.

Origin	ICSV number	Resistance source	Vareity/Restorer/Maintainer
PM 7348		IS 12573C	Variety/Restorer on A_1
PM 11344	ICSV 197	DJ 6514	Variety/Restorer on A_1
PM 14402-2-3-2	ICSV 743	DJ 6514 (ICSV 197)	Variety/Restorer on A_1
PM 14415-1-1	ICSV 745	DJ 6514 (ICSV 197)	Variety/Restorer on A_1
PM 15936-1	ICSV 88032	DJ 6514 (ICSV 197)	Variety/Restorer on A_1
PM 15936-2	ICSV 88013	DJ 6514 (ICSV 197)	Variety/Restorer on A_1
	ICSV 89057	DJ 6514 (ICSV 197)	Variety/Restorer on A_1
	ICSV 89058	DJ 6514 (ICSV 197)	Variety/Restorer on A_1
	ICSV 91006	DJ 6514 (ICSV 197)	Variety/Restorer on A_1
	ICSV 91017	IS 9608	Variety/Restorer on A_1
	ICSV 91008	CS 3541 Population derivative	Variety/Restorer on A_1
	ICSB 88019	DJ 6514	Maintainer on A_1 cytoplasm
	ICSB 88020	DJ 6514	Maintainer on A_1 cytoplasm
	ICSB 89002	Indian Synthetic 422 and Rs/R-20	Maintainer on A_1 cytoplasm
PM 7068		DJ 6514	Maintainer on all 4 cytoplasms
PM 17467		S-GIRL-MR-1	Maintainer on all 4 cytoplasms
PM 17682		DJ 6514	Maintainer on all 4 cytoplasms
PM 17500-2-1		DJ 6514, IS 2579C	Maintainer on A_1, A_3 and A_4
PM 19268		DJ 7514 (ICSV 197)	Maintainer on A_3 and A_4
	ICSV 89057	DJ 6514 (ICSV 197)	Maintainer on A_3 and A_4
	ICSV 89058	DJ 6514 (ICSV 197)	Maintainer on A_3 and A_4

were repeatedly screened for three seasons. Based on the damage rating (DR) of florets (on a 1–9 scale, where 1 = <10%, and 9 = >80% chaffy florets), ICSB 88019, ICSB 88020, and ICSB 89002 were selected. These, too, were derived from DJ 6514.

Conversion of promising resistant lines. Promising inbred lines were testcrossed with A_1, A_2, A_3, and A_4 (Maldandi) male-sterile cytoplasms (Schertz and Pring 1982), and the lines converted into male steriles were:

- PM 7068, PM 17467, and PM 17682, with A_1, A_2, A_3, and A_4 (Maldandi)
- PM 17500-2-1, with A_1, A_3, and A_4 (Maldandi)
- PM 19268, ICSV 89057, and ICSV 89058, with A_3 and A_4 (Maldandi)

These were derived from DJ 6514 and IS 12611C.

Improving A_1 male-sterile lines for resistance. The breeding program involved crossing high-yielding (HY) lines and resistant lines (RL) in a single cross, or three-way crosses (HY × RL_1 × RL_2 or HY_1 × RL_1 × HY_2); selection for agronomic desirability in F_2 and pedigree selection from F_3 onward (selection for lower midge damage among families, and high-yielding ability and agronomic desirability among individual plants within the selected resistant families); testcrossing and evaluating the testcrosses of the selected progenies for maintainer reaction from F_4 onward; and converting the maintainers selected for midge resistance in screening nurseries into male steriles through backcrossing (Reddy and Rao 1991).

Studies by Rao and Rana (1982) suggested that hybrid performances correlated well with the performance of the parents themselves, and that high-yielding parents in general produced high-yielding hybrids. Therefore, the selection strategy for male steriles at IAC is based on the line's performance rather than combining ability.

Table 6. Performance of midge-resistant male-sterile lines developed during 1990–93, ICRISAT Asia Center.

B-line	Grain yield[1] (t ha^{-1})		Time to 50% flowering (days)		Plant height (m)		Midge[2] score		100-grain mass (g)	
	R[3]	PR[3]	R	PR	R	PR	R	PR	R	PR
SPMD 2669	2.5	2	60	64	1.5	1.1	2	5	3.1	2.9
SPMD 2679	3.2	2.8	63	65	1.5	1.2	2	4.7	2.8	2.5
SPMD 2681	2.4	2	64	66	1.6	1.2	1.7	3.3	2.9	2.7
SPMD 2631	2.1	2.1	67	66	1.5	1.2	1.7	3	3.2	2.8
Controls										
296B	1.6	0.6	70	92	1.4	1	5.7	8	-	2.1
ICSV 745	2.4	1.6	71	82	1.8	1.4	2.7	3.7	-	2
Mean	1.7	1.7	71	75	1.5	1.2	2.7	4.3	-	2
SE[4]	±0.2	±0.34	±1	±1.8	±0.05	±5.3	±0.23	±0.59	-	±0.1

1. One location in each season.
2. Midge score on 1–9 scale, where 1 = highly resistant, and 9 = highly susceptible.
3. R = rainy season, 1992; PR = postrainy season, 1992.
4. Based on square root transformed values.

Two improved resistant source lines, PM 17467 and PM 17500-2-1, derived from DJ 6514, were crossed with 12 maintainer lines with diverse origins (Reddy and Sharma 1991). This program resulted in progenies at various stages of conversion from BC_1 to BC_4 (Reddy and Sharma 1993). These were further screened during the 1992 postrainy season, and selection for midge resistance and agronomic desirability, and backcrossing of the progenies were carried out simultaneously. At the end of the 1992 postrainy season, we had 155 progenies of which 13 were in BC_1, 8 in BC_2, 52 in BC_3 , and 82 in BC_4.

Some of the maintainers (30) were evaluated for grain yield and other traits. The selected lines, SPMDs 2669, 2679, 2681, and 2631 were significantly superior to the control 296B for grain yield and midge resistance levels (Table 6).

Relationship Between Midge Resistance and Grain Mass Levels

The 100-grain mass of midge resistance source DJ 6514, and improved ICSV 197 derived from DJ 6514 in the first cycle of improvement, is less than 2 g. This indicates possible linkage between resistance and low grain mass. The possibility of breaking this linkage in order to combine high grain mass and resistance levels was investigated. Correlation studies showed that resistance to midge did not correlate significantly with grain mass in the third-cycle material (r = -0.01 in 130 single-cross F_7s, and 0.14 in 206 three-way-cross F_6s), thus indicating that the negative association observed in the first-cycle material between seed mass and resistance had been broken (Reddy and Sharma 1993). Earlier studies by Reddy and Sharma (1992) also revealed a weak correlation between grain mass and resistance to midge (r = 0.18 in four-way-cross F_3s; 0.30** in three-way-cross F_4s; and 0.01 in single-cross F_5s).

Further evaluation of resistance levels under no-choice conditions of six selections in each of four groups with different grain mass but with the same levels of resistance (DR = 3.0 under field conditions) revealed that there was significant variation for midge resistance even in high grain mass groups, thus indicating the possibility of combining high grain mass with midge resistance.

Breeding of Resistant Hybrids

As indicated earlier, resistance in hybrids is mostly controlled by additive genes and it is therefore desirable for both parents to be resistant. However, if one of the parents is highly resistant, and the other parent is less highly susceptible, it is possible to produce a hybrid with moderate levels of resistance. Such hybrids with high grain yield and resistance to midge have been generated (Table 7).

Table 7. Performance of the parental lines and their hybrids for midge resistance, plant height, grain mass, and grain yield, ICRISAT Asia Center, postrainy season, 1991.

	Midge damage			Plant height (m)	100-grain mass (g)	Grain yield (t ha^{-1})	
	Rating (natural)[1]	Score (cage)[2]	Chaffy florets (%)			1 sowing	2 sowings
PM 7061B	2	1.8	8.2	1.2	2	2.6	5.1
PM 7068B	2	2.3	12.3	1.2	2.4	2.7	5.4
ICSB 42	7	9	82.4	1.2	2.2	2	4.5
296B	7	8.8	59.5	1.1	2	5	9.2
PM 15908-3R	2	2	15.9	1.3	1.8	6	8.4
PM 17422-3R	2	1.8	10.2	1.4	2	2.4	7.8
PM 17592-1R	2	3.1	14.9	1.6	2.2	4.3	7.8
ICSV 745R	2	4.1	9	1.3	2.9	4.7	9.3
MR 836	4	8.7	36.9	1	2.9	2.3	5.1
296A × PM 15908-3	3	6.9	46.2	1.2	2.5	6.6	18.9
296A × PM 17592-1	3	8.7	44	1.4	2.7	6.2	10.2
ICSA 42 × PM 17422-3	3	6.5	20.3	1.6	2.4	5.7	14
PM 7061A × PM 15908-3	2	1.6	14.4	1.5	2	7.6	12.3
PM 7068A × PM 17422-3	2	2.3	6.1	1.6	1.5	6.9	9.4
PM 7061A × ICSV 745	3	2	12.6	1.5	2.4	5.9	6.2
296A × MR 836	6	9	65.7	1.5	2.9	2.9	8
SE	±0.69	±0.71	±5.9	±0.03	±0.13	±0.42	±0.48
CV (%)	34	21	34	4	9	36	38

1. Damage rating where 1 = highly resistant, and 9 = highly susceptible.
2. Under cage.

Synthèse

La sélection pour la résistance à la cécidomyie du sorgho au Centre ICRISAT pour l'Asie. Les hybrides du sorgho sont très appréciés par les agriculteurs aux Etats-Unis et en Inde, mais tous les hybrides vulgarisés sont, en général, sensibles à la cécidomyie du sorgho, *Contarinia sorghicola*. Des lignées restauratrices et des matériels génétiques résistants à la cécidomyie sont nécessaires à la mise au point des hybrides résistants.

A l'aide d'une méthode de criblage à deux étapes—des techniques de rangs infectants et de criblage en cage avec choix unique—des sources de résistance (31 variétés locales) ont été identifiées à l'ICRISAT et dans les programmes nationaux aux Etats-Unis, en Australie et en Amérique latine. DJ 6514, TAM 2566 et IS 12666 C ont confirmé à plusieurs reprises leur haut niveau de résistance à la cécidomyie. TAM 2566, IS 12666 C, DJ 6514, AF 28 et IS 15107 ont montré de la non préférence à la cécidomyie, tandis que S-GIRL-MR-1 s'est avérée sensible au criblage en cage avec choix unique. TAM 2566, à part la non préférence peut aussi montrer l'antibiose grâce à la présence des tanins. Des parties florales courtes (la glume, la lemma, la paléa, l'anthère et le style) et le développement rapide des grains pourraient également contribuer à la résistance. L'aptitude générale à la combinaison a été plus élevée que l'aptitude spécifique à la combinaison pour les dégâts causés par la cécidomyie, ce qui indique des effets de gènes additifs. Nos études ont aussi indiqué la possibilité des effets cytoplasmiques dans la résistance à la cécidomyie.

A la suite de la sélection généalogique et du criblage des F_2 et des générations ultérieures au champ par la technique de rangs infectants et des lignées avancées par la technique de mise en cage avec choix unique dans des essais répétés, PM 11344 (ICSV 197), une variété issue de la lignée parentale résistante, DJ 6514, s'est révélée la plus prometteuse au cours de l'évaluation en 1983. Dans la deuxième étape, les lignées résistantes améliorées, PM 7348 et PM 11344, ont été croisées davantage avec des lignées performantes et les populations qui en ont résulté ont fait l'objet de criblage. Ce programme a produit des variétés très performantes et résistantes à la cécidomyie telles que ICSV 743 et ICSV 745. La variété ICSV 745 a été vulgarisée en 1993 dans l'Etat indien de Karnataka.

La plupart des variétés se comportent comme des restaurateurs sur les lignées A_1 cytoplasmiques mâles stériles. La collection de restaurateurs de l'ICRISAT (360 lignées) a été criblée pour les dégâts causés par la cécidomyie. Parmi ces lignées, ICSR 70, ICSR 114, ICSR 146, ICSR 154 (ICSV 197), ICSR 155, ICSR 89054, ICSR 89067, ICSR 89068, ICSR 89069, ICSR 90010, ICSR 90011, ICSR 90015, ICSR 90016, ICSR 91002, ICSR 91003, ICSR 91014, ICSR 91015, ICSR 91027 (ICSV 745) et ICSR 91030 se sont montrées résistantes à la cécidomyie.

Cent-huit lignées mâles-stériles sélectionnées pour le potentiel de rendement ont été criblées au sein d'un programme de l'élaboration de lignées femelles résistantes à la cécidomyie. Parmi ces lignées, ICSB 88019, ICSB 88020 et ICSB 89002 se sont révélées résistantes. Les variétés prometteuses à forte productivité et résistantes ont fait l'objet de testcross avec des cytoplasmes mâles-stériles A_1, A_2, A_3 et A_4. PM 7068, PM 17467 et PM 17682 ont été converties avec des cytoplasmes mâles-stériles A_1, A_2, A_3 et A_4; PM 17500-2-1 avec des cytoplasmes mâles-stériles A_1, A_3 et A_4; PM 19268, ICSV 89057 et ICSV 89058 avec des cytoplasmes mâles-stériles A_3 et A_4. De plus, le croisement d'une lignée conservatrice à haut rendement avec une lignée résistante à la cécidomyie dans un croisement unique et un croisement trois voies a produit plusieurs lignées conservatrices très performantes et résistantes, qui sont près de la dernière étape de conversion en lignées mâles-stériles. L'évaluation des lignées conservatrices résistantes ainsi sélectionnées a montré que le rendement en grain et la résistance à la cécidomyie de SPMD 2669, SPMD 2679, SPMD 2681 et SPMD 2631 ont été supérieurs de manière significative à ceux du témoin (296 B).

Notre programme d'hybridation a confirmé qu'il est possible de produire un hybride avec un niveau de résistance modéré si l'un des parents est très résistant et l'autre est moins sensible à la cécidomyie.

A part les études sur l'association de la résistance à la cécidomyie avec une forte productivité, des efforts sont déployés pour diversifier les sources de résistance, puisque la plupart des lignées améliorées résistantes qui sont disponibles actuellement sont issues de la même source de résistance (DJ 6514).

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Mechanisms and Inheritance of Resistance to Panicle-Feeding Insects in *Sorghum bicolor*

H C Sharma, J W Stenhouse, and K F Nwanze[1]

Abstract

*Sorghum midge (*Contarinia sorghicola *Coq.), head bugs (*Calocoris angustatus *Leth., and* Eurystylus immaculatus *Odh.), and head caterpillars (*Helicoverpa, Heliothis, Eublemma, Cryptoblabes, *etc.) are the major pests of sorghum worldwide.*

Nonpreference and antibiosis are the major components of resistance to C. sorghicola. *Evidence for compensation in grain mass following midge damage is not conclusive. Short, tight glumes make oviposition difficult, and this is the most important factor associated with resistance to midge. Faster grain development and high tannin content of grain are also associated with resistance. Resistance to midge is governed by additive and nonadditive gene action, but largely by the former.*

Resistance to head bugs is largely comprised of nonpreference for feeding and oviposition, antibiosis, and tolerance, of which nonpreference is the major component. Longer duration of glume covering of the grain, long glumes, panicle compactness, quicker grain hardening, and possibly high tannin content are associated with resistance to bugs. There is no information on the genetics of resistance to head bugs.

Loose-panicled genotypes are resistant to head caterpillars, and resistance is largely governed by additive gene action.

Introduction

Sorghum, *Sorghum bicolor* (L.) Moench is one of the most important cereals in the semi-arid tropics. It provides food, feed, and forage, but grain yields on smallholder farms are generally low, partly due to insect pest damage. Nearly 150 species of insects have been recorded as pests of sorghum (Sharma 1993), of which sorghum midge (*Contarinia sorghicola* Coquillett), head bugs (*Calocoris angustatus* Lethiery, *Eurystylus immaculatus* Odhiambo, and *Oebalus pugnax* Fabricius), and head caterpillars (*Helicoverpa armigera* Hübner, *Eublemma, Cryptoblabes, Pyroderces*, etc.) are the most important pests of grain sorghum worldwide.

Considerable progress has been made in the identification and utilization of resistance to panicle-feeding insects in sorghum over the past two decades. This paper summarizes the information available on the mechanisms and inheritance of resistance to these insects, and identifies areas that need attention in the near future to plan appropriate strategies to develop sorghum cultivars resistant to panicle-feeding insects.

Sorghum Midge

Research on the identification and utilization of resistance to sorghum midge has been carried out in India (Sharma et al. 1993a), USA (Peterson et al. 1985), Australia (Page 1979), and Latin America (Rossetto 1985). Sources of resistance to midge are also being utilized in breeding programs in Africa, Argentina, El Salvador, etc. IS 2579C, TAM 2566, AF 28, DJ 6514, IS 10712, Tift MR 88, IS 7005, and IS 8891 are diverse sources of resistance to sorghum midge.

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Mechanisms of resistance

Nonpreference. Nonpreference is one of the components of resistance to the sorghum midge (Wiseman and McMillian 1968, Sharma 1985a). TAM 2566, IS 12666C, and SGIRL-MR 1 are not preferred by midge females, and suffer less damage (5–11% florets with midge larvae) under natural conditions, but SGIRL-MR-1 becomes susceptible under no-choice conditions (Sharma 1985a). Genotypic nonpreference observed under field conditions is highly influenced by midge density at the time of flowering. Cultivar nonpreference observed in ICSV 197 and TAM 2566 has not been confirmed under cage tests while DJ 6514 and AF 28 show nonpreference both under field conditions and in cage tests (Fig. 1). Midge-resistant females, PM 7061A and PM 7068A (Sharma et al. 1993a), are less preferred than the midge-susceptible females (296A and ICSA 42).

Nonpreference for oviposition or low oviposition because of short, tight glumes is the most important component of resistance to the sorghum midge. Fewer eggs are laid in the florets of midge-resistant genotypes (<50 eggs 100^{-1} florets) compared with the midge-susceptible control, CSH 1 (153 eggs 100^{-1} florets) (Sharma 1985a, Franzmann 1993; Table 1).

Antibiosis. Fewer midge flies emerge from the panicles of midge-resistant cultivars than from susceptible cultivars (Sharma 1985a, Melton and Teetes 1984, Sharma et al. 1990a; Fig. 2). Post-embryonic developmental period (egg to adult) is prolonged by 5–8 days when the midges are reared on midge-resistant genotypes (DJ 6514, IS 3461, IS 15107, IS 7005, etc.). Adult emergence is delayed by 4–8 days on DJ 6514, IS 8571, IS 10712, IS 19474, IS 19512, ICSV 830, ICSV 197, and TAM 2566. Antibiosis to midge is also expressed in terms of smaller size of larvae, reduced fecundity, and/or low larval survival (Melton and Teetes 1984, Waquil et al. 1986, Sharma et al. 1993d).

Tolerance. There are conflicting reports on the compensation in grain mass due to damage by sorghum midge. Montoya (1965) reported slight compensation for midge damage. He observed that as the mean percentage spikelet damage increased from 5 to 47%, the weight of 1000 undamaged grains increased from 30.3 to 35.1 g. Harris (1961) found no relationship between midge damage and the mass of surviving kernels. Hallman et al. (1984) observed that there was a significant inverse relationship between the extent of midge damage and the mass of undamaged kernels in two of the three susceptible hybrids, and three of the seven midge-resistant hybrids. However, the relationships were not significant at damage levels below 40%. They suggested that at the economic threshold levels, there was no compensation for midge damage.

Manual removal of up to one-third of the spikelets in a panicle at the half-anthesis stage does not result in a significant reduction in grain yield (Henzell and Gillieron 1973). This indicates that there is some compensation in grain yield as a result of reduction of number of spikelets $panicle^{-1}$. However, studies by Hallman et al. (1984) indicate that partial sterility does not simulate midge damage. Manual removal of spikelets may not compare with midge damage

Table 1. Oviposition, larval numbers, adult emergence, and grain damage in 6 sorghum cultivars under no-choice conditions over 4 seasons (1982–84) at ICRISAT Asia Center.

Cultivar	Eggs 100 $florets^{-1}$	Larvae 100 $florets^{-1}$	Adults emerged $panicle^{-1}$	Midge damage (% chaffy florets)
DJ 6514	37 (6)[a1]	8 (2)[a]	15 (3)[a]	15 (22)[b]
AF 28	21 (4)	6 (7)	24 (4)	33 (34)
TAM 2566	37 (5)	41 (6)	33 (6)	30 (33)
IS 15107	38 (6)	59 (7)	71 (8)	39 (38)
CSH 1[2]	153 (12)	142 (12)	404 (19)	81 (65)
Swarna[2]	141 (11)	127 (11)	318 (18)	83 (66)
SE	±(0.9)	±(3.2)	±(1.2)	±(4.1)
CV (%)	27.6	14.6	24.2	20.9

1. Figures in parentheses are: a = square root transformed values; and b = arcsin transformed values. S = susceptible control.
2. Susceptible control.

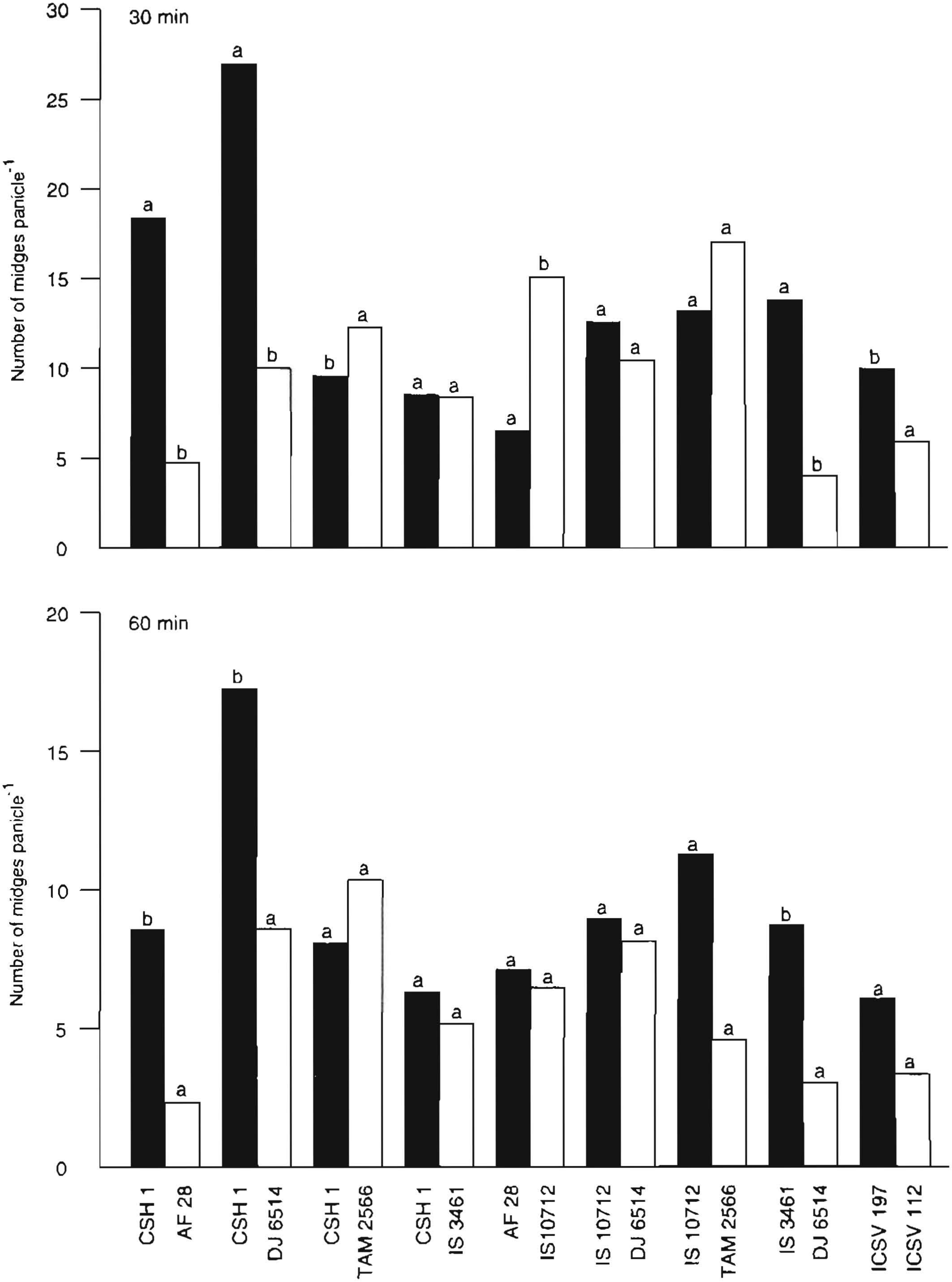

Figure 1. Relative preference of midge females for sorghum genotypes (nine pairs) under no-choice conditions in cage tests (ICRISAT Asia Center, postrainy season, 1990/91). The pairs with both the bars designated by the same letter (a or b) are not significantly different at $P < 0.05$.

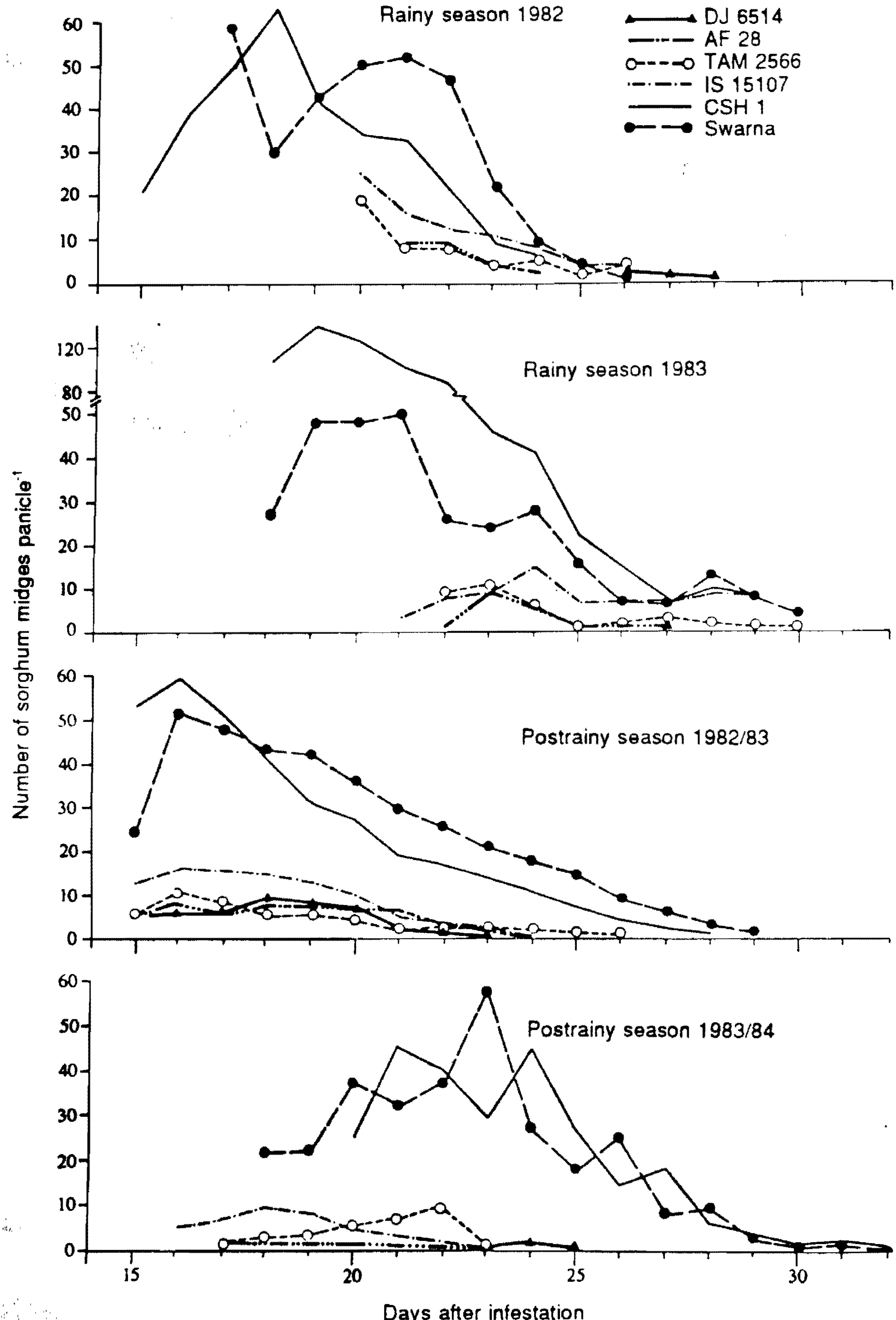

Figure 2. Midge emergence in six sorghum genotypes infested with 60 midges per panicle under a headcage (ICRISAT Asia Center, 1982–84). CSH 1 and Swarna were the susceptible controls.

because the midge larva feeds on the juices of the developing grain without removing the plant structures. In studies conducted at ICRISAT Asia Center, 1000-grain mass and 100-grain volume were greater in panicles in which 25–30% of the spikelets were removed, and infested with midges under a headcage, than in normal noninfested panicles (Table 2).

Increase in grain mass and volume in the infested panicles (over the noninfested panicles) was greater in hybrids based on midge-resistant females (PM 7061A and PM 7068A) than in hybrids based on midge-susceptible females (ICSA 42 and 296A). Similar differences were also observed between midge-resistant and midge-susceptible restorers. Thus, it appears that midge-resistant genotypes have a better capability for compensation in grain mass than do midge-susceptible genotypes.

Factors associated with resistance

Susceptibility to the sorghum midge is positively and significantly correlated with the length of glumes, lemma, palea, anther, and style (Sharma et al. 1990a). Rate of grain development between the third and seventh day after anthesis is negatively associated with midge damage (Sharma et al. 1990a). Short, tight glumes make oviposition difficult, and leave limited space between glumes and the ovary for the development of midge larvae. Componental analysis of the factors associated with midge resistance has shown that sources of resistance are diverse, and that these lines have different combinations of factors conferring resistance (Sharma et al. 1990b).

Santos and Carmo (1974) suggested that the tannin content of grain may be one of the factors imparting midge resistance, but there are distinct exceptions, e.g., DJ 6514 (Sharma et al. 1990a). Amounts of tannins and proteins have been found to be greater in some midge-resistant lines than in susceptible ones, while soluble sugar content was lower in midge-resistant lines. Composition of the sorghum grain varies over seasons, and these changes have been linked with the variation in expression of resistance to midge (Sharma et al. 1993d).

Inheritance of resistance

Resistance to *C. sorghicola* is inherited quantitatively and is controlled by quantitative gene action, and some cytoplasmic effects (Widstrom et al. 1984, Agrawal et al. 1988). Susceptibility to midge is completely or incompletely dominant in some parents. Boozaya-Angoon et al. (1984) found that resistance is controlled by recessive gene action at two or more loci. Resistance is controlled by more than one gene in TAM 2566 (Johnson 1974). At least two pairs of recessive genes determine the resistance of AF 28, and genes with minor effects are also present (Rossetto and Igue 1983). The resistance of Tift MR 88 has been reported to be under recessive gene control (Hanna et al. 1989). SGIRL-MR-1 and PI 383856 behave differently, and the resistance of SGIRL-MR-1 is lost when it is used as a female parent (Widstrom et al. 1984). DJ 6514 and TAM 2566 are good general combiners for resistance to sorghum midge. Both general and specific combining ability of

Table 2. Grain mass and volume of sorghum hybrids and restorers based on midge-resistant and midge-susceptible females, ICRISAT Asia Center, 1991/92 postrainy season.

	1000-grain mass (g)			100-grain volume (cm^3)		
Genotype(s)	Infested[1]	Normal[1]	Difference	Infested	Normal	Difference
Hybrids based on						
PM 7061 A	28.9	22.9	6.0	2.4	1.8	0.6
PM 7068 A	26.5	21.0	5.5	2.4	1.7	0.7
ICSA 42	29.9	26.9	3.0	2.6	2.1	0.5
296 A	30.0	26.3	3.7	2.6	2.5	0.1
Midge-resistant restorers	27.5	22.2	5.3	2.3	1.8	0.5
Midge-susceptible restorers	26.7	25.3	1.4	2.3	2.0	0.3
SE	±1.57	±1.2	±0.95	±0.1	±0.5	±0.37

1. Panicles infested with 40 midges for 2 days; and normal noninfested panicles.

the parents is important (Patil and Thombre 1985). Mean performance of parents and general combining ability effects are highly correlated (Agrawal et al. 1988).

We studied the gene action for midge resistance at ICRISAT Asia Center under uniform insect pressure using the headcage technique (Sharma et al. in press). The results indicate that general combining ability (GCA) effects were greater than the specific combining ability (SCA) effects for resistance to sorghum midge. GCA effects of the midge-resistant lines (PM 7061A and PM 7068A) were significant and negative, and such effects for the midge-susceptible lines (ICSA 42 and 296A) were positive (Table 3). Similar trends in GCA effects were also observed for the midge-resistant (ICSV 745, PM 15908-3, PM 17422-3, and PM 17592-1) and midge-susceptible (CS 3541, MR 750, MR 836, MR 844, and MR 923) testers. For genotypic nonpreference by the midge-resistant females, SCA effects were greater than GCA effects. There were considerable differences for the variance components, GCA, and SCA effects under natural and headcage screening, and over seasons, and this may explain the different patterns of gene action observed by different workers.

The expression of resistance to sorghum midge has not been observed in the genic-cytoplasmic male-sterile lines of midge-resistant genotypes. Midge-resistant male-sterile lines (A-lines) are as susceptible as midge-susceptible A-lines. However, the maintainer lines (B-lines) of midge-resistant females are significantly less susceptible than the corresponding A-lines, and the B-lines of the midge-susceptible females (Table 4). This suggests that the expression of midge resistance may be controlled by both cytoplasmic factors and nuclear genes (Sharma et al. 1993c).

Resistance based on DJ 6514 is not expressed in western Kenya, and Yemen, while AF 28 and IS 8891 show resistant reactions at these locations (H.C.

Table 3. General combining ability (GCA) effects of the lines and testers for 5 parameters in sorghum for midge resistance, ICRISAT Asia Center, 1990/91.

Lines/ Testers	1990 MD-C[1]	1991 MD-C	1990 DR-C	1991 DR-C	1990 DR-N	1991 DR-N	1991 MF	1991 YLD1	1991 YLD2
Lines									
PM 7061 B	−3.82	−13.04**	−0.87**	−2.42**	−0.45	−1.06**	−1.67**	0.05**	−0.02
PM 7068 B	−6.98*	−11.94**	−1.42**	−1.58**	−1.23**	−0.72**	0.85	0.01	−0.06*
ICSB 42	12.89**	12.99**	1.32**	2.44**	1.03**	0.91**	−0.63	−0.04**	0.06*
296 B	−2.09	11.99**	0.96**	1.56**	0.66*	0.87**	1.45*	−0.02	0.02
SE(gi)	2.975	1.967	0.329	0.238	0.269	0.229	0.630	0.013	0.023
SE(gi-gj)	4.208	2.783	0.466	0.337	0.381	0.323	0.892	0.018	0.032
Testers									
ICSV 745	−7.98	−10.39**	−1.89**	−0.94*	−1.15**	−0.71*	−2.29*	−0.01	−0.01
PM 15908-3	−3.76	−3.59	−2.26**	−0.99**	−1.82**	−0.88*	−1.54	0.07**	0.17
PM 17422-3	−10.84*	−16.73**	−2.19**	−2.46**	−0.82*	−1.29**	−1.95*	0.07**	0.02
PM 17592-1	−6.33	−2.49	−0.82	−0.26	0.02	−0.05	−0.70	0.01	0.03
CS 3541	3.83	−2.72	0.49	0.51	0.52	0.87*	1.29	−0.05**	−0.06
MR 750	1.62	−4.68	1.58**	−0.77*	0.69	0.45	0.79	0.01	−0.06
MR 836	7.86	17.09**	2.24**	1.59**	1.10**	0.79*	0.43	−0.07**	−0.13**
MR 844	9.66*	14.88**	1.87**	1.92**	1.27	0.70*	1.79	−0.02	−0.02
MR 923	6.11	8.63**	0.99*	1.39**	0.19	0.12	−2.43*	−0.04*	−0.08*
SE(gi)	4.463	2.951	0.493	0.358	0.403	0.342	0.945	0.019	0.034
SE(gi-gj)	6.312	4.174	0.699	0.716	0.571	0.485	1.337	0.028	0.048

1. MD-C = Midge damage under headcage. DR-C = Midge damage rating under headcage. DR-N = Damage rating under natural infestation. YLD1 and YLD2 = Grain yield plant^{-1} in first and second sowing, 1991. MF = Number of midge flies 5 panicles^{-1}.

* = Significant at P 0.05, and ** = significant at P 0.01.

Sharma, unpublished). This may be because of environmental influences on the factors conferring midge resistance in DJ 6514 or the prevalence of a different biotype of midge at these locations.

Head Bugs

Major efforts in the identification of resistance to head bugs (*Calocoris angustatus* Leth. and *Eurystylus immaculatus* Odh.) have been made in India (Sharma and Lopez 1992), and in West Africa (Sharma et al. 1992, 1994). IS 17610, IS 17645, IS 21443, and IS 17618 have moderate levels of resistance to *C. angustatus*. CSM 388, S 29, IS 14332, Malisor 84-7, and Sakoika are good sources of resistance to *E. immaculatus*. Most of the sources of resistance have either colored grain, high tannin content, or are guineense sorghums from West Africa. Malisor 84-7, derived from guineense sorghums, is medium dwarf, and has a moderate yield potential and good grain quality. It can be cultivated in areas endemic to bugs in West Africa, and utilized in resistance breeding programs.

Mechanisms of resistance

Nonpreference. Feeding nonpreference is one of the components of resistance to head bugs. IS 2761, IS 17610, IS 17618, and IS 17645 are not preferred by *C. angustatus* (Sharma and Lopez 1990, Fig. 3). Oviposition nonpreference is another component of resistance. Under headcage conditions, 9 eggs 100^{-1} spikelets were recorded in IS 17610 compared to 129 eggs 100^{-1} spikelets in CSH 5 (Sharma and Lopez 1990).

Cultivar nonpreference is also a component of resistance to *Eurystylus*. IS 14332, CSM 388, Malisor 84-7, 83F6-16, and 83F6-111 have been found to harbor <5 females panicle^{-1} compared to 11 females panicle^{-1} in E 35-1 under free-choice conditions in the field. The nonpreference of CSM 388 has also been confirmed in cage tests in the laboratory (Sharma et al. 1994).

Antibiosis. Post-embryonic development of *Calocoris angustatus* is prolonged by 1–2 days on IS 17610, IS 17618, and IS 17645. Survival and establishment of first instar nymphs is relatively lower on IS 17645 than on the susceptible controls, CSH 1 and CSH 5 (Sharma and Lopez 1990, 1993). Growth rate and efficiency of conversion of ingested food into body matter are lower on IS 6984 and IS 2761 than in CSH 5 (Sharma and Lopez 1990). A marginal decrease has been observed in the fecundity of head bug females when reared on head bug resistant genotypes IS 2761, IS 14334, IS 16357, IS 20740, and IS 17610 compared with those reared on the susceptible control CSH 1 (Sharma et al. 1993b).

Table 4. Effect of pollination by midge-resistant (DJ 6514) and midge-susceptible (Swarna) restorers on midge emergence (number of midges emerged panicle^{-1}) on midge-resistant and midge-susceptible male-sterile lines, ICRISAT Asia Center, postrainy season, 1991/92.[1]

	Pollination treatments (PT)				
Genotype	Swarna pollen	DJ 6514 pollen	Without pollination	B-line	Mean
ICSA 42	996 (31.5)[gh2]	617 (24.6)[ef]	354 (18.6)[d]	1202 (34.7)[hi]	792 (27.3)
296 A	1500 (38.6)[i]	1564 (39.4)[i]	1137 (33.6)[hi]	1182 (30.0)[fg]	1346 (35.4)
PM 7068 A	1097 (32.0)[gh]	699 (26.3)[fg]	407 (19.8)[de]	27 (4.1)[a]	555 (20.8)
PM 7061 A	84 (9.0)[ab]	168 (12.0)[bc]	247 (15.5)[cd]	17 (5.1)[a]	132 (10.4)
Mean	919 (28.0)	762 (25.6)	536 (22.6)	607 (18.4)	706 (23.7)
LSD for comparing					
Genotypes					(4.04)
PT					(4.04)
Genotypes × PT					(5.70)

1. Figures in parentheses are square root transformed values.
2. Figures followed by the same letter are not significantly different at P <0.05.

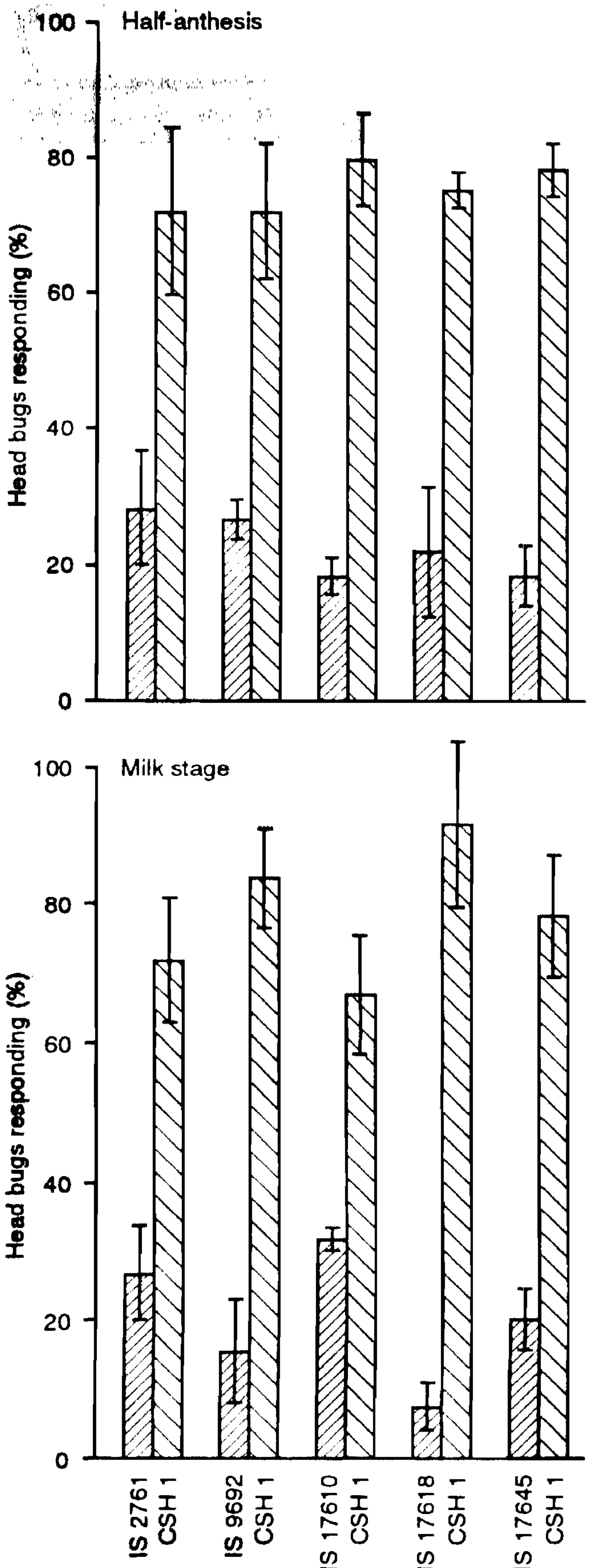

Figure 3. Relative preference of head bug adults for five sorghum genotypes in relation to CSH 1 under double-choice conditions in cage tests (ICRISAT Asia Center, postrainy season, 1986/87). CSH 1 was the susceptible control.

Tolerance. Tolerance to head bug feeding is greater in IS 9692, CSH 1, IS 17645, and IS 17610 than in IS 2761, IS 6984, and CSH 9 (Sharma and Lopez 1993). CSH 1 and CSH 5, although susceptible to head bugs, are more tolerant of bug feeding, and also suffer lower loss in grain yield, than CSH 9. Tolerance to head bug damage decreases with an increase in insect density.

Factors associated with resistance

Grain damage and bug population increase are positively associated with panicle compactness (Sharma 1985b, Sharma et al. 1994). However, under high bug density, genotypes with loose panicles also suffer heavy grain damage if other resistance factors are not involved. Cultivars relatively less susceptible to *C. angustatus* tend to have long, hard, and less hairy glumes (Sharma 1985b). Days to glume opening (>20 days from anthesis), longer glumes (>5 mm), >50% of the grain surface covered by the glumes, hard corneous grain, and quicker grain ripening contribute towards resistance to *E. immaculatus* (Sharma et al. 1994; Table 5). Touré et al. (1992) reported that faster grain filling, low water : carbohydrate ratio in grain, grain hardness, glume length, and days to glume opening are the major factors contributing to the resistance of Malisor 84-7 to *E. immaculatus*.

Inheritance of resistance

There is no documented study on the inheritance of resistance to head bugs. Factors that govern the inheritance of grain and glume characteristics in Guineense sorghums also influence the inheritance of resistance to head bugs.

Head Caterpillars (*Helicoverpa, Heliothis,* and *Eublemma*)

Chencholam, SPV 130, SPV 69, SPV 9, RS 160, and K Tall have been reported to be resistant to head caterpillars (Balasubramanian et al. 1979, Wilson 1976, Natarajan and Sundara Babu 1988). Genotypes with loose panicles suffer little damage by head caterpillars, possibly because of easier access to parasites and predators (Balasubramanian et al. 1979). Resistance to head caterpillars is largely governed by quantitative gene action (Patel et al. 1986).

Table 5. Correlation coefficients between head bug numbers, grain damage, and panicle and glume characteristics in sorghum, Sotuba, Mali, 1985.

Glume/panicle characters	Head bug numbers: Natural infestation	Head bug numbers: Headcage infestation	Damage rating: Natural infestation	Damage rating: Headcage infestation
Panicle compactness	0.45	0.72*	0.60*	0.55
Days to glume opening	–0.55	–0.72*	–0.82**	–0.73**
Glume length G1	–0.38	–0.42	–0.60*	–0.42
Glume length G2	–0.52	–0.35	–0.60*	–0.41
Glume hairiness	0.09	0.07	0.19	0.44
Glume covering	–0.83	–0.56	–0.67*	–0.52

*, ** = significant at P = 0.05 and 0.01.

Future Research Needs

Four areas of research will need to be emphasized in the future:

- Relative contribution of the componental characters in imparting resistance to panicle-feeding insects in sorghum.
- Causes of breakdown of resistance to midge in genotypes derived from DJ 6514 need to be studied in detail. A study of the nature and number of genes conferring midge resistance in different sources of resistance will help develop an appropriate strategy to diversify the basis and increase the levels of resistance to midge.
- Genetics and inheritance of resistance to head bugs.
- Role of allelochemicals in host-plant resistance to panicle feeding.

Synthèse

Les mécanismes et l'hérédité de la résistance aux insectes paniculaires chez le sorgho. La résistance des plantes-hôtes est l'une des composantes les plus importantes dans la lutte intégrée chez le sorgho. Des progrès considérables ont été faits dans l'identification et l'utilisation de la résistance à la cécidomyie du sorgho (*Contarinia sorghicola* Coq.), aux punaises des panicules (*Calocoris angustatus* Leth. et *Eurystylus immaculatus* Odh.) et à la chenille des panicules (*Helicoverpa armigera* Hub.). IS 2579 C, TAM 2566, AF 28, DJ 6514, IS 10712, Tift MR 88, IS 7005 et IS 8891 sont diverses sources de résistance à la cécidomyie. La non préférence fait partie des mécanismes de résistance à la cécidomyie. La non préférence étudiée en milieu réel est fortement influencée par l'époque de floraison et par la densité de cécidomyies lors de la floraison des différents génotypes. La non préférence variétale étudiée sur ICSV 197 et TAM 2566 n'a pas été confirmée aux essais en cage, alors que DJ 6514 et AF 28 présentent de la non préférence tant en milieu réel qu'aux essais en cage. La non préférence pour la ponte ou un faible niveau de ponte grâce aux glumes courtes et compactes est le plus important facteur de la résistance à la cécidomyie du sorgho. La période de développement post embryonnaire (de l'oeuf à l'adulte) de la cécidomyie se prolonge de 5 à 8 jours lorsqu'elle est élevée sur des génotypes résistants tels que DJ 6514, IS 3461, IS 15107, IS 7005, etc. L'antibiose à la cécidomyie s'exprime également par des larves plus petites, une fertilité réduite et/ou une faible survie des larves. Des rapports se contredisent sur la compensation dans le poids du grain suite aux dégâts causés par la cécidomyie. Dans des études effectuées au Centre ICRISAT pour l'Asie, une masse de 1000 grains et un volume de 100 grains étaient plus grands pour les panicules dans lesquelles 25 à 30% des épillets avaient été retirés et infestés de cécidomyies sous cage que dans les panicules non infestées. L'augmentation de la masse et du volume du grain dans les panicules infestées (par rapport aux panicules non infestées) a été plus accentuée chez les hybrides basés sur les femelles résistantes (PM 7061 A et PM 7068 A) que chez ceux basés sur les femelles sensibles (ICSA 42 et 296 A). Des différences similaires ont été également notées pour les restaurateurs résistants à la cécidomyie et les restaurateurs sensibles. Ainsi, les génotypes résistants ont une meilleure capacité pour la compensation dans le poids du grain que les génotypes sensibles. La sensibilité à la cécidomyie du sorgho a une corrélation positive et significative avec la longueur des glumes, de la lemma, de la paléa, de l'anthère et du style. Le taux du développement du grain entre le 3e et le 7e jour après l'anthèse est négativement associé aux dégâts causés par la cécidomyie. Les quantités de tanins et de protéines se sont montrées plus importantes dans certaines lignées résistantes à la cécidomyie que dans les lignées sensibles, tandis que les sucres solubles sont moindres dans les lignées résistantes. La composition du grain de sorgho varie suivant les saisons et ces changements ont été liés avec la variation de l'expression de la résistance à la cécidomyie.

La résistance à *C. sorghicola* est héritée quantitativement, et, est contrôlée par l'action quantitative génique et par quelques effets cytoplasmiques. La sensibilité à la cécidomyie est totalement ou partiellement dominante chez certains parents. Les effets de l'aptitude générale à la combinaison (AGC) des lignées résistantes à la cécidomyie (PM 7061 A et PM 7068 A) sont significatifs et négatifs et ces effets pour les lignées sensibles (ICSA 42 et 296 A) sont positifs. On a observé des tendances similaires dans les effets de l'AGC pour les testeurs résistants (ICSV 745, PM 15908-3, PM 17422-3 et PM 17592-1) et sensibles (CS 3541, MR 750, MR 836, MR 844 et MR 923). En ce qui concerne la non préférence génotypique des femelles résistantes à la cécidomyie, les effets de l'aptitude spécifique à la combinaison (ASC) se sont révélés supérieurs aux effets de l'AGC. L'expression de la résistance à la cécidomyie du sorgho n'était pas observée dans des lignées mâles stériles géniques-cytoplasmiques des génotypes résistants.

IS 17610, IS 17645, IS 21443 et IS 17618 ont montré des niveaux modérés de résistance à *C. angustatus*. CSM 388, S 29, IS 14332, Malisor 84-7 et Sakoika sont de bonnes sources de résistance à *E. immaculatus*. La non préférence pour l'alimentation et pour la ponte constituent d'importantes composantes de la résistance aux punaises des panicules. Le développement post embryonnaire de *C. angustatus* se prolonge d'un à deux jours chez IS 17610, IS 17618 et IS 17645. La survie et l'établissement des premières nymphes au stade larvaire sont relativement faibles chez IS 17645 par rapport à ceux chez les témoins sensibles, CSH 1 et CSH 5. Le taux de croissance et l'efficacité de conversion de la nourriture absorbée en matière organique sont inférieurs chez IS 6984 et IS 2761 que chez CSH 5. On a observé une faible baisse de fécondité des punaises des panicules quand elles sont élevées sur des génotypes résistants à la punaise, tels que IS 2761, IS 14334, IS 16357, IS 20740 et IS 17610 par rapport à celles élevées sur le témoin sensible, CSH 1. La tolérance à l'alimentation des punaises des panicules est plus élevée chez IS 9692, CSH 1, IS 17645 et IS 17610 par rapport à IS 2761, IS 6984 et CSH 9. Les dégâts du grain et l'augmentation de la population des punaises sont positivement corrélés à la compacité des panicules. Cependant à des niveaux élevés de densité des punaises, les génotypes ayant des panicules lâches subissent également des dégâts de grain si d'autres facteurs de résistance ne sont pas présents. Des variétés moins sensibles à *C. angustatus* ont tendance à avoir des glumes longues, dures et moins pileuses. Une durée d'ouverture des glumes (>20 jours à partir de l'anthèse), des glumes plus longues (>5 mm), plus de 50% de la surface du grain couverte de glumes, un grain corné dur et une maturation plus rapide du grain contribuent à la résistance à *E. immaculatus*.

Chencholam, SPV 130, SPV 69, SPV 9, RS 160 et K Tall se sont montrés résistants aux chenilles des panicules. Les génotypes à panicules lâches subissent peu de dégâts sans doute grâce à l'accès plus facile pour les parasites et les prédateurs. La résistance aux chenilles des panicules est gouvernée par l'action quantitative génique.

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A Simple Method to Assess Damage and Screen Sorghums for Resistance to *Eurystylus marginatus*

Y O Doumbia[1], K Conare[1], and G L Teetes[2]

Abstract

A simple method to assess damage and screen sorghums for resistance to a sorghum panicle bug, Eurystylus marginatus *Odh., using natural infestation was developed and evaluated at the Station de Recherche Agronomique de Sotuba, Mali, in 1989 and 1990. The method consisted in comparing the grain damage levels in unprotected panicles and panicles protected from bugs by the use of cages, plastic pollinating bags, and insecticide (diazinon). The efficacies of the three methods of protection were compared. Grain from unprotected panicles was extensively damaged. Grain mass (200 grains) was greatly reduced by bugs, and grain vitrosity changed to floury. The rate of germination was severely lowered by bug damage, and the number of floating or poor quality grains was much higher in unprotected panicles than in grains from protected panicles. These methods allow rapid and easy detection of resistance in sorghum varieties.*

Introduction

Sorghum is one of the most important crops, and a staple cereal, in Mali. Low sorghum yields are a result of the low productivity of local varieties, low or erratic rainfall, extended drought, and damage caused by insects and other pests. Most studies undertaken on sorghum insect pests during the last decade in the Sahel have concentrated on the severity of bug damage to sorghum grain and the effects of this damage on sorghum grain yield and quality. The bug problem has intensified as a result of the development of improved sorghum varieties with compact panicles and high yield potential (2.5 t ha^{-1}). These cultivars are severely attacked by panicle-feeding bugs, especially *Eurystylus* spp (Stäl) (Doumbia and Bonzi 1985, 1989, Gahukar et al. 1989). Sorghum panicles are damaged when bugs oviposit in grains or puncture grains while feeding. Damaged grains are subsequently infected by fungi, which exacerbate the loss in grain quality (Doumbia 1992b). The magnitude of the damage to sorghum grain has not been well quantified.

Research during the past 10 years has been conducted to identify sources of resistance in sorghum to panicle-feeding bugs in Mali and other parts of West Africa (Doumbia 1992a, Ratnadass et al. 1991, Sharma et al. 1992). The identification of sources of resistance to head bugs requires efficient and practical screening techniques. Using cages to artificially infest panicles with bugs is time consuming and labor intensive. Taking advantage of natural infestation while simultaneously protecting some panicles from bug infestation would provide a simple method to assess the magnitude of damage and to screen genotypes in preliminary trials and large screening nurseries. This simple method would allow sorghum breeders to quickly evaluate hundreds of sorghum genotypes.

Materials and Methods

Sharma et al. (1992) used 40 bugs inside cages placed over sorghum panicles, and after 20 days evaluated the resulting reduction in grain yield and quality. This method is time consuming and labor intensive. The method we used relied on natural bug infestations and allowed a comparison of bug damage in protected and unprotected grains.

1. Institut d'Economie Rurale (IER), Station de Recherche Agronomique de Sotuba, BP 438, Sotuba, Mali.
2. Department of Entomology, Texas A&M University, College Station, Texas 77843-2475, USA.

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Thirteen sorghum lines were used to evaluate this method in 1989 and 1990. A split-plot design was used with three replications. Sorghum was sown in plots of 2 rows, 5 m long with a spacing of 50 cm between rows and 75 cm between plots. Fertilizer application was the same as recommended by the extension service. The treatments were as follows: panicles protected from bug infestation using cages, plastic pollinating bags, insecticide (diazinon), and no protection.

Cages or bags were placed over five panicles per plot at panicle exsertion and left till the hard dough stage. Insecticide was applied thrice at 7-day intervals beginning when panicles were at the 50% anthesis stage, and ending when the panicles were at the hard dough stage. The insecticide diazinon (600 EC), was applied with a Berthoud manual hand-held sprayer.

Bug abundance

At the completion of the milk stage of grain development, five panicles randomly chosen for each variety and for each treatment, were covered with a plastic bag, cut, and taken to the laboratory where adult and immature bugs were identified to species level and counted.

Damage assessment

Damage by *E. marginatus* was rated on five panicles exposed to natural bug infestation. Also, damage to grain from five panicles that had been protected by cage, bag, or insecticide was evaluated for each plot of each sorghum variety. Bug damage to each variety was rated using a 1–5 scale, where 1 = grains with few egg laying and feeding punctures, and 5 = grains completely withered. A visual rating of mold infection of grain was also done using a 1–5 scale, where 1 = <10% moldy grain, and 5 = >60% moldy grain. Grains from panicles protected with cages, pollinating bags, or insecticide were compared with unprotected grain to assess the effect of bug infestation and measure damage levels in each sorghum genotype.

The other parameters measured to assess the effect of bugs on grain yield and quality were 200-grain mass, grain vitrosity, percentage germination, and proportion of low-density grains (floaters). The flotation test was conducted by submersing 1 000 grains in $NaNO_3$ solution with a relative density of 1.205. Bug-damaged grain floated on the top of the solution. Grain vitrosity was rated on a 1–5 scale, where 1 = hard, vitreous grain, and 5 = tender, floury grain.

Results and Discussion

Bug abundance

Eurystylus marginatus was the predominant species of head bug on sorghum at the Station de Recherche Agronomique de Sotuba in 1989 and 1990. Average infestation was 152 *E. marginatus* per five panicles in 1989 and 82 in 1990 (Table 1). The maximum number of bugs occurred on El Mota Galmi sorghum, with 730 bugs per five panicles in 1989 and 343 in 1990. It was important in these experiments to assess bug abundance during the dough stage of grain development because there is a relationship between bug abundance and damage. Sharma et al. (1992) reported that 20 female/male pairs of bugs were required to cause maximum damage to grain under caged conditions. Also, the abundance of immature and adult bugs increases on panicles from the milk stage to maturity (Doumbia 1992a). Abundance of *E. marginatus* is greatest during these two stages of grain development at Sotuba (Doumbia and Teetes 1991). These authors also reported data on the population dynamics of this insect that showed two peaks in abundance, the highest in Sep and a lesser one in Oct.

Damage assessment

Grain damage ratings on unprotected panicles and panicles protected with insecticide are presented in Table 1. Bug damage differed among varieties and between years. Damage to grain from unprotected panicles ranged from 2 to 5 in 1989, and the average damage rating to all varieties that year was 3.7. Average bug damage rating to all unprotected sorghum in 1990 was 2.2. The greater level of damage in 1989 was a reflection of the higher infestation level that year.

Sorghum varieties with damage ratings lower than the average for all varieties in 1989 were Malisor 84-7, R 8505, El Mota Galmi, SC 279 and Kendé. Varieties with damage ratings higher than the average were Sureno, ICSV 16-5, ICSV 1063, SC 283, S 34, CSM 388, Malisor 84-5, and Malisor 84-1. Bug abundance did not always relate well to grain damage. For example, bug abundance on SC 283 was low and damage high, while bug abundance on El Mota Galmi

Table 1. Abundance of bugs and visual damage ratings for 13 sorghum varieties at Sotuba, Mali, 1989 and 1990.

	Number of bugs 5 panicles⁻¹		Visual damage rating[1]			
			Naturally infested		Insecticide protected	
Variety	1989	1990	1989	1990	1989	1990
Malisor 84-7	69.3	27.0	2	1	1	1
Sureno	302.7	65.7	4	2	1	2
ICSV 16-5	42.7	133.7	4	2	3	2
ICSV 1063	107.7	29.0	5	3	2	2
SC 283	24.7	21.3	5	3	2	2
R 8505	49.0	40.0	3	2	1	2
El Mota Galmi	730.0	343.3	2	2	1	2
S 34	165.7	136.0	5	3	2	2
CSM 388	108.3	103.0	4	–	2	–
SC 279	100.3	8.3	2	2	1	2
Malisor 84-5	126.3	48.3	4	2	1	2
Malisor 84-1	128.3	100.7	5	2	2	2
Kendé	20.0	13.7	3	2	1	2
CV (%)	124.3	109.5	32.0	26.6	42.9	15.1
Mean	151.9	82.3	3.7	2.2	1.5	1.9
SE	±52.4	±25.0	±0.3	±0.2	±0.2	±0.1

1. Damage rating scored on a 1–5 scale, where 1 = grains with few egg laying and feeding punctures, and 5 = grains completely withered.

was high and damage low. Time to maturity and grain development stage in relation to the time of bug infestation probably affected these bug density-grain damage relationships.

In 1990, most varieties had bug damage ratings lower than the mean for all varieties. Malisor 84-7 was the least damaged, and ICSV 1063, SC 283, and S 34 were most damaged.

Bug damage ratings were reduced by insecticide application, especially in 1989, when infestation was higher than in 1990. In all cases, insecticide application reduced bug damage ratings by at least 50%. This difference was smaller in 1990, when bug infestation was lower.

A comparison of the effect of bug damage on lowering grain mass, vitrosity, and germination rate, and of increasing the number or percentage of floating grains, showed differences in the effect of protection (with headcages, pollinating bags, or insecticide) in 1989 and 1990 (Tables 1–5). These evaluations also showed that the severity of damage differed among sorghum varieties and between years. These results were similar to those obtained by Steck et al. (1989) in Niger.

In 1989, the average 200-grain mass from unprotected panicles was 3.2 g, while it was 4.0, 4.4, and 3.8 g from panicles protected with cages, pollinating bags, and insecticide (Table 2). Accordingly, bug damage reduced grain mass by 18.4% for all varieties regardless of method of protecting panicles. Grain mass from unprotected panicles was 17.5, 23.1, and 14.7% lower compared to grain from panicles protected with cages, bags, and insecticide. Pollination bags provided the best protection from bug infestation.

When expressed as percentage reduction in grain mass from unprotected versus protected panicles, the lower the percentage difference, the more resistant or less damaged the variety. Sorghum varieties with the least amount of damage in 1989, measured in terms of protected versus unprotected grain mass, were Malisor 84-7, SC 283, R 8505, El Mota Galmi, and Kendé (Table 2). Data on grain mass were consistent with bug damage ratings, except for SC 283 which had high damage ratings but little loss in grain mass.

Mean grain vitrosity ratings for all varieties, whether protected or not, did not differ greatly in 1989 (Table 3). Grain from unprotected panicles had a

Table 2. Comparison of bug damage based on grain mass from protected and unprotected panicles of different sorghum varieties at Sotuba, Mali, 1989 and 1990.

	1989				1990			
	200-grain mass (g) in unprotected	Percentage difference with			200-grain mass (g) in unprotected	Percentage difference with		
Variety	panicles	Cages	Bags	Insecticide	panicles	Cages	Bags	Insecticide
Malisor 84-7	3.4	2.9	0.9	9.2	2.4	19.9	15.6	–0.4
Sureno	2.3	26.6	36.2	33.1	2.4	14.8	12.7	7.0
ICSV 16-5	4.0	25.1	25.0	12.1	3.4	15.2	8.3	9.3
ICSV 1063	4.2	31.1	33.1	15.8	4.3	12.3	13.4	0.7
SC 283	2.9	3.3	1.3	1.3	2.2	28.3	24.1	18.3
R 8505	3.1	10.5	17.5	6.1	1.4	64.1	53.9	28.8
El Mota Galmi	3.3	7.4	15.7	17.8	3.3	18.2	17.8	11.0
S 34	2.9	36.1	49.2	32.4	2.9	–18.7	–8.6	13.9
CSM 388	4.1	20.3	23.6	13.6	–	–	–	–
SC 279	4.4	–6.3	10.4	11.7	4.7	–3.3	9.3	–8.3
Malisor 84-5	3.1	28.3	30.0	0.3	2.7	27.0	9.1	4.3
Malisor 84-1	1.8	53.7	58.0	34.8	2.6	25.6	23.9	14.0
Kendé	2.8	–11.3	–0.7	2.8	1.8	10.8	22.0	10.8
CV (%)	23.0	25.0	25.0	21.2	33.4	24.1	26.4	26.3
Mean	3.2	17.5	23.1	14.7	2.8	17.9	16.8	9.1
SE	±0.2	±0.3	±0.3	±0.2	±0.3	±0.2	±0.3	±0.2

Table 3. Comparison of vitrosity ratings of grain from protected and unprotected panicles of different sorghum varieties at Sotuba, Mali, 1989 and 1990.

	Vitrosity rating[1]							
	1989				1990			
Variety	Unprotected	Cages	Bags	Insecticide	Unprotected	Cages	Bags	Insecticide
Malisor 84-7	3.1	2.6	2.2	2.3	1.6	1.7	2.2	1.4
Sureno	4.0	3.9	3.3	2.7	2.9	2.3	2.3	2.6
ICSV 16-5	3.1	3.9	4.4	1.8	3.0	2.0	2.5	2.8
ICSV 1063	3.9	4.7	3.9	3.7	4.0	3.4	3.6	3.7
SC 283	4.6	4.9	2.8	2.4	2.2	2.3	1.6	2.1
R 8505	2.6	4.4	2.9	3.3	3.2	2.8	2.8	3.0
El Mota Galmi	3.5	5.0	5.0	5.0	4.6	4.0	4.0	4.5
S 34	5.0	4.7	3.4	3.8	4.3	3.7	3.7	3.9
CSM 388	5.0	3.1	2.3	2.3	–	–	–	–
SC 279	2.5	3.4	3.9	3.0	3.1	2.9	9.0	2.7
Malisor 84-5	3.0	4.1	3.0	3.0	3.1	2.9	2.8	3.0
Malisor 84-1	3.7	4.1	3.7	4.7	3.6	2.5	2.5	3.5
Kendé	3.7	2.7	3.0	3.1	1.3	1.4	1.6	1.4
CV (%)	22.2	20.4	23.7	29.6	32.3	29.2	61.3	32.8
Mean	3.7	4.0	3.4	3.2	3.1	2.6	3.2	2.9
SE	±0.2	±0.2	±0.2	±0.3	±0.3	±0.2	±0.6	±0.3

1. Rated on a 1–5 scale, where 1 = hard vitreous grain, and 5 = tender, floury grain.

mean vitrosity rating of 3.7 for all varieties, and 4.0, 3.4, and 3.2 for grain from panicles protected with cages, bags, and insecticide, respectively.

Grain vitrosity ratings varied according to variety in 1989. Based on this damage parameter, varieties S 34, CSM 388, ICSV 1063, and Sureno were severely damaged and SC 279, R 8505, Malisor 84-5, Malisor 84-7, and ICSV 16-5 were the least damaged (Table 3). The effect of bug damage on vitrosity was less perceptible on sorghum varieties such as El Mota Galmi which has naturally floury grain. Sorghum grains protected using insecticide had the lowest overall vitrosity quality (highest rating). Grain from cage-protected panicles had higher vitrosity ratings than unprotected ones.

In 1990, the average 200-grain mass was 2.8 g in unprotected panicles, while it was 3.5, 3.4, and 3.1 g for grain from panicles protected with cages, bags, and insecticide (Table 2). The percentage difference in grain mass between unprotected and protected panicles was greatest when cages and bags were used. Grain from unprotected panicles weighed 17.9, 16.8, and 9.1 g less than when panicles were protected by cages, bags, or insecticide. Using this measure, however, varieties with low damage in 1989 were more damaged in 1990, when infestation was lower.

Results of vitrosity ratings in 1990 showed as in 1989, that bug damage adversely affected vitrosity. The average vitrosity rating for all varieties in 1990 was 3.1 for unprotected grain, 2.6 and 2.9 for grain protected with cages and insecticide, and 3.2 using bags (Table 3).

Vitrosity ratings are probably less valuable than grain mass in assessing damage to sorghum grain by bugs. Discrepancies may occur because of the subjectivity of the evaluation and the natural differences in vitrosity of the varieties.

Unprotected grain in 1989 had a lower germination rate (43.7%) for all varieties than did grain protected with cages (79.5%), pollinating bags (79.7%), or insecticide (66.5%) (Table 4). Based on percentage difference in germination of unprotected and protected grain, cages and bags provided better protection from bugs than did insecticide. The percentage differences in germination were 42.1, 45.0, and 21.0%. Overall, bug damage severely reduced germination. Germination in Malisor 84-7, for example, was severely reduced even though based on other

Table 4. Comparison of germination rates of grain from protected and unprotected panicles of different sorghum varieties at Sotuba, Mali, 1989 and 1990.

	1989				1990			
	Germination (%) in unprotected	Percentage difference with			Germination (%) in unprotected	Percentage difference with		
Variety	panicles	Cages	Bags	Insecticide	panicles	Cages	Bags	Insecticide
Malisor 84-7	19	79.3	76.5	73.6	98.1	–9.8	–10.5	–6.2
Sureno	44	55.1	52.2	47.0	79.4	13.4	15.6	12.1
ICSV 16-5	57	39.4	38.0	20.8	93.7	–1.2	–1.5	0.1
ICSV 1063	37	61.5	60.6	51.9	89.1	2.6	3.0	5.1
SC 283	35	60.7	62.0	60.2	87.6	1.1	–7.3	0.8
R 8505	35	37.5	28.6	–94.4	83.3	–10.0	–20.3	–31.0
El Mota Galmi	10	28.6	85.1	83.6	65.9	28.1	26.6	8.0
S 34	19	77.4	74.7	–58.3	79.6	–5.8	–34.5	11.2
CSM 388	76	20.8	1.3	16.5	–	–	–	–
SC 279	42	48.1	48.1	48.8	75.4	10.7	9.6	19.4
Malisor 84-5	62	–12.7	6.1	8.8	88.2	2.9	1.8	–0.2
Malisor 84-1	38	57.8	47.2	11.6	90.1	1.4	0.7	4.0
Kendé	94	–5.6	4.1	3.1	94.3	2.2	–1.3	–0.7
CV (%)	54.0	30.4	17.7	40.2	10.7	7.5	12.6	11.2
Mean	43.7	42.1	45.0	21.0	85.4	3.0	–1.5	1.9
SE	±6.5	±6.7	±3.9	±7.4	±2.6	±1.9	±3.1	±2.8

damage parameters, this cultivar was usually the least damaged. Germination in Kendé was little affected when not protected from bugs.

The percentage of floating grains was high in 1989 (Table 5). On an average, 55.5% of the grain of all varieties floated when not protected from bugs. On the other hand, only 23.4 and 19.4% floaters were found in grain protected with cages and bags, respectively, and 45% in grain protected with insecticide. Based on percentage floating grain in 1989, Malisor 84-7, CSM 388, and Kendé were the varieties least damaged by bugs. Germination percentage was higher and percent flotation lower in 1990 than in 1989.

The method described here, of protecting panicles from bug infestation and comparing the effect of bug damage on grain from protected and unprotected panicles, provided a simple means to assess damage levels in different sorghum varieties and to evaluate them for resistance. This method would be easy for breeders to use and efficient in eliminating susceptible varieties in preliminary trials involving many genotypes.

Synthèse

***Une méthodologie simple d'estimation des dégâts et de criblage du sorgho pour la résistance à* Eurystylus marginatus.** Une méthodologie simple d'estimation des dégâts et de criblage du sorgho pour la résistance à la punaise des panicules, *Eurystylus marginatus* Odh. (Hemiptera: Miridae) dans les conditions d'infestation naturelle a été développée et testée à la Station de Recherche Agronomique de Sotuba, au Mali.

Cette méthode consiste à comparer les dégâts sur les grains des panicules protégées contre les attaques des punaises à ceux sur les grains non protégés. Les panicules étaient protégées par des cages, des sacs d'autofécondation en plastique et le traitement d'insecticide (diazinon). L'efficacité de l'emploi de ces trois moyens de protection des panicules contre l'infestation des punaises a été comparée.

Dans cette étude, treize variétés de sorgho ont été utilisées. L'estimation du niveau d'infestation des panicules a révélé que le nombre moyen des punaises par 5 panicules a varié de 20 à 730, avec une

Table 5. Comparison of flotation of grain from protected and unprotected panicles of different sorghum varieties at Sotuba, Mali, 1989 and 1990.

	1989				1990			
	Flotation (%) in unprotected	Percentage difference with			Flotation (%) in unprotected	Percentage difference with		
Variety	panicles	Cages	Bags	Insecticide	panicles	Cages	Bags	Insecticide
Malisor 84-7	29.2	62.6	36.5	31.1	11.7	53.7	27.8	–21.3
Sureno	52.8	55.0	61.1	64.9	24.7	75.0	65.5	37.8
ICSV 16-5	82.9	87.0	88.1	43.3	15.9	76.2	–0.9	40.9
ICSV 1063	88.3	86.9	87.5	52.3	25.8	72.1	69.0	50.8
SC 283	40.8	35.6	88.9	48.1	6.4	77.9	51.2	27.1
R 8505	72.8	61.2	62.3	1.6	27.1	54.7	61.7	50.6
El Mota Galmi	99.9	1.6	9.2	8.7	74.0	65.3	56.9	7.3
S 34	99.3	77.9	69.5	18.5	39.1	–3.5	–34.4	7.5
CSM 388	3.4	28.7	0.6	–449.0	–	–	–	–
SC 279	25.2	–32.6	64.0	–18.5	6.7	29.3	18.8	23.3
Malisor 84-5	49.2	64.0	84.3	–77.3	6.7	67.6	55.1	19.3
Malisor 84-1	71.5	85.6	74.6	18.5	48.4	74.8	58.4	36.9
Kendé	6.8	–25.6	84.2	53.0	1.1	76.4	60.9	56.4
CV (%)	59.8	103.7	119.8	65.7	88.9	116.0	106.7	106.8
Mean	55.5	45.2	62.4	–15.8	24.0	60.0	40.8	28.1
SE	±9.2	±6.7	±6.4	±8.3	±6.1	±3.4	±4.3	±5.5

moyenne de 152 en 1989 contre 82 en 1990. Le maximum des punaises a été enregistré sur la variété El Mota Galmi avec 730 individus en 1989 et 343 en 1990. Les grains des panicules non protégées étaient sérieusement endommagés.

La note visuelle des dégâts sur les grains se situe entre 2 et 5 en 1989, avec une moyenne de 3,7 pour l'ensemble des variétés contre 2,2 en 1990. Au cours des 2 années, la variété Malisor 84-7 a été la moins attaquée tandis que les variétés ICSV 1063, SC 283 et S 34 ont été les plus attaquées. Dans tous les cas l'emploi de l'insecticide réduit de moitié les notes visuelles des dégâts.

Le poids grain (200 grains) a été largement réduit par les punaises. En effet, une réduction de poids de 17,5 a été constatée avec la protection par la cage, 23,1 avec le sac d'autofécondation et 14,7 avec l'insecticide par rapport aux grains non protégés.

Avec les dégâts des punaises, les grains sont moins vitreux. Les grains des sorghos protégés par la cage étaient aussi moins vitreux, que ceux des panicules non protégées. L'évaluation des dégâts par la réduction de la vitrosité est moins fiable que par la réduction du poids grain.

En se basant sur la différence du taux de germination des grains protégés et non protégés, la cage et le sac d'autofécondation assurent une meilleure protection contre les punaises que l'insecticide.

Il a été constaté qu'en moyenne 55,5% des grains de toutes les variétés ont flotté lorsqu'ils n'étaient pas protégées contre les punaises.

L'utilisation de cette méthode pour protéger des panicules contre les punaises et pour comparer l'effet des dégâts des punaises sur les grains des panicules protégées permet de détecter facilement et rapidement la résistance des variétés de sorgho à *Eurystylus marginatus*.

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Host-Plant Resistance in Sorghum to *Eurystylus immaculatus* in West Africa

A Ratnadass[1], O Ajayi[2], G Fliedel[3], and K V Ramaiah[4]

Abstract

*Screening trials conducted in 1989–92 at Samanko (Mali) and Bagauda (Nigeria) showed that the loose-panicled sorghum cultivars IS 17645, IS 20740, and IS 20638 consistently supported fewer head bugs (*Eurystylus immaculatus*) than other* Calocoris angustatus*-resistant genotypes, under natural and artificial conditions of infestation. Malisor 84-7 was the most resistant under both natural and artificial infestation at Samanko and Cinzana (Mali) and Farako-Bâ (Burkina Faso) in 1989 and 1990, and under natural infestation at Bagauda in 1990. Malisor 84-7 confirmed high and stable head bug resistance, both under natural and artificial infestation, in terms of bug populations and damage at Samanko in 1991 and 1992, and at Farako-Bâ in 1991. Although relatively less attractive to bugs, ISIAP Dorado was severely damaged under artificial infestation, while 87W810 (an advanced progeny from a cross between ICSV 1002 and Malisor 84-7) was tolerant of bugs. Studies in Montpellier, France, in 1991 and 1992 showed that sorghum grain hardening was due to the endosperm rather than the pericarp, and that it was quicker in Malisor 84-7 than in susceptible S 34, and intermediate (and subcoated) IRAT 202. Resistance was therefore attributed to hardening pattern rather than to free phenolic compounds or tannin content. A study at Samanko in 1992 showed that resistance was recessive, with no maternal effect. In 1992 at Samanko, an advanced progeny from a cross between ICSV 1014 and Malisor 84-7 combined reasonable head bug tolerance and acceptable agronomic characteristics, confirming that resistance is transferable by pedigree breeding.*

Introduction

Head bugs (Heteroptera: Miridae), particularly *Eurystylus immaculatus* Odhiambo, have recently become important pests of sorghum in West Africa (MacFarlane 1989, Steck et al. 1989, Doumbia and Teetes 1991, Sharma et al. 1992). Both feeding and oviposition punctures by *E. immaculatus* in maturing sorghum caryopses result in severe quantitative and qualitative losses, and favor secondary infection by grain mold, particularly on improved compact-headed caudatum types. This pest is therefore potentially an important limiting factor in sorghum production because high-yielding improved cultivars are more susceptible to head bug damage than local loose-panicled guinea landraces.

Host-plant resistance to insect pests in sorghum has recently been reviewed by Sharma (1993). Earlier work in West Africa is limited. However, considerable efforts by ICRISAT and the national agricultural research systems (NARS), notably the Institut d'Economie Rurale (IER) in Mali, have resulted in the devel-

1. Centre de Coopération en Recherche Agronomique pour le Développement/Département des Cultures Annuelles (CIRAD/CA), ICRISAT West African Sorghum Improvement Program (WASIP)—Mali, BP 320, Bamako, Mali.

2. West African Sorghum Improvement Program (WASIP)—Nigeria, IITA Office, Sabo Bakin Zuwo Road, PMB 3491, Kano, Nigeria.

3. Laboratoire de technologie des céréales, Centre de Coopération en Recherche Agronomique pour le Développement/Département des Cultures Annuelles (CIRAD/CA), 2 place Viala, 34060 Montpellier Cedex 1, France.

4. Priya Agrotech Pvt. Ltd. Plot no. 46, ICRISAT Phase II, Hasmathpet Road, Secunderabad 500 011, Andhra Pradesh, India.

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opment of reliable artificial infestation techniques to screen sorghum lines for resistance to *E. immaculatus* (Sharma et al. 1992), and in the identification of sources of resistance and factors associated with head bug resistance in sorghum (Doumbia 1992, Sharma et al. 1994).

The studies presented in this paper were carried out between 1989 and 1992 in Burkina Faso, France, Mali, and Nigeria, and by the ICRISAT West African Sorghum Improvement Program (WASIP) and the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), France, with the following specific objectives:

- identification or confirmation of sources of resistance to sorghum head bug
- characterization of genotypic reactions to head bug infestation
- elucidation of the mechanism of head bug resistance
- determination of the genetic nature and mode of inheritance of resistance
- selection of sorghum varieties combining good levels of head bug resistance with acceptable agronomic characteristics.

Screening Sorghums for Resistance to *Eurystylus immaculatus*

International sorghum head bug nurseries (ISHBNs)

The ISHBNs of ICRISAT Asia Center, India, consist of a number of sorghum lines with moderate levels of resistance to the sorghum mirid head bug, *Calocoris angustatus* Lethiery (Sharma and Lopez 1992), to be tested under different environmental and pest situations, in a randomized complete block design (RCBD) with two replications.

In 1989, the ISHBN was sown on two dates of sowing (DOS) at Samanko, Mali (4 and 26 Jul). It consisted of 21 entries, with CSM 388, a local loose-panicled guinea cultivar, as control. For the second DOS, two infestor rows of head bug-susceptible cultivars, Framida and S 34 were sown after every eighth row, 3 weeks before sowing the test entries.

In 1990 and 1992, 19 entries of the 1989 ISHBN were tested at Bagauda, Nigeria, including the local cultivar, Farafara, with an infestor row of head bug-susceptible Nagawhite, sown after every eighth row, 1 month before sowing the test entries. The 1990 ISHBN was sown on two DOS at Samanko (10 and 24 Jul, and consisted of 20 entries, with the local CSM 388 as control.

In 1989 at Samanko, five cultivars had a bug-damage rating (DR) of ≤5.5 at maturity on both DOS (on a 1–9 scale, where 1 = all grains fully developed with a few feeding punctures, and 9 = most grains remaining undeveloped and barely visible outside the glumes), compared with a DR of ≥8.0 in both CSH 9 and ICSV 197, the susceptible controls. Only CSM 388 and IS 20740 had an infestation of <35 bugs (number of head bugs at the soft dough stage, measured on five randomly chosen panicles per plot) on the first DOS, compared with ≥600 bugs in CSH 9, ICSV 197, IS 27466, IS 27452, and IS 27397. IS 20740 had no bugs in the second DOS.

At Bagauda, in 1990, infestation ranged from 5 bugs per 5 panicles in IS 17465 to 66 bugs per 5 panicles in IS 27397. Infestation was <10 bugs on six entries. In 1992, only ICSV 197 with an infestation of 34 bugs per 5 panicles, and IS 23948 with 28 bugs per 5 panicles were more infested than the local Farafara, with 23 bugs per panicle. In 1990 at Samanko, on both DOS, 11 entries had a damage score of ≤2.5, compared with DR ≥5.0 in ICSV 197. IS 8064, IS 14108, IS 17645, and IS 19948 had <20 bugs per 5 panicles, compared with >400 bugs per 5 panicles in ICSV 197.

Head bug resistant varieties (HBRVs) screening trial

Thirty-one HBRVs from ICRISAT Asia Center, India, including selected entries of 1989 and 1990 ISHBNs, were evaluated at Bagauda in 1990 and 1991, along with Nagawhite as local in an RCBD with three replications, under both natural and artificial head bug infestation. In the latter case, the headcage technique developed by Sharma et al. (1992) was used. Twenty *E. immaculatus* nymphs of the last two instars were confined with two panicles per plot at the dough stage and bug numbers were recorded 20 days later.

In 1990, head bug numbers under natural infestation ranged from 3 per 5 panicles on IS 17645 to 30 on IS 13560 (Table 1). IS 17645, IS 20740, and IS 20638 had the least number of bugs per panicle. Under artificial infestation, bug numbers ranged from 34 per 2 panicles on Nagawhite, to 271 on IS 16123. In 1991, head bug numbers per 5 panicles under natural infestation ranged from zero on IS 14108 to 37 on IS 13560. Under artificial infestation, bug numbers ranged from 10 per 2 panicles on IS 20740, to 694 on

Table 1. Head bug (*Eurystylus immaculatus*) numbers and damage on selected sorghum genotypes in the Head Bug Resistant Varieties Screening Trial, Bagauda, Nigeria, rainy seasons 1990 and 1991[1].

	Head bug number				Damage rating[2] (1991)	
	Natural infestation[3]		Artificial infestation[4]			
Entries	1990	1991	1990	1991	Natural infestation	Artificial infestation
IS 17645	3 (1.7)[5]	9 (2.3)	44 (6.7)	15 (3.8)	1.6	1.7
IS 20740	3 (1.8)	8 (2.7)	52 (7.2)	10 (2.9)	1.5	2.0
IS 20638	4 (1.9)	0 (0.3)	58 (7.6)	12 (3.4)	1.6	2.5
IS 8064	4 (2.1)	10 (3.0)	–	197 (13.5)	1.2	2.2
IS 14108	5 (1.7)	0 (0)	–	57 (7.5)	1.3	1.8
Nagawhite (local control)	8 (2.7)	8 (2.8)	34 (5.8)	197 (11.8)	1.9	3.0
SE	(±0.47)	(±0.59)	(±1.62)	(±3.0)	±0.15	±0.39
Mean (32 entries)	(3.1)	(2.9)	(10.2)	(11.8)	1.5	2.3
CV (%)	(27)	(35)	(28)	(47)	17	29

1. Randomized complete block designs with 3 replications.
2. Damage scored on a 1–9 scale, where 1 = all grains fully developed with a few feeding punctures, and 9 = most grains remaining undeveloped and barely visible outside the glumes.
3. Per 5 panicles.
4. Per 2 panicles.
5. Figures in parentheses are square root values.

IS 16123. Fewer than 50 bugs were recorded on IS 20740, IS 20638, IS 17645, and IS 23748. Damage rating under natural infestation varied from 1.2 to 2.1; it was 1.6 on IS 17645, 1.5 on IS 20740, and 1.6 on IS 20638. Under artificial infestation, DR varied between 1.7 and 3.2. The DR on IS 17645 was 1.7, it was 2.0 on IS 20740, and 2.5 on IS 20638. These genotypes consistently supported fewer head bugs than the other genotypes tested.

Advanced head bug screening trials

During the 1989 and 1990 rainy seasons, 12 sorghum cultivars were evaluated under both natural and artificial head bug infestation, in two DOS at Samanko (5 and 26 Jul in 1989, and 23 Jun and 13 Jul in 1990), and Cinzana, Mali (15 and 24 Jul in 1989, and 11 and 26 Jul in 1990) and at Farako-Bâ, Burkina Faso (11 and 21 Jul in 1989, and 7 and 28 Jul in 1990). Among the entries tested were six improved caudatum varieties from the ICRISAT West African Sorghum Improvement Program, three cultivars from the ICRISAT/IER–Mali bilateral program with CSM 388 as the local control, and Malisor 84-7 as the resistant control (Shetty et al. 1991), S 34 (a compact-panicled caudatum cultivar as the susceptible control), ICSV 2 (an improved cultivar from ICRISAT Asia Center, India), and Gadiabani (a local Malian durra cultivar).

The results of this study have been reported elsewhere (Ratnadass et al. 1991). Head bug infestation, population buildup, damage rating, 1000-seed mass, proportion of low-density grains, vitrosity, and germination rate were measured for infested and noninfested panicles. In addition, grain from the protected and infested panicles of selected entries were analyzed for dehulling recovery rate and quality of *tô*, a porridge made from sorghum.

Results confirmed high and stable resistance to bugs in Malisor 84-7, for all parameters measured under both natural and artificial infestation, and the dramatic effect of head bug damage in susceptible cultivars such as S 34 and Gadiabani.

In 1990, the same trial was conducted at Bagauda under natural head bug infestation. Head bug numbers per 5 panicles were <10 in ICSV 2 and Malisor 84-7, compared with 93 bugs per 5 panicles in ICSV 16-5 BF.

Breeding Sorghum for Resistance to *E. immaculatus*

In 1989 at Samanko and Farako-Bâ, we evaluated 89 F_6 progenies from crosses between high-yielding cultivars and cultivars less susceptible to *E. immaculatus* under natural head bug infestation. Malisor 84-7 served as the resistant control.

Eleven entries had a DR of ≤4.0 at both sites compared with 3.0 in Malisor 84-7 and >5.5 in 87W754, the most susceptible entry. Seven entries—87W736 and 87W795 [progenies from the cross (899-4 × ICSV 1002) × 84-F4-104] and 87W762, 87W769, 87W772, 87W807, and 87W810 [progenies from the cross ICSV 1002 × Malisor 84-7]—had <50 bugs per 5 panicles compared with 37 bugs per 5 panicles in Malisor 84-7.

In 1990, 80 of the same progenies were evaluated at Bagauda, along with two controls (Nagawhite and Farafara). The lowest head bug number, 4 per 5 panicles, was recorded on 87W810 compared with 54 per 5 panicles on Farafara.

Also in 1990, 42 F_7 and F_8 progenies, selected from the 1989 trials, were evaluated along with four controls under natural infestation in two DOS at Samanko (23 Jun and 13 Jul in 1990). In the first DOS, 13 entries had a DR lower than Malisor 84-7 (3.3), and the best were CSM 388 (1.7) and 87W810 (2.0), compared with 4.0 in susceptible S 34. On the second DOS, no entry had a score lower than Malisor 84-7 (2.7) except CSM 388 (2.0), compared with 5.3 in S 34 and 3.0 in 87W810.

In 1992 at Samanko, we evaluated 53 F_9 progenies derived from a cross between Malisor 84-7 and ICSV 1014, and five F_9 progenies from a cross between Malisor 84-7 and ICSV 1078, along with four controls, under natural head bug infestation. The most promising entry, 91W113-2-1 (derived from Malisor 84-7 × ICSV 1014), had 94 bugs per 5 panicles, compared with 41 on Malisor 84-7 and 450 on S 34. It had a DR of 3.7 compared with 2.0 for CSM 388, 3.0 for Malisor 84-7, and 5.3 for S 34. Time to 50% flowering was similar for the resistant and susceptible entries, with a mean of 86 days. Yield was slightly higher for 91W113-2-1 (1.04 t ha^{-1}) than for Malisor 84-7 (0.81 t ha^{-1}).

These results suggest that it is possible to transfer head bug resistance into good agronomic backgrounds using pedigree breeding selection.

Characterization of Genotypic Reaction Under *E. immaculatus* Infestation

Advanced Head Bug Trials were conducted during the 1991 rainy season at Samanko and Farako-Bâ, and during the 1992 rainy season at Samanko. We evaluated nine compact-panicled sorghum cultivars in two DOS in 1991 (1 and 22 Jul at Samanko, and 29 Jun and 19 Jul at Farako-Bâ), and 12 in one DOS in 1992. A local guinea cultivar served as control. The ten cultivars evaluated in 1991 consisted of the best two entries from the 1990 Preliminary Head Bug Screening Trial (87W810 and 89W891, advanced progenies from a cross between high-yielding ICSV 1002 and Malisor 84-7), three less susceptible entries (ISIAP Dorado, Gadiabani, and 84 F4-104), and five controls [ICSV 1063 (high yielding), S 34, and ICSV 197 (susceptible), Malisor 84-7 (resistant), and the local cultivars CSM 388 at Samanko, and Gnofing at Farako-Bâ]. In 1992, in addition to these 10 entries, we also evaluated Hadien-Kori (a Heggeri sorghum from the river Senegal region), ICSV 1002 (the high-yielding parent of 87W810 and 89W891), and ICSV 1079 (an improved cultivar). Observations were recorded as in the 1989 and 1990 Advanced Head Bug Screening Trials.

Data obtained in 1991 on head bug numbers and DR under natural and artificial infestation are presented in Tables 2 and 3. Infestation was maximum at Samanko on the first DOS, and at Farako-Bâ on the second DOS. On Malisor 84-7, we recorded 37 head bugs per 5 panicles at Samanko on the first DOS, and 30 head bugs per 5 panicles at Farako-Bâ on the second DOS, compared with 301 (at Samanko) and 331 (at Farako-Bâ) on ICSV 197. Under natural infestation, Malisor 84-7 had a visual DR of 3.8 at Samanko (first DOS), and 3.3 at Farako-Bâ (second DOS), compared with 6.7 on S 34 at both locations. These differences were partially confirmed under cage conditions. At Samanko, we recorded 57 bugs per panicle on the first DOS, and 69 bugs per panicle on the second DOS on Malisor 84-7, compared with >100 bugs on both DOS in CSM 388, ICSV 197, and 89W891. Under artificial infestation, Malisor 84-7 had a DR of 3.7 and 3.8, compared with 4.0 and 2.8 in CSM 388, and 7.2 and 6.5 in S 34.

In 1992 at Samanko, we recorded 28 head bugs per 5 panicles on CSM 388 and 67 bugs per 5 panicles on Malisor 84-7, compared with 340 on S 34 and 355 in Hadien-Kori. Under natural infestation, CSM 388 had a mean DR of 2.5 and Malisor 84-7 had 3.2, compared with 5.7 for S 34 and ICSV 197. Under cage conditions, we recorded 75 bugs per panicle on CSM 388 and 95 bugs per panicle on Malisor 84-7, compared with 510 on Hadien-Kori, and 484 on 89W891. DR under artificial infestation was 3.7 for CSM 388 and 4.8 for Malisor 84-7, compared with 4.5 for 87W810 and 7.7 for ICSV 197.

Table 2. Head bug numbers and damage under natural infestation on 10 sorghum cultivars in the Advanced Head Bug Screening Trial at Samanko (SA), Mali, and Farako-Bâ (FB), Burkina Faso, rainy season 1991.[1]

	Number of head bugs per 5 panicles				Damage rating[2]			
Cultivar	SA1	SA2	FB1	FB2	SA1	SA2	FB1	FB2
87 W 810	184 (13.4)[3]	82 (8.8)	69 (8.2)	154 (12.2)	4.5	4.3	4.8	5.5
89 W 891	163 (12.7)	107 (10.0)	49 (6.9)	147 (12.0)	5.7	6.0	5.2	5.5
ISIAP Dorado	94 (9.6)	41 (6.3)	35 (5.8)	108 (10.3)	5.0	5.7	5.2	5.8
Gadiabani	168 (12.7)	90 (9.3)	52 (7.0)	240 (14.7)	5.8	6.3	5.7	5.7
84 F4-104	143 (11.8)	67 (7.5)	80 (8.5)	75 (8.6)	5.2	4.3	5.3	5.2
Controls								
ICSV 1063 BF (high-yielding)	312 (17.6)	106 (9.8)	75 (8.1)	241 (15.5)	6.2	5.5	5.5	7.0
S34 (susceptible)	167 (12.4)	64 (7.9)	37 (5.8)	204 (13.9)	6.7	7.5	5.7	6.7
ICSV 197 (susceptible)	301 (17.2)	196 (13.3)	73 (8.2)	331 (18.1)	5.5	5.7	5.7	5.3
Malisor 84-7 (resistant)	37 (5.8)	14 (3.7)	5 (2.3)	30 (5.4)	3.8	2.8	4.3	3.3
Local control[4]	143 (11.7)	41 (6.3)	23 (4.8)	67 (8.2)	2.0	1.5	3.1	3.5
SE	(±1.45)	(±1.81)	(±1.18)	(±1.71)	±0.39	±0.43	±0.32	±0.32
Mean	(12.5)	(8.3)	(6.6)	(11.9)	5.0	5.0	5.0	5.4
CV (%)	(20.1)	(37.8)	(31.1)	(24.9)	13.4	15.1	10.9	10.4

1. Randomized complete block design with 3 replications for each location and date of sowing (DOS); 1 = first, and 2 = second DOS.
2. Damage scored on a 1-9 scale where 1 = all grains fully developed with a few feeding punctures, and 9 = most of the grains remaining undeveloped and barely visible outside the glumes.
3. Figures in parentheses are square-root values.
4. CSM 388 at Samanko; Gnofing at Farako-Bâ.

Table 3. Head bug numbers and damage under artificial infestion on 10 sorghum cultivars in the Advanced Head Bug Screening Trial at Samanko (SA), Mali, and Farako-Bâ (FB), Burkina Faso, rainy season 1991.[1]

	Number of head bugs per panicle			Damage rating[2]		
Cultivar	SA1	SA2	FB2	SA1	SA2	FB2
87 W 810	111 (10.3)[3]	141 (11.7)	78 (8.8)	5.0	4.0	5.5
89 W 891	199 (13.9)	156 (12.0)	74 (8.5)	5.7	5.0	6.0
ISIAP Dorado	53 (7.3)	72 (8.6)	53 (7.2)	6.5	6.5	6.2
Gadiabani	62 (7.8)	107 (10.2)	78 (8.8)	7.5	5.2	6.7
84 F4-104	66 (8.0)	71 (8.4)	75 (8.5)	7.2	5.8	5.0
Controls						
ICSV 1063 BF (high-yielding)	76 (8.7)	94 (9.5)	79 (8.6)	6.7	5.5	7.0
S34 (susceptible)	98 (9.7)	84 (9.2)	62 (7.8)	7.2	6.5	6.5
ICSV 197 (susceptible)	114 (10.6)	161 (12.6)	76 (8.6)	5.5	5.2	6.5
Malisor 84-7 (resistant)	57 (7.5)	69 (8.3)	43 (6.5)	3.7	3.8	3.5
Local control	176 (12.7)	100 (9.9)	96 (9.5)	4.0	2.8	2.7
SE	(±1.26)	(±1.21)	±0.33	±0.33	±0.36	±0.38
Mean	(9.7)	(10.0)	5.9	5.9	5.0	5.6
CV (%)	(23)	(21)	10	10	13	12

1. Randomized complete block design with 3 replications for each location and date of sowing (DOS); 1 = first and 2 = second DOS.
2. Damage scored on a 1-9 scale where 1 = all grains fully developed with a few feeding punctures, and 9 = most of the grains remaining undeveloped and barely visible outside the glumes.
3. Figures in parentheses are square-root values.

The proportion of light grains (percentage of floaters) in the first DOS and germination rate in the second DOS differed significantly ($P = 0.05$) in Malisor 84-7 between protected and artificially infested panicles. In contrast, ICSV 197 and S 34 showed markedly reduced quality for all parameters. Malisor 84-7, 87W810, and CSM 388 showed almost no reduction in dehulling recovery rate, while S 34 showed a marked reduction of 55% (Table 4). Malisor 84-7 showed no change in *tô* quality, whereas CSM 388 showed a noticeable decrease in acceptability of *tô* color.

Table 4. Effect of head bug infestation on dehulling recovery of selected sorghum cultivars in the Advanced Head Bug Screening Trial (first DOS), Samanko, Mali, rainy season 1991.[1]

	Dehulling recovery (%)[2]	
Cultivar	Protected[3]	Caged[3]
87W810	80 (63.6)[4]	66 (54.3)
S 34	73 (58.6)	32 (34.7)
Malisor 84-7	68 (56.1)	65 (54.0)
CSM 388	88 (70.1)	68 (55.5)
SE	(±3.01)	(±3.32)
Mean	(62.1)	(49.6)
CV (%)	(7)	(9)

1. Analyzed as a randomized complete block design with 2 replications.
2. Percentage recovery at dehulling with a tangential abrasive dehulling device (TADD).
3. Grains from protected panicles; and grains from panicles caged with 40 head bug (*Eurystylus immaculatus*) adults for 3 weeks.
4. Figures in parentheses are arc-sine transformed values.

In 1992, 1000-seed mass was not affected under natural head bug infestation in Malisor 84-7, ISIAP Dorado, and CSM 388, whereas it was reduced by over 30% in 89W891. Under artificial infestation, ISIAP Dorado, Malisor 84-7, CSM 388, and 87W810 showed <20% reduction in 1000-seed mass, compared with 48% in S 34, and 59% in Hadien-Kori. In the latter, quantitative loss was further aggravated by a reduction of 94% in dehulling recovery rate. The germination rate was similar for all the protected panicles, with a mean of 94%, while there were large differences for the artificially infested panicles. The local control, CSM 388 had a germination rate of 85%, while the only other varieties with a germination rate above 55% were Malisor 84-7 and 87W810.

Although the 1991 results confirmed the high level and stability of head bug resistance reported earlier in Malisor 84-7 (Shetty et al. 1991, Ratnadass et al. 1991, Sharma et al., 1994), this cultivar did not perform as well in 1992, particularly under artificial infestation. However, it remains our best source of head bug resistance among the compact-panicled types. ISIAP Dorado, although less infested and damaged by head bugs under natural conditions, had a high DR despite a medium level of infestation under cage conditions, and therefore was super-susceptible. On the other hand, 87W810 had a low DR despite medium infestation levels, and showed reasonable tolerance for head bug damage. In addition, its yield in 1992 was higher (1.44 t ha^{-1}) than those of Malisor 84-7 (1.23 t ha^{-1}) and CSM 388 (1.25 t ha^{-1}). In contrast, Hadien-Kori was highly susceptible. Although this cultivar genetically accounts for 12.5% of the Malian base population of sorghum from which the Malisor series was derived (Shetty et al. 1991), it is obviously not responsible for the resistance found in Malisor 84-7.

Mechanism of Resistance

As glume characteristics (e.g., length of period to glume opening) do not seem to be the factors imparting head bug resistance to Malisor 84-7, it has been suggested that the mechanism involved in this genotype might be a faster grain-hardening pattern (Sharma et al., 1994). Attempts to document this evidence were not quite conclusive (Touré et al. 1992). We therefore conducted studies in 1991 and 1992 at Montpellier, France, to further examine physical and chemical characteristics of maturing sorghum grains. These included the evaluation of the pericarp and endosperm hardness, dry matter content, free phenolic compounds, and tannins. Three sorghum cultivars, resistant Malisor 84-7, susceptible S 34, and moderately resistant IRAT 202 were used in this study.

The results of this study have been reported elsewhere (Fliedel et al. 1993). They suggested that grain hardening was due to the endosperm rather than the pericarp. Head bug resistance in Malisor 84-7 seemed to be related to endosperm hardening rather than to free phenolic compounds or tannin content which were much higher in IRAT 202, due to the presence of a subcoat in the grain of this cultivar.

Genetics of Resistance to *E. immaculatus*

As a first step in our attempts to elucidate the mode of inheritance of the resistance to head bugs in Malisor 84-7, we evaluated three sorghum cultivars, namely Malisor 84-7 (head bug resistant: R), S 34 and ICSV 197 (both susceptible: S), and the F_1s of the R × S crosses, at Samanko during the 1992 rainy season.

Results presented in Table 5 suggest that resistance is recessive in nature, and that there are no maternal effects. Although this resistance is apparently due to endosperm characteristics (Fliedel et al. 1993), it seems that its genetics follow the classical rules of diploidy. As a matter of fact, the hardening pattern of the endosperm could be controlled by the diploid cells of the plant rather than by triploid cells.

Table 5. Results of a preliminary study of the genetics of resistance to head bugs in sorghum[1].

Entries	No. of head bugs per panicle[2]	Damage rating[3]
Parents[4]		
Malisor 84-7 (R)	61 (7.8)	3.7
S 34 (S1)	157 (12.5)	8.0
ICSV 197 (S2)	186 (13.5)	7.4
F1		
R × S1	342 (18.5)	7.4
S1 × R	390 (19.6)	7.1
R × S2	284 (16.7)	7.0
S2 × R	243 (15.5)	6.4
SE	(±1.14)	±0.26
Mean	(14.8)	6.7
CV (%)	(13)	7

1. Randomized complete block design with 3 replications; artificial infestation under headcages with 40 head bug (*Eurystylus immaculatus*) adults for 3 weeks.
2. Figures in parentheses are square root transformed values.
3. Damage scored on a 1–9 scale, where 1 = all grains fully developed with a few feeding punctures; and 9 = most grains remaining undeveloped and barely visible outside the glumes.
4. Parents R = head bug resistant; S1 and S2 = head bug susceptible.

Conclusion

The availability of a reliable screening technique, under uniform pest pressure and no-choice conditions (Sharma et al. 1992), made it possible to identify sources of resistance to head bugs, and particularly to confirm the high and stable resistance in compact-panicled sorghum cultivar Malisor 84-7. The mechanism associated with resistance seems to be a quicker endosperm-hardening pattern in this cultivar, resulting in a shorter period during which head bugs can feed and lay their eggs in the maturing grains. These results need to be confirmed and the nature of this resistance elucidated.

Using pedigree breeding, it was possible to transfer head bug resistance from crosses between Malisor 84-7 and high-yielding cultivars, and from these were obtained two promising advanced progenies which combine reasonable head bug tolerance and acceptable agronomic characteristics. This result has been partly confirmed by a preliminary study of the mechanism of resistance, which showed the recessive nature of the gene(s) involved. These lines will be further evaluated in multilocational trials, and other populations and lines derived from similar crosses will be evaluated.

In addition to parents and F_1s evaluated in 1992, F_2s and BC_1s are currently being evaluated. The expected outcome of this study is to provide knowledge on the genetics of resistance. This information is needed to define the most appropriate breeding strategies to develop sorghum cultivars which combine head bug resistance with other desirable characteristics.

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Synthèse

Résistance variétale du sorgho à* Eurystylus immaculatus *en Afrique de l'Ouest. Des essais de criblage menés de 1989 à 1992 à Samanko au Mali et

Bagauda au Nigéria, il est ressorti que les variétés de sorgho IS 17645, IS 20740 et IS 20638 étaient constamment moins infestées par la punaise des panicules *Eurystylus immaculatus* que les autres variétés évaluées, toutes également à panicule lâche, et résistantes à *Calocoris angustatus* en Inde.

Malisor 84-7, une variété à panicule très compacte, issue de la population composite de base de sorghos du Mali (PCBSM), s'est montrée la plus résistante des 12 variétés évaluées, à la fois en conditions naturelles et artificielles d'infestation, à Samanko et Cinzana au Mali, et à Farako-Bâ au Burkina Faso, en 1989 et 1990, et sous infestation naturelle à Bagauda en 1990.

A Farako-Bâ, en 1991, et à Samanko en 1991 et 1992, Malisor 84-7 a confirmé le haut niveau et la stabilité de cette résistance, à la fois sous infestation naturelle et infestation artificielle, en termes de populations de punaises et de dégâts (note visuelle sur une échelle de 1 à 9), effet de l'attaque sur le poids de 1000 grains, la proportion de grains à faible densité, la germination, la vitrosité, le rendement au décorticage et la qualité du *tô*.

Bien que peu attractive pour les punaises, ISIAP Dorado était sévèrement attaquée sous infestation artificielle. Hadien-Kori, dont la contribution théorique au niveau génétique à la PCBSM est pourtant importante, se montrait la plus sensible de toutes les variétés évaluées en 1992. A l'inverse, 87W810, une descendance avancée d'un croisement entre ICSV 1002 et Malisor 84-7, s'est montrée tolérante aux attaques de punaises, ne présentant que des symptomes modérés malgré une infestation moyenne.

En 1992 à Samanko, 91W113-2-1, une descendance avancée d'un croisement entre ICSV 1014 et Malisor 84-7, combinait également un niveau raisonnable de résistance aux attaques de punaises avec des caractéristiques agronomiques acceptables.

Dans une tentative d'élucidation du mécanisme de résistance rencontré chez Malisor 84-7, on a effectué en 1991 et 1992 à Montpellier (France) diverses analyses physico-chimiques (mesure de la dureté par pénétrométrie, de la teneur en matière sèche, de celles en composés phénoliques et en tanins) sur les grains en maturation de trois variétés de sorgho. Au vu des résultats, qui ont montré que le durcissement des grains était le fait de l'albumen plutot que du péricarpe, et était plus rapide chez Malisor 84-7 (variété résistante aux punaises), que chez S 34 (sensible), et IRAT 202 (qui se classe intermédiaire malgré la présence d'une couche brune), on a attribué la résistance à ce durcissement plus rapide de l'albumen, plutôt qu'à une plus forte teneur en composés phénoliques libres ou en tanins.

Dans une étude préliminaire de l'hérédité de cette résistance, effectuée à Samanko en 1992, Malisor 84-7 et deux parents sensibles, ainsi que leurs F_1 ont été évalués sous infestation artificille par les punaises. L'étude a montré que la résistance est de nature récessive, et qu'il n'y a pas d'effet maternel, confirmant qu'il est possible de transférer cette résistance en la combinant avec des caractéristiques acceptables, par sélection généalogique.

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Screening and Breeding for Resistance to Millet Head Miner

O Youm and K A Kumar[1]

Abstract

The millet head miner, Heliocheilus albipunctella *de Joannis, is a key pest of millet in sub-Saharan Africa. To develop control strategies for reducing pest incidence, studies were conducted and focused on varietal resistance. These studies involved both natural infestation and artificial head cage infestation. While there were differences among genotypes in their reaction to head miner infestation, studies have shown that screening under natural conditions often yields variable results that can lead to erroneous conclusions. Furthermore, varieties with a shorter growing cycle (shorter time to 50% flowering) were more damaged than those with a longer cycle. To develop a more reliable screening technique, a headcage was used in conjunction with artificial infestation. Results showed that controlled cage infestation was more reliable than screening under natural infestation. Interactions occurred between panicle stage and stage of infesting larvae; and both affected the level of panicle damage. The infestation of millet at 1/3 panicle exsertion with 1-week old larvae resulted in more panicle damage than infestation with 1-day old larvae, based on a 1–9 rating scale (1 = <10%; 9 = >80% damage). Implications of these findings in future screening and breeding for head miner resistance are discussed.*

Introduction

Pearl millet, *Pennisetum glaucum* (L.) R. Br., is a major staple food crop in Africa, particularly in the Sahelian countries characterized by low and erratic rainfall (250–900 mm per year) and subsistence farming (Nwanze and Harris 1992). In recent reviews on insect pests of pearl millet in West Africa, the millet head miner, *Heliocheilus albipunctella* de Joannis (Lepidoptera: Noctuidae) was reported as a major insect pest (Ndoye and Gahukar 1987, Nwanze and Harris 1992). Damage to millet by *H. albipunctella* is caused by larvae feeding on floral glumes and peduncles. Severe damage can result in skeletonized panicles because larger larvae cut the floral peduncles, and grains are easily dislodged by the wind.

Given the importance of this pest, it is important to develop reliable control techniques. Among possible control techniques, host-plant resistance offers good potential. Resistant varieties would demand minimal farmer involvement in pest control, compared with chemical control which requires substantial inputs.

Field screening is relatively easy provided the insect under study is present at optimum density under natural conditions during the crop season. Resistance is determined by making comparative measurements at appropriate stages between material under test and known susceptible cultivars (Harris 1979). Field screening usually results in a range of 'core' parental material from which to identify resistant material for further use (Harris 1979). Another method is to evaluate plants under controlled infestation with a predetermined mean level of infestation. Abnormally high infestation levels are often as unsatisfactory for testing for resistance as are unusually low infestations. High infestation can overwhelm the expression of useful resistance in the former, and pseudo-resistance contaminates the latter (Painter 1951, Harris 1979). Screening and breeding for resistance therefore requires careful evaluation of these conditions so that reliable screening techniques and reliable resistant genotypes can be developed.

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ICRISAT Conference Paper no. CP 982.

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This paper reports findings on studies conducted to screen and select for resistance to *H. albipunctella* under both natural infestation and uniform artificial infestation at the ICRISAT Sahelian Center, Sadoré, Niger. The significance of these findings in relation to previous reports and future screening and breeding for resistance to head miner are discussed.

Materials and Methods

Field screening under natural conditions

These studies were conducted during the 1992 and 1993 rainy seasons at Sadoré to determine/identify varietal resistance from selected germplasm. Several experiments were conducted. Experiment 1 in 1992 consisted of a randomized block design with 10 replications comprising 20 subplots (each representing a variety), of 4 rows × 5 m long. Recommended agronomic practices were followed. In Experiment 2, eight replications and five varieties representing the following characteristics—bristled subcompact, non-bristled subcompact, compact, bristled hybrid, and a control—were used. Experimental procedures in 1993 were the same as in 1992 except that the subplot size was 3 rows × 5 m long. Experiment 1 in 1993 was a combined evaluation of the stem borer and head caterpillar and is not reported here. In Experiment 2, six varieties and nine of their related hybrids were evaluated. For Experiment 3, three near-isogenic bristled hybrids and their parents were compared with a known susceptible control for the effect of the bristled trait.

For all experiments, observations consisted of determining the number of larvae per panicle, the percentage of infested panicles at harvest, the number of mines per panicle, and the extent of panicle damage. Panicle damage rating was done at harvest by taking samples of panicles from each plot, and rating them for head miner damage on a 1–9 scale, with 1 = <10%, and 9 = >80% damage (Table 1).

Table 1. Rating scale used in screening reaction to millet head miner.

Rating scale[1]	Severity of panicle damage (percentage of infestation)	Classification
1	<10	Highly resistant
2	10–20	Resistant
3	21–30	
4	31–40	Moderately resistant
5	41–50	
6	51–60	Moderately susceptible
7	61–70	
8	71–80	Susceptible
9	>80	

1. Rating scale (1–9) described and recorded based on visual assessment of panicle damage.

Field screening under artificial infestation

The artificial infestation technique was a modification of the headcage technique for sorghum head bugs and sorghum midge (Sharma et al. 1992). Cage size was much larger (70–90 cm long × 30 cm diameter) in order to accommodate the long panicles of pearl millet.

In order to standardize this technique, an experiment was designed to provide information on the most susceptible panicle stage and the most damaging stage of early head miner instars for obtaining uniform panicle infestation. The experimental design was a split plot with panicle stage (1/3, 2/3, and full panicle exsertion) as the main plot, and the larval stage (1- and 7-day old) as the subplot. In order to obtain the required number of panicles at each stage, a susceptible dwarf variety, 3/4 KH-B78, was sown on two dates at 15-day intervals with 10 replications for each date. Larvae for artificial cage infestation were obtained in two ways: (a) field-collected eggs from a naturally infested head miner susceptible cultivar sown 2 weeks before sowing the experimental plots, and (b) eggs from light trap collected adults which had been held in pairs in the laboratory, in oviposition cages containing freshly cut millet heads. Both field- and laboratory-generated eggs were collected daily and transferred to an incubation room. After hatching, larvae were either used immediately (for 1-day-old larvae) or held on artificial diet until they were 7 days old. Fifteen larvae were transferred onto each test panicle using a fine camel hair brush. At crop maturity, the level of damage (based on a 1–9 rating scale) and head miner survival were recorded for each developmental stage of the panicle and infesting larvae.

Results

Field screening under natural infestation

There were significant differences among genotypes for the percentage of infested heads, the number of mines head^{-1}, panicle damage, and yield (Tables 2, 3, and 4). In 1992 (Experiment 1), varieties with the least infestation included ICMV IS 88201 (54%) and ICMV IS 85333 (56% head infestation). The highest infestation occurred on 410 × DGP1 (75%) and ICMV IS 86330 (73%). The improved local control CIVT had 67% infested heads. Results also showed a positive relationship between percentage head infestation, number of mines head^{-1}, and head miner damage rate. The yield for the hybrid 410 × DGP1 was not significantly different from that of CIVT, but twice as high as the yield of other varieties (Table 2). In 1992 (Experiment 2), a hybrid 488-99 × ICMV IS 86330 and its parent ICMV IS 86330 had the highest number of mines head^{-1} (3.7 and 2.9, respectively), and damage rate (2.7 and 2.2). MBH-110 and CIVT had the least number of mines head^{-1} (0.6 and 1.6) and the least damage rate (1.3 and 1.7). However, although CIVT consistently gave high yield, MBH-110 yielded the lowest among varieties, despite being the least infested (Table 3).

Reactions of nine inbred × variety hybrids to head miner in 1993 are shown in Table 4. Generally, inbred × variety hybrids were more infested than their pollinators. The greatest infestation occurred on 563 × P3 Kolo and 438 × CIVT among inbred × variety hybrids, and 3/4 KH-B78, a susceptible control. Generally, varieties that were more infested suffered the greatest damage. The lowest damage rates were observed on DGP1 (3.0), 2537 × GB8735 (3.2), and P3 Kolo (3.4). The susceptible control had a damage rating of 4.1. P3 Kolo, 2557 × DGP1, DGP1, and CIVT performed better. However, yields were generally low in all trials, and possibly due to additional damage by such other pests as the millet stem borer, blister beetles, or seed-sucking bugs, as no insecticide was used.

Reactions of the three near-isogenic bristled and non-bristled genotypes are shown in Figure 1. Since the presence and absence of bristles was the only differentiating character between the two groups, data were analyzed and compared for each group rather than for individual genotypes. Contrary to previous reports, the presence of a bristled head contributed to higher damage ratings. At low damage ratings (1–3), nonbristled head plants occurred more frequently than bristled head plants, while the reverse was true at high damage ratings (7–9). In the intermediate range (4–6), results were variable and not significant.

Table 2. Reaction of selected pearl millet varieties to the millet head miner, ICRISAT Sahelian Center, Niger, rainy season 1992 (Experiment 1).

Variety	Infested heads (%)	Number of mines head^{-1}	Damage rating[1]	Grain yield (t ha^{-1})
ICMV IS 90313	58.6	1.4	1.8	0.39
ITMV 8001	72.1	1.9	2.0	0.61
SOSAT-C88	57.7	1.4	1.8	0.29
ICMV IS 85327	68.4	1.7	1.9	0.37
ICMV IS 86330	73.4	3.0	2.6	0.41
ICMV IS 85333	55.6	1.1	1.7	0.50
410 × DGP1	74.6	2.4	2.1	0.98
ICMV IS 89200	71.1	2.0	2.0	0.37
ICMV IS 88201	54.0	1.1	1.6	0.41
Ex Bornu	57.7	1.2	1.7	0.43
CIVT	66.9	1.5	1.8	0.77
Mean (20 entries)	65.2	1.7	1.9	0.47
LSD (0.05)	10.6	–	0.2	0.5
CV (%)	18.4	27.5	11.6	48.0

1. Damage assessed on a 1–9 scale (see Table 1).

Table 3. Reaction of selected entries to the millet head miner, ICRISAT Sahelian Center, Niger, rainy season 1992 (Experiment 2).

Entry	Number of mines head-1	Damage rating[1]	Grain yield (t ha-1)
MBH-110	0.6	1.3	0.3
ICMV IS 86330	2.9	2.2	1.0
SOSAT C88	2.3	2.1	0.8
488-99 × ICMV IS 86330	3.7	2.7	1.0
CIVT	1.6	1.7	1.3
Mean (5 entries)	2.2	2.0	0.9
LSD (0.05)	0.8	0.4	–
CV (%)	33.7	19.5	20.3

1. Damage assessed on a 1–9 scale (see Table 1).

Table 4. Reaction of nine inbred × variety hybrids and their pollinators to the millet head miner, ICRISAT Sahelian Center, Niger, rainy season 1993.

Entry		Time to 50% flowering[1]	Infested heads (%)	Damage rating[2]	Yield (t ha-1)
Inbred	Variety				
563	P3 Kolo	60	92.1	4.8	0.16
	P3 Kolo	61	84.1	3.4	0.36
438	CIVT	58	93.3	4.0	0.24
513	CIVT	53	87.7	4.4	0.18
538	CIVT	59	86.1	3.7	0.17
	CIVT	59	88.8	3.9	0.26
488	DG P1	60	88.7	4.4	0.26
2557	DG P1	59	86.3	3.7	0.30
	DG P1	62	80.5	3.0	0.26
413	GB 8735	51	79.4	3.6	0.13
363	GB 8735	52	83.0	3.8	0.04
2537	GB 8735	51	75.8	3.2	0.15
	GB 8735	51	71.2	4.1	0.06
Controls					
	3/4 HK-B78	–[3]	90.3	4.1	0.20
	Ex Bornu	–	86.9	4.1	0.15
Mean (15 entries)		57.0	85.3	3.9	0.19
LSD (0.05)		1.7	9.5	0.9	0.12
CV(%)		3.0	12.5	25.9	68.6

1. Data from yield trial.
2. Damage assessed on a 1–9 scale (see Table 1).
3. – = not available.

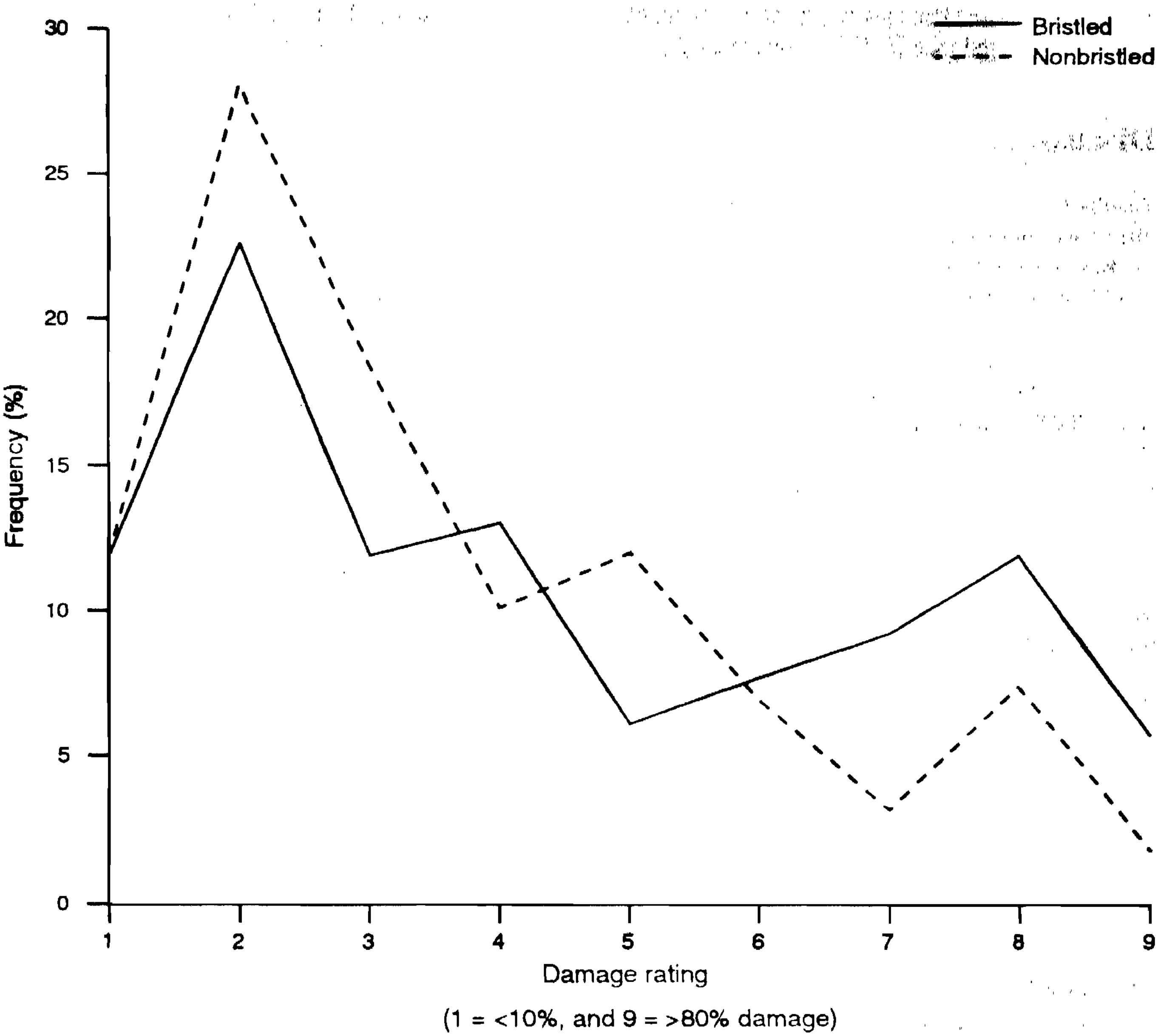

Figure 1. Frequency of damage rating on panicles of bristled and nonbristled near-isogenic pearl millet genotypes, ICRISAT Sahelian Center, Niger, rainy season 1993.

Results show that early-flowering inbred × variety hybrids are more susceptible to insect attack and suffer more yield losses than do late-flowering genotypes (Table 4).

Field screening under artificial infestation

Results on the development of a screening technique for pearl millet resistance using head cages are shown in Table 5. The infesting larval stage and the growth stage of the infested panicle significantly affected the extent of damage due to the head miner. Highest damage was caused by 1-week old larvae when infestation occurred at the beginning of panicle exsertion. One-week-old larvae caused more panicle damage than

Table 5. Damage caused by millet head miner larvae of two ages to millet panicles at three growth stages, ICRISAT Sahelian Center, Niger, rainy season 1993[1].

Stage of panicle	Infesting larval stage		
	1-day old	1-week old	Mean ± SE
1/3 exsertion	2.0 ± 0.4	4.0 ± 0.5	3.0 ± 0.4
2/3 exsertion	2.0 ± 0.3	1.9 ± 0.2	1.9 ± 0.2
Full exsertion	1.3 ± 0.1	2.5 ± 0.5	1.9 ± 0.3
Mean ± SE	1.8 ± 0.2	2.8 ± 0.3	

1. Damage assessed on a 1–9 scale (see Table 1).

1-day old larvae. Panicles were more susceptible when 1/3 exserted than at 2/3 or complete exsertion.

Discussion

Results from the current studies have shown varietal differences in reaction to the millet head miner (Table 1). Based on a 1–9 rating, most if not all varieties would be classified as resistant or tolerant. However, these results should be interpreted with caution. As shown in Tables 2 and 4, infestation levels were much higher in 1993 than in 1992, and for the same variety (e.g., CIVT), damage ratings were 1.8 and 1.7 in 1992 (Experiments 1 and 2), compared with a damage rating of 3.9 in 1993. This suggests that although varietal screening based on damage rating is consistent within a year, some variability can occur between years and does complicate assessment of resistance. Thus, screening under low population levels may result in the misidentification of varieties as resistant or susceptible. This scenario was described previously by Painter (1951). Abnormally high infestation levels are often as unsatisfactory for testing for resistance as are unusually low infestations. High infestation can overwhelm the expression of useful resistance in the former and pseudo-resistance contaminates the latter (Painter 1951, Harris 1979). From the present studies, it is clear that varieties tolerant of the head miner include CIVT, P3 Kolo, DGP1, 410 × DGP1, and MBH-110. Most of these varieties have a long time to 50% flowering, except for MBH-110. The latter variety is likely to have some resistance traits and should be re-evaluated under uniform artificial infestation. However, it is obvious from its yield that this variety may not be fully adapted to conditions in the West African Sahel.

Lack of reliable and reproducible screening techniques for uniform and optimum infestation of test material has justified screening genetic material for resistance under natural infestation (Nwanze and Harris 1992). In addition, breeding for insect resistance requires a range of germplasm and optimum technology and infrastructure for multilocational testing of identified sources of resistance.

Gahukar (1987) reported that both early and delayed flowering conferred resistance to the head miner. This mechanism of resistance (pseudo-resistance) is due to escape of plants at critical stages of infestation. He reported that open-pollinated varieties (ICMS 7703 and ICMS 7838) and a hybrid (ICH 165, bred in India) escaped millet head miner infestation because of their earliness, and varieties Souna (ex Senegal) and CIVT II (ex Niger) because of their lateness. However, considerable variation (genotype and genotype × year) in time to 50% flowering, the extent of the spike attacked, number of larvae per spike, and grain yield were reported. Not many studies have been carried out to understand the mechanisms of resistance to the millet head miner and only some explanations were provided based on field observations (Table 6). In many cases, the resistance mechanism reported was pseudo-resistance, which relates to temporal escape from pest attack. In this case, the susceptible stage of the millet panicle does not coincide or overlap with adult emergence and oviposition.

Nonpreference for head miner adult oviposition as a mechanism of resistance has been attributed to variations in the density, length, and orientation of involucral bristles (Nwanze and Harris 1992). Short involucral bristles and long floral pedicels do not favor oviposition as the eggs are normally laid at the base of the flowers, or stuck to rachis and floral peduncles (Guevremont 1982, 1983). Bal (1992) observed that the presence of involucral bristles did not reduce the extent of head miner attack in the variety IBMV 8413. Our observations have confirmed these results on a set of inbred × variety hybrids (Fig. 1). These results suggest that bristles alone do not offer protection or confer resistance as indicated by previous studies (Table 6).

In previous studies, low levels of head miner damage have been attributed to long and compact panicles (Vercambre 1978, in Nwanze and Harris 1992). However, these mechanisms are not clearly known and need further assessment and confirmation.

Table 6 provides a non-exhaustive summary and overview of findings on past research on breeding and screening for resistance to the millet head miner. Mechanisms of resistance previously reported include temporal escape (pseudo-resistance), nonpreference for female oviposition, tolerance, antibiosis, nonpreference due to the presence of bristles, their position and length, and other traits such as panicle compactness. In this table, there are conflicting results/findings, and some varieties have been reported resistant based on different mechanisms. Furthermore, the genotype IBMV 8001 has been reported as resistant in one study and as a susceptible in another. Guevremont (1982) reported that Souna III, CIVT, IBMV 8001, and Malian Souna were resistant, primarily due to pseudo-resistance through temporal escape. Therefore, as discussed early in our findings, screening under natural infestation where insect density is variable may prove to be difficult and unreliable. Based on available literature, the true

Table 6. Varieties reported as resistant to the millet head miner, and probable mechanisms involved.

Variety	Mechanism	Observations/ comments	Author
ICMS 7703 ICMS 7838 ICH 165 Souna CIVT II	Temporal escape (pseudo-resistance)	Results based on a 3-year study. High variability in percentage of attack. Other factors involved not investigated.	Gahukar (1987)
IBMV 8001 Souna ICMS 7838 H24 38 ICMS 7819	Nonpreference for oviposition	Mechanisms not known, further re-evaluation needed. IBMV 8001 reported susceptible (Bal 1992).	Gahukar (1984) (in Gahukar et al. 1986), N'Doye and Gahukar (1987), Gahukar et al. (1986) (in Bal 1992)
H9-127 ICMS 7819	Tolerance	True mechanism probably unknown.	Gahukar et al. (1986) (in Bal 1992), N'Doye and Gahukar (1987)
IBMV 8001 3/4 HK-78	Antibiosis	Tolerance and nonpreference mechanisms attributed to ICMS 7819.	
Nigerian Composite HK B-Tif CIVT HKP Zongo Nieluva Boudouma IBMV 8302 INMG1 INMG 52 SRM-Dori P3 Kolo, ITMV 8001 Kassa-blaga Youmee-Nini Tass-Yombo	Mentions bristles to lower infestation Other characteristics mentioned: e.g., compactness, position, and length of bristles.	HKP susceptible (ICRISAT 1987) Mechanisms not studied, further evaluation may be necessary.	[Gahukar (1981, 1984, 1986), ICRISAT (1984), Guevremont (1982, 1983), Maïga (1984), CILSS (1985) in N'Doye and Gahukar 1987]

mechanisms of resistance to head miner (except for reported pseudo-resistance) are not known, and no specific work has been conducted to determine the mechanisms involved. These findings outline the inconsistencies of previous reports linking the low infestation of long-cycle varieties with resistance to the millet head miner.

Conclusions

Lack of a reliable screening technique for resistance to the millet head miner has slowed the progress that can be realized by breeding resistant varieties. Both the literature and our own observations indicate that screening under natural infestation is unreliable. This has invariably led to reports that both early- and late-flowering genotypes possess pseudo-resistance (escape). Bristles do not appear to offer any protection at higher infestation levels. To overcome this problem and the variability associated with screening under natural infestation, the development of a uniform artificial infestation technique is critical. Thus, the technique based on caged-head infestation reported here is an important step in developing a more reliable screening method. From our studies, the most susceptible panicle stage and the most virulent early instars were identified. These findings are important in designing future screening methods. However, there is some merit in reconsidering the use of newly hatched larvae so that we do not lose on resistance due to very low larval establishment.

The commercial variety MBH-110 yielded less than any other variety tested, but had the lowest damage rating, suggesting that this variety may possess resistance traits, but was not adapted to West African conditions. Therefore this variety should be considered for re-evaluation under artificial uniform infestation. In an effort to develop a reliable screening method using cages, the most virulent stage of the pest and the most susceptible stage of the millet plant have been determined. This information will be used in future screening efforts to re-evaluate reported resistant varieties, identify resistant parental material, and understand the interactions between flowering and infestation levels.

Further studies should (a) investigate early-instar establishment on millet heads at 1/3 panicle exsertion, (b) determine the number of larvae per head required to cause a damage rating ≥7 on a known susceptible variety, (c) improve laboratory rearing techniques to reduce the time-consuming collection and processing of adults from light traps to laboratory oviposition chambers, and (d) re-evaluate genotypes previously reported to be resistant and determine the mechanisms involved.

Synthèse

Criblage et la sélection pour la résistance à la mineuse de l'épi du mil. La mineuse de l'épi, *Heliocheilus albipunctella* de Joannis est un important ravageur du mil en Afrique sub-saharienne. Des études portant sur la résistance variétale ont été menées dans le but de développer des moyens de lutte visant à réduire l'incidence de l'insecte nuisible. Ces études ont consisté à utiliser une technique d'infestation naturelle en champ, et une technique d'infestation artificielle de mise en cages des épis. Bien que des différences variétales existent parmi les génotypes au niveau de leur réaction à l'infestation par la mineuse de l'épi, ces études ont montré que le criblage en conditions naturelles souvent aboutit à des résultats variables pouvant mener à des conclusions erronées. En plus, les variétés à cycle court (temps à 50% floraison plus court) ont été plus endommagées que les variétés à cycle long. Dans le but de développer une technique de criblage plus fiable, une méthode de mise en cage des épis en conjonction avec une infestation artificielle a été utilisée.

En condition d'infestation naturelle, les résultats des essais de 1992 ont montré une différence significative parmi les variétés testées pour le pourcentage d'épis infestés, le nombre de mines par épi, le niveau des dégâts, et le rendement. Les variétés les moins infestées étaient ICMV IS 88201 (taux d'infestation de 54%) et ICMV IS 85333 (taux d'infestation de 56%). Les variétés les plus infestées étaient 410 × DGP1 (taux d'infestation de 75%) et ICMV IS 86330 (taux d'infestation de 73%). Cependant, le rendement de l'hybride 410 × DGP1 était meilleur que celui des autres variétés. Le nombre de mines par épi était moins élevé pour CIVT and MBH-110. Les résultats ont aussi montré que les hybrides résultant des croisements inbred × variétés étaient plus infestés que leur parents. Cependant, il y avait une variabilité au niveau des résultats. Les résultats ont montré que la technique de criblage par infestation en cage s'avère plus fiable que la technique de criblage en condition d'infestation naturelle. Il y avait des interactions entre le stade de développement des épis et le stade de développement des larves infestantes; et tous deux ont eu un effet sur le niveau des dégâts sur l'épi. L'infestation du mil au stade correspondant à 1/3 épiaison par des larves âgées d'une semaine a donné un plus grand niveau de dégâts que celui causé par les larves âgées d'un jour, d'après une méthode d'évaluation des dégâts échelonnée de 1 à 9 (1= <10% de dégâts; 9 = >80% de dégâts). Ces études nous ont permis de confirmer que le criblage en conditions naturelles n'est pas fiable et peut aboutir à des conclusions erronées. L'existence de caractères aristés n'a pas réduit l'infestation par la mineuse en présence d'une forte densité des populations.

Les études futures visant à développer des variétés résistantes à la mineuse de l'épi doivent (a) déterminer la survie des larves du premier stade sur les panicules en début (1/3) d'épiaison, (b) déterminer le nombre de larves par épi pouvant causer un niveau de dégâts égal ou supérieur à 7, (c) améliorer la technique d'élevage de la mineuse de l'épi afin de réduire le temps de collecte des adultes à partir des pièges lumineux et leur transfert au laboratoire pour la ponte, et (d) réévaluer les variétés précédemment signalées comme étant résistantes à la mineuse de l'épi et élucider les mécanismes de résistance.

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Short Communication/*Communication courte*

Breeding for Resistance to Sorghum Midge in West Africa

C C Nwasike[1]

Sorghum midge (*Contarinia sorghicola* Coq.) infestations have been reported from Nigeria (Harris 1961, 1976), Ghana (Bowden 1965), Burkina Faso (Nwanze 1988), and Senegal (Gahukar 1984).

Surveys in West Africa suggest that the intensity of midge attack is highest above 9°N latitude in the main sorghum-growing areas.

Most farmers in these areas do not recognize that the empty heads of sorghum are caused by midge and are unaware of the midge itself. Until they have learned to recognize cause and effect, control measures depending on their cooperation may not be successful. Physical and economic difficulties make cultural and chemical control methods unattractive to farmers.

Resistant varieties offer the most effective way of overcoming yield losses that may be due to sorghum midge. The development of a good resistant variety will entail a comprehensive breeding program that not only encompasses good insect pest management environments, but also effective selection methods. Existing knowledge of midge bioecology has increased the understanding of the mechanisms that influence the insect's response to sorghum plant characters (nonpreference) or the adverse effects of the host plant on the insect (antibiosis).

In West Africa, the development of insect-resistant sorghum cultivars has not been particularly targeted at midge compared to similar approaches on stem borers and head bugs. However, breeding methods that have been used elsewhere would be appropriate for this region.

Pedigree selection encourages the quick transfer of high levels of resistance to agronomically superior material which is used as the nonresistant parent. Advancing the generations and selection of desirable midge-resistance traits either at hot spots or under no-choice headcage conditions (Sharma et al. 1992) and backcrossing in the F_4 generation have resulted in high-yielding midge-resistant cultivars in Australia, India, and USA. Population improvement using composite bulks and male steriles and appropriate selection methods such as S_1 testing and recurrent mass selection can also generate materials that combine midge resistance with desirable agronomic characters. The introduction of elite varieties and use of low selection pressure in the population can enhance the selection process.

The ability to apply a rigorous set of evaluation criteria is pivotal in a pest resistance breeding program. Several parameters are used for midge resistance, including numbers of visiting adult flies during flowering, proportion of infested florets, proportion of damaged (chaffy) florets, and damage rating score.

Sélection pour la résistance à la cécidomyie du sorgho en Afrique de l'Ouest. Des infestations de la cécidomyie (*Contarinia sorghicola* Coq.) ont été enregistrées au Nigéria (Harris 1961, 1976), au Ghana (Bowden 1965), au Burkina Faso (Nwanze 1988), et au Sénégal (Gahukar 1984).

Les études entreprises en Afrique de l'Ouest laissent à croire que l'intensité de l'attaque par la cécidomyie du sorgho s'élève au maximum au-delà de la latitude 9°N, dans les zones principales de culture du sorgho.

La plupart des paysans de ces régions ne peuvent pas reconnaître que les panicules vides du sorgho sont causées par la cécidomyie et ignorent parfois l'existence même de l'insecte. D'où, la possibilité peu élevée de réussite des mesures de lutte qui dépendent de leur coopération, à moins qu'ils apprennent à reconnaître la cause et l'effet. Des difficultés physiques et

1. Department of Plant Science, Institute for Agricultural Research/Ahmadu Bello University (IAR/ABU), PMB 1044, Zaria, Nigeria.

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économiques ne peuvent que rendre peu attrayants au paysans, les méthodes de lutte chimique et culturale.

Les variétés résistantes représentent la solution la plus efficace pour maîtriser les pertes de rendement qui peuvent être attribués à la cécidomyie. Le développement d'une bonne variété résistante exigera l'organisation d'un programme de sélection d'une grande envergure, comprenant non seulement des environnements de lutte contre les insectes nuisibles, mais aussi des méthodes efficaces de sélection. Les connaissances actuelles sur la bioécologie de la cécidomyie ont permis d'améliorer la compréhension des mécanismes qui influencent la réaction de l'insecte aux caractères de la plante de sorgho (nonpréférence) ou les effets défavorables de la plante-hôte sur l'insecte (antibiose).

En Afrique de l'Ouest, la mise au point des cultivars de sorgho résistants aux insectes nuisibles n'a pas été ciblée à la cécidomyie en particulier, contrairement aux approches semblables sur les borers des tiges et les punaises des panicules. Cependant, les méthodes de sélection qui ont été utilisées ailleurs seraient appropriées à cette région.

La sélection généalogique favorise le transfert rapide de niveaux élevés de résistance au matériel de meilleure qualité agronomique qui est utilisé comme parent non-résistant. L'avancement des générations et la sélection de caractères souhaitables de résistance contre la cécidomyie soit à des sites de forte infestations ('hot spots'), soit dans des conditions en cage (Sharma et al. 1992), ainsi que le rétrocroisement dans la génération F_4 ont donné des cultivars performants et résistants à la cécidomyie en Australie, en Inde et aux Etats-Unis.

L'amélioration des populations en utilisant des bulks composites et des mâles-stériles, ainsi que des méthodes de sélection appropriées telles l'essai S_1 et la sélection massale récurrente peuvent également engendrer des matériels qui comprennent la résistance à la cécidomyie tout en retenant des caractères agronomiques souhaitables. L'introduction des variétés élites et l'utilisation d'une pression de sélection basse au niveau de la population peuvent améliorer le processus de sélection.

La possibilité d'appliquer une série rigoureuse de critères de sélection est essentielle à tout programme de sélection pour la résistance aux insectes nuisibles. Nombre de paramètres s'emploient pour la résistance à la cécidomyie, y compris le nombre d'adultes visitant au cours de la floraison, la proportion de fleurons infestés, la proportion de fleurons endommagés (fleurons stériles), et le score de dégâts.

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Summary of Discussion

Session 3

Midge resistance is governed by additive genes. Resistance is required in both parents, but crosses of resistant and moderately resistant parents could result in a susceptible hybrid due to cytoplasmic effects. Sources vary in their level of expression of resistance because the latter is affected by the level of midge infestation.

Using biotechnological tools it would be possible to identify sections of a chromosome with resistance genes, and resistant lines with the optimum combination of different genes can be identified through marker-aided selection.

Current research at the Texas A&M University, USA, indicates that it is possible to identify genes for midge resistance in a large F_2 population of sorghum. TAM 2566 and DJ 6514 are the major sources of midge resistance. The AF 28 type of resistance is very high and the other identified sources are potentially useful.

Resistance sources from India and USA reacted differently in West Africa under natural levels of infestation. DJ 6514 (India) and TAM 2566 (USA) were not used in these studies.

ICRISAT uses a 1–9 rating scale that is internationally accepted in resistance screening programs. Nearly 10 000 germplasm accessions have been screened for resistance to *Calocoris angustatus* in India, and about 40 lines have been identified with various levels of resistance to this species. Most of these lines showed cross-resistance to *Eurystylus* sp in West Africa. For optimum results, 20 pairs of bugs (female:male) are sufficient to cause maximum damage to grains in cages.

Characters such as short glumes that confer resistance to the sorghum midge, predispose the same genotypes to attack by head bugs. Although no attempt has been made to combine resistance in the same genotype to both pests, a panicle pest resistant population containing sources of resistance to both midge and head bugs has been developed at ICRISAT Asia Center, in India. The effectiveness of selection is yet to be evaluated.

At ICRISAT Asia Center, the focus is on breeding midge-resistant lines with bold seed, preferably white/cream colored, and with low tannin content. These lines are similar to the zerazera types of Ethiopia and Sudan which have high food value. Studies in Australia showed no difference in feeding value to livestock fed on midge-resistant and susceptible lines. Farmer/consumer food preferences should be incorporated into resistance breeding programs and collaboration with food technology/quality laboratories is highly desirable.

The range of material that has been screened for resistance to the millet head caterpillar includes varieties that have been in cultivation for several years, as well as varieties identified recently at Tarna, Niger, by H Guevremont and at Bambey, Senegal, by R T Gahukar. Several new varieties developed by ICRISAT in collaboration with national agricultural research systems have also been evaluated.

The choice of 1-week-old larvae and panicles at 1/3 exsertion is based on several studies to determine the larval and panicle stages for optimum infestation. The high mortality of newly hatched larvae would necessitate more larvae for infestation. However, specific studies on the optimum larval stage for artificial infestation may be needed since young and old larvae cause different types of damage.

Synthèse de discussion

Session 3

La résistance à la cécidomyie est gouvernée par des gènes additifs et doit être présente chez les deux parents. Cependant, le croisement entre des parents résistants et légèrement résistants peuvent aboutir à un hybride sensible à cause des effets cytoplasmiques. Le niveau de l'expression de la résistance des sources varie selon le niveau de l'infestation par la cécidomyie.

A l'aide des outils biotechnologiques, il serait possible d'identifier des sections d'un chromosome avec des gènes de résistance et des lignées résistantes avec une combinaison optimale de divers gènes grâce à une sélection appuyée par des gènes marqueurs.

Des activités de recherche conduites à l'Université Texas A&M, aux USA, indiquent qu'il est possible d'identifier chez le sorgho des gènes de résistance à la cécidomyie dans une grande population de F_2. TAM 2566 et DJ 6514 comptent parmi les importantes sources de résistance à la cécidomyie. La résistance de type AF 28 est très élevée et d'autres sources identifiées sont prometteuses.

Une réaction différentielle entre des sources de résistance provenant de l'Inde et des Etats-Unis a été observée sous l'infestation naturelle en Afrique de l'Ouest. DJ 6514 (Inde) et TAM 2566 (Etats-Unis) n'ont pas été utilisées dans ces études.

L'ICRISAT se sert d'une échelle de notation 1–9, qui est reconnue au niveau international dans les programmes de criblage. Près de 10 000 lots de ressources génétiques ont été criblés pour la résistance à *Calocoris angustatus* en Inde et environ 40 lignées avec divers niveaux de résistance à cette espèce ont été identifiées. La plupart de ces lignées ont manifesté de la réaction croisée à *Eurystylus* sp en Afrique de l'Ouest. Pour obtenir des résultats optimaux, 20 paires de punaises (femelle:mâle) sont assez nombreuses pour occasionner les plus importants dégâts aux grains dans les cages.

Des caractéristiques telles que des glumes courtes qui accordent au sorgho la résistance à la cécidomyie le rendent à la fois sensible aux punaises des panicules. On n'a pas réussi à combiner la résistance à ces ravageurs chez un seul génotype. Cependant, une population pourvue de résistance aux cécidomyies ainsi qu'aux punaises a été sélectionnée au Centre ICRISAT pour l'Asie, en Inde. L'efficacité de la sélection reste à être évaluée.

Au Centre ICRISAT pour l'Asie, la recherche est axée sur l'amélioration des lignées résistantes à la cécidomyie avec de gros grains, de préférence blancs ou crème et une teneur faible en tanin. Ces lignées sont semblables au type zerazera à valeur nutritive élevée de l'Ethiopie et du Soudan. Des études effectuées en Australie n'ont pas révélé de différence entre les lignées résistantes et sensibles en fonction de l'alimentation animale. Il importe d'incorporer des préférences alimentaires des agriculteurs et des consommateurs dans les programmes de sélection pour la résistance et collaborer avec des laboratoires de transformation et de qualité alimentaire.

La gamme des matériels qui ont fait l'objet du criblage pour la résistance aux chenilles des panicules du mil comprend des variétés qui ont été cultivées durant plusieurs ans ainsi que celles identifiées récemment à Tarna, au Niger, par H Guevremont et à Bambey, au Sénégal, par R T Gahukar. Plusieurs nouvelles variétés mises au point par l'ICRISAT en collaboration avec des programmes nationaux ont été aussi évaluées.

La choix des larves âgées d'une semaine et des panicules à 1/3 exsertion est basée sur des résultats de nombreuses études pour déterminer des stades larvaire et paniculaire pour une infestation optimale. Davantage de larves sont nécessaires pour l'infestation à cause de la mortalité élevée des larves nouvellement écloses. Cependant, il faut faire des enquêtes plus intensives sur le stade larvaire optimal pour une infestation artificielle puisque des larves jeunes et anciennes causent différents types de dégâts.

Session 4

Crop Management and Biological Control

Gestion des cultures et lutte biologique

Table 1. Natural enemies associated with *Heliocheilus albipunctella* (from Gahukar et al. 1986).

Parasites	
Egg	*Trichogrammatoidae* sp
	Litomastix sp (Encyrtidae)
Larva	*Pristomerus* sp (Ichneumonidae)
	Apanteles sp (Braconidae)
	Goniozus sp (Bethylidae)
	Bracon hebetor (Braconidae)[1]
	Cardiochiles sp (Braconidae)
	Chalcididae sp
	Goniphthalmus halli (Tachinidae)
Pupa	*Hadromanus* sp (Ichneumonidae)
	Thyridanthrax sp nr *kappa* (Tachinidae)
Predators	
Egg, larva	*Orius* sp (Anthocoridae)
Larva	*Glypsus conspicuus* (Pentatomidae)
	Ectomocornis fenestratus (Reduviidae)
	Katanga etiennei (Reduviidae)
	Chlaenius boiduvalii (Carabidae)
	C. dusaultii (Carabidae)
	Pheropsophus sp nr *lafertei* (Carabidae)
	Polistes sp (Vespidae)
	Eumenidae sp
	Formicidae sp
	Chrysopa sp (Chrysopidae)
Prepupa	*Formicidae* sp
Pupa	*Formicidae* sp
Diseases	
Nematodes	
Larva	*Hexamermis* sp (Mermithidae)
Fungus	
Larva	*Aspergillus flavus*
Larva, pupa	*Aspergillus* sp (*Ochraceus* group)
Bacteria	
Larva	Unidentified

1. Hyperparasites: *Eurytoma* sp (Pteromalidae), *Pediobius* sp (Eulophidae).

tissima Walker, *H. graminivora* Laporte, and *H. vercamrei* Laporte (Vercambre 1978). However, *H. albipunctella* is predominant in the Sahel, constituting 95% of the larval population and 98% of the captured moths (Gahukar et al. 1986). The geographic distribution of millet head caterpillar includes Burkina Faso, Chad, Gambia, Ghana, Mali, Mauritania, Niger, Nigeria, Senegal, and Sudan (Vercambre 1978). Information on the biology and ecology of *H. albipunctella* is fragmentary, and is found mostly in unpublished and inaccessible research reports. However, some published reports provide an excellent information base for a research plan to improve its management. In our view, the weakest links in this information base are the identity and ecology of associated natural enemies, and the impact of these enemies on *H. albipunctella* populations. Research on its natural enemies is essential before assessing possible biological control strategies, and to implement a comprehensive strategy for its management.

Ecology and biology

The millet head caterpillar has one generation per year, and bridges the noncrop, dry season as a diapausing pupa. Rain suitable for sowing millet at the end of the dry season also breaks diapause, and pupae resume development. Moths emerge about 30 days after the rain, and at about the same time millet panicles begin to develop. Peak moth emergence usually occurs in August. Adults live for about 5 days, and each female moth can oviposit 200 or more eggs. Eggs are oviposited individually or in small batches of up to 20; they are initially white but turn yellow as they mature. About 70% of eggs are oviposited during spike emergence, 10% during female flowering, 16% during male flowering, and 2.5% during the milky grain stage. About 90% of all eggs occur on the distal 3 cm of the panicle. Incubation is 2–6 days. Newly hatched larvae are quite mobile and their damage can be detected by the presence of white granular excreta around the flowers upon which they feed on the external surface of the panicle. Later they enter the spike where they feed internally in spiral tunnels and destroy flower peduncles. Larvae develop in 23–39 days through 4–6 instars. Mature larvae, or prepupae, drop from the plant to burrow into the soil. Soil texture dictates how deep the larvae burrow, but most stop at 10–15 cm beneath the soil surface in clay-loam soil, and 15–25 cm in sandy soil. Soil moisture content also affects the depth of burrowing. Pupae located in areas between plants occur at greater depths than those within 25 cm of plant hills. Pupation occurs 2–3 days after the larva drops to the soil, and pupae remain in the soil until the first good rain of the next season.

Table 2. Natural enemies associated with *Heliocheilus albipunctella*) (from Guevremont 1982).

Parasites	
Egg	Trichogrammatidae
	Encyrtidae (most abundant)
Larva	Ophioninae (sp no. 1) (Ichneumonidae)
	2 Braconid spp
	Goniozus sp (Bethylidae)
	Bracon hebetor
Pupa	Ophioninae (sp no. 2)
Predators	
Larva	*Glypsus conspicuus* (Pentatomidae)
	A eumenid wasp
Prepupa	An ant

Survival/mortality during development

Only 20–30% of hatched larvae reach maturity. Many unidentified mortality factors affect the young larvae. Diapausing pupae die as the dry season progresses from Nov to May. This mortality occurs mostly in upper soil levels, and is closely associated with soil temperatures and moisture at different depths. During Feb to May, soil surface temperatures can approach 45°C, and soil moisture is also lowest during this period. Pupal mortality is lower at greater depths, and is high at upper soil levels (where temperature reaches 50–55°C in Apr and May).

Natural enemies

Parasitism of immature stages of *H. albipunctella* occurs mostly late in the season when 80–90% of all stages may be parasitized. *Helicoverpa armigera* and *H. albipunctella* have common natural enemies; in areas where cowpea is sown simultaneously with millet, natural enemies which initially attack *H. armigera* on cowpea reportedly could move to *H. armigera* and *H. albipunctella* on millet. *Bracon hebetor* is commonly regarded as the most important larval parasite of *H. albipunctella*. This polyphagous, gregarious, ectoparasite was found to oviposit a maximum of 56 eggs on a single host larva, but averages only 12 eggs per host. Two chalcidoids (i.e., a eulophid and a pteromalid) hyperparasitize *B. hebetor* and reportedly reduce its efficiency by one third. Adults of *B. hebetor* have been observed aggregating on foliage of the gao tree, *Acacia albida*. Millet plants growing near the tree were only moderately infested by the head caterpillar and parasitism was high on these plants. *Bracon hebetor* also parasitizes larvae of *Ephestia* and *Corcyra* in stored millet, sorghum, maize, and rice, thus ensuring an effective carryover population in storage. *Cardiochiles sahelensis* and *C. variegatus* (Braconidae) are parasites of early- and middle-instar *H. albipunctella* larvae; and *C. variegatus* also attacks *H. armigera* larvae on millet, cowpea, maize, and sorghum. *Copidosoma* (= *Litomastix*) sp nr *truncatellum* (Encyrtidae), in the Sahel, parasitizes larvae of *H. armigera* on cowpea and *H. albipunctella* on millet. *Palexorista quadrizonula* (Tachinidae) parasitizes larvae of *Amsacta*, *Helicoverpa*, and *Mythimna* in pearl millet-cowpea cropping systems in the Sahel. *Goniphthalmus halli* (Tachinidae) also attack larvae of *H. armigera* on grain legume and cereals in the Sahel. Reportedly, prepupae are preyed on by ants. Parasitism of *H. albipunctella* pupae is not common, and apparently does not exceed 2%. Pupae are parasitized by the dipterous parasite, *Thyridanthrax* sp nr *kappa*, and by an ophionine species that attacks late larvae. A cohesive control strategy is not available for millet pests. Most control methods are cultural, and these include early sowing, deep plowing, and residue removal and destruction. Early sowing decreases stem borer damage, but increases head caterpillar numbers; deep plowing decreases pupal populations, but increases wind erosion; and residue destruction and removal decreases borer populations, increases wind erosion of the soil, and eliminates stems as a building material.

Research Plan

A clear need exists to identify and quantify the sources of *H. albipunctella* mortality. We are engaged in collaborative research to assess extant natural enemies. The results will provide a basis to develop and appraise biological control strategy for this pest. We plan to construct life tables and conduct exclusion studies on the insect's developmental stages which have high levels of mortality caused by natural enemies. The 1993 activities focus on field trials of methodology and materials to quantify mortality to each developmental stage. We are also experimenting with maintaining a continuous culture of *H. albipunctella* and developing the collaborative ties needed for this work in Niger.

Beginning in 1994, experiments will be conducted to construct an age-specific life table for the millet head caterpillar. Our experiments will focus specifically on identifying and assessing mortality caused by natural enemies. Sources of mortality will be investigated for all developmental stages throughout the growing season, and on pupae after harvest. Our research approach will use host exposure techniques, caged exclosures, and natural population monitoring. Host exposure techniques place millet head caterpillar developmental stages (i.e., cohorts) in different habitats, including millet crops and wild noncrops. These studies seek to determine linkages between a natural enemy and its host. Our design will assess sources and magnitude of mortality for each *H. albipunctella* stage in these habitats. Additionally, samples of naturally occurring stages will be taken at regular intervals throughout the year.

Naturally oviposited eggs of *H. albipunctella* on millet heads will be counted and held in the laboratory for hatching or emergence of parasites. Naturally occurring larvae will be collected from the field and held in the laboratory for emergence of parasites. Pupae will be sampled in the soil during the dry season to determine viability, and to assess mechanisms to break diapause and sources of pupal mortality. Adult insects will be monitored using light traps, and dissections will be made to assess female mating and fecundities. Finally, in 1994, we will begin paired comparisons of caged exclosures to directly examine population trends in the presence and absence of natural enemies. Natural enemies will be excluded from one-half of the experimental plots by using fully enclosed cages, and permitted free access to the other half by using partially enclosed cages.

Synthèse

La lutte biologique contre la mineuse de l'épi de mil—besoins, stratégies et perspectives. L'historique des programmes sur la lutte biologique contre les arthropodes témoigne des résultats très encourageants. Or, ces programmes n'ont concerné que l'emploi des ennemis naturels exotiques pour maîtriser des insectes ravageurs sur des cultures pérennes. Ces expériences jettent peu de lumière sur les possibilités ou les besoins de la lutte biologique pour des cultures annuelles ou sur l'emploi des ennemis naturels indigènes. Il faut donner une grande priorité aux efforts soutenus de conservation ou d'exploitation des ennemis naturels, surtout dans les pays moins développés. Cependant, l'élaboration de ces stratégies de lutte doit se fonder sur une base de données fiable d'évaluation des ennemis naturels. Lorsque des ennemis naturels s'avèrent efficaces contre des ravageurs spécifiques, ils peuvent servir de moyens de lutte peu coûteux et de grande envergure. Leur utilisation est généralement compatible avec d'autres méthodes de lutte non pesticides.

La mineuse de l'épi de mil, *Heliocheilus albipunctella* (de Joannis) (Lepidoptera: Noctuidae) est l'un des plus redoutables insectes nuisibles au mil en Afrique occidentale sahélienne. Les pertes de rendement du mil occasionnées par des larves en développement peuvent atteindre 50%. Le cas de *H. albipunctella* présente un excellent exemple pour la lutte biologique puisque le ravageur occupe un habitat prévisible dans un écosystème relativement stable, a une génération par an sur une culture annuelle, s'attaque à plusieurs espèces sauvages de mil et est attaqué par une assez large gamme d'ennemis naturels. Mais la difficulté est que l'écologie des ennemis naturels et leur impact sur les populations de *H. albipunctella* sont mal connus. La recherche sur leur écologie et efficacité est indispensable à l'élaboration des stratégies de lutte biologique globales contre la mineuse de l'épi de mil.

Vu la nécessité d'identifier et de quantifier les sources de la mortalité de *H. albipunctella*, des activités de recherche conjointes ont été entreprises sur des ennemis naturels et les résultats de la recherche serviront de base pour la mise au point et l'estimation d'une méthode de lutte biologique. Nous projetons de dresser des tableaux sur les cycles biologiques et de réaliser des études sur les étapes de développement de *H. albipunctella* qui montrent des niveaux élevés de mortalité à cause des ennemis naturels. Nos activités sont axées sur des essais en champs sur la méthodologie et les matériels pour déterminer le taux de mortalité due aux ennemis naturels par rapport à chaque étape de développement. Les techniques de l'exposition de l'hôte, la mise en cage et la surveillance de la dynamique des populations naturelles seront utilisées dans la recherche.

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Genotype-pest-parasitoid interactions in sorghum: sorghum midge

K G Kausalya[1], K F Nwanze[2], Y V R Reddy[2] and D D R Reddy[1]

Abstract

The results of a study on the effect of host-plant resistance on the development and population dynamics of the sorghum midge, Contarinia sorghicola *and one of its parasitoids,* Tetrastichus *sp, are presented. Three resistant (ICSV 745, ICSV 89058, and IS 10712) and three susceptible (Swarna, CSH 9, and ICSV 112) sorghum genotypes were sown on three dates each during the rainy and postrainy seasons of 1992/93. A modified headcage was developed for monitoring insect populations. The onset of parasitoid emergence was similar in resistant and susceptible genotypes, but commenced 2–3 weeks after initiation of midge emergence.* Tetrastichus *activity was higher in the first and third sowing dates than in the second, and greater numbers were recovered from susceptible than from resistant genotypes. The lowest levels of parasitization were recorded from midge-resistant ICSV 745, but no significant differences were found in the pattern of parasitoid emergence or the level of midge parasitization between resistant and susceptible genotypes. These results suggest that antagonistic effects on midge parasitoid development are not always associated with resistance factors. This indicates that there is the possibility of interphasing the breeding for host-plant resistance with enhanced biological control in the integrated management of sorghum midge.*

Introduction

The sorghum midge, *Contarinia sorghicola* Coquillett (Diptera: Cecidomyiidae) is a widely distributed pest of grain sorghum in Africa, Australia, India, and USA. Most commercially available high-yielding varieties and hybrids are usually more susceptible to midge damage than local landraces. Annual yield loss from midge damage has been estimated at $292 million worldwide (ICRISAT 1992). Research on midge has focused on the development of resistant cultivars. This effort has produced several midge-resistant varieties and hybrids in India, Australia, and USA. Some attention has also been given to integrated pest management (IPM) strategies with host-plant resistance (HPR) as a major component (Teetes 1985). Improved cultural practices, chemical insecticides, and biological control methods have been advocated in IPM. Although there are reports indicating the efficacy of biocontrol agents in reducing midge infestation (Chundurwar 1977, Garg and Taley 1978), it is not known if plant resistance factors influence parasitoid activity, i.e., if host-plant resistance and biocontrol have complementary, antagonistic, or synergistic effects. This could happen through the modification of host-plant cues which could be an important factor in the orientation of parasitoids to their hosts or in the effect of antibiotic resistance factors on parasitoid development. *Aprostocetus diplosidis* Crawford, a parasitoid of midge, is attracted to sorghum plants from a distance of about 3 m but not to midge larvae located at the same distance (McMillian and Wiseman 1979). The incorporation of resistant maize in the meridic diet of the armyworm, *Spodoptera frugiperda* Smith, resulted in prolonged developmental time in progenies of *Campoletis sonorensis* Cameron,

1. Andhra Pradesh Agricultural University, Rajendranagar 500 030, Andhra Pradesh, India.
2. ICRISAT Asia Center, Patancheru 502 324, Andhra Pradesh, India.

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a parasitoid of *Heliothis zea* Boddie (Isenhour and Wiseman 1989).

Franzmann et al. (1989) reported that the parasitization of midge larvae was higher on resistant than on susceptible sorghum genotypes; however, no explanation was given for this observation. The effects of resistance factors in sorghum genotypes on developing midge larvae are likely to be exhibited on the next trophic level of association, i.e., on midge parasitoids.

We examined this hypothesis in field experiments conducted at ICRISAT Asia Center, India. This paper presents the results of the first part of this study, in which we monitored the development and population dynamics of sorghum midge and its predominant parasitoid (*Tetrastichus* sp), on resistant and susceptible genotypes. Experiments were conducted during two crop seasons in 1992 and 1993. The possible interactions between identified resistance factors and parasitoid activity are also discussed.

Materials and Methods

Field studies were conducted during both rainy and postrainy seasons of 1992/93 using three resistant (ICSV 745, ICSV 89058, and IS 10712) and three susceptible (Swarna, CSH 9, and ICSV 112) sorghum genotypes. Experiments were laid out in randomized blocks of eight rows each of 9 m length, with three replications on three sowing dates (6, 15, and 30 Jul 1992 in the rainy season and 29 Oct, 13 Nov, and 1 Dec 1992 in the postrainy season) in order to monitor midge and parasitoid activity throughout the season. A basal dose of ammonium phosphate @ 150 kg ha^{-1} was applied at sowing. Thinning was done 10 days after crop emergence (DAE) and all other agronomic practices were carried out where necessary. Shoot fly, *Atherigona soccata* (Rondani) infestation was controlled during early seedling growth by applying cypermethrin (22.5 g a.i. ha^{-1}) at weekly intervals. The rainy-season crop received supplementary irrigation as necessary while the postrainy-season crop was grown under irrigation.

In each season, three sorghum panicles at half anthesis, in each replicate, for the six genotypes and three sowing dates were artificially infested with 40 midge females on two successive days using the headcage technique (Sharma et al. 1988). Five days after infestation, the panicles were exposed to natural parasitization for 10 days and thereafter re-caged for parasitoid development and emergence. Similarly, another set of unexposed panicles was used to determine the level of midge infestation.

For collecting emerging insects, the upper end of the head cage was modified by fitting a 5 cm long (1 cm diameter) plastic tube over the central ring of the head cage. This tube was held in place at its lower end by a thermocole cork while the collection chamber, which consisted of an inverted 15 mL plastic cup, was fitted over the upper end of the connecting tube. For insect collection, the cage was covered with a black cloth bag the previous evening, leaving the collection container as the only source of light. Emerging insects were attracted to light and could thus be collected in the plastic cup the following morning. After insect collection, the cloth bags were removed and the open end of the connecting tube was closed with a plastic lid. This procedure was repeated daily for about 10 days, to ensure collection of all emerging midge flies and parasitoids.

Data were recorded on the number of emerging midge flies and parasitoids on a daily basis and averaged for standard weeks. The level of parasitization was calculated on the basis of total emerging parasitoids (p) and midge flies (m) from exposed panicles as follows:

$$\frac{p}{m+p} \times 100$$

Results

Collections of natural enemies of sorghum midge during both seasons revealed three larval parasitoids (*Tetrastichus* sp, *Eupelmus* sp, and *Apanteles* sp) and one predator, *Orius* sp (Fig. 1). All four species were active throughout each season. *Tetrastichus* sp was by far the predominant species, constituting 95% and 98% of the total parasitoids in the rainy and postrainy seasons. The other parasitoid species and *Orius* sp, occurred in very low numbers, but the predator was relatively more abundant in the postrainy than in the rainy season.

Rainy season 1992

Tetrastichus sp was active during the second and third weeks of Oct and during the second fortnight of Nov. The first peak in activity occurred during the second and third weeks of Oct (Fig. 2, weeks 41 and 42) when mean weekly collections ranged from 4 to 6 parasitoids earhead^{-1}. However, the major peak in

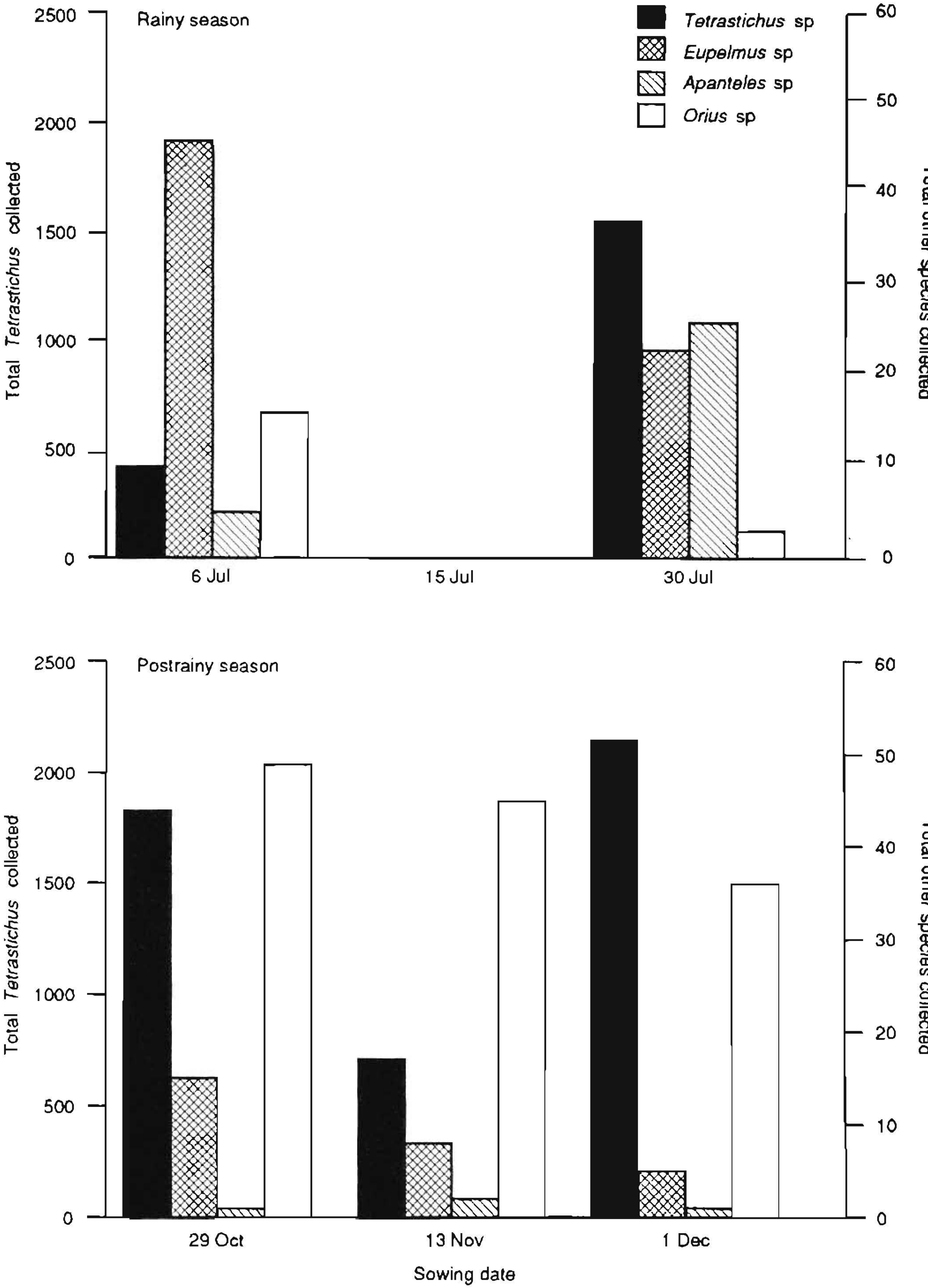

Figure 1. Total emerging natural enemies from midge-infested sorghum panicles at ICRISAT Asia Center, 1992/93.

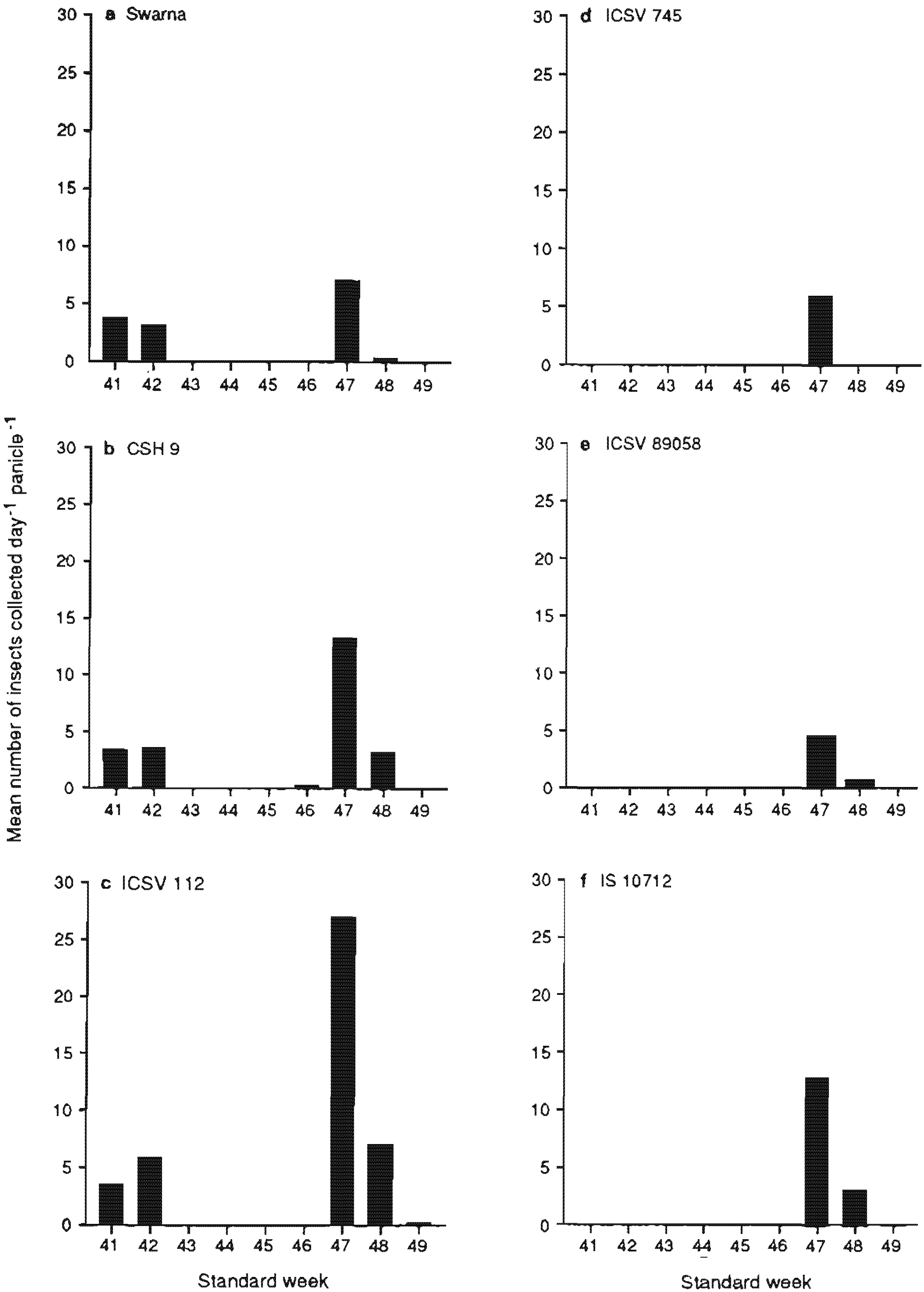

Figure 2. Population dynamics of *Tetrastichus* sp, ICRISAT Asia Center, rainy season 1992.

Table 1. Levels of parasitization of midge (*Contarinia sorghicola*) in resistant and susceptible sorghum genotypes, ICRISAT Asia Center, rainy season 1992.

	Level of parasitization (%)[1]		
	Sowing dates		
Genotype	6 Jul	15 Jul	30 Jul
Swarna	19.2	0.0	13.3
CSH 9	2.6	0.0	22.4
ICSV 112	4.9	0.0	28.2
ICSV 745	0.0	0.0	0.0
ICSV 89058	0.0	0.0	13.5
IS 10712	2.2	0.0	17.0
SE (Rep)	1.08	±0.0	±4.59
Rep × Genotype	±2.80	±0.0	±12.40

1. Based on percentage chaffy florets with parasitoid exit holes.

activity occurred on the late-sown crop during the third week of Nov (Fig. 2, week 47) when the weekly collections were 7–27 parasitoids earhead^{-1} in susceptible genotypes and 5–13 parasitoids earhead^{-1} in resistant genotypes.

Data on midge emergence was unavailable for the rainy season. Therefore, the level of parasitization was assessed from chaffy florets with parasitoid exit holes (Table 1). In the first sowing date, the level of parasitization was high on susceptible Swarna but negligible on other genotypes. No parasitoids were recovered from resistant ICSV 745 and ICSV 89058. No parasitoids were recorded from any genotype in the second sowing date although midge infestation (% chaffy florets) ranged from 13 to 23% in the resistant and 48 to 56% in the susceptible genotypes. In the third sowing, parasitization was recorded in all genotypes except in resistant ICSV 745. The levels ranged from 13 to 28%, with the highest population being recorded on ICSV 112.

Postrainy season 1992/93

Adult midge flies emerged 2–3 weeks earlier than the parasitoids. The first distinct peak in midge emergence occurred in the second week of Feb (Fig. 3, week 7) in susceptible ICSV 112, CSH 9, Swarna, and resistant ICSV 89058. Several generations of midge were produced on susceptible genotypes during the season and the highest occurred on ICSV 112 in the fourth week of Feb (Fig. 3c, week 9). The first adult *Tetrastichus* sp was recorded in the third week of Feb. As in the rainy season, major activity occurred at the end of the crop season in Feb (week 9) and in late Mar and early Apr (weeks 13 and 14). More individuals were recovered from susceptible than from resistant sorghum genotypes. Parasitoid activity was always associated with midge infestation in resistant genotypes even at low midge populations. This relationship was present to a lesser extent in susceptible genotypes.

Although there were clear differences in midge infestation and parasitoid numbers between resistant and susceptible genotypes (Fig. 3), the levels of parasitization were consistent across genotypes and within each sowing date (Table 2). Among the susceptible genotypes, parasitization was lowest in Swarna (lower than in resistant ICSV 89058). The lowest level of parasitization was recorded in ICSV 745 across all sowing dates.

Discussion

The results of our study showed that *Tetrastichus* sp was the predominant parasitoid of sorghum midge on the ICRISAT Asia Center farm in 1992/93. Other species were present in negligible numbers, and species composition and predominance was not affected by crop sowing date or varietal resistance to midge.

Table 2. Levels of parasitization of midge (*Contarinia sorghicola*) in resistant and susceptible sorghum genotypes, ICRISAT Asia Center, postrainy season 1992/93.

	Level of parasitization (%)[1]		
	Sowing dates		
Genotype	29 Oct	13 Nov	1 Dec
Swarna	35.8	16.8	56.1
CSH 9	48.8	23.7	76.3
ICSV 112	41.1	28.5	68.0
ICSV 745	29.7	20.2	28.8
ICSV 89058	44.8	30.5	72.2
IS 10712	36.2	15.0	51.9
SE (Rep)	±32.90	±0.82	±0.48
Rep × Genotype	±9.76	±5.27	±8.65

1. Based on total emerging parasitoid (p) and midge flies (m) from exposed panicles and calculated as: p/(m+p) × 100.

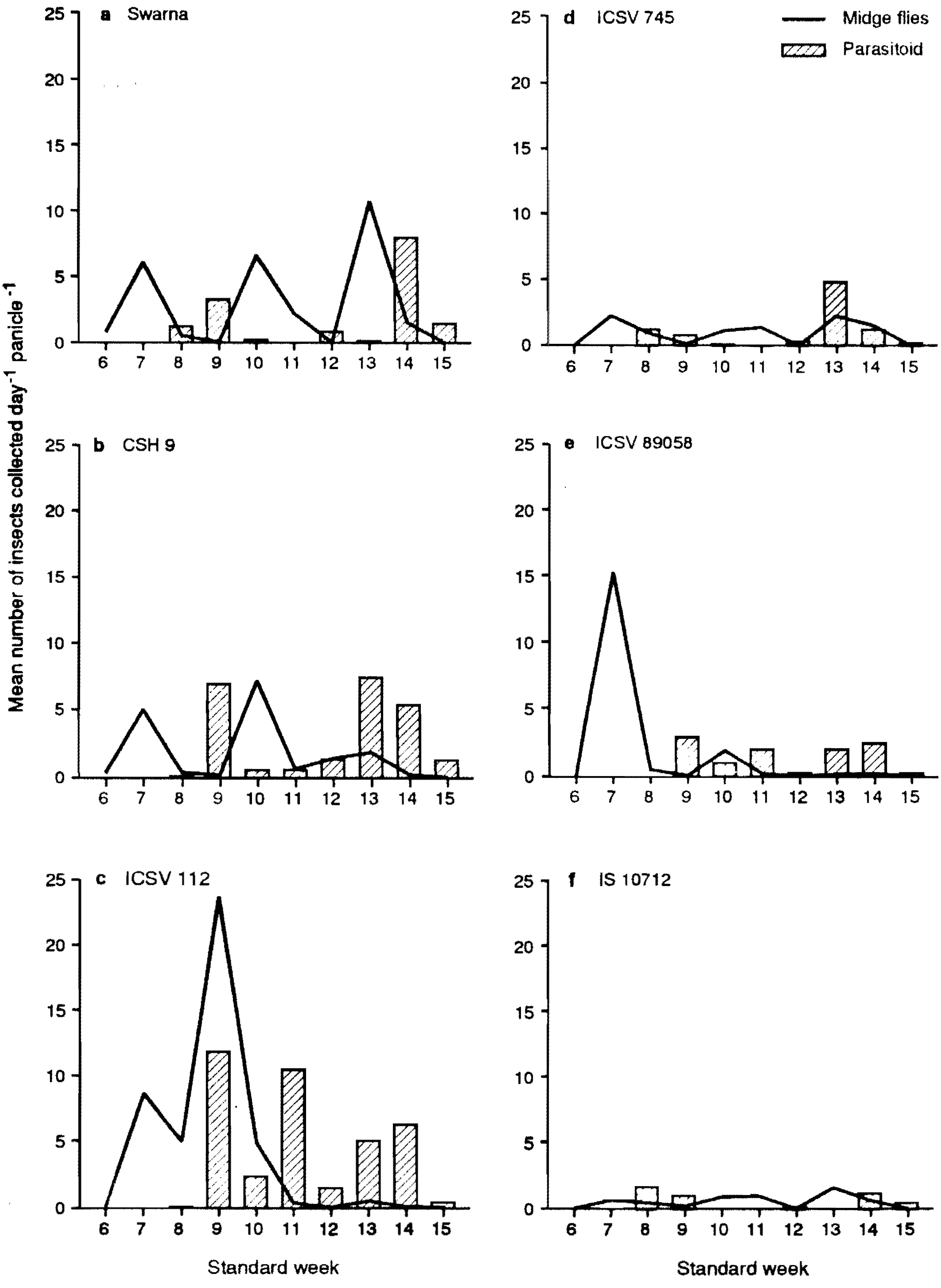

Figure 3. Population dynamics of sorghum midge and *Tetrastichus* sp, ICRISAT Asia Center, postrainy season 1992/93.

Though *Apanteles* sp has been recorded only in our studies, *Tetrastichus* sp and *Eupelmus* sp are well documented parasites of midge larvae in other parts of the world, although the predominant species varied with location. *Eupelmus* sp was reported as the predominant species in India (Chundurwar 1977) and in Senegal (Coutin 1970), whereas a different species, *Aprostocetus diplosidis*, was the predominant parasitoid species in Australia (Franzmann et al. 1989) and USA (Wiseman et al. 1978).

The high numbers of *Tetrastichus* sp obtained at the end of each crop season at the ICRISAT farm confirms earlier reports of Garg and Taley (1978) and Chundurwar (1977). Gahukar (1984) also reported effective control of midge by *Tetrastichus* sp at the end of the cropping season. These reports associated increased parasitoid activity with high midge infestations which occurred with delayed sowing. However, no explanation has been given for the decline in parasitoid activity in the intervening period even when host insects were available.

In this study, although more parasitoids were recovered from susceptible than from resistant genotypes, the level of parasitization was high in some resistant genotypes in spite of low midge activity; an observation which confirms an earlier report by Franzmann et al. (1989). This indicates that varietal resistance did not adversely affect parasitoid development and activity. However, differences in *Tetrastichus* sp parasitization rates among resistant genotypes suggest that there may be differences between genotypes in the effect of midge resistance factors on *Tetrastichus*.

Two resistance factors, faster grain development and short glume length, have been associated with resistance in DJ 6514 (Sharma et al. 1990), a parental line from which ICSV 745 was developed. These characteristics effectively restrict the space within the floret for larval development and larvae are known to become dislodged and exposed to desiccation and predation. These factors would similarly not favor the survival of *Tetrastichus* sp and may explain the low level of successful parasitization in ICSV 745. Sharma et al. (1993) also suggest that resistance in IS 10712 is due to antibiotic factors. Our results indicate that these factors have no antagonistic effect on parasitoid activity in IS 10712. The mechanism and factor(s) of resistance in ICSV 89058 are not known, but it is clear from our results that they do not interfere with the development of *Tetrastichus* sp.

Fecundity in midge is high. Each female fly produces an average of >100 eggs (Murthy and Subramaniam 1975, Passlow 1973) and a life cycle is completed in 17–20 days under favorable conditions. In contrast, fecundity in *Tetrastichus* sp is much lower (50 eggs female^{-1}) and the life cycle is completed in 21–25 days (Taley et al. 1978, Thontadarya et al. 1983, Garg 1979). In susceptible sorghum genotypes, with such a disparity in fecundity and developmental period between the parasitoid and its host insect, high levels of parasitization will still result in considerable pest damage. In resistant genotypes, especially where resistance mechanisms and factors are not antagonistic to parasitoid development, varietal resistance and biological control are highly complementary.

There were intervals during the crop season when *Tetrastichus* sp populations were low in spite of high midge populations, and no explanation has been given for this observation. This merits further examination in the context of integrated pest management since it may offer the possibility of crop management practices that could enhance parasitoid activity during critical periods of pest population development.

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Synthèse

Les interactions génotypes-ravageurs-parasitoïdes chez le sorgho. On est bien renseigné sur les ennemis naturels de la cécidomyie du sorgho, mais on l'est beaucoup moins sur leur efficacité sur les génotypes du sorgho résistants ou sensibles. Des études en champs ont été effectuées au cours de 1992/93 pendant les saisons pluviale et postpluviale. Trois génotypes résistants à la cécidomyie (ICSV 745, ICSV 89058 et IS 10712) et trois sensibles (Swarna, CSH 9 et ICSV 112) ont fait l'objet d'analyse des interactions de niveau tritrophique entre le sorgho, la cécidomyie, et son parasitoïde principal, *Tetrastichus* sp.

Les panicules de sorgho à demi-anthèse ont été artificiellement infestées de cécidomyies à l'aide de la technique de mise en cage des épis (Sharma 1988). Cinq jours après l'infestation, les panicules ont été exposées au parasitisme naturel pendant 10 jours et remises en cage pour permettre le développement et l'émergence du parasitoïde.

Pour prélever des parasitoïdes émergents, nous avons modifié la partie supérieure de la cage en fixant un tube de plastique de 5 cm de long et de 1,0 cm de diamètre au-dessus de l'ouverture centrale de la cage. Ce tube a été maintenu en place à son extrémité inférieure par un bouchon de polystyrène expansé tandis que la cellule de prélèvement, qui consistait en un petit verre en plastique de 15 mL mis à l'envers, a été fixée au-dessus de la partie supérieure du tube en connexion. Pour collecter les insectes, la cage a été couverte d'un sac à toile noire la veille au soir. On n'a laissé comme seule source de lumière que le récipient de prélèvement. Les insectes émergents sont attirés par la lumière et on a ainsi pu les récupérer dans le récipient le lendemain matin. Après le prélèvement des insectes, on a retiré les sacs de toile et on a fermé l'extrémité du tube de prélèvement avec un bouchon de plastique. Ce procédé a été répété tous les jours pendant 10 jours afin d'assurer l'émergence complète des cécidomyies et des parasitoïdes.

Des collections d'ennemis naturels de la cécidomyie du sorgho pendant et après la saison des pluies ont révélé trois larves parasitoïdes (*Tetrastichus* sp, *Eupelmus* sp et *Apanteles* sp) et un prédateur (*Orius* sp). *Tetrastichus* sp était de loin l'espèce prédominante pendant les deux saisons. Dans la saison des pluies on a enregistré une intense activité de *Tetrastichus* sp au cours des 2e et 3e semaines d'octobre (Fig. 2, semaines 41 et 42) et la pointe d'activité a eu lieu au cours de la 3e semaine de novembre (Fig. 2, semaine 47). Le niveau du parasitisme des larves de la cécidomyie en fin de saison déterminé à partir de fleurons stériles ayant des trous de sortie du parasitoïde s'est situé entre 13 et 28%.

Pendant la saison post-pluviale, l'émergence des adultes de la cécidomyie a eu lieu 2 à 3 semaines plus tôt que le parasitoïde chez les génotypes résistants et sensibles. La première pointe distincte d'émergence de la cécidomyie s'est produite au cours de la 2e semaine de février (Fig. 3, semaine 7) chez les génotypes sensibles ainsi que le génotype résistant, ICSV 89058. Les premiers adultes de *Tetrastichus* sp ont été signalés au cours de la 3e semaine de février (Fig. 3, semaine 8) chez tous les génotypes. L'intense activité s'est produite à la fin de février (Fig. 3, semaine 9), fin mars et début avril (Fig. 3, semaines 13 et 14).

Malgré de très nettes différences dans les infestations de la cécidomyie et le nombre de parasitoïdes entre les génotypes résistants et sensibles (Fig. 3), le niveau du parasitisme n'a pas varié sur l'ensemble des génotypes et au cours de chaque date de semis (Tableau 2). Parmi les génotypes sensibles, le parasitisme était le plus faible chez Swarna. En fait le niveau du parasitisme chez Swarna a été plus faible que celui du génotype résistant, ICSV 89058. Parmi tous les génotypes, ICSV 745 a eu le niveau du parasitisme le plus faible pour toutes les dates de semis.

Dans cette étude, bien qu'on ait prélevé un plus grand nombre de parasitoïdes chez les génotypes sensibles que résistants, le niveau du parasitisme a été élevé chez certains génotypes résistants malgré une faible activité de cécidomyies; cette observation confirme un rapport antérieur de Franzmann et al. (1989). L'étude indique que la résistance variétale n'a pas eu d'effet négatif sur le développement et l'activité du parasitoïde. Cependant, les différences dans le niveau du parasitisme de *Tetrastichus* sp chez les génotypes résistants suggèrent qu'il peut y avoir des différences entre les génotypes relatives aux effets des facteurs de résistance à la cécidomyie sur *Tetrastichus* sp. Les mécanismes et les facteurs de résistance sont examinés en fonction de l'importante disparité qui existe entre la fécondité et la période de développement de l'hôte et du parasitoïde. Même si l'activité du parasitoïde est plus élevée chez les génotypes sensibles, les dégâts causés par la cécidomyie auraient été tout de même considérables. Cependant, chez les génotypes résistants, surtout là où les mécanismes et les facteurs de résistance ne s'opposent pas au développement du parasitoïde, la résistance variétale et la lutte biologique pourraient très bien se révéler complémentaires.

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Effect of Crop Management Practices on *Eurystylus immaculatus* on Sorghum

O Ajayi and R Tabo[1]

Abstract

Different crop management practices were examined in relation to the incidence of the head bug Eurystylus immaculatus: *date of sowing, intercropping, nitrogen levels, and plant density. Four dates (15 and 29 Jun, 13 and 27 Jul) were tested in 1991 and five dates (3 Jun, 1, 15, and 22 Jul, 5 Aug) in 1992 at Bagauda, Nigeria. Date of sowing significantly affected the population of* E. immaculatus; *peak infestation occurred in the mid-Jul sowing in 1991 and in the 3 Jun sowing in 1992. Depending on the sorghum cultivar used, intercropping sorghum with soybean decreased head bug incidence on sorghum by up to 22% in 1989 and by 8–49% in 1991. Both the 1:1 and 1:2 sorghum:soybean row arrangements had fewer head bugs than sole sorghum. Intercropping with pigeonpea reduced head bug infestation by 3% averaged over three sorghum and two pigeonpea cultivars. Intercropping sorghum with pearl millet and cowpea had no effect on head bug numbers on ICSV 247 but increased them 2–3 fold on the taller and later-maturing Gaya Early. Significantly more head bugs were found on the compact-headed ICSH 507 than on ICSV 247, but Samsorg 14, a later-maturing variety, had more head bugs than either. Neither variations in plant density between 2.7 and 17.8 plants m^{-2} nor level of nitrogen fertilizer between 0 and 90 kg N ha^{-1} significantly affected head bug populations on sorghum.*

Introduction

Head bugs have recently been identified as key pests of improved sorghum cultivars in West Africa. *Eurystylus immaculatus* Odhiambo is the most important of these pests in terms of population and damage inflicted on the grain (MacFarlane 1989). Yield losses of up to 86% have been attributed to head bug damage (ICRISAT 1990) and the need to apply control measures is recognized. As part of the development of an integrated pest control strategy, the effect of sorghum management practices on the incidence of *Eurystylus* was studied at Bagauda, Nigeria, from 1989 to 1992. These practices were date of sowing, intercropping, nitrogen fertilizer levels, and plant density. The effect of sowing date was examined by Ratnadass (1993) in Mali, where the highest population of head bugs was recorded on sorghum sown on 22 Jun. Ratnadass (1993) also reported that intercropping sorghum with legumes (soybean, cowpea, and groundnut) did not significantly affect the incidence of head bugs at Samanko and Longorola in Mali. The effects of fertilizer and plant density have not been documented before.

Materials and Methods

Effect of intercropping

Sorghum/soybean intercrop. In 1989, a short-duration sorghum variety (ICSV 247) and a short-duration sorghum hybrid (ICSH 507) were either intercropped with short-duration soybean (TGX 1486-1D) in a 1:1 alternate row arrangement or sown as sole crops. In both cases, the ridges were 75 cm apart, the intra-row spacing was 25 cm (2 plants hill^{-1}) for sorghum, and 10 cm (2 plants hill^{-1}, 2 rows

1. ICRISAT West African Sorghum Improvement Program (WASIP)—Nigeria, IITA Office, Sabo Bakin Zuwo Road, PMB 3491, Kano, Nigeria.

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per ridge) for soybean. Each intercrop plot was 6 m × 7.5 m while sole crop plots measured 5 m × 9 m. All component crops were sown on 28 Jun and fertilizer was applied @ 300 kg NPK (15:15:15) ha^{-1} at sowing with a topdressing of 100 kg urea ha^{-1} (on sorghum only) 4 weeks after sowing. At the soft dough stage of grain development, five randomly selected sorghum panicles per plot were excised and placed in polythene bags. The number of *Eurystylus* nymphs and adults were counted in the laboratory. In 1991, a long-duration sorghum variety, Samsorg 14, was added and three row arrangements (1:1 and 1:2 sorghum: soybean, and alternate stands within the row) were used. The trial was sown on 19 Jun in 1991. Observations were made as in 1989.

In 1992, the same three sorghum cultivars were used to evaluate the effect of row arrangement and plant density on *Eurystylus* infestation in an intercrop with soybean (TGX 1497-1D). The 18 treatment combinations (3 sorghum cultivars × 1 soybean cultivar × 3 row arrangements × 2 soybean densities) were arranged as a randomized 3 × 3 × 2 factorial design. The row arrangements were the same as in 1990 and 1991. Plant densities were 10.6 plants m^{-2} for sole sorghum, 5.3 plants m^{-2} for intercropped sorghum, and 13.3 or 26.6 plants m^{-2} for soybean in both the sole and intercrops. The trial was sown on 30 Jun. All other treatments and data collection were as described for 1989.

Sorghum/pigeonpea intercrop. In 1991, three sorghum cultivars (Sor)—ICSV 247, ICSH 507, and Samsorg 14—and three pigeonpea cultivars (P)—ICPL 84023 (extra short-duration), ICPL 151 (short-duration), and ICPL 87067 (medium-duration)—were intercropped in a 1:1 Sor:P row arrangement. The trial was sown on 18 Jun. In 1992, ICSV 247 and Samsorg 14 were intercropped with ICPL 87 and ICPL 87067 in two row arrangements (1:1 and 2:1 Sor:P). The trial was sown on 30 Jun. A randomized block design with three replications was used in both trials. Each plot was 6 m × 6 m with rows spaced 75 cm apart. Intercropped sorghum and pigeonpea were sown at densities of 5.3 and 2.7 plants m^{-2} respectively. The density of sole sorghum was 10.6 plants m^{-2} while that of sole pigeonpea was 5.3 plants m^{-2}. A basal application of 300 kg NPK (15:15:15) ha^{-1} was given and urea (100 kg ha^{-1}) was applied to sorghum only, approximately 3 weeks after sowing. In each year, the population of *Eurystylus* on sorghum panicles was estimated as described for the 1989 sorghum/soybean intercrop.

Sorghum/millet/cowpea intercrop. In 1992, the population of *Eurystylus* on sole sorghum (ICSV 400) was compared with that in mixtures with pearl millet (Ex-Bornu) and cowpea (Kannanado and IT715). Sorghum and millet were sown on the same day (30 Jun) in alternate rows at 2.6 or 5.3 plants m^{-2}. Cowpea was sown on 17 Jul either in alternate rows or in alternate stands within millet rows. IT 715 a short-duration IITA cultivar with a semi-erect growing habit, was sown at 2.6 plants m^{-2} while Kannanado a later-maturing, spreading local variety was sown at a density of 1.3 plants m^{-2}. *Eurystylus* populations on sorghum were determined as described earlier.

Effect of plant density, fertility, and cultivars. In 1989, ICSV 247 and ICSH 507 were sown on 29 Jun in 75 cm rows in a split plot design. The main plots consisted of five plant densities (2.7, 5.3, 10.6, 13.3, and 17.8 plants m^{-2}) and the two cultivars were subplots. There were three replications. Each plot measured 25 m × 6.75 m. Fertilizer application and insect counts were as described earlier.

In 1991, ICSV 247, ICSH 89002 NG, and Samsorg 14 were each grown at three densities (5.3, 10.6, and 17.8 plants m^2), each receiving four rates of nitrogen (N) fertilizer (0, 30, 60, and 90 kg ha^{-1}). A split plot design was used, with nitrogen as the main plots and cultivars as the subplots, each treatment being replicated three times. Each plot measured 52.5 m^2 (10 m long × 5.25 m wide).

Effect of sowing date. ICSV 247 was sown on four dates (15 and 29 Jun, 13 and 27 Jul) in 1991 and five (3 Jun, 1, 15 and 22 Jul, 5 Aug) in 1992. Each plot was 5 m × 3 m with four rows spaced 75 cm apart, and each treatment was replicated four times. Fertilizer application and *Eurystylus* counts were as reported above for the intercropping trials. In addition, grain yield was recorded at harvest and the extent of grain damage caused by *Eurystylus* was determined at grain maturity by visually scoring on a 1–9 scale, where 1 = grains with few feeding punctures, and 9 = grains undeveloped and not visible outside the glumes.

Results and Discussion

Effect of sowing date

In the 1991 trial, the head bug population was lower on the first (15 Jun) and last (27 Jul) sowings than on the others, reaching a peak on the 13 Jul sowing (Table 1).

Table 1. Effect of sowing date on head bug (*Eurystylus immaculatus*) incidence and damage on sorghum (ICSV 247), Bagauda, Nigeria, rainy season 1991[1].

Sowing date	Head bug number[2]		Damage rating[4]	Grain yield (t ha^{-1})
15 Jun	90.5	(9.5)[3]	1.4	4.17
29 Jun	165	(12.7)	2	2.88
13 Jul	198.3	(14.1)	5	1.52
27 Jul	55.5	(7.2)	4.4	0.66
Mean	127.3	(10.9)	3.2	2.31
SE		(±0.85)	±0.37	±0.250
CV (%)		(15)	23	21

1. Randomized complete block design with 4 replications; plot size 15 m^2.
2. Counted on 5 randomly selected panicles at the dough stage.
3. Figures in parentheses are square root transformed values.
4. Damage scored on a 1–9 scale, where 1 = grains with few feeding punctures, and 9 = grains undeveloped and not visible outside the glumes.

Grain damage was lower in the first sowing than in the others, with the greatest damage occurring on the 13 Jul sowing. Grain yield decreased with an increase in head bug population and damage, being highest in the 15 Jun sowing and lowest in the 27 Jul sowing. The reduction in yield with progressive delay in sowing was partly due to plant physiological factors, particularly soil moisture, and to head bug feeding damage.

In 1992, there were large differences in head bug populations between sowing dates. For example, 20 days after half-anthesis, there was a mean of 604 *Eurystylus* per 5 panicles for the earliest date (15 Jun), 272 for the 1 Jul date; and 103, 88, and 63 for the 15 Jul, 22 Jul, and 5 Aug sowings (Table 2). The corresponding damage ratings showed the same decreasing pattern. The results suggested that sorghum sown early attracted more *Eurystylus* than did later sowings. While infestation of the earliest sowing occurred at the milky stage, infestation commenced progressively earlier, at the flowering and pre-flowering stages, for the later sowing dates. The combined effects of head bug damage and moisture availability caused a reduction in grain yields if sowing was delayed beyond 1 Jul. The low grain yield in the 3 Jun sowing was caused by a severe early-season drought.

These results clearly demonstrate that sowing date strongly affects the level of infestation and damage to sorghum by *Eurystylus*. Of the dates tested in 1989, the best date for sowing for low head bug damage and high yield was 15 Jun. However, in 1992, the earliest dates, which had the highest infestation and damage levels, also gave the best grain yields. Ratnadass (1993) also recorded more head bugs on the 22 Jun sowing than on the 13 Jul sowing in Samanko. Dates of sowing can therefore be manipulated to avoid severe damage to sorghum by *Eurystylus*.

Table 2. Effect of sowing date on head bug (*Eurystylus immaculatus*) incidence and damage on sorghum (ICSV 247), Bagauda, Nigeria, rainy season 1992[1].

Sowing date	Head bug number[2]		Commencement of infestation	Damage rating[3]	Grain yield (t ha^{-1})
3 Jun	6.4	(24.52)[4]	Milky stage	5.6	2.4
1 Jul	272	(16.43)	Half-anthesis	4.5	4.5
15 Jul	103	(9.77)	Half-anthesis	3.8	3.8
22 Jul	88	(9.12)	Preflowering	3.7	2.3
5 Aug	63	(7.148)	Preflowering	3.4	0.6
SE		(±1.128)		±0.24	±0.17
Trial mean	226	(13.46)		4.2	2.7
CV (%)		(16)		11	12

1. Randomized complete block design with 4 replications; plot size 15 m^2.
2. Counted on 5 randomly selected panicles 20 days after half-anthesis.
3. Damage scored on a 1–9 scale, where 1 = grains with few feeding punctures, and 9 = grains undeveloped and not visible outside the glumes.
4. Figures in parentheses are square root transformed values.

Table 3. Effect of plant density on head bug (*Eurystylus immaculatus*) incidence and damage on sorghum at Bagauda, Nigeria, rainy seasons 1989 and 1991[1].

Plants m^{-2}	Number of head bugs[2]							
1989	ICSV 247		ICSH 507		Samsorg 14		Mean	
17.8	52	(7.21)[3]	166	(12.48)	-		109	(9.85)
13.3	99	(9.69)	308	(17.38)	-		203	(13.53)
10.6	80	(8.70)	311	(16.9)	-		196	(12.80)
5.3	48	(6.78)	190	(13.56)	-		119	(10.17)
2.7	106	(9.71)	244	(15.54)	-		175	(12.63)
Mean	77	(8.42)	244	(15.17)	-			
SE (plant density)		(±1.263)						
SE (cultivars)		(±0.516)						
CV (%)		(26)						
1991	ICSV 247		ICSH 89002 NG		Samsorg 14		Mean	
17.8	9.3	(3.27)	11.1	(3.21)	34.7	(6.78)	18.37	(4.42)
10.6	10.1	(3.08)	17.1	(4.00)	51.5	(6.24)	26.23	(4.47)
5.3	11.7	(2.89)	10.9	(3.12)	50	(5.58)	24.20	(3.87)
Mean	10.37	(3.08)	13.03	(3.48)	45.4	(6.20)		
SE (plant density)		(±0.198)						
SE (cultivars)		(±0.392)						
CV (%)		(28)						

1. Split plot design with 3 replications (main plot: density, subplot: cultivars).
2. Counted on 5 randomly selected panicles 20 days after half-anthesis.
3. Figures in parentheses are square root transformed values.

Table 4. The effect of N fertilizer rates on incidence of head bug (*Eurystylus immaculatus*) on sorghum at Bagauda, Nigeria, rainy season 1991[1].

N rate (kg ha^{-1})	Number of head bugs[2]							
	ICSV 247		ICSH 89002 NG		SAMSORG 14		Mean	
0	8.06	(2.76)[3]	10.3	(3.10)	29.4	(5.34)	15.90	(3.73)
30	10.7	(3.14)	14.6	(3.71)	47.2	(6.28)	24.17	(4.38)
60	14.6	(3.66)	10.8	(3.10)	74	(7.72)	33.13	(4.83)
90	8.1	(2.76)	16.4	(4.00)	31	(5.47)	18.50	(4.07)
Mean	10.30	(3.08)	13	(3.48)	45.4	(6.20)		
SE (N rates)		(±0.504)						
SE (Cultivars)		(±0.392)						
CV (%)		(20)						

1. Split plot design with three replications (main plot: nitrogen rates, subplot: cultivar).
2. Counted on 5 randomly selected panicles 20 days after half-anthesis.
3. Figures in parentheses are square root transformed values.

Effects of plant density, fertility, and cultivars

In both 1989 and 1991, there was no consistent trend in the effect of plant density on head bug numbers (Table 3). However, in 3 out of 5 cases, there were more head bugs at 10.6 plants m^{-2} than at other densities, possibly because at this density, plants were taller, more vigorous, gave higher yields, and were therefore more attractive to head bugs (ICRISAT Sahelian Center 1990, p. 109, ICRISAT Sahelian Center 1992, p. 94).

Table 5. Effect of intercropping sorghum with soybean (TGX 1497-1D) on the population of head bugs (*Eurystylus immaculatus*) on sorghum at Bagauda, Nigeria, rainy season 1989[1].

Crop combination	Number of head bugs[2]	
	ICSH 507	ICSV 247
Sole sorghum	208 (14.4)[3]	49 (6.9)
1 sorghum: 1 soybean intercrop	165 (12.5)	38 (5.8)
SE	(±1.31)	
Mean	187 (13.5)	44 (6.4)
CV (%)	(12)	

1. Randomized block design with 3 replications.
2. Counted on 5 randomly selected panicles at soft dough stage.
3. Figures in parentheses are square root transformed values.

In 1991, the number of head bugs averaged over three cultivars increased with an increase in the rate of nitrogen from 0 to 60 kg ha^{-1} (Table 4) and then decreased. The increase between 0 and 60 kg N ha^{-1} is due to the better performance and attractiveness of the crops with higher levels of N. However, the decrease in head bug population after 60 kg N on ICSV 247 and Samsorg 14 is inexplicable.

The population of head bugs was 2–4 times higher on the semi-compact panicled ICSH 507 than on the semi-loose panicled ICSV 247 (Tables 3 and 5), but there was little difference between ICSH 89002 NG and ICSV 247 (Table 3), both of which have semi-loose panicles. There were 15–39 times more *Eurystylus* on Gaya Early than on ICSV 400 when either was intercropped with pearl millet and cowpea (Table 8). Significantly more head bugs were found on Samsorg 14, a tall, and long-duration variety, than on the shorter and earlier maturing ICSV 247 and ICSH 507 (Tables 3, 4, 6, and 7). Since both Gaya Early and Samsorg 14 are taller and mature later than ICSV 247, ICSH 507, and ICSH 89002 NG, head bugs are likely to move from the earlier maturing to the later maturing plants and develop larger populations there. In addition, Gaya Early, being a kaura type sorghum, has softer grains which favor head bug feeding and development.

Malisor 84-7 is recognized as the only cultivar that has shown stable resistance to *Eurystylus* (Ratnadass et al. 1991, 1992, 1993) but the current study indicates that early maturity may enable some susceptible sorghum varieties to suffer less damage than later maturing ones.

Table 6. Effect of intercropping sorghum with soybean (TGX 1497-1D) on the population of head bug (*Eurystylus immaculatus*) on sorghum at Bagauda, Nigeria, rainy season 1991[1].

Sorghum cultivar	Soybean plant density	Number of head bugs[2]			
		1Sor:1Soy[3]	1Sor:1Soy	Alternate stand	Sole
ICSV 247	1[4]	23.33 (4.80)[5]	15 (3.85)	18.67 (4.17)	37 (5.96)
	2	12 (3.39)	18.33 (4.26)	25 (4.78)	
ICSH 507	1	16.30 (3.99)	10.67 (3.24)	22.33 (4.67)	22.67 (4.63)
	2	17.67 (4.14)	12.67 (3.54)	24 (4.81)	
Samsorg 14	1	81 (8.62)	70.66 (7.96)	139 (10.08)	118.67 (9.71)
	2	53.33 (7.25)	113.66 (10.67)	196 (13.34)	
Mean		33.94 (5.37)	40.17 (5.59)	70.83 (6.98)	59.45 (6.77)
SE			22.22 (±1.423)		
CV (%)			(40)		

1. Randomized block design with 3 replications.
2. Counted on 5 randomly selected panicles at soft dough stage.
3. Row arrangement: Sor = sorghum, Soy = soybean.
4. Density 1 = 13.3 plants m^{-2}, density 2 = 26.6 plants m^{-2}.
5. Figures in parentheses are square root transformed values.

Effect of intercropping

Intercropping sorghum with soybean in a 1:1 row ratio decreased head bug infestation by 21% in 1989 (Table 5) and by 43% in 1991 (mean of three cultivars, Table 6). The decrease was 32% with a 1 sorghum: 2 soybean row arrangement (Table 6). The alternate stand within the row arrangement decreased head bug numbers by 41% on ICSV 247, had little effect on ICSH 507, but increased infestation by 25% on Samsorg 14 (Table 6). A higher density of soybean increased infestation in 7 out of 9 cases (Table 6). Irrespective of the varieties used, intercropping sorghum with pigeonpea had no effect on the population of head bugs (Table 7).

Intercropping sorghum with pearl millet and cowpea did not affect head bug numbers on ICSV 400 (Table 8) but in Gaya Early, head bug numbers were 2–3 times higher on the intercropped than on the sole sorghum. Sorghum/millet density, and row arrangement of the three crops, did not alter head bug populations (Table 8).

The results confirm the finding of Ratnadass (1993) that intercropping sorghum with legumes does not significantly affect infestation by head bugs. Nevertheless, the reductions in the *Eurystylus* population due to intercropping soybean and the increase recorded in mixtures of Gaya Early with cowpea and pearl millet indicate the potential importance of this management practice as a control measure. This study suggests, however, that intercropping pigeonpea with sorghum is not effective in reducing head bug population and damage.

Table 7. Effect of intercropping sorghum with pigeonpea on the infestation of sorghum by head bugs (*Eurystylus immaculatus*) at Bagauda, rainy season 1991[1].

Sorghum cultivar	Pigeonpea	Number of head bugs[2]	
ICSV 247	–	23	(4.77)
	ICPL 151	32	(5.58)
	ICPL 87067	20.30	(4.47)
	ICPL 84023	25	(4.96)
ICSH 507	–	49.30	(6.97)
	ICPL 151	19	(4.34)
	ICPL 87067	38	(5.96)
	ICPL 84023	31	(5.41)
Samsorg 14	–	117.30	(10.62)
	ICPL 151	123.30	(11.10)
	ICPL 87067	123	(11.04)
	ICPL 84023	138.70	(10.96)
SE			(±1.177)
CV (%)			(28)

1. Randomized block design with 3 replications.
2. Counted on 5 randomly selected panicles at soft dough stage.

Table 8. Effect of intercropping sorghum with pearl millet and cowpea on incidence of head bug (*Eurystylus immaculatus*) on sorghum at Bagauda, Nigeria, 1991[1].

Treatment	Number of head bugs[2]	
Cultivar		
ICSV 400 sole	2.2	(1.39)[3]
ICSV 400/Ex-Bornu/Kannanado	1.6	(0.78)
ICSV 400/Ex-Bornu/IT 715	2.1	(1.06)
Gaya Early sole	31.9	(3.93)
Gaya Early/Ex-Bornu/Kannanado	58.9	(6.56)
Gaya Early/Ex-Bornu/IT 715	81.4	(8.04)
SE	±9.63	(±0.652)
Density (plants m^{-2})[4]		
5.3 (S) + 5.3 (M)	29.2	(3.54)
5.3 (S) + 2.6 (M)	27.1	(3.37)
2.6 (S) + 2.6 (M)	32.7	(3.96)
SE	±6.81	(±0.461)
Row arrangement[5]		
Alternate stand	27.8	(3.34)
Alternate row	31.5	(3.91)
SE	±5.56	(±0.376)
CV (%)	137	(76)

1. Randomized complete block design with 3 replications; plot size 30 m^2.
2. Counted on 5 randomly selected panicles at soft dough stage.
3. Figures in parentheses are square root transformed values.
4. Density of sorghum and millet varied; density of cowpea remained the same; Kannanado: 1.3 plants m^{-2}; IT 715 = 2.6 plants m^{-2}.
5. Alternate stand: millet and cowpea on same row, sorghum on separate rows; alternate row: millet, cowpea, and sorghum on separate rows.

Conclusion

The following conclusions are suggested by the results presented in this study:

- Sowing date of sorghum affects the incidence of and damage by *Eurystylus immaculatus*;
- Application of nitrogen fertilizer encourages high infestation;
- Loose panicle, soft grain, and late maturity can enhance the development of high populations of *E. immaculatus* on sorghum;
- Intercropping sorghum with legumes can reduce infestation by *E. immaculatus* but not in all cases. However, if used in combination with other measures, such as date of sowing, early maturity, hard grain, and resistant cultivars, intercropping could be an effective control measure.

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Synthèse

Les effets des pratiques culturales sur *Eurystylus immaculatus* chez le sorgho. Les pratiques culturales tels que la date de semis, la culture associée, les niveaux d'azote, et la densité de semis ont été examinées par rapport aux incidences et aux infestations des punaises des panicules du sorgho, *Eurystylus immaculatus* Odhiambo. Quatre dates de semis (15 et 29 juin, 13 et 27 juillet) ont été évaluées en 1991 et cinq dates de semis (3 juin, 1er, 15 et 22 juillet, 5 août) en 1992 à Bagauda, au Nigéria. La date de semis a eu un effet significatif sur la population de *E. immaculatus*; la pointe d'infestation a eu lieu dans le cas du semis de mi-juillet en 1991 et de 3 juin en 1992. Les dégâts au grain ont suivi la même tendance que la population des punaises des panicules. Le rendement en grain a été corrélé négativement avec la population des punaises des panicules et les dégâts, mais il a été aussi influencé par la disponibilité en eau. La date de semis peut donc être modifiée afin d'éviter les dégâts sévères occasionnés par *E. immaculatus*. Selon le cultivar du sorgho utilisé, l'association culturale de sorgho et de soja a diminué l'incidence des punaises des panicules chez le sorgho de 22% en 1989 et de 8-49% en 1991.

La disposition alternée des rangs (1 rang de sorgho:1 rang de soja; et 1 rang de sorgho:2 rangs de soja) a eu un nombre moins important de punaises des panicules que la culture pure du sorgho, leur population ayant diminué de 43% et 32% respectivement en 1991. La disposition alternée à l'intérieur des rangs a eu des effets différents selon la variété utilisée. La culture associée avec le pois d'Angole a permis de réduire très légèrement le nombre de *E. immaculatus*. L'association des cultures sorgho/mil et sorgho/niébé n'a eu aucun effet sur le nombre des punaises chez la variété ICSV 247, mais en a doublé et triplé le nombre chez Gaya Early, une variété locale plus grande à maturation plus tardive. Il est important de noter qu'on a trouvé davantage de punaises sur ICSH 507, un hybride à panicules compactes que sur ICSV 247, une variété à panicules semi-lâches. Mais, Samsorg 14, une variété plus tardive, a eu beaucoup plus de punaises que ICSH 507 et ICSV 14. On a trouvé des infestations similaires de *E. immaculatus* sur ICSV 247 et ICSH 89002 NG, tous deux ayant des panicules semi-lâches. On a compté de 15 à 39 fois plus de punaises sur Gaya Early que sur ICSV 400, lorsque l'un ou l'autre était cultivé en association avec le mil et le niébé. La variation de densité de semis de 2,7 à 17,8 plants m^{-2} n'a pas affecté de manière consistante l'infestation des punaises des panicules; cependant le nombre des punaises a été plus élevé sur des plants à densité de 10,6 plants m^{-2} qu'à d'autres densités. L'infestation des punaises des panicules a augmenté avec le niveau d'engrais azoté (0 à 60 kg ha^{-1}). Ces observations sont examinées à la lumière de stratégies de lutte intégrée contre *E. immaculatus*.

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Sorghum Management Options to Reduce Insect-induced Stress

G L Teetes[1]

Abstract

Grain sorghum production in USA will not escape the consequences of the current public and political sensitivity to environmental and human-health issues. The sustainable agriculture agenda also is an issue relevant to sorghum production in less developed countries. Insecticide-based integrated pest management strategies are being forced to change to biological/ecological-based strategies, implying that technology is available to US agriculture to manage insect pests without chemical insecticides and still maintain crop production at levels that allow abundant supplies of cheap food, fiber, and other agricultural products. The parallel implication is that this approach will ensure adequate levels of food in lesser developed countries. An important issue is whether nonchemical sorghum insect management technology is currently available, and if the time is right for cultural as well as biological insect pest management tactics to be exploited.

In this paper, insect management tactics including crop rotation, insect-resistant plants, crop refuse destruction, tillage, sowing and harvesting time, plant spacing, fertilizer and water management, and trap crops, as well as biological control, are assessed to define their level of use, value, and potential to reduce insect-induced stress in sorghum.

Introduction

Grain sorghum production in USA will not escape the consequences of the current public and political sensitivity to environmental and human health issues. Activities associated with agricultural crop production, especially crop protection and the use of insecticides, place the sorghum grower in the role of culprit in the environmental issue. This is despite the fact that agriculturists in general and sorghum growers in particular are and have been, by the very nature of their business, conscious of the need to preserve the environment and the earth's natural resources. Some US governmental agencies and other groups intend to force a change from the liberal use of insecticides to exclusively nonchemical insect pest control methods to reduce insect-induced stress to plants. The implication is that the technology is available to manage insect pests without chemical insecticides and still maintain crop production at levels that allow abundant supplies of cheap food, fiber, and other agricultural products. This concept directly affects sorghum growers, those of us who are involved in sorghum improvement research, the sorghum seed industry, and industries that utilize sorghum.

The most commonly used reasons for the need to force a change from liberal insecticide use to 'biological' or 'ecological' methods to reduce insect-induced stress to plants are cost, the toxic and pollution dangers of insecticides, and the demand for safe food, clean water, and wildlife conservation, expressed as concern over human health and the environment. However, there has been a dramatic change in attitude from one that considers risk/benefit comparison, whereby certain actions are justified if the benefits are greater than the harm, to one in which almost no risk is acceptable.

Chemical vs Nonchemical Control

It is true that insecticides are toxic to nontarget organisms, and attempts are being made to produce selective insecticides and to use them in a more selective

1. Department of Entomology, Texas A&M University, College Station, Texas 77843-2475, USA.

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manner. It is also true that resistance of insect pests to insecticides is a persistent problem that leads to more insecticide use and an increase in the cost of crop production. From an ecological standpoint, one of the most serious negative aspects of insecticides is that they simplify the ecosystem. They reduce diversity, and thus reduce stability which often intensifies the problems they were originally intended to solve, because of insect pest resurgence and secondary pest outbreaks.

There are, however, real advantages to the use of insecticides that may not be realized using nonchemical insect management methods. For example, insecticides have curative ability, i.e., they can fix an insect pest problem quickly and easily after it has occurred. And, regardless of the contentions of many people, if properly used, insecticides work, and for the most part they work very well.

The concept of using nonchemical insect management methods to reduce insect-induced stress is much different from that of using insecticides. The use of nonchemical management methods must be a planned part of the total crop production system at the very beginning, because nonchemical tactics are preventive in nature and not curative. Their use consequently requires good, serious, and long-range planning. The use of nonchemical management tactics requires consideration of an insect pest problem long before it occurs. Insecticides allow the problem to be dealt with when it occurs. The advantage of nonchemical management tactics does not lie totally in their effectiveness, but in the fact that they are nonpolluting. Their action is slow and perceived to be less dependable than the rapid curative action of chemical insecticides.

Integrated Pest Management

The attack on chemicals used in agriculture forces us to ask if the hour is nearly over for using insecticides to protect crops such as sorghum from insect pests. For the last 30 years entomologists have led crop protection specialists in integrated pest management. The concept is still very real and is the cornerstone for the approach to crop protection from pests, especially insect pests.

Perhaps some people are just catching up to where entomologists have been for a long time with integrated pest management. However, the level of use and conformity with the principles of integrated pest management by growers appear to be directly correlated with the effectiveness of insecticides. When insecticides work well, integrated pest management is not considered; when they do not work well, integrated pest management provides the only viable option.

The paradox has to do with existing technology, and current use of that technology. Sorghum and its insect pest complex are a good example of this paradox. Also, they provide the opportunity to address current sorghum management options to reduce insect-induced stress.

Nonchemical Control in Sorghum

There are a number of nonchemical control tactics. Some of these are referred to as cultural control methods, which is the use of agronomic practices that result in a reduction of insect pest abundance and/or damage and include: crop rotation, insect-resistant plants, crop refuse destruction, tillage, sowing and harvesting time, plant spacing, fertilizer and water management, and trap crops (Table 1).

Other tactics include biological control (Table 2), genetic or autocidal methods, regulatory methods, and mechanical and physical methods, the latter being labor-intensive practices that have limited practical application in modern agriculture.

There are chemical approaches, other than 'hard' insecticides, and basically their use is to achieve selectivity by being nontoxic to nontarget organisms. Insect growth regulators and microbial insecticides are good examples of these.

To address the sorghum management options to reduce insect-induced stress requires an examination of the nonchemical insect management approaches and assessment of their utility in reducing the damage caused by insect pests of sorghum. I have taken the cultural control and biological control methods and attempted to evaluate their use in managing specific sorghum insect pests or insect pest groups.

This evaluation is based on a 1–5 rating scale, where 1 = no use or effect, 2 = little use or effect, 3 = some use, 4 = moderate use, and 5 = major use or effect. The ratings assigned take into consideration the actual use of the practice and the potential effectiveness of the tactic if it was used on a regular, intentional basis. Also, the ratings are my opinions based on my experience as a sorghum entomologist.

An overview of the cultural control tactics as applied to sorghum insect pests in USA, shows that there are far more low ratings than high ratings, indicating that there are more insect pests or insect pest groups that are not affected by cultural control practices than

Table 1. Nonchemical control methods employable against sorghum insect pests in USA.

Insect pest	Crop rotation	Plant resistance	Refuse destruction	Tillage	Sowing time	Plant spacing	Fertilizer management	Water management	Trap crops
	Cultural control method								
Soil insects									
Wireworms	5[1]	1	3	3	3	1	2	2	1
White grubs	5	1	3	3	3	3	2	2	1
Rootworm	5	1	5	3	1	2	2	2	1
Cutworms	5	1	5	3	2	2	2	2	1
Aphids									
Greenbug	1	5	1	4	3	2	2	2	1
Yellow sugarcane aphid	1	1	2	1	3	2	2	2	1
Corn leaf aphid	1	4	1	1	2	2	2	2	1
Foliage feeders									
Fall armyworm	1	2	1	1	5	1	2	2	1
Corn earworm	1	1	1	1	5	1	2	2	1
Chinch bug	1	2	3	1	2	4	3	3	1
Spider mites	1	3	1	1	3	2	2	5	1
Stem borers									
Southwestern corn stalk	1	1	5	1	3	3	2	2	1
Sugarcane	1	1	5	1	5	3	2	2	1
Lesser cornstalk	1	1	3	1	2	2	2	2	1
Sugarcane rootstock	4	1	3	4	2	2	2	2	1
Panicle feeders									
Sorghum midge	1	3	2	1	5	1	1	1	1
Sorghum webworm	1	2	4	1	5	1	1	1	1
Corn earworm	1	2	1	1	5	1	1	1	1
Fall armyworm	1	1	1	1	5	1	1	1	1
Kernel-feeding bugs	1	1	1	1	4	1	1	1	1

1. 1 = no use, 2 = little use, 3 = some use, 4 = fair use, 5 = major use.

are affected by such tactics (Table 1). Evaluating nine cultural control methods against 20 sorghum insect pests or insect pest groups produces 180 different ratings. An assessment of these revealed that 49% rated 1 (no use or effect), 26% rated 2 (little use or effect), 12% rated 3 (some use or effect), 7% rated 4 (fair use or effect), and 9% rated 5 (major use or effect).

Soil insect pests

Insect pests that inhabit the soil are affected by some cultural control methods. This group of pests includes wireworms (*Aeolus* spp), white grubs (*Phyllophaga* spp), southern corn rootworm [*Diabrotica undecimpuncta howardi* (Barber)], and cutworms. Crop rotation is used and is effective in reducing the abundance of these insect pests. Wireworms and white grubs, especially, meet the criteria for insect pests that would be affected by crop rotation. That is, they have a long life cycle and a fairly limited capability to migrate. Crop refuse destruction is important in reducing damage by the southern corn rootworm and cutworms. The cultural practices that promote rapid seed germination and strong, vigorous sorghum plants also provide some protection against soil insect pests. Trap crops are not important.

Table 2. Nonchemical control methods employable against sorghum insect pests in USA.

Insect pest	Biological control method		
	Classical	Conservation	Augmentation
Soil insects			
Wireworms	1[1]	1	1
White grubs	1	1	1
Rootworm	1	1	1
Cutworms	1	1	1
Aphids			
Greenbug	1	5	1
Yellow sugarcane aphid	1	1	1
Corn leaf aphid	1	5	1
Foliage feeders			
Fall armyworm	1	2	1
Corn earworm	1	2	1
Chinch bug	1	2	1
Spider mites	1	2	5
Stem borers			
Southwestern corn stalk	1	2	1
Sugarcane	5	1	1
Lesser cornstalk	1	2	1
Sugarcane rootstock	1	1	1
Panicle feeders			
Sorghum midge	1	2	1
Sorghum webworm	1	5	1
Corn earworm	1	5	1
Fall armyworm	1	5	1
Kernel-feeding bugs	1	2	1

1. 1 = no use, 2 = little use, 3 = some use, 4 = fair use, 5 = major use.

Aphids

The three aphid pest species of sorghum—greenbug (*Schizaphis graminum* Rondani), yellow sugarcane aphid (*Sipha flava* Forbes), and corn leaf aphid (*Rhopalosiphum maidis* Fitch)—are not much affected by most cultural control tactics. The greenbug can often be managed by using plant resistance, and germplasm resistant to the corn leaf aphid is available but not often used. Sorghums resistant to the yellow sugarcane aphid have been recently identified, but improved parent lines for hybrids are not available. Minimum-tillage practices have been shown to reduce greenbug abundance, but the practice has not been used intentionally for that purpose. Practices that improve plant vigor have some benefit, and in some areas late-sown sorghum is usually less infested with greenbug and sometimes yellow sugarcane aphid than is early-sown sorghum.

Foliage feeders and borers

Sorghum foliage feeders are only minimally affected by most cultural management tactics. Sorghums sown early often escape damaging whorl infestations of corn earworm (*Helicoverpa zea* Boddie) and fall armyworm (*Spodoptera frugiperda* J E Smith) compared to late-sown sorghum. Sorghum with a uniform, fairly dense plant stand is less favorable to chinch bug (*Blissus leucopterus* Say) than sorghum in a poor stand. Where irrigation is available, managing water to prevent moisture-stressed plants is helpful in reducing damage by the Banks grass mite (*Oligonychus pratensis* Banks) and two-spotted spider mites (*Tetranychus* spp) in sorghum.

Insects that bore into sorghum stalks are reduced in abundance by killing overwintering larvae that hibernate in stalks by stalk destruction during the winter. Early-sown sorghum is usually less infested with borers, especially sugarcane borer, than late-sown sorghum. Tillage practices to prevent Johnsongrass is helpful in preventing infestations of sugarcane rootstock weevil [*Anacentrinus deplanatus* (Casey)]. Cultural practices (especially plant spacing) that produce strong plants, provide protection from stalk lodging and peduncle breakage due to borer infestation.

Almost all panicle-feeding insect pests of sorghum are more abundant and more damaging in late-sown than early-sown sorghum. This is especially true for sorghum midge (*Contarinia sorghicola* Coq.), corn earworm (*Helicoverpa zea* Boddie), fall armyworm (*Spodoptera frugiperda* J E Smith), sorghum webworm (*Celama sorghiella* Riley), and panicle-infesting true bugs such as the rice stink bug. Midge-resistant sorghums have been identified and have great potential, but are not widely available or used as yet. Because sorghum webworm overwinters on sorghum plants, crop refuse destruction is important in the management of this insect pest. Sorghums with more open panicles are usually considered to be less damaged, especially by lepidopterous larvae.

Biological Control

Biological control is not practiced against most sorghum insect pests (Table 2). The only classical (introduced natural enemies) biological control program in practice is for the sugarcane borer (*Diatraea saccharalis* Fabricius), and the parasite of this borer is most effective in sugarcane. The same parasite does attack the borer in sorghum and maize in the Lower Rio Grande Valley. Most biological control in sorghum is by conservation, which refers to the enhancement of the numbers of already existing natural enemies by improving their environment or by removing suppressive conditions. Very often, a major suppressive condition for natural enemies is insecticide use, not only in sorghum, but drift from other crops being sprayed. Also, most conservation-based biological control occurs in the absence of a producer decision. Thus, conservation of effective natural enemies is a by-product of a nondecision, not the basis for the decision. If the decision does not focus on conserving the natural enemy, then the conserved natural enemy activity is by definition due to natural control and not to biological control, which implies human intervention. In any case, conservation-based biological control is important in managing greenbug, corn leaf aphid, sorghum webworm, corn earworm, and fall armyworm.

Augmentation (mass culturing and periodic release of a natural enemy) is typically a high-cost activity, and spider mite predators are the only natural enemies for sorghum pests with utility broad enough to be cost-effective in augmentation biological control. However, augmentation biological control is not being practiced to reduce insect-induced stress to sorghum.

Of the other direct control tactics discussed earlier, two chemical approaches considered not to be 'hard' insecticides are insect growth regulators and microbial insecticides. Neither of these types of products is specific for use on sorghum, but some are available after being developed for other insect pests on other crops. Their advantage is specificity, not being toxic to nontarget organisms. The microbial insecticide of the *Bacillus thuringiensis* toxin is an example.

From this evaluation of nonchemical control tactics it might appear that there are fewer options to chemical insecticides than one might expect. But the data in Tables 1 and 2 could be misinterpreted, as some of the most important insect pests of sorghum, sorghum midge and greenbug, can be fairly adequately managed by nonchemical means. For example, sorghum midge can be managed by early, uniform, regional sowing. The population dynamics of the sorghum midge are such that damaging infestation levels are usually only reached after a generation of the insect is completed in the earliest-sown sorghum in an area. The development of midge-resistant sorghums has been a long-term effort with moderate levels of success. Although commercial midge-resistant sorghums are not readily available, breeding lines and experimental hybrids have been developed by the Texas Agricultural Experiment Station Plant Breeding/Entomology team. This program focuses on plant resistance to sorghum midge, producing resistant germplasm, and attempting to understand the effect of the resistant plants on the insect pest and the effect of the insect on the resistant plants, and incorporating plant resistance into an integrated pest management strategy. Despite slow progress, good achievements have been made. Hopefully, the sorghum seed industry will make a commitment to develop a commercial midge-resistant hybrid in the near future. The material for those hybrids is available from Texas A&M University.

Greenbugs can usually be managed by plant resistance. Resistant hybrids are commercially available. The resistance level to biotype E greenbug is not as high as the resistance level to biotype C greenbug, but the genetic resistance does add an important component to the sorghum integrated pest management strategy. The existence of greenbug biotypes and greenbugs resistant to insecticides continue to be troublesome. Biotype I greenbug has been identified and its distribution is being monitored by Texas A&M University and Kansas State University entomologists. Sources of resistance to biotype I greenbug have been identified. PI 550610 from Syria and PI 550607 from China are highly resistant. Crosses have been made to transfer the resistance gene into elite material. F_2s are being screened.

More research is needed on cultural control methods. These tactics have not been sufficiently researched or tested. Biological control has good potential, but potential does not control insect pests. However, the future is bright for biological control, especially against the aphid pests of sorghum.

To be prepared for the changes that must occur in order to manage sorghum insect pest-induced stress without insecticides will require a major effort by researchers, the sorghum seed industry, and sorghum growers. If preparation is not made, the results could be dramatic and devastating.

Synthèse

Des options de lutte contre les insectes ravageurs du sorgho. La production du sorgho grain aux Etats-Unis ne peux pas éviter les conséquences des préoccupations courantes tant publiques que politiques aux sujets de l'environnement et la santé humaine. On considère la défense des cultures par des insecticides comme nuisible à l'environnement. Les agences gouvernementales ainsi que d'autres groupes projettent d'obliger les agriculteurs à remplacer l'emploi non judicieux des insecticides par l'emploi exclusif des méthodes de lutte non chimiques. Ils supposent que la technologie est disponible pour lutter contre les insectes ravageurs sans utiliser des insecticides chimiques tout en assurant une production agricole (alimentation et fibre) élevée et peu onéreuse. Cela laisse supposer que les pays moins avancés disposeraient d'alimentation en quantité adéquate.

Des insecticides sont toxiques aux organismes non ciblés et peuvent rendre les insectes ravageurs résistants. Ils entraînent également la déstabilisation de l'écosystème en réduisant la biodiversité. Mais, il faut signaler que lorsque les insectes nuisibles atteignent le seuil de nuisibilité économique, les insecticides ayant un effet rapide, sont parfois les seuls moyens pour les contrôler. Des méthodes de lutte non chimiques, bien que non polluantes, ont un effet peu rapide et sont considérées comme moins fiables que les insecticides. Au cours des trois dernières décennies, on a eu des spécialistes en défense des cultures dans le cadre de lutte intégrée. Cependant, souvent les agriculteurs n'utilisent pas de méthodes de lutte intégrée à moins que les insecticides ne soient pas efficaces.

Des stratégies non chimiques de lutte intégrée utilisées contre les insectes nuisibles au sorgho comprennent des méthodes de lutte culturale et biologique. En lutte biologique, il s'agit de conserver ou d'accroître le nombre d'ennemis naturels en améliorant leur environnement ou en supprimant les conditions défavorables à leur développement. La lutte biologique de conservation est importante à la maîtrise des pucerons et des larves lépidoptères du sorgho. Le seul agent de lutte biologique classique utilisé aux Etats-Unis est un parasitoïde introduit contre le borer américain de la canne à sucre.

La lutte culturale comprend des pratiques agronomiques qui permettent de limiter la population des insectes ravageurs et/ou les dégâts. Aux Etats-Unis, des stratégies du lutte—dont seulement 9% sont particulièrement efficaces—s'avèrent en général inefficaces contre 75% des 20 ravageurs du sorgho. L'assolement des cultures permet de maîtriser les insectes nuisibles habitant dans le sol tels que les vers fil de fer, les vers blancs, les galéruques américaines du sorgho et les vers gris. La destruction des déchets culturaux réduit la pullulation des galéruques américaines du sorgho, des vers gris et des borers du maïs. Les plants de sorgho, semés tôt, évitent les dégâts causés par des borers, surtout le borer américain de la canne à sucre; des larves lépidoptères qui s'attaquent aux feuilles; et des larves lépidoptères qui s'alimentent sur des panicules, des cécidomyies du sorgho ainsi que des punaises. Des sorgho résistants sont disponibles ou sont en train d'être développés contre les pucerons verts et les cécidomyies du sorgho, les plus importants ravageurs du sorgho. Des méthodes culturales de lutte pourraient limiter en partie les infestations par ces ravageurs, mais il importe de conduire davantage de travaux de recherche sur les méthodes non chimiques de lutte contre les insectes nuisibles du sorgho.

Short Communication/*Communication courte*

Panicle Insect Pests of Sorghum and their Control in Samaru, Nigeria

M C Dike and S Ekesi[1]

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the most important cereals grown in Nigeria. It is an extremely important staple food in northern Nigeria. Estimated national annual production is about 4 million t (Ajayi 1978). Grain yields under traditional farming conditions are low and average about 670 kg ha^{-1} compared with 4 t ha^{-1} obtainable under improved agricultural practices. Low yields are due partly to insect pest damage.

Most of the sorghum panicle insect feeders which include several species belonging to Hemiptera, Coleoptera, Lepidoptera, Diptera and Orthoptera are usually of minor importance in Samaru. However, the sorghum midge *Contarinia sorghicola* Coquillett and several species of panicle-feeding bugs can cause severe damage. Panicle insect pests of sorghum are categorized into three distinct groups in this paper, depending on the stage at which they infest sorghum:

- at the flowering stage;
- at thé soft to hard dough stage;
- at the maturing grain stage.

The most important insects infesting the crop at the flowering stage are the sorghum midge, *C. sorghicola*, and some earhead beetles. Late-sown grain sorghum may be severely attacked and damaged by sorghum midge larvae, which feed on the developing grain. Losses caused by the midge can be reduced by such cultural practices as early and uniform sowing that allow sorghum flowering to occur before damaging midge infestations develop. The sorghum midge can also be controlled using uniform-flowering and midge- resistant varieties.

Several species of blister beetles attack sorghum panicles. The most common species are *Cylindrothorax westermanni* Mäklin, *Mylabris* spp, and *Psalydolytta* spp. Cypermethrin at 100 g a.i. ha^{-1} applied at 50% head emergence gives adequate control of head beetles.

Insects infesting sorghum at the soft to hard dough stage are mainly earhead bugs and grasshoppers. Several species of panicle-feeding bugs have been reported to attack sorghum at this stage. In Nigeria sorghum panicle bugs are currently considered of little importance because most farmers plant Farafara sorghums with an open panicle, and it is known that the open panicles support lower populations of head bugs than compact panicles. MacFarlane (1989) reported a total of 17 species of hemipteran insects from sorghum panicles in Samaru and Kano in 1982 and 1983. He considered six species, *Eurystylus immaculatus* Odhiambo, *Campylomma angustior* Poppius, *C. subflava* Odhiambo, *Paramixia suturalis* Reuter, *Taylorilygus vosseleri* Poppius, and *Orius* spp as accounting for 95% of all hemipterans collected. *Eurystylus immaculatus* and *Campylomma* spp were the most abundant species and caused most of the deterioration in sorghum grain quality. In Samaru, it has been shown that decamethrin applied at 30 g a.i. ha^{-1} decreased infestation of panicle bugs and increased yield by 6% (IAR 1984). Early sowing has also been shown to reduce populations of head bugs.

Oedaleus senegalensis (Krauss), *O. nigeriensis* (Krauss), *Aliopus simulatrix* Walker and *Zonocerus variegatus* L. are major grasshopper species that can cause severe damage to young sorghum panicles. They, however, occur in very low numbers and may be temporary migrants from nearby crops.

A complex of lepidopterous larvae infests sorghum earheads at the maturing grain stage. However, of the different species recorded, *Helicoverpa armigera* (Hübner) and occasionally *Sitotroga cereallela* (Olivier) can cause severe damage and require attention (Ishaku 1987). Cypermethrin applied at 100 g a.i. ha^{-1} gives good control, particularly if applied when the larvae are young.

1. Department of Crop Protection, Institute for Agricultural Research, Ahmadu Bello University, PMB 1044, Zaria, Nigeria.

Dike, M.C., and Ekesi, S. 1995. Panicle insect pests of sorghum and their control in Samaru, Nigeria. Pages 247–248 *in* Panicle insect pests of sorghum and pearl millet: proceedings of an International Consultative Workshop, 4–7 Oct 1993, ICRISAT Sahelian Center, Niamey, Niger (Nwanze, K.F., and Youm, O., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Les insectes nuisibles des panicules de sorgho à Samaru, au Nigéria et la lutte contre ces insectes. Le sorgho [*Sorghum bicolor* (L.) Moench] est une des plus importantes céreales cultivées au Nigéria. C'est un aliment de base clé dans le nord du Nigéria. La production annuelle nationale du sorgho est estimée à environ 4 millions de tonnes (Ajayi 1978). Sous conditions traditionnelles de culture, les rendements en grains sont faibles (670 kg ha^{-1} en moyenne) par rapport aux rendements obtenus avec des pratiques améliorées (4 t ha^{-1}). La baisse de rendement est due, entre autres, aux dégâts causés par les insectes.

La plupart des insectes nuisibles des panicules de sorgho, qui comprennent plusieurs espèces appartenant au Hemiptera, Coleoptera, Lepidoptera, Diptera, et Orthoptera, sont généralement moins importants à Samaru. Cependant, la cécidomyie du sorgho *Contarinia sorghicola* Coquillett et plusieurs espèces de punaises des panicules peuvent occasionner des dégâts importants. Les insectes nuisibles des panicules de sorgho sont classés en trois groupes dans cette communication, en fonction du stage auquel ils infestent le sorgho:

- à la floraison;
- au stade pâteux doux et dur;
- à la maturation de la graine.

Les insectes les plus importants qui attaquent la culture à la floraison sont la cécidomyie, *C. sorghicola*, et des punaises de panicules. Le sorgho à grain semé tardivement est particulièrement susceptible de subir des dégâts sévères par les larves de la cécidomyie, qui se nourrissent sur les graines en développement. Ces dégâts peuvent être réduits par les pratiques culturales tels le semis précoce et uniforme, qui permet l'arrivée de la floraison avant que les infestations importantes de la cécidomyie ne développent. On peut également lutter contre cet insecte en employant des variétés à floraison uniforme et résistantes à la cécidomyie.

Plusieurs espèces de méloïdes s'attaquent aux panicules de sorgho. Les espèces les plus communes sont *Cylindrothorax westermanni* Mäklin, *Mylabris* spp, et *Psalydolytta* spp. L'application du cyperméthrine à 100 g m.a. ha^{-1} à 50% d'émergence de panicules permet une lutte adéquate des méloïdes.

Ce sont essentiellement les punaises des panicules et les sauteriaux qui infestent le sorgho aux stades pâteux doux et dur. Plusieurs espèces de punaises des panicules ont été signalées sur le sorgho à ces stades. Au Nigéria, les punaises des panicules sont considérées peu importantes, à l'heure actuelle, car les paysans préfèrent généralement les sorghos Farafara à panicules lâches; on sait que les panicules lâches soutiennent moins de punaises que les panicules compactes. MacFarlane (1989) a constaté un total de 17 espèces hémiptères sur les panicules de sorgho à Samaru et à Kano en 1982 et en 1983. D'après lui, six espèces—*Eurystylus immaculatus* Odhiambo, *Campylomma angustior* Poppius, *C. subflava* Odhiambo, *Paramixia suturalis* Reuter, *Taylorilygus vosseleri* Poppius et *Orius* spp—ont constitué 95% de tous les hémiptères collectés. *Eurystylus immaculatus* et *Campylomma* spp se sont avérées les plus abondantes, responsables de la plupart de la détérioration de la qualité de sorgho grain. A Samaru, on a démontré que l'application du décaméthrine (30 g m.a. ha^{-1}) a eu pour effet de réduire l'infestation par les punaises et d'augmenter le rendement de 6% (IAR 1984). Par ailleurs, il s'avère que le semis précoce réduit les populations des punaises des panicules.

Oedaleus senegalensis (Krauss), *O. nigeriensis* (Krauss), *Aliopus simulatrix* Walker et *Zonocerus variegatus* L. sont des espèces importantes de sauteriaux qui peuvent causer des dégâts sévères aux jeunes panicules de sorgho. Cependant, elles se présentent en nombres relativement faibles et constituent probablement des migrations provisoires en provenances des cultures avoisinantes.

Un complexe de larves lépidoptères infestent les panicules de sorgho au stade de la maturation de la graine. Parmi les différentes espèces observées, *Helicoverpa armigera* (Hübner) et parfois *Sitotroga cerealella* (Olivier) peuvent causer des dégâts importants et demandent une attention particulière (Ishaku 1987). Le cyperméthrine (100 g m.a. ha^{-1}) s'est révélé très efficace, particulièrement si l'application est effectuée lorsque les larves sont petites.

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Summary of Discussion

Session 4

The effectiveness of the parasitoid *Tetrastichus* sp in sorghum midge control is not fully assessed, since the information that is available on pest-parasitoid interactions is still limited. Although some resistant genotypes can directly or indirectly suppress parasitoid activity, the complementarity between plant resistance and natural enemies offers good prospects in integrated pest management, and these should be further explored.

The natural enemies of the millet head caterpillar should be properly documented, and the most efficient species, and the ways and means by which their efficiency can be improved, should be identified. The contribution of earlier research in Senegal should be exploited, and in particular, the work by V S Bhatnagar on the larval parasite *Bracon hebetor*. Unlike their host insects, information on the biology and behavior of natural enemies is incomplete and is often the missing link in our efforts in biological control.

Farmers' pest control practices to combat panicle-feeding insect pests should be documented and exploited. The outcome of earlier attempts at this exercise should be made available as published information. Although it is recognized that insecticide application is a viable option in the control of head bugs, the option holds little promise for the resource-poor farmer. Plant resistance should receive priority focus, and in the delivery process, the attributes of local landraces should not be ignored. The transfer of resistance into high-yielding lines, hybridization with local landraces, and increased exploitation of Malisor 84-7 hold good potential.

Synthèse de discussion

Session 4

Il reste à déterminer le degré d'efficacité du parasitoïde *Tetrastichus* sp dans la lutte contre la cécidomyie du sorgho, puisque on dispose de peu d'information sur les interactions ravageur-parasitoïde. Bien que certains génotypes résistants puissent empêcher, de manière directe ou indirecte, l'activité du parasitoïde, la complémentarité entre la résistance des plants et les ennemis naturels offre des possibilités de lutte intégrée qui doivent faire l'objet d'étude approfondie.

Les ennemis naturels de la mineuse de l'épi du mil devraient être recensés. Il importe aussi d'identifier les ennemis les plus efficaces dans la lutte et les moyens par lesquels on pourrait améliorer leur efficacité. Il faut tirer parti de la contribution des travaux de recherche effectués précédemment au Sénégal, surtout les études faites par V S Bhatnagar sur le parasite larvaire *Bracon hebetor*. Contrairement à leurs hôtes, l'information sur la biologie et le comportement des ennemis naturels est incomplète et constitue souvent le maillon qui manque à la chaîne dans nos travaux de lutte biologique.

On doit recenser et exploiter les pratiques traditionnelles de lutte des paysans contre les ravageurs des panicules. Les résultats précédemment obtenus dans ce domaine doivent être publiés. Bien que la viabilité de l'application d'insecticides soit un fait reconnu dans la lutte contre les punaises des panicules, cette méthode est hors de portée des paysans. L'attention doit se porter tout particulièrement sur la résistance variétale tout en considérant les caractéristiques des variétés locales. Le transfert de la résistance à des lignées productives, l'hybridation avec des variétés locales et une plus grande exploitation de Malisor 84-7 sont prometteurs.

Session 5

Integrated Pest Management

Lutte intégrée contre les insectes

Integrated Pest Management of Sorghum Midge in USA

G L Teetes[1]

Abstract

Multiple insect pest management tactics are used to manage the sorghum midge Contarinia sorghicola *in USA, and the emphasis is on cultural management tactics such as insect pest avoidance by sowing date manipulation, alternate host elimination, natural/biological control, insecticide use, and plant resistance. The philosophy and research oriented to dealing with this serious insect pest of sorghum are addressed. The role and function of different management tactics are defined and described. Also discussed is the research needed for nonchemical management tactics to be deployed and accepted by crop protection specialists and farmers.*

Introduction

Davies (1982), in an article in the proceedings of the Sorghum in the Eighties symposium, reflected back to the Sorghum in the Seventies symposium and stated that at that time, the most ubiquitous and serious insect pest of sorghum worldwide was the sorghum midge, *Contarinia sorghicola* (Coquillett), and it remains so. It is safe to say that the sorghum midge is still a pervasive and serious insect pest of sorghum. Accordingly, have the research efforts to develop management strategies for this insect pest failed? Has no new technology been developed that lessens the destructiveness of this insect pest? This presentation addresses the technology available to manage this insect pest, describes that technology and its development, and suggests additional research required that will lessen the threat of this important panicle-infesting insect pest of sorghum in USA.

Origin

The sorghum midge is an alien Texan and American. Although first described in 1895 from specimens from Texas, there is ample support for the contention that the sorghum midge originated with sorghum in its aboriginal home of northeastern Africa (Teetes 1988). Support for this contention is as follows:

- Only grasses of the genus *Sorghum* are hosts of the sorghum midge, and sorghums are indigenous to Africa, not USA;
- Examination of herbarium material of the genus *Sorghum* collected in the Sudan in 1869 revealed the presence of sorghum midge larvae and pupae and proved that sorghum midges were present in Africa 26 years before the insect was discovered in USA;
- Species diversity of *Contarinia* and perhaps associated parasite species is probably greater in Africa than USA;
- The sorghum midge is a more severe insect pest in USA than in northeastern Africa;
- Most sources of plant resistance to sorghum midge are zera zera types from Ethiopia and Sudan.

Because the sorghum midge is an exotic insect pest in USA, there may be opportunities to use classical biological control. Also, the limited host species available to the midge in USA may provide better opportunities than are currently used to suppress the abundance of the insect by destroying wild host-plants. It is apparent that plant resistance to this exotic insect pest needs greater exploitation, and that resistant sources come from areas where the insect and sorghum have had the longest association.

1. Department of Entomology, Texas A&M University, College Station, Texas 77843-2475, USA.

Teetes, G.L. 1995. Integrated pest management of sorghum midge in USA. Pages 253-262 *in* Panicle insect pests of sorghum and pearl millet: proceedings of an International Consultative Workshop, 4-7 Oct 1993, ICRISAT Sahelian Center, Niamey, Niger (Nwanze, K.F., and Youm, O., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Management tactics

The management tactics applicable to suppress the sorghum midge commonly include insect pest avoidance by sowing sorghum early and uniformly in an area; destruction of Johnsongrass; abiotic and biotic natural control including indigenous parasites and predators; insecticide use; and resistant sorghum cultivars.

Avoidance. The nature of the biology and population dynamics of the sorghum midge provides an opportunity to exploit an avoidance management tactic. The low temperatures during winter in USA terminate the growth of sorghum midge host plants. Cold temperatures and a host-free period result in the insect surviving the winter in fairly low numbers. Suitable environmental conditions, hosts, and time are required for the insect to increase in abundance to levels that would cause economic damage to sorghum. Consequently, it is possible to sow sorghum early enough in the spring for it to develop past the susceptible flowering stage before sorghum midges increase enough in abundance to be injurious to the crop.

Avoidance of the insect by early sowing is an effective way to reduce losses. However, sowing early in the growing season is not always possible, because sowing may be delayed or extended due to drought or frequent spring rains.

Wild host-plant destruction. Johnsongrass is the host of significance to the sorghum midge, as the insect could probably survive without cultivated sorghum, but not without Johnsongrass. Johnsongrass is a persistent and troublesome weed in most sorghum-growing areas of USA, and is currently classified as one of the 10 worst weeds of field crops in the country (Anderson 1969). Its role in the biology and population dynamics of the sorghum midge is well documented (Anderson 1969, Teetes 1988).

In USA, Johnsongrass is essential for the survival of the sorghum midge. In the spring, sorghum midges emerge from overwintering before cultivated sorghum in the area is flowering. Usually, sorghum midges terminate diapause and emerge at about the time cultivated sorghum is being sown. However, the time that Johnsongrass flowers coincides with the emergence from diapause of the first sorghum midge adults. These adults lay eggs in the flowering spikelets of Johnsongrass to produce the first generation of the season. Typically, a second generation is produced in Johnsongrass before cultivated sorghum in the area is in the flowering stage of panicle development. Once sorghum in the area begins to flower, sorghum midges disperse to it, but usually at abundance levels below those required to cause economic damage. However, midge abundance at damaging levels is usually reached in a single additional generation (Baxendale et al. 1984a,b). Sorghum flowering after this time is subject to severe sorghum midge damage. Very late in the season, sorghum midge abundance declines to non-economic levels. Despite the apparent preference for panicles of cultivated sorghum, sorghum midges infest Johnsongrass throughout the season.

Theoretically, reducing the abundance of this important wild, maintenance host would dramatically suppress the ability of the insect to increase in abundance quickly enough to be at levels high enough to significantly damage sorghum sown as early in the spring as possible. However, control of this grass weed has been impractical because of its abundance in cultivated and noncultivated areas.

Natural/biological control. Natural mortality factors of the sorghum midge are not well known, nor has the effect of natural mortality factors been quantified. Of the abiotic factors that might affect the survival of sorghum midge, moisture is probably more important than temperature, except for extremes of the latter. Sorghum midge is of tropical origin, and thus it would be normal to expect moisture to have as much of a regulating force on the insect as temperature. The insect has, however, adjusted well to a temperate environment.

Natural enemies include most general predators found in a sorghum field. The cryptic habit of the immature stages of the sorghum midge ensures a level of protection from predators. Adult midges would be vulnerable to predators; however, their impact on midge abundance is not known, though it is probably rather small.

Lippincott and Teetes (1983) found four hymenopterous parasitoid species of the sorghum midge in central Texas and studied their nature of parasitism and biology. The parasite species they reported were *Eupelmus popa* Girault, *Aprostocetus diplosidis* Crawford, *Tetrastichus* near *venustus*, and *T.* near *blastophagi*. Over the course of the season, 20% of sorghum midges were parasitized in Johnsongrass, and 8.2% in sorghum. Parasitism did not appear to provide significant midge abundance suppression. Other parasites reported are several eupelmids, eulophids, and several other unidentified *Tetrastichus* species. Much research is needed to assess the impact of sorghum midge parasites, and to determine ways to exploit their presence. Importation biological control or augmentation biological control of sorghum midge have not been attempted in USA. Conservation biological control of the insect is not intentionally practiced.

Insecticide control. Insecticide use in USA is becoming more and more restricted, and for low insecticide use crops like sorghum, insecticides are being lost. The registration and re-registration costs for insecticides are so high that companies do not consider it a profitable investment to get or keep insecticides registered for use on sorghum. Currently, insecticides registered and available for use on sorghum for sorghum midge include chlorpyrifos (Lorsban®), methomyl (Lannate®), and parathion. Chlorpyrifos is the labelled insecticide of choice, but farmers prefer to use synthetic pyrethroids. Attempts for full registration of a pyrethroid have been unsuccessful, and the use of this class of insecticides has been through crisis exemption programs that provide temporary use labels. The insecticide situation with sorghum is indicative of the troubled future of insecticides, especially for commodities that do not have support organizations with lobbying capability or that are willing to spend the time and money to fight the situation politically.

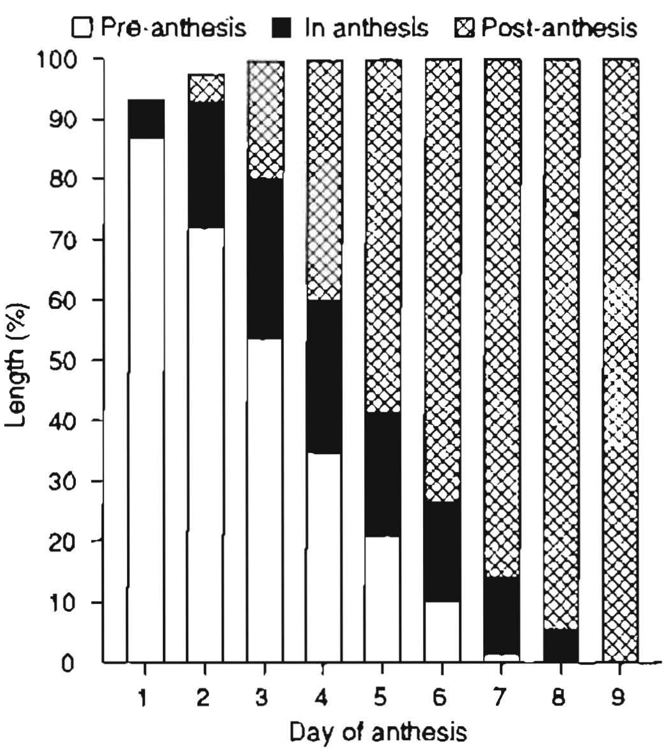


Figure 1. Mean daily percentage pre-anthesis, in anthesis, and post-anthesis per individual panicle of sorghum.

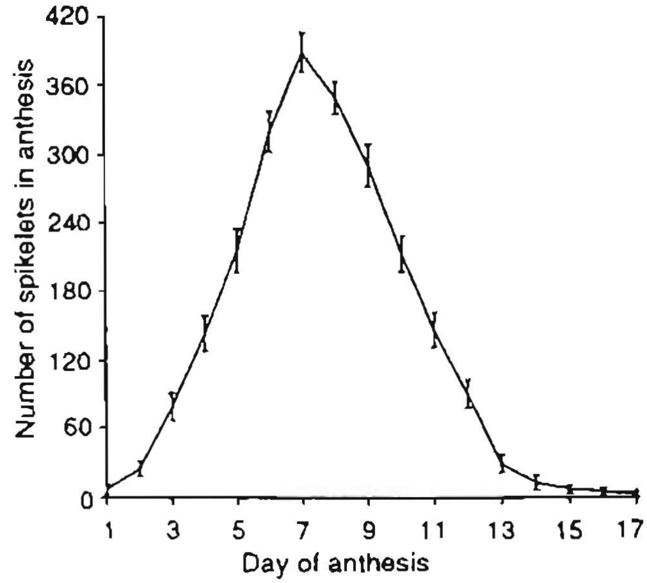


Figure 2. Mean daily number and 95% confidence interval of sorghum spikelets in anthesis per panicle in a field.

To determine the need for insecticidal control of the sorghum midge, an assessment of crop development, yield potential, and sorghum midge abundance is required. Daily evaluation of these factors is critical during the flowering stage of sorghum, especially if sorghum flowers slightly later than normal in an area.

Infestation and subsequent damage by ovipositing sorghum midges can occur until each entire panicle and all panicles in a field have completed flowering. Sorghum flowers and is susceptible to sorghum midge for about 8 days for individual panicles (Fig. 1), and about 2 weeks for sorghum in an entire field (Fig. 2) (Pendleton 1992). The latter depends on the uniformity of development and flowering of sorghum plants in a field.

To determine the presence of sorghum midges, sorghum should be inspected during mid-morning until shortly after noon, when midges are most abundant on flowering panicles. Each day a new brood occurs, so fields must be inspected regularly as midge abundance changes quickly. Adult midges are small and may be difficult to see crawling on or flying about flowering panicles. A clear plastic bag can be used as a trapping device by quickly slipping the bag over a sorghum panicle. Sorghum midges are easily seen within the bag. Windy conditions make sorghum midges more difficult to locate and their abundance difficult to assess accurately.

The need to apply insecticidal control is based on the number of adult midges during the flowering

Table 1. Economic threshold tables for sorghum midge infesting resistant and susceptible sorghum hybrids.

Control cost (US$ ha^{-1})	Market value (US$ ha^{-1})										
	250	300	350	400	450	500	550	600	650	700	750
					Susceptible hybrid						
7.50	1.2[1]	1.0	0.9	0.8	0.7	0.6	0.6	0.5	0.5	0.4	0.4
10.00	1.6	1.3	1.1	1.0	0.9	0.8	0.7	0.7	0.6	0.6	0.5
12.50	2.0	1.7	1.4	1.3	1.1	1.0	0.9	0.8	0.8	0.7	0.7
15.00	2.4	2.0	1.8	1.5	1.3	1.2	1.0	1.0	0.9	0.9	0.8
17.50	2.7	2.3	2.0	1.8	1.6	1.4	1.3	1.2	1.1	1.0	0.9
20.00	3.0	2.7	2.3	2.0	1.8	1.6	1.5	1.3	1.2	1.1	1.1
					Midge-resistant hybrid						
7.50	6[1]	5	5	4	4	3	3	3	3	2	2
10.00	8	7	6	5	5	4	4	4	3	3	3
12.50	10	9	7	7	6	5	5	4	4	4	4
15.00	12	10	9	8	7	6	6	5	5	5	4
17.50	14	12	10	8	8	7	7	6	6	5	5
20.00	15	14	12	10	9	8	8	7	6	6	6

1. Number of midges $panicle^{-1}$.

stage of sorghum development. The density of adults per panicle that would justify chemical control can be determined by first estimating the per-hectare value of the crop, based on the condition of the crop at that time and past experience (Table 1). Second, determine the cost of control per hectare, which includes both the cost of the insecticide and cost of application. Read across the column closest to the cost of control and down the column under the expected value of the crop. The number of adult sorghum midges at that point in the table is the density of the insect pest that would cause damage sufficient to offset the cost of insecticidal control. If adults are present three to five days later, immediately apply insecticide a second time. In some cases, if sorghum flowering is extended and adult sorghum midge abundance remains above the economic threshold, a third application may be required. More than three insecticide applications are probably not economically feasible.

Insecticidal control of sorghum midge is often not as effective as would normally be expected. The flowering characteristics of sorghum, daily infestation by new adult sorghum midges, and the fact that only adult midges are affected by the insecticide, often result in less than adequate or desired control. The production cost/profit ratio of sorghum is not high enough to allow for much insecticide use.

Plant resistance. Of the integrated pest management components used to suppress damage by the sorghum midge, none has received as much attention during the last decade as plant resistance (Teetes 1985). Sorghums resistant to sorghum midge were reported as early as 1908 (Ball and Hastings 1912), but not until the 1970s were sources of resistance discovered that could be used to produce agronomically improved midge-resistant hybrids. In USA, TAM 2566, a converted exotic sorghum, has been the major resistance source used (Johnson et al. 1982), although other sources have been identified and used to a limited extent.

Efforts have been made in USA to determine resistance mechanisms, improve the agronomic qualities of sorghum midge resistant hybrids, and increase the resistance level. The genetic complexity of midge resistance has made these efforts difficult and time consuming. The major resistance mechanism has been described as a nonpreference for oviposition, but the cause of this insect-to-plant response is not understood. In general, resistant hybrids are damaged about five times less than susceptible hybrids at the same sorghum midge infestation level. This level of resistance is significant, but sorghum midge infestations reach such high levels in some areas of USA that the resistance level is not high enough to provide protection in all situations. To deal with this and yet take advantage of the resistance, economic thresholds have been established specifically for midge-resistant hybrids (Table 1). Insecticide application to such hybrids when midge infestation levels are very high is much more effective than they are on susceptible hybrids.

A common approach to elevating the level of resistance in plants to insect pests is to stack or pyramid genes. Several sources of resistance to sorghum midge have been incorporated into the same genotypes, but have not resulted in a significantly higher level of resistance.

To exploit the nonpreference resistance mechanism to improve the effectiveness of the resistance, resistant and susceptible plants have been mix-sown in the same row. This approach is used to draw sorghum midges from the resistant plants to the susceptible plants. The approach does result in less damage to resistant plants as the percentage of susceptible plants increases. This lesser damage is reflected in increased per-panicle yield of the resistant hybrid. Up to a point, per-hectare yields are also increased, and that increase is greater than when the resistant hybrid was grown alone (Fig. 3).

The agronomic qualities of the midge-resistant hybrids have certainly been improved. The leaf discoloration problem common to TAM 2566 hybrids has been resolved. Also, some disease resistance has been added. Yield levels of midge-resistant hybrids are as good or better than many commercial hybrids in performance trials. When sorghum midges are present the resistant hybrids far outyield susceptible hybrids.

The issue to be addressed, therefore, is why are midge-resistant hybrids not being commonly used in USA? The problem must be one of lack of confidence. Farmers in USA want to avoid risk. They perceive insect-resistant cultivars to increase risk. Farmers trust insecticides because of their remedial capabilities. But the group most responsible for the lack of development and deployment of commercial midge-resistant hybrids are the seed companies. And there are reasons for this. To produce such a hybrid is a major commitment in effort and expense. Because the resistance is inherited in a complex manner, a complete inventory of material must be maintained. Most companies also acknowledge their fear of lawsuits if they sell a resistant hybrid that becomes damaged. Established economic thresholds should resolve this problem, but the companies are still reluctant. A way must be found to convince seed companies to carry though with the development and deployment of commercial midge-resistant sorghum hybrids.

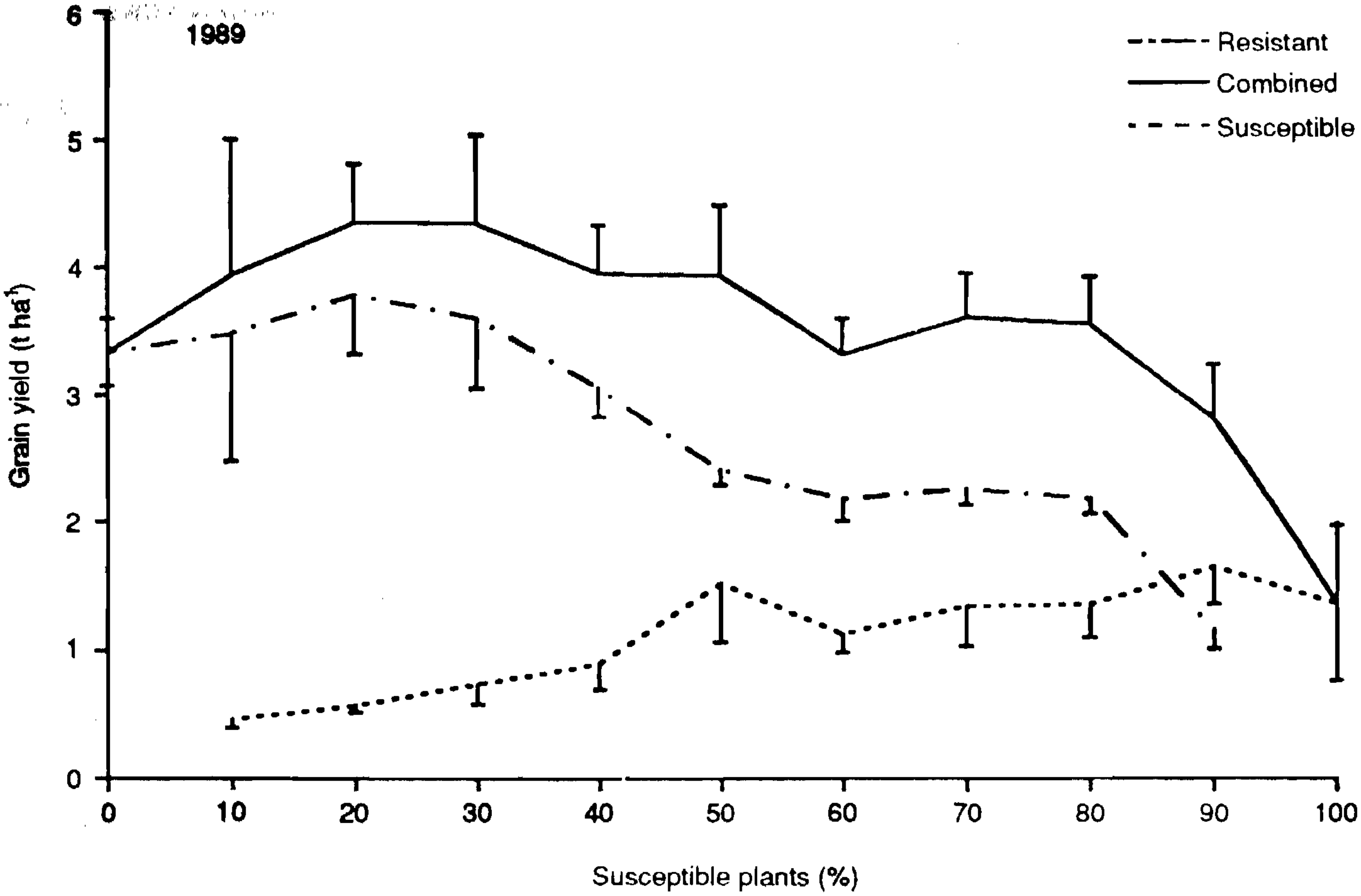
Future Needs to Improve IPM of Sorghum Midge in USA

There are two areas of research that still need much effort relating to integrated pest management of sorghum midge. One has to do with determining the actual cause of the resistance. The other is the ability to better predict the occurrence of sorghum midges and the point in time when they would be expected to reach damaging proportions. These two areas of needed research are addressed below.

Causes of resistance to sorghum midge

Research is currently under way to determine the causes of midge resistance. The manner in which midges respond to resistant sorghums suggests that there are differences between the spikelets of susceptible and resistant sorghums. Based on assessments of the mechanisms of resistance, midge-resistant sorghums interfere with oviposition. This insect-to-plant response has been described as a nonpreference response for oviposition. There has been speculation that this disruption of oviposition is due to morphological factors, the presence of deterring volatiles, or the absence of attracting volatiles. There are significant differences in spikelet morphology of sorghums, and all midge-resistant sorghums have small glumes. However, there are susceptible sorghums with small glumes, so glume size alone is not the cause of resistance. Also, among sorghums there are differences in spikelet morphology, spikelet size, pollen shed, anther extrusion, and other features. The effect of these on midge resistance have not been adequately explored.

Spikelet condition in relation to flowering and the presence or abundance of sorghum midges is probably associated with resistance. Jimenez (1992) reported asynchrony between when adult sorghum midges were present in the field and when spikelets of resistant hybrids flowered (Fig. 4). She found a marked difference between when spikelets of resistant and susceptible sorghums flowered. The resistant hybrid flowered primarily at night when ovipositing sorghum midges were not present. Flowering of the resistant sorghum began at about 2400, was greatest between 0200 and 0300, and was completed by 0900. On the other hand, spikelets of the susceptible sorghum began flowering at about 0600, with most spikelets flowering at 0830, the time when sorghum midges were beginning to occur on panicles bearing flowering spikelets. The glumes of many spikelets of susceptible sorghum remained open and vulnerable to ovipositing sorghum midges until noon or later.



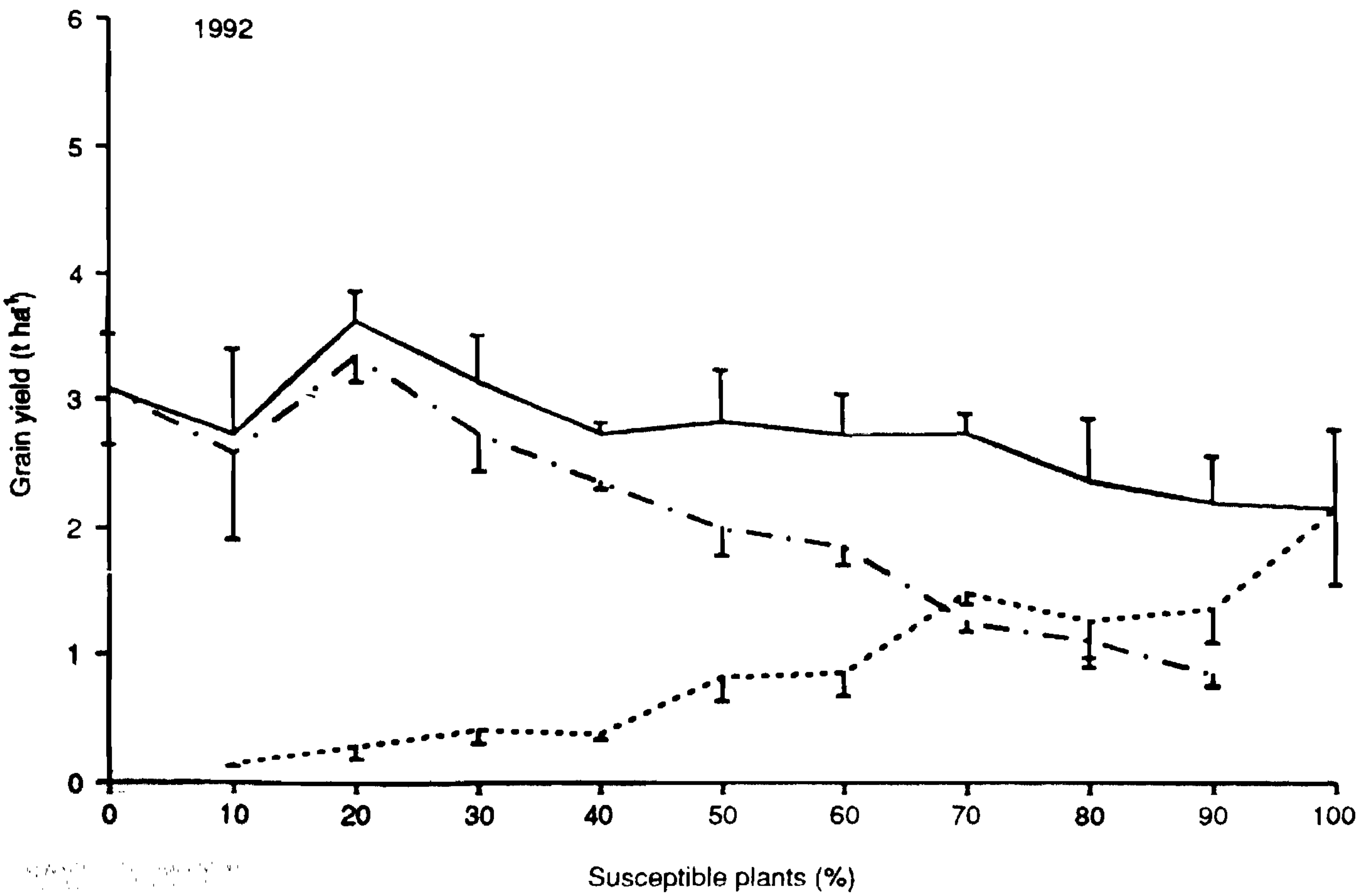


Figure 3. Sorghum grain yield from plots of mixed sorghum midge resistant and susceptible hybrids, 1989 and 1992.

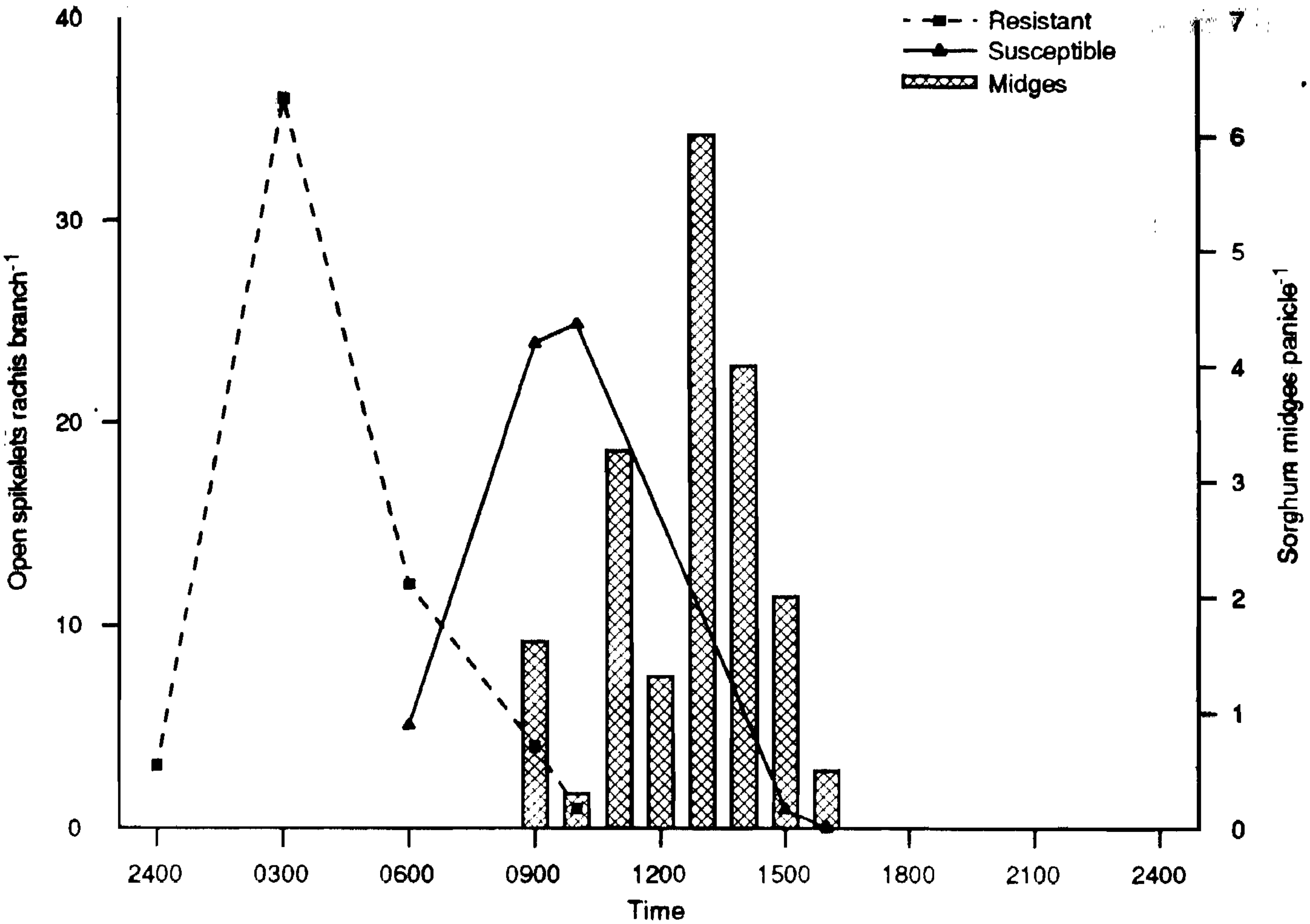


Figure 4. Time patterns of flowering of sorghum midge resistant and susceptible genotypes in relation to the abundance of female sorghum midges.

Capability to predict sorghum midge occurrence

Although not yet published, considerable effort has been directed toward developing computer simulation models to predict sorghum midge occurrence and abundance. One such effort has been to refine the grain sorghum crop growth model, SORKAM, that couples crop phenology with sorghum midge abundance to predict abundance and time of occurrence of sorghum midges in relation to crop yield (Jost 1993). A second model, the sorghum midge simulation model, has been used on a limited basis to predict sorghum midge occurrence, but predictions of the incidence and abundance have varied in accuracy (Pendleton 1992).

Baxendale's (1983) estimates of heat units required for nondiapausing sorghum midges to complete development, measurements of temperature for 1984–92, and a refined simulation model were used to estimate mid-points of sorghum midge generations at College Station, Texas (Pendleton 1992). Beginning 26 Apr, the date Baxendale and Teetes (1983) found that sorghum midges began emerging from diapause at College Station, 15.8–21.0 days were estimated to be required for development of the F_1–F_5 generations (Table 2).

Table 2. Estimated abundance of sorghum midges at College Station, Texas, at the mid-point of each generation following diapause termination, 1979–81.

Generation	Day of mid-point of generation	Midges panicle^{-1}	Sorghum host available for oviposition
P	26 Apr	0.002	*S. halepense*
F_1	17 May	0.005	*S. halepense*
F_2	5 Jun	0.019	*S. bicolor*
F_3	22 Jun	0.46	*S. bicolor*
F_4	8 Jul	5.79	*S. bicolor*
F_5	23 Jul	4.18	*S. bicolor*

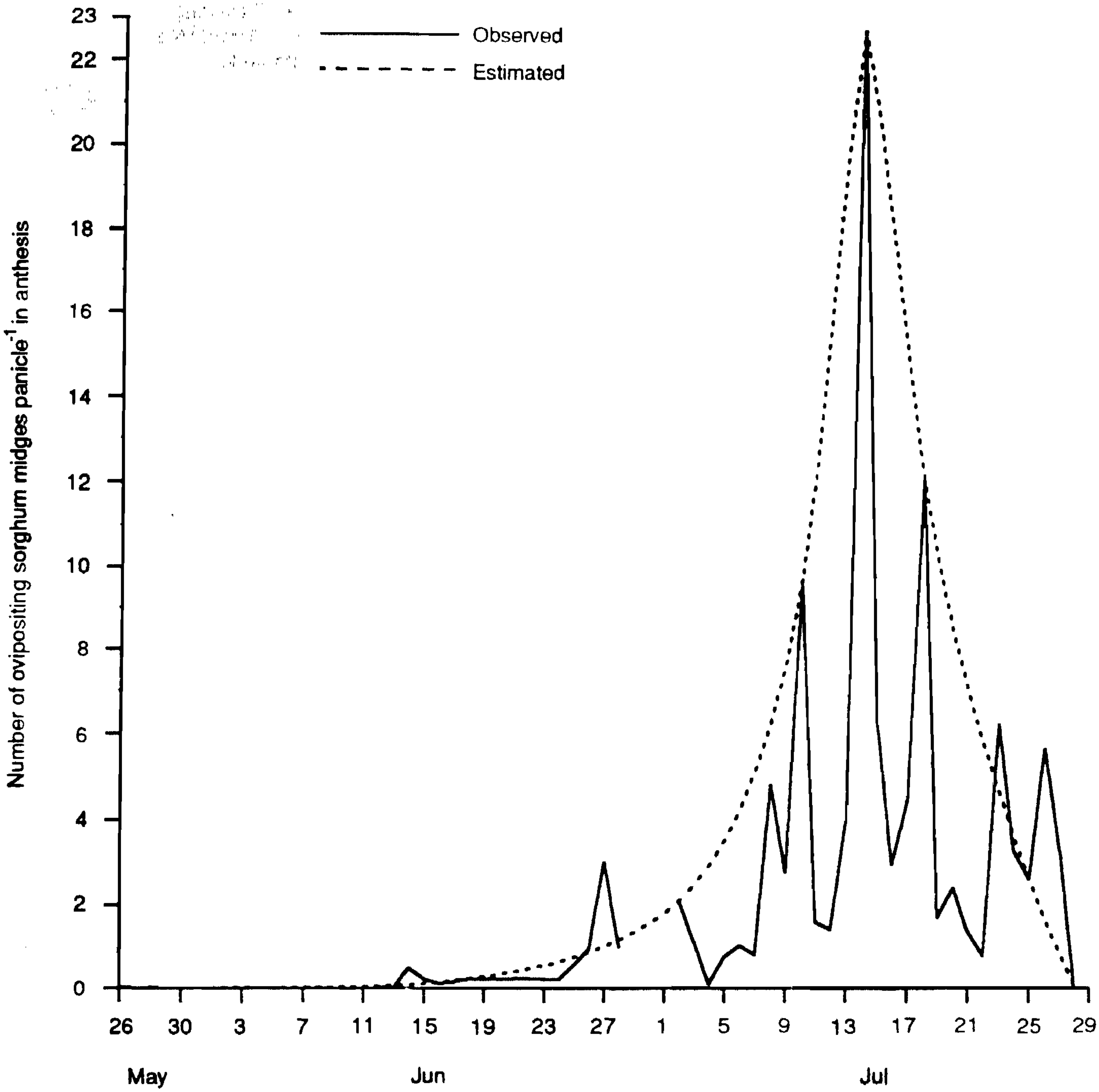


Figure 5. Observed and estimated daily abundance of ovipositing sorghum midges during the sorghum growing season.

Observed abundance increased from zero or few ovipositing sorghum midges per panicle in mid-May to a maximum of 22.7 sorghum midges on 14 Jul and then declined (Fig. 5). Abundance increased 2.5- and 3.7-fold in the first two generations. Johnsongrass was the only host available for the first two generations. Sorghum midge abundance increased 24.6-fold between the F_2 and F_3 generations, the first generation of sorghum midges to develop within spikelets of sorghum rather than Johnsongrass. The economic threshold level was estimated to have been exceeded on 27 Jun during the last days of the F_3 generation and sorghum midge abundance greatly exceeded the economic threshold during the F_4 generation.

These computer model-aided prediction capabilities provide a unique opportunity to better assess the effectiveness of management tactics, and to determine the likelihood of the need for remedial action in the form of insecticides. Even more important, they can be used to assess risk that is perceived by farmers to exist when management of the sorghum midge is based on non-insecticidal means.

Conclusions

The sorghum midge remains a key pest of sorghum in most sorghum-growing areas of USA, but tactics applicable and available for management are becoming more readily available and more reliable. These advances will significantly improve the capability to effectively manage this insect and reduce its persistent threat to sorghum yields. Reduction in the severity of the threat from the sorghum midge will remove an important production constraint and increase the sustainability of sorghum production in developed and developing countries.

Synthèse

Lutte intégrée contre la cécidomyie du sorgho aux Etats-Unis. Diverses stratégies de lutte sont utilisées aux Etats-Unis contre la cécidomyie du sorgho, *Contarinia sorghicola* (Coquillett), le ravageur le plus redoutable et répandu du sorgho *Sorghum bicolor* (L.) Moench. La cécidomyie provient sans doute de l'Afrique du Nord-est avec le sorgho, car seules les graminées du genre *Sorghum*, indigène de l'Afrique, sont des plantes-hôtes de ce ravageur.

Des cécidomyies en hivernage terminent leur diapause au début du printemps lorsque les adultes émergent. Aux Etats-Unis, les 1-2 premières générations des cécidomyies infestent le sorgho d'Alep avant que le sorgho cultivé ne soit disponible. Des femelles émergent des épillets peu après l'aube, s'accouplent, se dispersent vers des sorghos en floraison, pondent des oeufs et meurent en une journée. Chaque femelle pond à peu près 50 oeufs entre les glumes des épillets en floraison des sorghos d'Alep et cultivé. En se nourrissant sur les ovaires, les larves empêchent le développement du grain dont il résulte l'avortement de tous les grains. Une génération dure 16–18 jours et il peut y avoir de multiples générations par an. Jusqu'à très tard dans la saison, la population des cécidomyies s'accroît entre les générations si les conditions climatiques sont favorables et le sorgho en floraison est disponible.

Plusieurs stratégies de lutte peuvent être utilisées pour limiter l'abondance des cécidomyies. Un semis précoce et uniforme dans une région permet aux plants de sorgho de développer au-delà du stade sensible de floraison avant que la population de cécidomyies ait le temps d'atteindre un seuil de nuisibilité. La destruction des plants de sorgho d'Alep peut empêcher l'accroissement de l'infestation par des cécidomyies au début de la saison. Des facteurs de mortalité naturelle telles que l'humidité et la température affectent la survie des cécidomyies. Au Texas du centre, 20% des cécidomyies chez le sorgho d'Alep et 8,2% des cécidomyies chez le sorgho sont parasités par l'un des quatre parasitoïdes hyménoptères.

L'utilisation de l'insecticide aux Etats-Unis est de plus en plus déconseillé, surtout pour des cultures tel que le sorgho. Le rapport coût/bénéfice de la production du sorgho n'étant pas assez élevé, il se peut que la lutte à l'aide des insecticides ne soit pas très pratique et que très peu d'insecticides soit utilisé sur le sorgho. Il en résulte que seules les cécidomyies adultes sont affectés par des insecticides. Or, tous les jours de nouvelles cécidomyies réinfestent les plants. En plus, au cours de la floraison, le sorgho est sensible pour 8 jours dans le cas des panicules individuelles et pour 2 semaines en champs.

Dans les années 1970, la résistance a été découverte chez TAM 2566, un sorgho exotique converti qu'on a employé pour produire des hybrides agronomiques améliorés. Les dégâts chez des hybrides résistants sont de cinq fois moins que ceux des hybrides sensibles. Aux Etats-Unis, on s'est efforcé de déterminer des mécanismes de résistance, d'améliorer les qualités agronomiques des hybrides résistants et d'élever le niveau de résistance. Il reste à convaincre les industries semencières d'entreprendre le développement et la dissémination des hybrides commerciaux résistants à la cécidomyie.

La mise au point des modélisations à l'aide d'ordinateur est en cours afin d'être en mesure de prévoir les dégâts causés par des cécidomyies et de déterminer l'efficacité et l'époque d'utilisation des mesures de lutte, y compris les insecticides. En plus, des modèles de simulation peuvent être utilisés pour évaluer les risques constatés par des paysans, lorsque des mesures de lutte non insecticides contre les cécidomyies du sorgho sont employées.

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Possibilities for Integrated Management of Millet Earhead Caterpillar, *Heliocheilus albipunctella*

K F Nwanze[1], M C Klaij[2] and R H Markham[3]

Abstract

Heliocheilus albipunctella *is the major panicle insect pest of pearl millet in West Africa. Chemical insecticides are not a viable strategy for controlling this pest in traditional pearl millet-based farming systems of the region. Field experiments in Niger showed that deep plowing (30 cm) at the end of the season reduced the number of surviving pupae in the soil (>50%), with highest pupal mortalities in the top 10 cm of the profile. In trials on varietal resistance, the local landrace pearl millet cultivars had low (<3 on a 1–5 scale) panicle damage. However, low damage was associated with time of flowering, and therefore with escape rather than genetic resistance. A survey of natural enemies in Niger and Burkina Faso indicated that although the number of parasitoid and predator species were few, three genera of egg parasitoids,* Trichogrammatoidea *sp nr* lutea *and* Telenomus anates *Nixon and an encyrtid; two egg predators,* Orius *sp and* Glypsus conspicuus *Westwood; and several larval parasites,* Bracon hebetor *Say,* Copidosoma obscurum *Nikolskaya and* Goniophthalmus halli *Mesnil were present. These results show good potential for an integrated approach for the management of this pest.*

Introduction

The major areas of production of pearl millet (*Pennisetum glaucum* (L.) R. Br.) in Africa are in the Sudano-Sahelian and Sahelian zones of West Africa, where this crop constitutes the major staple cereal. Next to erratic rainfall, frequent droughts, and poor soil conditions, insect pests are the major biotic constraint in pearl millet production and can cause estimated crop losses of over US$200 million annually (ICRISAT 1992). Of the several pest species reported on pearl millet, the stem borer, *Coniesta ignefusalis* Hampson [= *Acigona ignefusalis*] and the earhead caterpillar, *Heliocheilus albipunctella* de Joannis [= *Raghuva albipunctella*], are considered the major species of importance in West Africa. They are not known to occur in India, which is the world's largest producer of pearl millet.

Heliocheilus albipunctella is widely distributed in the Sahel (Vercambre 1978, Doumbia and Bonzi 1989, Nwanze and Sivakumar 1990) and studies on its bioecology and economic importance are well documented (Vercambre 1982, Gahukar et al. 1986, Ndoye and Gahukar 1987, Gahukar 1987, Ndoye 1988, Bal 1989, Bernardi et al. 1989, Nwanze and Sivakumar 1990). Eggs are laid on newly exserted panicles and young larvae of *H. albipunctella* feed on the floral glumes. Older larval instars cut the floral spikelet branches and produce characteristic spiral mines. Extensive damage can result in skeletonized panicles. Mature larvae migrate into the soil, where they diapause. Only one generation is produced per year. Moth emergence occurs in the following season, coinciding with panicle exsertion in traditional millet varieties.

1. ICRISAT Asia Center, Patancheru 502 324, Andhra Pradesh, India.
2. ICRISAT Sahelian Center, BP 12404, Niamey, Niger.
3. CAB International Institute of Biological Control, Kenya Station, Box 76520, Nairobi, Kenya.

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Because of the low commercial value of pearl millet [less than one third the value per kilogram of rice in Nigeria (M.C.S. Bantilan, ICRISAT, personal communication 1993)], the use of expensive and often unavailable chemical insecticides is nonsustainable in traditional pearl millet farming systems of West Africa. This situation calls for an integrated approach with emphasis on cultural, biological, and genetic pest control tactics.

This paper summarizes the results of field experiments conducted in 1984–85 at the ICRISAT Sahelian Center in Niger on (a) the effects of plowing and removal of crop residues at the end of the crop season on the survival of diapausing pupae and (b) the evaluation of a working collection of pearl millet genotypes for varietal resistance under natural pest infestation. The results of a survey of natural enemies of *H. albipunctella* in Niger and Burkina Faso, and possibilities for biological control, are also presented.

Materials and Methods

Soil management

In order to determine the effect of soil tillage on the population of soil-diapausing pupae during the long dry season (Nov–May), we selected a field of pearl millet (var HKBTif) with a known high level of infestation (85% infested panicles and a damage rating of 3.5, where 1 = zero to low severity and 5 = high severity). After the harvest in Oct 1984, the experimental area was demarcated into 20 m × 20 m plots with the following treatments: T1, crop residue removal and no plowing; T2, crop residue incorporation by deep plowing (30 cm); and control T3, no crop residue removal and no plowing.

Beginning in Nov, diapausing pupae were monitored by monthly soil sampling in four randomly selected 1 m × 1 m subplots in each plot of 20 m × 20 m. Pupae were collected by excavating the soil in 5 cm layers to a depth of 30 cm and sieving it through 2 mm sieves. The number of diapausing and empty pupal cases in each 5 cm layer were recorded. Observations were terminated in May 1985 at the end of the dry season.

Soil thermometers were installed at soil depths of 5, 15, and 25 cm in T3 only, and soil temperatures were recorded at 1400 each day from Nov 1984 to May 1985.

Varietal resistance

Information is lacking on the level of resistance to *H. albipunctella* in commonly cultivated landraces, improved local landrace cultivars, and introduced breeding material. Between 1983 and 1986 we assembled and evaluated a working collection consisting of entries from various collaborative entomology and breeding trials and nurseries generated by ICRISAT's West African programs and national agricultural research systems (NARS) of the region (Table 1). A set of germplasm entries originating from southern African countries (Botswana, Malawi, South Africa, Tanzania, Zambia, and Zimbabwe) were also evaluated.

All trials were hand-sown in 5 × 5 m row plots in four replications, except for the germplasm from southern Africa which was not replicated due to nonavailability of seed. At 21 days after seedling emergence (DAE), plants were thinned to 2 plants hill^{-1} at an intrarow spacing of 40 cm between hills. All other agronomic practices were carried out as recommended.

The following observations were recorded: total plant stand and number of tillers hill^{-1} at 45 DAE, days to 50% flowering, percentage infested panicles, and damage severity scored on a 1–5 scale. Grain yield was recorded at harvest.

Survey of natural enemies

In collaboration with the Commonwealth Agricultural Bureaux International Institute of Biological Control (IIBC), UK, we conducted a survey on the species complex, relative frequencies, and distribution of natural enemies of *H. albipunctella* in the Southern Sahelian and Northern Sudanian zones of Niger and Burkina Faso. Most collections of pests and natural enemies were made in farmers' fields along the route, plus a few at the ICRISAT Sahelian Center in Niger and the National Agricultural Research Station at Kamboinse, Burkina Faso. A total of 58 sites were covered in both countries.

During the surveys, farms were selected at random at 10–30 km intervals along a chosen route depending on the distribution of millet fields and the growth stage of the crop. Collections were made to represent a wide range of environments. Small collections were made from each infestation encountered and then supplemented by more intensive sampling from a small number of contrasting sites. In this way

Table 1. Summary of results obtained in seven trials evaluated for varietal resistance under natural infestation of *Heliocheilus albipunctella*, ICRISAT Sahelian Center, Niger, 1983–85[1].

Trial/Nursery[2]	Year of evaluation	Number of entries	Time to 50% flowering (days) ±SE	Infested plant hills (%) ±SE	Infested heads (%) ±SE	Damage rating[3] ±SE
ICRISAT/IAR	1983	68	61±1.8 (54–70)[4]	47±6.3	21±3.4	1.6±0.3
ICRISAT/INRAN	1984	20	54±2.2 (50–65)	28±4.2	8±2.6	1.3±0.1
IMZAT	1984	16	70±1.1 (64–85)	32±5	31±4.1	1.4±0.2
Advanced population	1984	33	56±2.3 (51–69)	83±12.4	39±9.2	2.0±0.3
ICRISAT/INSAH	1984	10	66±2.1 (59–82)	43±5.4	22±3.2	1.3±0.4
Southern African germplasm	1984	54	>70	24±6.1	13±1.3	1.2±0.9
ICRISAT/INRAN	1985	14	57±3.4 (53–69)	72±14.6	41±13.1	1.6±0.6
IMZAT	1986	17	70±1.6 (64–85)	95±11.2	71±14.3	4.4±0.5

1. Under natural infestation.
2. IAR: Institute for Agricultural Research, Nigeria; INRAN: Institut National de Recherches Agronomiques du Niger; IMZAT: ICRISAT Pearl Millet African Zone A Trial (conducted at Chikal, Niger); INSAH: Institut du Sahel (IPM Project), Mali.
3. Trial mean, based on a 1–5 damage rating scale, where 1 = zero to low severity, and 5 = high severity.
4. Range in parentheses.

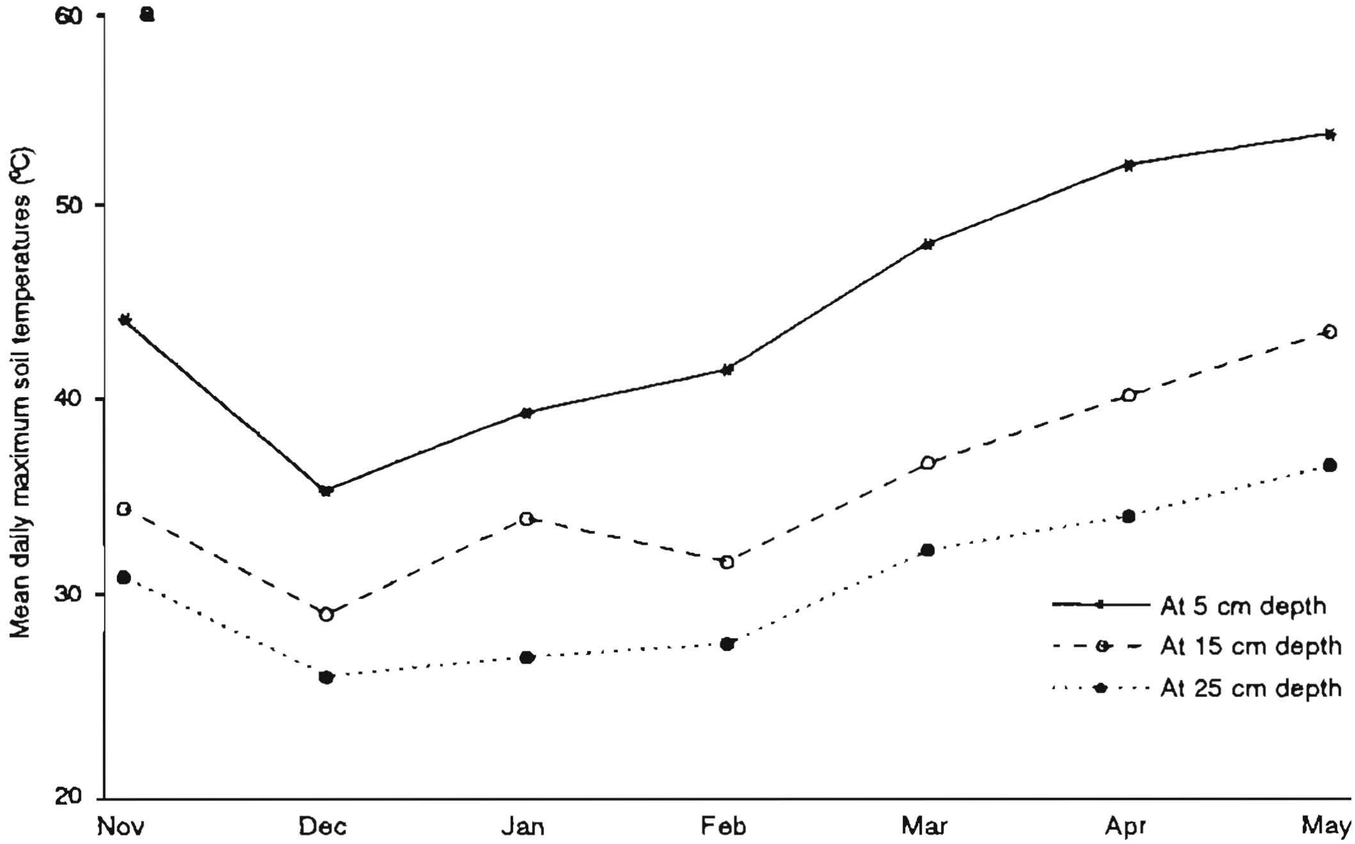
we achieved an acceptable compromise between the need to estimate rates of parasitism and the necessity to obtain an overview of the host-parasite situation. Millet panicles were inspected for eggs and larvae of both parasites and *H. albipunctella*. Parasitoid larvae and cocoons were placed immediately into individual glass vials until emergence. Host eggs from each collection site were kept separately but batches were not isolated. The collected host larvae were usually kept in individual vials containing a modified *Chilo partellus* diet (Taneja and Leuschner 1985) or pieces of millet panicles until emergence of parasitoids. Representative samples of all parasitoids and predators were identified at the CAB International Institute of Entomology (IIE).

Results

Soil management

An indication of the usual distribution of pupae in the soil was obtained from the control treatment, T3. The majority (66%) of diapausing pupae were found in the upper 20 cm soil zone, with 40% in the 10–20 cm layer, 26% in the 0–10 cm layer, and 34% in the 20–30 cm layer. The total number of pupae collected and live diapausing individuals declined sharply from Nov to May and was closely associated with increasing soil temperatures (Fig. 1).

Deep plowing reduced the number of surviving pupae at all soil depths sampled and the effect was



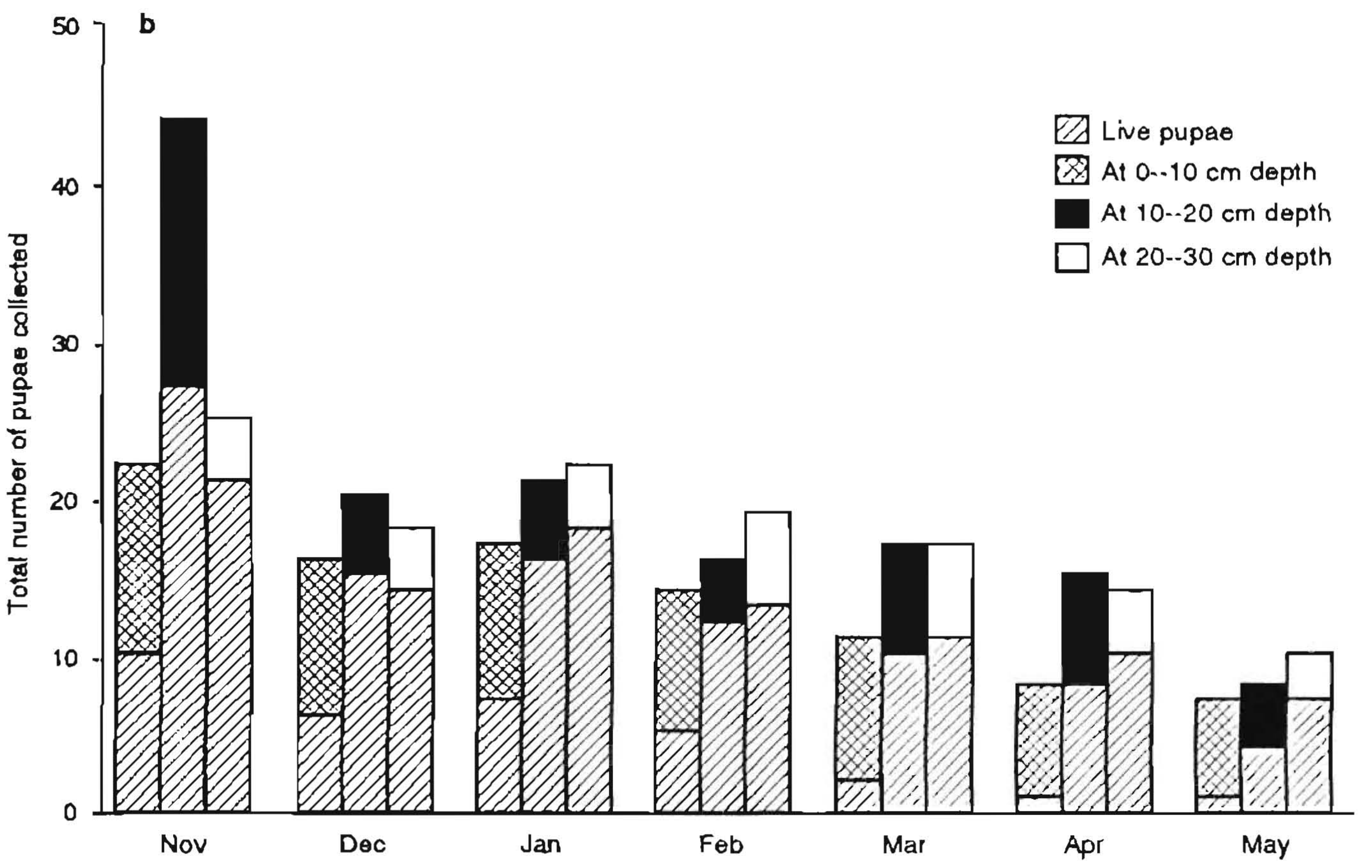


Figure 1. Mean soil temperatures (a) and monthly counts (b) of diapausing *Heliocheilus albipunctella* pupae at different soil depths, ICRISAT Sahelian Center, Niamey, Niger, dry season 1984/85.

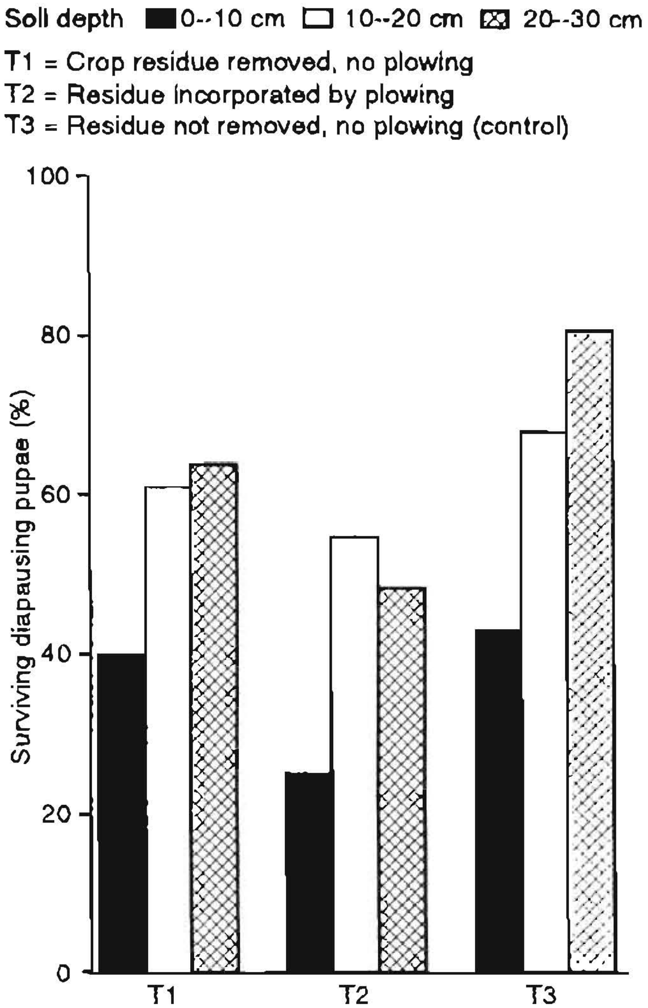


Figure 2. Effect of soil management at the end of the cropping season on the survival of diapausing *Heliocheilus albipunctella* pupae at different soil depths, ICRISAT Sahelian Center, Niamey, Niger, dry season 1984/85.

most pronounced ($P = 0.05$) in the upper 10 cm zone (Fig. 2). During the sampling period (Nov to May), only 25% of the total pupae in the 0–10 cm layer were alive in the plowed treatment (T2) compared to 40% and 41% in T1 and T3. These differences were not as significant in the 10–20 and 20–30 cm soil layers. However, both plowing (T2) and crop residue removal (T1) resulted in a faster decline and higher total mortality of pupal populations from Nov to May. In Nov 1984, the proportion of live pupae at all soil depths combined were 57%, 50%, and 70% for T1, T2, and T3, whereas the figures in May 1985 were 39%, 8%, and 62%.

Varietal resistance

The incidence of *H. albipunctella* at the ICRISAT Sahelian Center, Sadoré, Niger, varied considerably in 1983, 1984, and 1985. The proportion of infested hills (scored on the basis of at least one infested tiller per hill) ranged from 0–100%, and the proportion of infested panicles (irrespective of the number and length of larval mines) between 0 and 75%. However, damage severity rating, which is a critical measure of the level of infestation/resistance, was generally low (<2 on a 1–5 scale) (Table 1). Consequently, meaningful evaluation of test entries in the seven trials conducted during that period was not possible.

However, in all trials, short-duration entries, especially those originating from ICRISAT Asia Center, India, were generally more susceptible to damage than longer-duration local entries. The latter group included Toriniou and Souna from Mali, Haini Kirei from Niger, and a few breeding lines originating from crosses between genotypes of West African origin (IBMV 8302, INMG1-1, INMG 52, and ITMV 8001). Data analysis indicated a high correlation ($r = -0.69$, $P = 0.05$) between time to 50% flowering and number of infested panicles (Fig. 3), indicating that escape from infestation through late flowering was the major reason for the observed differences in cultivar ratings.

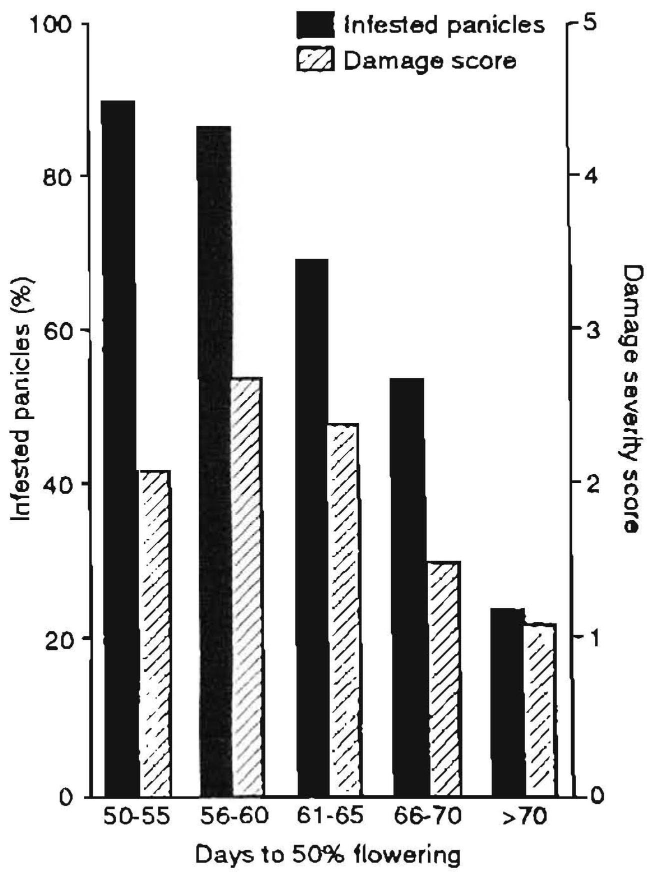


Figure 3. Relationship between time to flowering and infestation by *Heliocheilus albipunctella* in pearl millet.

In 1986, the ICRISAT Pearl Millet African Zone A Trial (IMZAT) was evaluated at a *H. albipunctella* hot-spot location at Chikal in northern Niger. Infestations of earhead caterpillars were very high and most entries recorded a damage score of >4. Several entries, e.g., ITMV 8001, HKP, and ITMV 8304 that had registered low damage (rating <2), in 1984 suffered severe damage (>4). The local entry was the least damaged (rating 2.5).

Survey of natural enemies

Earhead caterpillar attack was delayed in 1985 by the late onset of rains. In Niger, infestations were found sporadically between Maradi and Tessaoua and more generally between Niamey and Filingue. In Burkina Faso, only the northern part of the country, with lower rainfall and sandy soils, is subject to *H. albipunctella* attack. No adults had been recorded in light traps at Ouahigouya at the time of the survey (22 Aug to 8 Sep 1985).

An estimated 1600 *Heliocheilus* eggs were collected from 18 sites in Niger. At the completion of emergence, only three genera of egg parasitoids were recorded—a trichogrammatid (*Trichogrammatoidea* sp nr *lutea*), a scelionid (*Telenomus anates* Nixon), and an unidentified encyrtid. The trichogrammatid was the sole parasite at three sites and the encyrtid at two; a mixed population was found at one site. The overall rate of parasitism was less than 10%, with a maximum of 40% being recorded from one site at the ICRISAT Sahelian Center research farm at Sadoré.

In addition to these egg parasites, two Hemipteran egg predators, *Orius* sp (Anthocoridae) and *Glypsus conspicuus* Westwood (Pentatomidae) were also recorded. *Orius* sp was observed on millet panicles at almost all sites where *H. albipunctella* eggs were found. Several unidentified tetranychid mites, although less common, were associated with eggs of *H. albipunctella* and may have been predating upon them.

Over 400 larvae of *H. albipunctella* were collected from 16 sites and held for emergence of parasites. Over 60% mortality was recorded, mostly from those held as bulk samples. Successful pupation and diapause of several individuals and limited adult emergence clearly indicated very low larval parasitism. Less than 4% of the initial collection was parasitized and only two species were frequently present: *Bracon hebetor* Say (Braconidae) and *Copidosoma obscurum* Nikolskaya (Encyrtidae) [= *Litomastix* sp]. A third species, *Goniophthalmus halli* Mesnil (Tachinidae), was also recovered from a few specimens.

Several unidentified predatory Coleoptera larvae were occasionally encountered within larval mines. In the area between Zinder and Magaria in Niger, the number of dead *Heliocheilus* larvae was considerable but facilities did not permit us to test for the presence of microbial agents.

Discussion

The results from our study on soil tillage agree with earlier reports from Senegal on the effect of this practice in reducing soil populations of *H. albipunctella* (Vercambre 1978, Gahukar 1990). No evidence has been presented on the mechanism involved, although it can be assumed that diapausing populations are thereby exposed to predation and high soil temperatures. Otherwise, once inside the soil, larvae are largely protected from natural enemies. Evidence of a temperature effect is supported by the rapid decline in pupal populations after Feb, which corresponded with a steep rise in soil temperatures (Fig. 1). Residue removal or destruction has been shown to reduce post-season larval and pupal populations of the millet stem borer, *Coniesta ignefusalis* in Senegal (Ndoye and Gahukar 1987) and similar results were obtained for the African maize stem borer, *Busseola fusca* Fuller in Nigeria (Adesiyun and Ajayi 1980). However, the impact of soil tillage on the earhead caterpillar will significantly affect pupal populations only in the top 10 cm of the soil profile.

The timing and method of soil tillage is very important; if done properly when soil moisture is adequate, apart from reducing *H. albipunctella* pupal population it also provides an uneven surface, thereby reducing soil wind erosion. There are, however, counter-arguments against this practice—the use of crop residue for construction, fencing, livestock feed, and as firewood. Moreover, when done at the wrong time, tillage could expose the soil to severe wind erosion.

The results obtained from our screening trials were limited because of a lack of uniform and optimum natural infestations. Other authors have reported varying degrees of resistance to *Heliocheilus* under natural infestation (Guevremont 1983, Doumbia et al. 1984, Gahukar 1984, Maïga 1984, Ndoye and Gahukar 1987). Resistance was attributed to panicle length, compactness, and presence of bristles, and several genotypes were selected and recommended as promising. These need to be re-evaluated under conditions of high and uniform *H. albipunctella* infestation.

Since *H. albipunctella* is univoltine, under natural infestation, long-duration pearl millet cultivars will be exposed to declining pest populations and therefore less damage. This may explain the low damage rating recorded in 1983, 1984, and 1985, in spite of the high levels of incidence in terms of numbers of infested hills and panicles (Table 1).

A prerequisite for a successful screening program is access to a broad and variable germplasm collection and provision for adequate screening under enhanced or artificial (but optimum and uniform) infestation which is consistent, reliable, and repeatable. This aspect has already been addressed by Youm and Anand Kumar in an earlier session of this workshop (see elsewhere in this publication). Their results show that there is genetic resistance in existing material which can be improved by current breeding techniques. Varietal resistance is therefore of relevance in the management of *Heliocheilus*.

The problems encountered in rearing collected host larvae make it difficult to draw firm conclusions from our survey on the importance of larval parasites in regulating *Heliocheilus* populations. Observations made during our surveys appear to indicate that high mortality occurs between oviposition and establishment of first instar larvae. While egg parasites do not seem to have an impact on *H. albipunctella* populations, predators such as *Orius* sp may play a major role. The difficulties of demonstrating that predators observed in a field survey necessarily attack the pest being surveyed are compounded by the fact that predatory events, which is the best indicator, are occasionally seen in the field. Confining predator and putative prey in a cage is indicative, but not conclusive. Simple experiments could be designed to demonstrate the role of predators and panicle characteristics in larval establishment and to determine which factors are responsible for the mortality of early larval stages.

Studies by Bhatnagar (1987), Gahukar et al. (1986), and Guevremont (1983) identified over 20 auxillary parasites of the earhead caterpillar. The most important species, *Bracon hebetor*, *Copidosoma obscurum* and *Cardiochiles* spp (Braconidae) were claimed to result in unusually high levels of larval parasitism of up to 54% in Niger and 80% in Senegal. Such levels have not been encountered elsewhere. The supposed existence of ecological barriers preventing the spread of parasites common in some regions to other millet-growing areas does not seem to be a valid explanation for these differences. The lists of parasites from various countries of the Sahel indicate that the same major species are involved throughout. It is most likely, therefore, that the reported differences in efficacies in different parts of the region result from local agroecological factors. Surveys only give spot samples, location-specific detailed studies are necessary to demonstrate the impact of natural enemies. Information from the results presented here emphasizes the need for such studies on host-parasite interactions to demonstrate the impact of natural enemies on *Heliocheilus* populations in farmers' fields.

Heliocheilus albipunctella is well adapted to a harsh environment. Any control strategy will require emphasis on tactics that integrate both the physical and biotic environments of this pest; any approach based entirely on a single management practice is less likely to provide a solution to a chronic problem such as this pest. The development of an integrated control strategy is essential, and crop management, plant resistance, and biological control tactics should be included. It is obvious that, given the environment of the Sahel, the introduction of exotic natural enemies does not look promising. The approach must utilize crop management practices that can effectively reduce pest populations and enhance the buildup and spread of natural enemies. The development of reliable laboratory mass rearing methods is needed for ecological studies of *Heliocheilus* and its natural enemies, and also to provide reliable cultures for resistance screening.

Acknowledgments

Soil temperature measurements were taken by M V K Sivakumar. Abdoulkarim Mamalo recorded field observations and Idi Saley maintained the field experiments. F R Bidinger and N J Armes reviewed the first draft of this paper.

Synthèse

***Possibilités d'utiliser la lutte intégrée contre la mineuse de l'épi,* Heliocheilus albipunctella.** La mineuse de l'épi, *Heliocheilus albipunctella* de Joannis, est le plus important ravageur paniculaire du mil en Afrique de l'Ouest. Ce sont des larves qui provoquent des dégâts. Les panicules fortement infestées ont une apparence squelettique. Le mil ayant peu d'importance économique, l'utilisation des insecticides chimiques n'est pas une mesure de lutte viable dans les systèmes culturaux traditionnels à base du mil. La défense du mil donc fait appel à une approche de lutte intégrée contre les insectes nuisibles axée sur des mesures culturale, biologique et génétique. On présente ici les résultats d'une étude conduite en Afrique de l'Ouest en 1983–86.

Une étude sur la gestion du sol effectuée en 1984–85 au Niger a permis de comparer les effets de diverses combinaisons des résidus de culture et du labour profond (30 cm) sur la population des pupes en diapause dans le sol au cours de la saison sèche (novembre-mai). Le labour profond combiné avec l'enlèvement des résidus de culture à la fin de la saison ont réduit de moins de 50% le nombre des pupes qui ont survécu dans le sol par rapport aux traitements utilisés seuls. Ce traitement a entraîné une chute rapide et totale des populations pupales depuis novembre jusqu'en mai et son effet a été particulièrement important dans les 10 cm de la couche supérieure du sol que dans les couches 10–20 cm et 20–30 cm.

Entre 1983 et 1986, une collection de travail comprenant des entrées dans divers essais et pépinières conjoints a été évaluée pour la résistance à *H. albipunctella* dans des conditions d'infestation naturelle au Niger. L'évaluation a été basée sur une notation de sévérité des dégâts aux panicules (1–5), ou 1 = incidence nulle à faible; et 5 = incidence très élevée. En 1983, 1984, et 1985, l'étude a été réalisée à Sadoré et les infestations ont été assez faibles pour faire une évaluation significative. Cependant, en 1986, l'étude a été effectuée à Chikal au nord du Niger où les infestations étaient très élevées et la plupart des entrées ont eu une notation de >4. Dans tous les essais, des lignées précoces et améliorées au point de vue agronomique ont été, en général, plus sensibles que les entrées locales tardives. Une analyse plus approfondie a révélé une corrélation élevée (r = 0,69) entre le nombre de jours à la floraison et les dégâts causés par la mineuse de l'épi du mil. Aussi est-il évident que le faible niveau de dégâts chez les cultivars locaux est plutôt associé à la durée du cycle—et ainsi à l'échappement des plants aux infestations—qu'à la résistance génétique.

L'ICRISAT et l'Institut international de lutte biologique (CAB, Royaume-Uni) ont entrepris une enquête conjointe pour évaluer le complexe d'espèces, les fréquences relatives et la distribution des ennemis naturels de *H. albipunctella* au Niger et au Burkina Faso. La plupart des collections des ravageurs et des ennemis naturels ont été prélevées sur les champs paysans et complétées par certains échantillons des stations de recherche dans les deux pays. La mission de collecte a pu couvrir 58 emplacements. L'Institut international de l'entomologie a identifié des échantillons représentatifs de tous les parasitoïdes et de prédateurs.

On a enregistré trois espèces de parasitoïdes d'oeufs, *Trichogrammatoidea* sp nr. *lutea*, *Telenomus anates* Nixon, un encyrtidé inconnu ainsi que deux prédateurs d'oeufs, *Orius* sp et *Glypsus conspicuus* Westwood. Toutefois, le taux général du parasitisme des oeufs a été moins de 10%. Les parasitoïdes larvaires ont compris deux espèces souvent rencontrées, *Bracon hebetor* Say et *Copidosoma obscurum* Nikolskaya (= *Litomastix* sp). Une troisième espèce, *Goniophthalmus halli* Mesnil, a été retenue à partir de certains échantillons.

L'article évalue les avantages de la gestion du sol à la fin de la campagne dans la lutte contre la mineuse de l'épi par rapport à l'érosion éolienne du sol et plusieurs facteurs sociologiques. Les auteurs soulignent la nécessité d'avoir des paramètres d'infestation et d'évaluation uniformes et fiables afin qu'on puisse répéter les résultats dans le criblage pour la résistance. Bien que l'enquête indique la présence des ennemis naturels, il importe d'effectuer des études spécifiques à une région donnée sur les interactions hôte-parasite afin de démontrer leur impact. En conclusion, les auteurs constatent que toute approche basée sur une seule mesure de lutte ne pourrait pas parvenir à maîtriser le ravageur et qu'une plus grande place doit être accordée à la stratégie intégrée et écologique.

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Environmental and Socioeconomic Variables in the Development of Sustainable IPM Strategies for Sorghum and Millet

M V K Sivakumar and J Baidu-Forson[1]

Abstract

A major goal of integrated pest management (IPM) is to maintain pest populations below economic thresholds while utilizing suitable techniques to protect both the environment and nontarget species. Assessment of pest population dynamics requires an understanding of the soil-plant-atmosphere continuum. The immediate environment in which a pest survives can be characterized by a number of climatic variables such as rainfall, radiation, temperature, relative humidity, and wind speed and direction, and soil variables including soil moisture, soil temperature, etc. Cultural control of pests involves manipulation of these environmental variables to make them less favorable to the pest. Design of appropriate IPM techniques also requires knowledge of decision rules used by farmers to guide pest management actions, types and quantities of resources used in pest management, and farmer perceptions of the economic efficacy (expected profit or reduction in unit cost of production) of indigenous management methods. Improvements that can be obtained from the application of alternative non-indigenous methods of pest management depend on crop value, cost of new inputs, productivity gains, risks associated with the use of new IPM techniques, and the threshold levels and doses of insecticide required for effective control of pest damage.

Introduction

Millet and sorghum are important staples and sources of household income in the semi-arid tropics. Damage by panicle insect pests causes substantial losses, and reduction of these losses would improve food availability and farmers' incomes.

Depending on the pest, achievement of a substantial reduction in crop losses requires the integration of relevant biological, cultural, genetic, and chemical control methods in an integrated pest management (IPM) system (Pathak 1991). This approach concentrates on a given crop or cropping system and seeks, first of all, a thorough holistic understanding of environmental and socioeconomic variables in the development of sustainable IPM strategies.

A major goal of IPM is to maintain pest populations below economic thresholds while utilizing suitable techniques to protect both the environment and nontarget species. To achieve this goal, quantification and interpretation of pest population dynamics is necessary. This requires an understanding of the agroecosystem and its driving forces. The goal of IPM can be achieved through incorporation, in the design of an IPM technology, of relevant scientific data or information on crop-pest relationships, pest behavior, and physical and agronomic environments under which the pests thrive (Fig. 1). However, durable technical management of a pest, while necessary, is not sufficient to guarantee the adoption of IPM by farmers. Adoption of IPM depends on the simplicity, economic efficiency, or profitability of components of the IPM within a defined target area. In addition, components of the IPM must be socially acceptable.

In this paper, we discuss the importance of environmental and socioeconomic variables in developing

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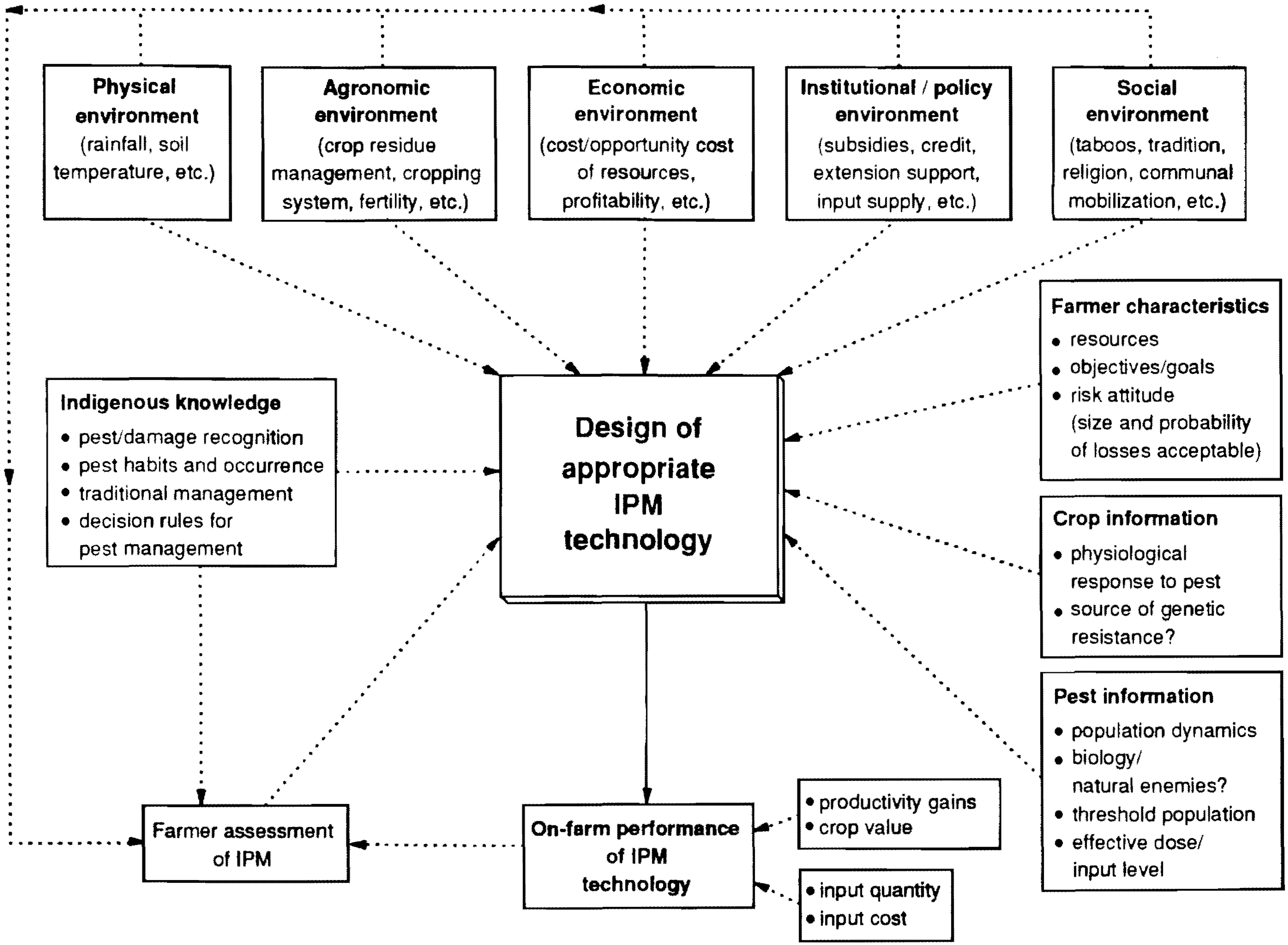

Figure 1. Decision variables for the design and assessment of IPM technology.

sustainable IPM strategies for sorghum and millet. To the extent possible, we have used examples for panicle pests, the principal subject of the workshop. Where necessary, we have used examples for other pests to illustrate the point.

Environmental Variables

In a given cropping system, environmental variables such as rainfall, soil moisture and fertility, and temperature determine crop growth. Here it is important to consider crop management because it can modify air temperature, wind speed, radiation, and relative humidity within the canopy through its effect on canopy growth or ground cover. Crop growth and all other factors combine to determine potentials for growth and reproduction of the other organisms in the crop ecosystem, i.e., insect pests, weeds, plant pathogens, and also their parasites and predators. Hence an integrated approach to pest management requires a study of the interactions between the physiology and biochemistry of the plant and the pest, as well as the interactions between both organisms and the microclimate.

Pests that invade crops either develop within the microclimate or are transported into the microclimate. They live, grow, and reproduce within the microclimate. Hence the microclimate of a pest can be defined, in general, as the immediate environment in which it survives (Doraiswamy 1982). For example, sorghum earhead caterpillars thrive in large and compact earheads which provide an excellent microclimate for their feeding and survival. Compact earheads also offer better shelter from attack by natural enemies. A quantitative understanding of the interactions between plants, pests, and their microenvironments can help us evaluate the possibility of modifying the microclimate by management and the impact of such modification on pest populations.

Although the influence of different climatic variables on the incidence of pests has long been recognized, it was not until the early 1970s that the need for increased monitoring of meteorological data became acute. The advent of IPM models raised questions on the type and accuracy of the data needed for applications. Haynes et al. (1973) proposed specific climatic variables and accuracies as shown in Table 1.

Table 1. Proposed meteorological variables with accuracies required for integrated pest management.

Variable	Accuracy required
Air temperature	±1°C
Soil temperature	±1°C
Wind speed	±0.5 m s^{-1}
Wind direction	±10°
Barometric pressure	±0.1 kPa
Humidity	±1%
Precipitation	±2.5 mm
Soil moisture	±1%
Irradiance	±210 kJ m^{-2} d^{-1}

Rainfall

The rainfall pattern in the semi-arid tropics is predominantly monomodal, with over 90% of the annual rainfall occurring in a short period of 4–5 months followed by a long dry season. Because millet and sorghum, the host plants, are also grown mainly during the rainy season, the life cycle of the pests is intimately linked to rainfall. Nwanze and Sivakumar (1990) showed that the emergence of spikeworm (*Heliocheilus* [=*Raghuva*] *albipunctella* de Joannis) moths from the soil generally occurred 40–50 days after the first good rains (15–25 mm) of the season. The diapause of the sorghum midge, *Contarinia sorghicola* Coquillett, which overwinters inside the attacked spikelets, is broken with the onset of subsequent rains (Harris 1985).

Gahukar (1988) concluded that rainfall distribution and the coincidence of pest abundance with the vulnerable stages of millet were the major factors responsible for population fluctuations of pearl millet pests in the Sahel. Because of the variable rainfall in the Sahel, there is a movement towards growing short- or medium-duration varieties of millet and sorghum depending on the length of the rainy period at a given location. This could result in 'hot spots' for particular pests depending on how well the pest cycle matches the crop phenology. The population of the pearl millet grain midge *Geromyia penniseti* (Felt) increases rapidly early in the season, and the local millet flowering in late Sep is exposed to severe infestation, which could result in up to 90% loss in grain yield (Coutin and Harris 1988). Ndoye (1979) observed that 100% infestation may occur on late millets (sanio) cultivated mainly in the Casamance region of southern Senegal. On the other hand, long-duration varieties of sorghum in India and West Africa are generally reported to escape midge and head bugs (Leuschner 1985).

The effect of drought on insect populations depends on the environmental requirements of the insect under consideration. Spikeworms have become major pests since the 1972–74 drought (Vercambre 1978, Laporte 1977, Ndoye 1979). On the other hand, early cessation of rains and the consequent drought in 1983 in Mali was reported to have resulted in lower populations of sorghum midge (Bonzi and Doumbia 1985).

Air and soil temperatures

Temperature is an environmental variable that directly affects an insect's habitat (Doraiswamy 1982). In moving from or to a sunny or shady environment, the insect may select a combination of heat load and dissipative flux. A suitable combination of temperature and humidity is essential for maintaining proper internal water balance, which is of great importance to the functioning and survival of organisms.

Ambient temperatures influence the level of insect infestation. The sorghum midge is active in southern India where air temperatures are higher, while under the cooler, winter conditions in the northern and central regions midge populations decline rapidly (Srivatsava 1985). In Mexico, high temperatures also resulted in increased populations of the sorghum green bug (*Schizaphis graminum* Rondani), which is usually not a major problem (Castro 1985). Air temperatures also regulate the period of mating. Mating activity generally occurs earlier on cooler nights than on warm nights (Lingren et al. 1982).

Development of crops and insects are functions of temperature accumulation, which is usually expressed as day-degrees or accumulated heat units above a base temperature. Use of the heat unit concept in predicting pest emergence and outbreak is becoming more popular (Inayatullah 1982, Knutson et al. 1989). Baxendale and Teetes (1983) reported that adult midges of sorghum initiate emergence after accumulating 431 heat units above a threshold temperature of 14.8°C, and that 679 and 979 heat units were required for 50 and 90% emergence.

The biological significance of soil temperature to plants and organisms that live in the soil for part or all of their life cycle is well documented. Certain insects spend a part of their life cycle in the soil, dormant in winter and at times in summer to avoid excessive heat (Doraiswamy 1982). From field studies on sandy soils in Niger, Nwanze and Sivakumar (1990) showed that the survival of diapausing pupae of *H. albipunctella* was closely associated with changes in soil temperature. When the mean soil temperatures during Feb to May were over 40°C, mortality of diapausing pupae increased to >60%. The chafer beetle *Rhinyptia* spp, which causes severe damage to flowers and developing grains in sorghum and millet, develops in the soil and is influenced by soil temperature.

Relative humidity

Relative humidity within crop canopies is influenced by ambient relative humidity, the rate of crop transpiration, and to some extent by soil evaporation rates under wet soil conditions. Systematic field studies linking pest incidence to relative humidity are rare because of the difficulties associated with separating the effects of several other interacting factors. Higher rainfall and more frequent rains influence ambient relative humidity, but these conditions also favor rapid crop growth and provide a good substrate for insects. Generally, adult fecundity and larval survival depend on a combination of favorable humidity and temperature (Stinner et al. 1982).

One important effect of relative humidity is to increase the infestation of head bugs and midge when grain ripening takes place under high humidity. If short-duration sorghums are sown late but mature under conditions of high humidity, head bugs and midge could become a problem (Leuschner 1985). Viana (1985) reported high midge populations in southern and central Brazil where sorghum is grown between Oct and Mar under conditions of high humidity. More midges emerge at high humidity (90%) than at lower humidities of 10 and 50% (Fisher and Teetes 1982).

Wind speed and direction

Wind movement within a canopy affects, to varying degrees, the growth and development of plants, insect activity, and population growth. The effects of wind can be divided into three categories (Shaw 1982):

- Through heat and mass exchange at the leaf surfaces, and through the diffusion of heat and mass between the canopy air spaces and the atmosphere above, the air flow regulates the microclimate of the vegetation. For example, the extent to which transpiration could increase humidity inside the canopy depends on the amount of ventilation, which is determined by the strength of the wind and the extent to which the wind can penetrate the canopy layers.

- The direct mechanical action of the wind on both plants and small insects sitting on or physically attached to the plant parts.
- The wind acts as a vector for a myriad of gaseous and particulate materials, e.g., insect pheromone release and diffusion. The response of males to sex pheromones emitted by females for mating is affected by wind velocity.

To understand, or perhaps predict, events such as lodging, re-suspension of particulates, and detachment of insects from plant surfaces, it is necessary to know the probability of occurrence of wind speeds significantly higher than the time-averaged value.

An additional atmospheric factor that could be of relevance is atmospheric stability, which can be instrumental in insect flight behavior on a daily or seasonal scale. According to Fares et al. (1980), atmospheric stability and turbulent diffusion within the canopy were considered to be two of the major factors influencing pheromone dispersion. Vité et al. (1964) observed that insect behavioral patterns such as aggregation, flight, and infestation were regulated by pheromones. These studies demonstrated the need for wind speed and turbulence measurements both above and within the crop canopy. For migrating insects, the direction of migration is largely determined by wind velocity at flying height, which may be selected by the insect (Pedgley 1982). In addition to wind speed, wind direction also is an important environmental variable in influencing insect movement and spread of infestation. Pheromone diffusion in a given direction is related to wind speed as well as direction.

Soil moisture

Soil moisture is one of the key environmental variables influencing the survival of diapausing insects in the semi-arid tropics. The millet spikeworm is a univoltine species and off-season carryover is through diapausing pupae. Hence soil moisture affects both survival and timing of development of pupae. Nwanze and Sivakumar (1990) showed that a majority of diapausing pupae (51%) were found at 10–20 cm soil depth. Favorable soil moisture is a key factor affecting the duration of post-diapause development and hence the population dynamics of *Heliocheilus*.

Management

Crop management is considered the oldest crop protection method, because of its impact on the biological and ecological relationships between insects and crop and noncrop vegetation. Among the important management variables are variety, date of sowing, row spacing, tillage, fertilizers, sanitary methods, trap crops, intercropping, rotations, irrigation, and time of harvest.

Vercambre (1978) reported that deep plowing at the end of the crop season could reduce the population of diapausing pupae of *Heliocheilus* by exposing them to desiccation and predators. Ajayi (1990) reported that infestation and damage caused by the millet stem borer was strongly influenced by date of sowing and the rate and time of fertilizer application. Sukhani (1986) reported that early sowing was an effective means of reducing *Atherigona soccata* Rondani and *Contarinia sorghicola* Coquillett. Dhaliwal et al. (1992) suggested that delayed sowing of forage sorghum till Jun could reduce the damage due to shoot fly. Dissemond and Hindorf (1990) showed that intercropping of sorghum/maize/cowpea was successful in controlling sorghum stem borers in Kenya.

An interesting case of the role of management in insect infestation was described by Passlow et al. (1985) in Australia. In the northern territories of Australia, sorghum midge is not a problem because of poor survival of diapausing larvae during the long, hot, dry season that follows the rainy season. But in Queensland, a continuity of flowering hosts allows the midge to breed from Sep to May-Jun. Hence, selection of sowing date to avoid flowering immediately after a major wet season was employed as a management mechanism to escape midge.

One important consideration in crop management is the issue of feedback effects, as microenvironment alteration by one pest may result in changes in another pest, which then alters the situation for the original pest. This can be illustrated with the case of weed management, which is an essential component of the crop production system. Weed control, regardless of the method employed, involves removal or destruction of vegetation, with resulting changes in the microclimate, through changes in shelter and food supply for pest or beneficial organisms. The damage done by other pest organisms can modify crop growth, which can then alter the severity of a weed problem. The control tactics applied against these other pests may also modify the growth of weeds. When herbicides are used for weed control, additional interactions with pests occur in the form of habitat modification or as a direct consequence of the herbicide action.

Implications for IPM strategies

The studies discussed in the previous sections show that environmental variables play an important role in the growth, development, and infestation rate of panicle insect pests of sorghum and millet. To keep abreast of their ever-changing status in a crop, we must carefully monitor the environment-crop-pest complex by monitoring weather factors and all insect pests affecting the crops, crop stage when insect attack occurs, damage done, control measures, and their efficacy, as well as natural enemies associated with the various pests. An understanding of the quantitative relationships between environmental variables and pest infestation should help formulate effective IPM strategies.

Socioeconomic Variables

Adoption of IPM strategies by farmers is influenced by social, economic, institutional, and policy environments in the target area (Fig. 1). An IPM component that involves radical changes in traditional cultural practices is unlikely to be accepted by farmers unless mechanisms exist to facilitate the changes. As explained earlier, research recommends delayed sowing of short-duration millet as a method to control millet head caterpillar or spikeworm (Vercambre 1978, Ndoye and Gahukar 1987, Youm and Gilstrap 1993). This is technically feasible but farmers traditionally sow long-duration millet varieties with the first rains and are reluctant to replace the traditional varieties with shorter-duration varieties in the absence of widespread adoption of the latter. Widespread adoption of short-duration varieties in the Sudano-Sahelian zone of West Africa is constrained by lack of seed production and input distribution infrastructure that could assure the supply of needed inputs at the farm level. This illustrates the need to identify and consider possible socioeconomic constraints when assessing pest management practices that should be components of an IPM.

Relevance of indigenous knowledge to IPM design

The design of appropriate IPM strategies should incorporate information on indigenous knowledge of insect pest behavior and traditional management practices. Indigenous insect pest management practices and strategies may include deliberate and incidental pest management practices used by farmers, that can be directly incorporated in IPM. Even in cases where traditional management practices are ineffective, research could examine modifications to improve the effectiveness of the techniques. For example, field surveys in the Kirtachi and Gullenyi districts of Niger showed that farmers burned onion peels to repel millet head pests. Onions are readily available at farm level and the technique was relatively simple, with no deleterious environmental or human health effects. But the effectiveness of the technique on panicle insect pests was temporary. Could a more durable repellent effect be obtained when solutions of extracts from onion peel are sprayed on millet heads or the onion peels are managed differently? If the repellent effect is due to an active ingredient, could research examine how to obtain a more durable repellent effect and include it in an IPM practice? The example illustrates the usefulness of farmer knowledge and perception. Yet, there is a dearth of studies on farmer knowledge, attitudes, and practices (KAP) (Rola and Pingali 1993). Since farmer perceptions influence decision making while indigenous knowledge could contribute to research on acceptable pest management systems, KAP studies are needed to provide the basis for the evolution of appropriate IPM methods.

Farmer and farm household characteristics

A review of agricultural technology adoption literature shows the importance of farmer characteristics in the adoption of technologies in general (Feder et al. 1985) and pest management techniques in particular (Troost et al. undated, Mueller and Jensen 1988, Pingali and Carlson 1985). Experience, formal education, and targeted training are socioeconomic characteristics that reduce probability errors and hence improve farmers' perceptions (Pingali and Carlson 1985). Also, farm household resources (Hooks et al. 1983), farmers' objectives and goals as well as attitudes towards risks importantly influence choice decisions. For example, an IPM practice tested for the control of millet spikeworm includes the use of an insecticide, endosulfan (Ndoye and Gahukar 1987). However, research showed that the chemical component of IPM for the control of spikeworm would be constrained by lack of cash, water, trained personnel, and input delivery systems (Nwanze 1985). Therefore, where cash outlays required for application of the insecticide exceed the capabilities of resource-poor subsistence farmers, institutional mechanisms are needed to alleviate cash and input delivery constraints.

Farmer decision rules

Farmers' personal decisions determine what methods of pest control are applied (Reichelderfer et al. 1985). Farmers choose whether, when, and how to allocate resources to pest management (Mumford and Norton 1984). But what decision rules guide the choice of method of intervention and a decision to intervene at all? In particular, what do farmers consider as important pest management decision variables? Figure 2 presents a schematic illustration of the factors and variables considered by farmers when faced with pest management decisions. At the first level of decision making, a farmer is faced with a choice between two options: do nothing, and employ a pest management method. At this stage of decision making, the farmer's goal and objectives, and assessment of pest importance, would be the main guiding criteria to a decision. At the second stage of decision making, resources of the farm household, on-farm performance of the new pest management method as compared with traditional management, risks, and other socioeconomic, physical and agronomic factors, would largely determine what choices are made by farmers (Fig. 2). If a particular sorghum or millet panicle insect pest causes grain losses that compromise the food production goals of farmers then it is likely that resources (labor and/or cash) will be invested in control of the insect pest, if profitability can be demonstrated through partial budgeting, using data on crop productivity and value, input quantities, and unit costs. On the other hand, studies have shown that when pest populations are low, farmers may decide that the most economic pest management strategy is to do nothing (Smith et al. 1989) or to rely on natural control (Rola and Pingali 1993). However, it is also possible that a resource-poor or subsistence farmer may not have enough resources to invest in control of the pest despite its importance and despite the profitability of controlling the insect pest. For example, if the unit cost of production and risk increase beyond levels acceptable to a farmer, a proposed insect pest management technique may not be accepted by farmers. Also, labor scarcity and its opportunity cost could affect adoption behavior of farmers (Deuson and Day 1990). Therefore, resource requirements may preclude the effective use of new technology. Hence, profitability by itself is not a sufficient criterion for farmer acceptance of any proposed technology (Nagy and Sanders 1990).

Public policy

Public policies such as environmental health laws (Reichelderfer et al. 1985), government subsidies on pest management inputs, and regulation of produce prices (Norton and Mumford 1983) influence pest management decisions by farmers. For example, Nigerian farmers used an insecticide to control cowpea insects while it was subsidized but reverted to traditional practices devoid of insecticide application as soon as the subsidies were removed (O Ajayi, ICRISAT, personal communication 1993). It is also important to note that the external effects of pest control decisions can distort economic incentives and prevent maximization of benefits to society (Mumford and Norton 1987). Therefore, public policy interventions may be needed to internalize the costs and benefits of pest control.

Modeling Farmer Choice Decisions

Mumford and Norton (1984) identify and discuss models—economic threshold, marginal analysis, decision theory, and behavioral decision models—that can be used to analyze pest management choice decisions. However, the appropriateness of a model depends on the certainty with which outcomes or variables are known. For example, if level of pest attack (h), yield per hectare lost per unit area of presence of pest (d), mortality coefficient associated with control strategy (k), price of crop (p), and cost of applying pest control (c) are known, then it is possible to estimate the economic threshold level (h^*) from the equation: $h^* = c/pdk$ (Rola and Pingali 1993). This approach assumes that a farmers' objective in using the pest control method is profit maximization. However, benefits need not exceed costs where risk avoidance is the farmers' objective. In such instances, pest management is considered as a form of insurance against catastrophic losses. This tends to be the more prevalent overall pest management objective of farmers (Mumford and Norton 1984). The uncertainties associated with decisions are due to inability to estimate level of pest attack, unknown effects of climatic and agronomic variables, difficulty in estimating future prices and costs, and lack of adequate information on damage. If pest attack levels are not known with certainty but probability information does exist, a decision theory approach can be used to analyze pest management options. Illustrative examples of the decision tree methodology used for analysis of pest management problems are provided in the literature (Valentine et al. 1976, Norton and Mumford 1983). In this paper, Figure 2 provides a framework for the collection of data appropriate for decision tree analysis. On the other hand, Figure 1 shows the multi-

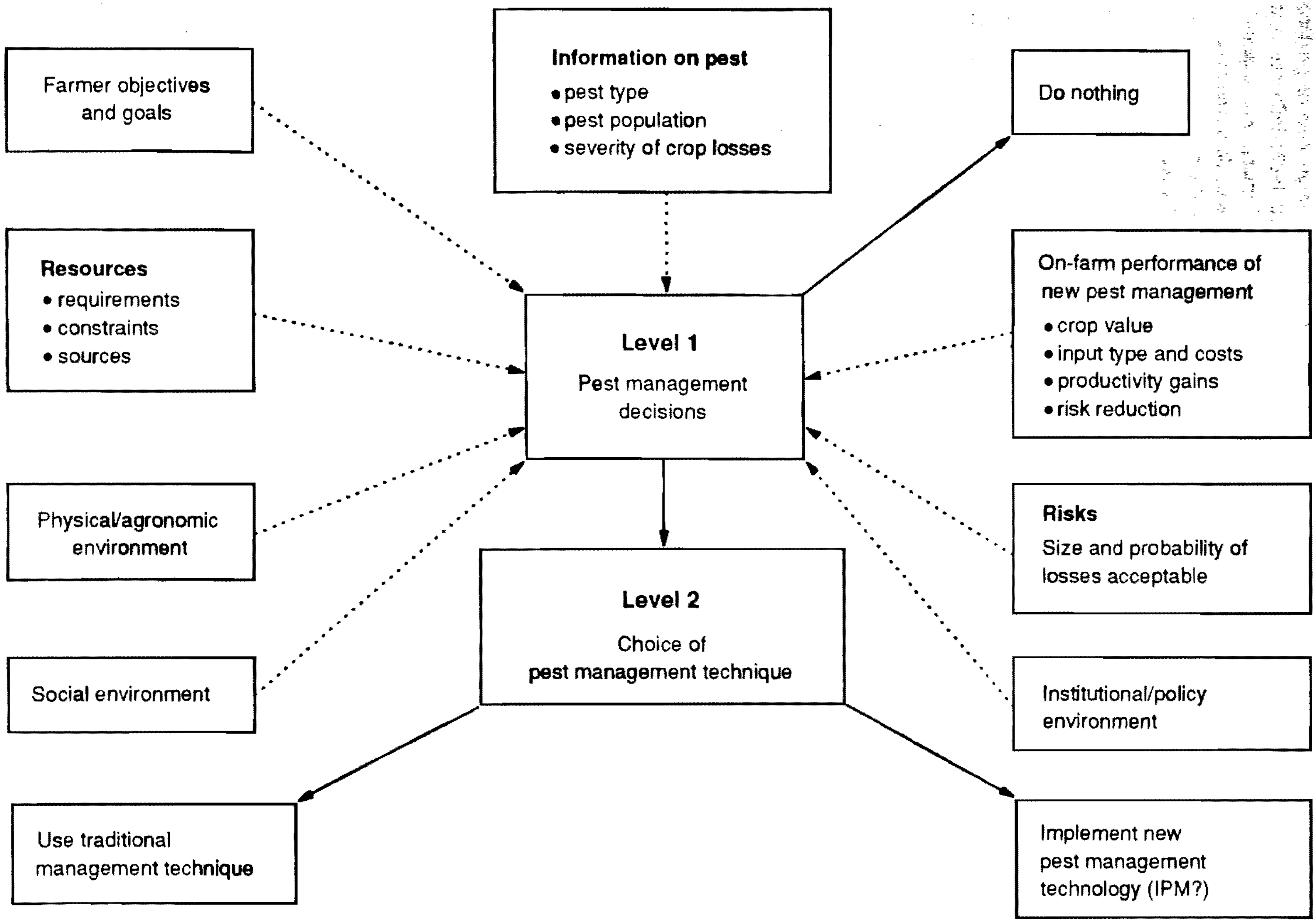

Figure 2. Pest management decision variables at farmer level.

disciplinary data requirements for a comprehensive analysis of pest management. Equations estimated from the different components can be aggregated in a simulation model.

Conclusions

In this paper, we have presented a brief review of the importance of environmental and socioeconomic variables that must be considered in developing sustainable IPM strategies. Despite recognition of the importance of these variables and of the growing knowledge of the intricate relationships and interactions between the variables, few comprehensive studies addressing these issues have been conducted in the sorghum and millet growing regions of the semi-arid tropics. Comprehensive modeling of pest management strategies requires a multidisciplinary approach in the estimation of component equations of a simulation model by entomologists, agroclimatologists, agronomists, soil scientists, and economists.

Synthèse

Importance des variables environnementales et socio-économiques dans le développement de stratégies de lutte intégrée durables pour le sorgho et le mil. Le but majeur d'une lutte intégrée contre des insectes nuisibles est de maintenir les populations des insectes ravageurs sous des niveaux économiques en utilisant les techniques appropriées pour la protection de l'environnement et des espèces utiles. L'évaluation des dynamiques des insectes nuisibles demande une compréhension des relations entre le sol, la plante et l'atmosphère. L'environnement immédiat de survie de l'insecte nuisible peut être caractérisé par des variables de climat telles que la pluviométrie, le rayonnement, la température, l'humidité relative, la vitesse et la direction du vent, en tenant compte des variables liées au sol telles que l'humidité du sol, la température et les flux de chaleur. La lutte culturale contre des insectes nuisibles comprend une manipulation de ces variables environnementales afin de les rendre moins favorables aux insectes nuisibles. Il est également important de considérer la gestion des cultures car elle peut modifier le microclimat du feuillage à travers son effet sur la croissance du feuillage et la couverture du sol.

La quantité et la distribution des pluies ainsi que la longueur de la période culturale influencent les fluctuations des populations d'insectes au Sahel. Les températures ambiantes influencent le développement et le niveau d'infestation des insectes et règle la période d'accouplement. La fécondité des adultes et la survivance des larves dépendent d'une combinaison d'humidité et de température favorables.

Le vent peut influencer l'activité et la population des insectes à travers la régulation de l'échange de chaleur et de masse, action mécanique directe, et en tant que vecteur pour la libération et la diffusion de phéromone. La stabilité atmosphérique et la diffusion turbulente à l'intérieur du feuillage peuvent aussi influencer la dispersion de phéromone. L'humidité du sol est une clé variable qui influence la survivance des insectes en diapause.

La mise au point d'une technique appropriée de lutte intégrée demande aussi une connaissance des critères de décision utilisés par les paysans pour guider le choix des actions de contrôle à mener, les types et les quantités des ressources utilisées dans la maîtrise des insectes nuisibles, et les perceptions des paysans de l'efficacité (le profit ou les réductions des coûts de production) des méthodes de lutte locales. Pour faciliter l'adoption d'une technique de lutte intégrée, il y a lieu d'étudier les facteurs socio-économiques, institutionnelles et politiques qui prévalent dans une région donnée. Par exemple, les pratiques paysannes incluent des stratégies délibérées et incidentales qui peuvent contribuer directement ou avec un peu d'amélioration, à une lutte intégrée contre les insectes nuisibles. Egalement, les ressources des ménages, objectifs et buts des paysans ainsi que les attitudes envers le risque sont les caractéristiques qui peuvent être prises en compte dans la mise au point d'une stratégie de lutte intégrée.

Les améliorations que l'on peut obtenir de l'application des méthodes de contrôle non-locales dépendent de la valeur de la culture, des coûts des intrants nouveaux, de la productivité obtenue, des risques associés à l'utilisation d'une nouvelle technique de lutte intégrée et des seuils et doses requises pour le contrôle effectif des insectes nuisibles.

En dépit de la reconnaissance de l'importance des paramètres environnementaux et socio-économiques et de la connaissance croissante des relations et interactions complexes entre les paramètres, peu d'études détaillées abordant ces domaines ont été conduites dans les régions tropicales semi-arides où l'on cultive le sorgho et le mil. Ceci demande une approche multidisciplinaire incluant les entomologistes, les agroclimatologistes, les agronomistes, les pédologues et les économistes.

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Impact du Projet CILSS sur la lutte intégrée contre les insectes nuisibles des panicules de mil et de sorgho

D D Bâ[1], G Pierrard[1], et A B Bal[2]

Résumé

Le Projet de Lutte intégrée contre les ennemis des cultures vivrières du Comité Permanent Inter-Etats de Lutte Contre la Sécheresse dans le Sahel (CILSS), en renforçant les centres nationaux de recherche agricole des pays sahéliens en moyens humains et matériels a permis d'établir un réseau de surveillance et d'effectuer des recherches bioécologiques sur les principaux nuisibles des cultures vivrières dont les insectes des panicules de mil et de sorgho. Ces recherches ont abouti à la définition de stratégies de lutte ou à des recommandations pour des recherches futures.

Introduction

Le Projet CILSS de Lutte intégrée contre les ennemis des cultures vivrières, financé par l'Agence des Etats-Unis pour le développement international (USAID) et exécuté de 1980 à 1987 avec l'appui technique de l'Organisation des Nations Unies pour l'Alimentation et l'Agriculture (FAO), avait comme objectifs: de renforcer les centres nationaux de recherche agricole pour étudier le complexe bioécologique des principaux ennemis des cultures vivrières, en vue de développer des méthodes de lutte intégrée, de former le personnel national, d'implanter un réseau de surveillance de ravageurs importants des cultures et d'implanter en milieu paysan des actions de démonstration des résultats de la recherche. Le mil et le sorgho figuraient parmi les cultures vivrières traitées par le projet.

En entomologie, le projet a créé six laboratoires et a formé 12 spécialistes de niveau supérieur. En outre, le projet a mis en place à travers le Sahel un réseau de 55 postes de surveillance des nuisibles. Pour le mil et le sorgho, les insectes ravageurs des panicules retenus par le projet ont été la chenille mineuse de l'épi de mil, les méloïdes, la cécidomyie du sorgho et les punaises des panicules de sorgho. Les résultats obtenus datent de la fin de la campagne 1986. Après la fin du projet, les programmes de recherche ont été poursuivis par les instituts nationaux de recherche agricole.

Mil

Chenille mineuse de l'épi

Avant le projet, des études avaient déjà été menées sur *Heliocheilus albipunctella* de Joannis. Cependant, à partir du démarrage du projet ces recherches ont été renforcées notamment au Niger et au Sénégal.

Pour ce nuisible, une méthode d'évaluation des pertes utilisable dans des enquêtes de régions a été mise au point (Bos 1985 et 1986a,b). Les dégâts sont les plus élevés dans la zone septentrionale de culture du mil, sans toutefois être négligeables dans les zones plus au Sud. Dans les zones touchées, les pertes moyennes occasionnées varient entre 10 et 20%.

Les études sur la dynamique des populations de l'espèce, sur son éthologie et sur ses ennemis naturels ont conduit à orienter la lutte selon trois stratégies complémentaires:

La résistance variétale. Après une sélection préliminaire, le matériel génétique a été évalué quant à

1. Projet Lutte Intégrée, Comité Permanent Inter-Etats de Lutte Contre la Sécheresse dans le Sahel (CILSS), Institut du Sahel, BP 1530, Bamako, Mali.

2. Département de Formation en Protection des Végétaux (DFPV), BP 12625, Niamey, Niger.

Bâ, D.D., Pierrard, G., and Bal, A.B. 1995. Impact du Projet CILSS sur la lutte intégrée contre les insectes nuisibles des panicules de mil et de sorgho. Pages 285–290 *in* Panicle insect pests of sorghum and pearl millet: proceedings of an International Consultative Workshop, 4–7 Oct 1993, ICRISAT Sahelian Center, Niamey, Niger (Nwanze, K.F., and Youm, O., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

son comportement vis-à-vis de la mineuse. Des différences de sensibilité ont été observées, et pouvaient permettre une réduction des dégâts de l'ordre de 30%, tant ce qui concerne les variétés de mil à cycle court que les variétés à cycle intermédiaire. Il n'a pu être établi cependant de relation entre la sensibilité variétale et diverses caractéristiques morphologiques de la plante (CILSS 1986 et 1987, Gahukar 1986a,b).

La lutte biologique. Parmi les espèces inventoriées d'ennemis naturels de la chenille mineuse, *Bracon hebetor* Say (Hymenoptera: Braconidae), parasite de la chenille, a été jugé le plus adéquat potentiellement pour réduire les déprédations de la mineuse. Une technique d'élevage et de multiplication simple du parasite a été développée. Elle peut être pratiquée dans les villages, par les paysans eux-mêmes, car elle ne requiert presqu'exclusivement que des matériaux locaux peu coûteux. A partir de l'élevage de base, le parasite est disséminé aux moments opportuns dans les champs de mil à partir d'unités d'élevage plus petites (Bhatnagar 1986 et 1987).

La lutte chimique. Une lutte préventive ne pouvait être considérée qu'en fonction d'un niveau prévisible des dégâts. D'une part, l'éthologie de la mineuse restreint la période pendant laquelle la lutte peut intervenir, et d'autre part, les relations qui existent entre le niveau des populations du stade nuisible de l'insecte et celui des stades antérieurs sont fluctuantes, donc de fiabilité limitée, et rendent dès lors difficile la fixation de seuils économiques d'intervention. Deux méthodes alternatives de lutte chimique étaient envisagées:

- traitement au moment approprié en prévision des dégâts sur la base du niveau des populations des stades antérieurs, dans les zones à risque permanent et où le niveau de production assure une bonne rentabilité du traitement. Cette méthode peut faire appel à des insecticides non classiques (biologiques, régulateurs de croissance) et est compatible avec la lutte biologique définie ci-dessus;
- traitement sur auto-avertissement par le paysan. Cette méthode repose sur le relevé de dégâts bien perceptibles; elle exige une intervention immédiate avec une action létale très rapide de l'insecticide. Elle est incompatible avec la lutte biologique, mais est plus appropriée s'il y a, à la même époque, d'autres déprédateurs à éliminer, tels que les méloïdes.

De bonnes efficacités ont été obtenues, avec des insecticides tant classiques (deltaméthrine) que non classiques (diflubenzuron, *Bacillus thuringiensis*) (Gahukar 1985 et 1986a,b, Maïga 1985 et 1986, van Elesen 1986).

Méloïdes

Parmi la douzaine d'espèces de méloïdes il a été déterminé que les plus nuisibles sont *Psalydolytta fusca* Olivier, *P. vestita* Dufour et dans une moindre mesure, *Mylabris holosericea* Klug. *Psalydolytta fusca* et *M. holosericea* sévissent en Gambie et *P. vestita* est l'espèce la plus nuisible en Mauritanie (Magema et Delhove 1986, Zethner et al. 1986). Dans certaines régions du Mali, des dégâts considérables dus à *P. vestita* et *P. fusca* ont été observés.

Il a été déterminé une méthode d'estimation des populations de ces coléoptères et un seuil économique d'intervention pour des variétés non résistantes valable dans les régions à risque permanent d'infestation. Il s'agit d'un méloïde par 25 épis, ce qui correspond à un niveau de dégâts de 5% pour une production de l'ordre de 800 à 1000 kg ha^{-1} (Zethner et al. 1986).

L'efficacité des méthodes traditionnelles de lutte contre les méloïdes a été évaluée en Gambie et en Mauritanie: capture manuelle des adultes sur les épis, action répulsive de fumées. Ces méthodes se sont révélées partiellement efficaces, ce qui pourrait être exploitée dans une lutte intégrée (Magema et Delhove 1986, Zethner et al. 1986 et 1987).

Psalydolytta spp se réfugiant au pied des plants de mil pendant les heures chaudes, une application d'insecticide localisée à ces endroits a été jugée suffisante, s'il n'y a pas lieu de lutter au même moment contre d'autres ravageurs des épis. Le carbaryl, insecticide à toxicité réduite pour nombre d'ennemis naturels, s'est avéré très toxique pour cet insecte (Zethner et al. 1986 et 1987).

Des études sur la résistance variétale ont montré que les variétés aristées présentaient une bonne résistance aux attaques des méloïdes, les populations de ceux-ci étant réduites de plus de 50% (Doumbia et Bonzi 1986, Magema et Delhove 1986, Zethner et al. 1986). Ce comportement devra être vérifié en monoculture de mil aristé (CILSS 1987).

Sorgho

Cécidomyie

La cécidomyie ou moucheron du sorgho (*Contarinia sorghicola* Coquillett), stérilise les épillets. Les particularités biologiques de cet insecte font que le milieu des stations de recherches agricoles favorise sa pullulation, et c'est ainsi qu'il lui avait été conféré un statut généralisé de ravageur économiquement important et que, antérieurement au projet, des programmes de sélection variétale pour la résistance avaient été développés.

Au cours du projet, une méthode améliorée d'échantillonnage des populations larvaires de ce déprédateur a été définie, en vue d'évaluer les pertes causées par cet insecte.

D'après les observations et les enquêtes conduites par le projet, il ressort que la cécidomyie n'a qu'une importance faible en milieu paysan, sauf dans certaines régions et le plus souvent sur variétés tardives. Les méthodes de lutte les plus efficaces et les moins coûteuses consistent à grouper les semis dans le temps, à ne pas cultiver dans une même zone des variétés de cycles différents, et à éliminer les résidus de récolte et de battage. Si ces mesures s'avèrent inapplicables, notamment dans les régions où des variétés de cycle différent sont cultivées en fonction d'usages différents, il y a lieu de veiller à ce que la période de coïncidence des époques de floraison de la variété précoce et de la variété tardive n'excède pas 2 semaines et que si le niveau de dégâts le justifie, l'utilisation de variétés résistantes soit envisagée. Au Sénégal et au Burkina Faso, des variétés ayant un degré de résistance intéressant ont été identifiées (Dakouo et Yaro 1986a,b et 1987, Gahukar 1986a,b).

Punaise des panicules

Parmi les insectes du sorgho ayant retenu l'attention du projet, figurent les punaises des panicules dont la plus importante était *Eurystylus marginatus* Odhiambo. Des informations sur le comportement variétal ont été obtenues. Il a été noté que pour *E. marginatus*, le caractère induisant la résistance est incompatible avec celui de la résistance à la cécidomyie.

Action pilote Mil en milieu paysan

Implantation et thèmes phytosanitaires

Le projet commençant à obtenir des résultats vulgarisables sur le mil, il convenait de tester leur acceptabilité par les paysans ou d'identifier les contraintes qui hypothèquent cette acceptabilité. Pour ce faire, il a été adopté l'implantation d'actions pilotes en milieu paysan qui devraient aussi constituer un premier chaînon dans la prévulgarisation des méthodes de lutte intégrée.

Le but premier des actions pilotes était qu'elles servent de démonstration, et non d'expérimentation pour vérifier des résultats obtenus. Le suivi et l'analyse de ces actions devraient apporter aux chercheurs des éléments permettant, éventuellement, d'adapter les techniques de lutte préconisées.

En 1984, cette implantation était limitée à un seul pays, la Gambie, afin de déterminer les principales difficultés et contraintes, et d'en tirer enseignement pour étendre le système à tous les pays du Sahel. C'est ainsi qu'en 1985, des actions pilotes, en culture du mil, étaient mises en place dans tous les pays, sauf au Cap Vert, où cette céréale n'est pas cultivée, et au Tchad où le projet venait de démarrer. Un suivi socio-économique approfondi était assuré au Burkina Faso; une analyse de cet aspect était réalisée en Mauritanie, au Sénégal, au Mali et au Niger, et une enquête harmonisée était menée dans tous les pays participants.

Le schéma général de l'implantation des actions pilotes en première année était le suivant: choix de trois villages et cinq paysans par village pour participer à l'action pilote. Le choix des villages et des paysans reposait sur divers critères afin que l'opération fournisse des informations fiables et qu'elle ait un rayonnement auprès des paysans des environs. La culture du paysan comprenait deux parcelles d'environ 0,5 ha chacune, l'une étant conduite selon les pratiques habituelles (qui pouvaient être traditionnelles ou améliorées), l'autre selon les pratiques recommandées par la recherche et incluant diverses méthodes de lutte. En fonction des contraintes et problèmes locaux, des variantes étaient ajustées à ce schéma général.

En deuxième année, suite à la demande des paysans des villages encadrés ou des villages voisins et en fonction des ressources humaines du projet, l'action pilote a été étendue. Ainsi au Burkina Faso, l'action pilote a inclus 61 paysans répartis dans 12 villages; en Gambie, 30 paysans dans 3 villages; en Mauritanie 42 paysans dans 5 villages; au Mali, au Niger, au Sénégal et au Tchad, 15 paysans chacun.

Les thèmes communs dans tous les pays ont été la désinfection des semences, l'arrachage précoce des plantes infestées par le mildiou et leur destruction, l'arrachage du *Striga* avant la floraison, ainsi que l'application localisée de l'engrais, pour éviter de favoriser la croissance des mauvaises herbes.

D'autre part, étaient appliquées en réponse à des situations parasitaires locales les thèmes suivants:

- au Mali, l'action pilote était menée dans la plaine du Séno (pluviométrie 400 mm), où la quasi monoculture du mil est pratiquée de longue date. Ceci explique, sans doute, que des dégâts importants de la mineuse de l'épi y soient enregistrés chaque année. Il était ajouté aux interventions phytosanitaires communes, une application insecticide pour contrôler la mineuse des épis, et la comparaison de deux variétés.

- au Niger, des applications insecticides contre la mineuse de l'épi étaient réalisées en fonction de la survenance d'infestations.
- en Mauritanie, la région choisie pour l'action pilote était le Guidimaka, situé dans la partie la plus méridionale du pays, là où les cultures pluviales peuvent réussir et où la pression parasitaire est habituellement élevée. La fertilisation n'ayant pas été retenue, l'absence de *Striga* et la faible manifestation du mildiou ont fait que le seul thème commun appliqué était la désinfection des semences, à laquelle se sont ajoutées deux pulvérisations contre les méloïdes, particulièrement *Psalydolytta vestita*. Cet insecte est d'ailleurs la cause principale de l'abandon de la culture du mil dans la région, et c'est à l'instigation du Projet Lutte intégrée que les paysans, pleins d'espoir, ont repris la culture de cette céréale. Après une étude des structures sociales, il a été décidé d'inclure des 'paysannes pilotes' dans l'opération.

Résultats

En première année dans tous les villages, la culture selon les techniques action pilote a donné un rendement supérieur à la culture paysanne, de 34 à 95% en moyenne. Le rendement moyen est passé de 823 à 1298 kg ha^{-1}. Sur les 90 champs pilotes, 88 avaient un rendement supérieur aux champs cultivés traditionnellement. Dans plusieurs pays, une analyse économique de l'augmentation de production a pu être faite.

En deuxième année, les rendements moyens étaient de 34% à plus de trois fois plus élevés (Gambie et Tchad) dans les champs pilotes que dans les champs traditionnels. Le rendement général moyen était de 556 kg ha^{-1} en champ traditionnel contre 1000 kg ha^{-1} en champ pilote.

Les diverses investigations d'ordre socioéconomique ont révélé plusieurs types de contraintes dont les plus fréquents étaient:

- les contraintes agricoles: temps de travaux pour la préparation correcte du sol, semis en ligne, sarclages en temps opportun, appréciation correcte des quantités d'intrants à utiliser (dosage du produit de désinfection des semences, estimation des surfaces cultivées), le démariage à deux ou trois plants;
- la contrainte économique: disponibilités financières pour l'achat des intrants autres que le désinfectant de semences;
- la contrainte organisationnelle: approvisionnement en temps voulu en intrants, conditionnement non adéquat des intrants;
- la contrainte sociale: réticence à se démarquer des pratiques traditionnelles, même lorsqu'on est convaincu de l'apport positif des méthodes recommandées.

Conclusion

Trois stratégies de lutte ont été développées par le projet pour contrôler la chenille mineuse de l'épi de mil; elles sont indépendantes et peuvent être complémentaires. La stratégie basée sur la résistance variétale pouvait être diffusée après que le spectre de résistance aura été élargi à d'autres ravageurs selon les nécessités locales. Celle basée sur la lutte biologique ne s'adresserait qu'à des paysans ayant un bon niveau de production et le choix de l'insecticide dépendrait de la présence ou non d'autres insectes ravageurs notamment les méloïdes.

Pour lutter contre les méloïdes, le projet proposait de poursuivre les recherches sur la résistance des variétés aristées. Le ramassage manuel et la production de fumées répulsives ont été recommandés dans les zones à forte infestation. Dans les zones où ne sévit pas la mineuse de l'épi, il a été proposé un traitement chimique localisé au pied des plantes.

Dans les zones où les dégâts de la cécidomyie du sorgho atteignent un niveau économique élevé, la méthode de lutte recommandée par le projet est la pratique culturale qui évite un étalement dans le temps de la floraison dans l'ensemble des champs. Des informations sur la résistance de variétés à cet insecte ont été obtenues.

Le projet avait identifié les punaises des panicules de sorgho comme des ravageurs d'importance économique.

Enfin, comme principaux impacts, le projet a permis tout d'abord de renforcer les centres nationaux de recherche en moyens matériels et humains, de réaliser des recherches dont certaines ont permis de définir des stratégies de lutte ou de déterminer les axes futurs de recherche. Ces moyens humains et matériels ont été utilisés par les programmes nationaux pour poursuivre les travaux de recherche initiés par le projet.

Extended summary

Impact of the CILSS Project on integrated management of panicle insect pests of sorghum and millet. The USAID-funded Project of the Comité Permanent Inter-Etats de Lutte Contre la Sécheresse dans le Sahel (CILSS) on the integrated management of food crop pests, implemented with technical support from the FAO, set up six research laboratories in the Sahel, and established a network of 55 centers to monitor pest behavior. Twelve entomologists were trained to conduct research on the main food crops of the region, including pearl millet and sorghum.

Studies on the millet head miner (*Heliocheilus albipunctella* de Joannis) dealt with host-plant resistance, biological control, and insecticide protection. The evaluation of germplasm with and without control revealed large differences in susceptibility levels, translating into differences in damage as high as 30%. A mass-production rearing technique for *Bracon hebetor* Say, a natural parasitoid of *H. albipunctella*, was developed. Two chemical control methods were studied: application of insecticide either as a prophylactic measure, on the basis of nymphal population levels, or on threshold, on the basis of damage perceived and recorded by the farmer himself.

Studies were also conducted on meloid beetles. An intervention threshold of 1 beetle per 25 millet heads was determined for susceptible cultivars grown in regions with a constantly high risk of infestation. The effectiveness of traditional control methods was assessed.

Research on the sorghum midge (*Contarinia sorghicola* Coquillett) and on the sorghum head bug (*Eurystylus marginatus* Odhiambo) enabled the development of a technique for sampling larval midge populations to assess losses caused by this pest. The most effective control methods were synchronized sowing, cultivation of varieties with uniform duration, and destruction of crop residues. Cultivars with favorable midge-resistance levels were identified.

Data obtained on genotypic responses indicated that the characters in sorghum conferring resistance to head bug in sorghum are not compatible with the characters responsible for midge resistance.

During the course of the project, pilot on-farm activities for integrated pest management of pearl millet demonstrated yield increases of 34–95% over traditional farmers practices.

The material and human resources provided by the Project have enabled national research programs to continue their activities after the completion of the Project.

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Farmers' Perceptions of Insect Pests and Control Strategies, and their Relevance to IPM in Pearl Millet

O Youm and J Baidu-Forson[1]

Abstract

Surveys on farmers' perceptions of insect pests and their control were conducted in western Niger. Respondents were generally aware of the important millet panicle pests and the damage they cause. Farmers differed in their ability to identify insect pests from samples in collection boxes. However, even some respondents who were unable to identify pests perfectly described insect damage and the stage of plant growth at which the damage occurred. The findings suggest that farmer knowledge of pest behavior can be exploited in developing integrated pest management (IPM) methods, but there is also a need for education on pest recognition for some farmers. Important panicle insect pests were mostly controlled mechanically. No cultural practices were deliberately used by farmers to control incidence or reduce severity of damage. Therefore, farmers will have to be educated on the significance of cultural components of IPM in reducing pest incidence and damage.

Introduction

Pearl millet, *Pennisetum glaucum* (L.) R. Br. is a major staple crop in sub-Saharan Africa. Losses from insect pests are an important constraint to increasing millet production. Over 100 species of insect pests have been reported to be associated with pearl millet (Nwanze and Harris 1992, Ajayi 1987). Yield losses caused by insect pests provide the rationale for the development of effective pest management methods. This requires studies on the bioecology of important insects and identification of damage they cause. The complexities of the interactions between crop production practices and pest damage on small-scale mixed farms, which predominate in sub-Saharan Africa, require the design of integrated pest management (IPM) strategies. Further, pest control methods such as the use of chemical pesticides are not appropriate in subsistence farming for several reasons, e.g., high cost, lack of farmer training on pesticide use, and biosafety (Nwanze 1985, Youm et al. 1990).

Researchers' understanding of indigenous knowledge embodied in farmers' practices, perceptions of pest behavior and damage identification, as well as efficacy of current control methods are essential ingredients for the development of an appropriate IPM strategy for each pest. It is also necessary to identify constraints farmers would encounter if current cultural practices are changed as part of an IPM strategy. For example, delayed sowing and crop sanitation requirements may conflict with household requirements (Gahukar 1988) and with traditional practices in response to the erratic nature of rains in the Sahel. This paper reports the findings of surveys conducted in western Niger villages to ascertain pest and pest damage identification, indigenous pest management methods, and the implications for the development of IPM for key millet panicle pests.

Materials and Methods

Surveys were conducted in six villages: Kirtachi Seybou, Sayo, Sounga Dossado, Gullenyi, Yerima Dey, and Dantiandou, which were randomly selected in the Kollo district of Niger. Due to similarities within and across villages in the characteristics of farmers, varieties grown, cropping practices, crop-

1. ICRISAT Sahelian Center, BP 12404, Niamey, Niger.

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ping patterns, and residue management, sample farmers were chosen randomly. Samples of 26 and 40 farmers were interviewed during the 1992 dry and rainy seasons respectively, using structured questionnaires. The difference in the sample size was due to the fact that many more farmers are available during the rainy season, while some farmers are absent during the dry season due to seasonal migration.

During the dry season, sample farmers were requested to identify insects pinned in a collection box (adult insects) or immersed in 70% alcohol (immature stages). Farmers were asked if they had ever seen the insect and on which crop. They were subsequently requested to describe the damage associated with each insect pest and the stage of plant growth at which the damage occurred. In surveys conducted during the rainy season, no insect collection box was used. Farmers were asked to list the insects that cause damage to millet, show the insect in the field, or collect a sample where possible and indicate whether or not the insect was important or would justify control. Farmers also ranked the order of importance of the different millet pests identified and indicated the control methods practiced.

Results and Discussion

Insect pest identification by farmers

Tables 1 and 2 present summaries of farmer identification of insect pests and damage. Generally, respondents demonstrated familiarity with both the important millet panicle insect pests and the damage

Table 1. Insect pest and pest damage identification by farmers, Niger, dry season 1992.

	Farmers[1]					
	Insect pest identification			Identification of pest damage		
Insect pest	Confused	Not identified	Identified	Confused	Not identified	Identified
Heliocheilus albipunctella	23	23	54	23	15	62
Rhinyptia infuscata	0	23	77	0	23	77
Mylabris spp	0	15	85	0	15	85
Psalydolytta spp	0	62	38	0	62	38
Dysdercus voelkeri	0	8	92	0	15	85
Grasshoppers/locusts	0	15	85	0	19	81

1. Sample size: 26 farmers. Figures shown are percentage of respondents.

Table 2. Farmer identification of insect pest and associated damage, dry season 1992[1].

	Insect and damage identification[2]						
Insect pest	Insect C Damage C	Insect C Damage Y	Insect N Damage Y	Insect Y Damage C	Insect Y Damage N	Insect Y Damage Y	No response
Heliocheilus albipunctella	19	4	8	4		50	15
Rhinyptia infuscata						77	23
Mylabris spp						85	15
Psalydolytta spp						38	62
Dysdercus voelkeri					8	84	8
Grasshoppers/Locusts					4	81	15

1. Sample size: 26 farmers; figures shown are percentage of respondents.
2. For both insect and damage, C = identification confused, Y = correctly identified, N = incorrectly identified. For pest identification, insect samples were shown to farmers in collection boxes.

they cause. Similar observations about farmers' ability to identify major pests and damage were made in Tanzania (Mohammed and Teri 1989). More than three-quarters of the respondents correctly identified samples of *Dysdercus voelkeri* Schmidt, grasshoppers, *Mylabris* spp, and *Rhinyptia infuscata* Burmeister (Table 1). Similarly, a very high percentage of the sample farmers were able to correctly identify damage caused by these pests (Table 2). Only a little more than half the respondents were able to identify *Heliocheilus albipunctella* de Joannis. This may be partly due to confusion between the larvae of *H. albipunctella* and the millet stem borer, *Coniesta ignefusalis* (Hampson) or the damage they cause. Table 2 shows that 19% of the farmers failed to identify *H. albipunctella* and also the damage it caused, while 8% could not recognize the pest but correctly described the damage. There were even a few farmers who believed that the larva that attacked millet stems later moved up the panicle to cause damage attributed to *H. albipunctella*. Since the two pests were properly identified by other farmers resident in the same localities, the pests are known to occur in the study villages. Therefore, farmers who were unable to distinguish between the two pests would require some education on pest recognition. This suggestion is supported by the fact that only slightly less than a third of the respondents were able to identify samples of *Psalydolytta* spp. The inability of some farmers to identify pests could be due to the fact that some farmers are not direct recipients of crop protection training in Niger (Moussa 1989).

Surveys conducted during the rainy season showed that the respondents were most concerned with losses caused by *Rhinyptia infuscata* and *H. albipunctella* (Table 3). Even though damage from *H. albipunctella* was noticed on most farms visited, only a small percentage of the respondents considered the insect to be highly important. This may also be due to confusion between *H. albipunctella* damage and that of *C. ignefusalis*.

Pest Control Practices Used by Farmers

Insect pests were mostly hand-picked by farmers and squashed or immersed in receptacles that contained water or burning coals. The limitations and lack of incentives noted by Nwanze (1991) partly explain the absence of investment in other types of insect pest management. The mechanical/manual methods (hand-picking, burning, immersion in water, squashing) were mainly used to control *Rhinyptia infuscata*, *Dysdercus voelkeri*, and blister beetles (Table 4). Some farmers relied on the repellent effects of burning onion skins or insects such as blister beetles. However, farmers who practiced this method acknowledged that the repellent effects were temporary and that insect pests moved to other fields. Insecticide use was mainly restricted to the control of locusts or grasshoppers. This may be explained by the availability of government-supported efforts to limit locust and grasshopper outbreaks and damage, through the use of village brigades trained by the crop protection services. Pest control through the use of chemical pesticides is not appropriate for subsistence farmers, because the high cost of pesticides translates into marginal economic benefits. Furthermore, there is lack of extension services and trained personnel, lack of poison control centers, limited income to purchase and maintain pesticide application equipment, and lack of farmer training in pesticide use and biosafety (Nwanze 1985, Youm et al. 1990). In addition, the low

Table 3. Relative importance of panicle insect pests in six villages of Kollo district, Niger, rainy season 1992.

	Percentage of farmers ranking insects[1]			
Insect pest	High importance	Average importance	Little importance	No response or no importance
Rhinyptia infuscata	80	12	8	0
Heliocheilus albipunctella	20	55	10	15
Dysdercus voelkeri	0	10	25	65
Grasshoppers/locusts	8	5	13	74
Pachnoda interrupta	5	15	3	77

1. Sample size: 40 farmers. Ranking according to importance.

Table 4. Control methods used by sample farmers in Niger against millet head pests[1].

	Control method[2]					
Insect pest	Chemical	Mechanical[3]	None	Insects[4]	Onions[4]	Religious
Grasshoppers/locusts	10	6	9			4
Dysdercus voelkeri		21	5	3	1	
Mylabris spp		17	7	4	1	
Psalydolytta spp		5	17	1		
Rhinyptia infuscata	1	20	9	1		
Heliocheilus albipunctella	1	1	15			

1. Sample size: 26 farmers.
2. Number of responses: farmers often cited more than one control method.
3. Hand-picking, burning, squashing, immersing in water, other.
4. Repellent effect of burning blister beetles or onion skins.

cash value of millet makes it unattractive to use insecticides (Youm et al. 1990). Table 4 shows that most farmers had no method for the control of *H. albipunctella*. The development of tolerant and resistant varieties, whose susceptible stages do not coincide with the main pest emergence and flying period, is recommended as an IPM strategy to control losses due to *H. albipunctella* (Schulten 1989). In a few instances, religious prayers were said to control grasshoppers and locusts attacks.

Implications of Findings for IPM Strategies

The findings showed that only mechanical control methods are widely practiced. Yet, mechanical/manual control of insect pests is quite tedious and labor-demanding, while widespread use of the less labor-demanding option of insecticide application is inhibited by socioeconomic constraints in the resource-poor environments that characterize the farming communities of the Sahel. Therefore, a logical alternative is the rapid development and introduction of diversified and less labor-demanding pest control methods compatible with farmers' socioeconomic needs, within the framework of integrated pest management. Also, education on correct identification of insect pests and pest damage may be necessary for a few farmers. This is because of the importance of the farmers' role in a system of surveillance as a permanent basis for all control activities (Zethner 1991). More importantly, no farmer suggested a cultural practice as a deliberate method used to reduce pest incidence and/or damage. This may be due to a lack of exposure to cultural components of IPM. Therefore, any beneficial effects from current cultural practices used by farmers in the survey areas are purely incidental. Yet, there are cultural practices that effectively contribute to limiting losses to millet panicle insect pests. For example, deep plowing reduces pupal populations of *H. albipunctella* (Vercambre 1978, Nwanze and Sivakumar 1990) but this can increase soil exposure to wind erosion. Therefore, it is necessary to evaluate deep plowing as a cultural component of IPM strategies for reduction of pest incidence and damage. Further, any proposed cultural control practice should be evaluated to assess its economic efficiency and compatibility with the socioeconomic context. There is evidence that where socioeconomic constraints are not considered in the development of insect pest control methods, adoption of recommended practices is low (Alghali 1991). Therefore, research will be needed to identify constraints to cultural components of IPM strategies in order to alleviate them or provide a basis for modification of intended IPM components. This will require close collaboration between biological and social scientists in national, regional, and international organizations, extension agents, and nongovernmental organizations working with farmers.

Conclusions

Generally, farmers surveyed were able to identify the important millet panicle insect pests and the type of damage they cause. Therefore, farmers could provide indigenous knowledge on insect pest behavior which could be useful in the development of IPM for target areas. However, there were a few instances where the larvae of *H. albipunctella* and *C. ignefusalis* were confused. Also, no cultural practice was cited as a control method. Therefore, there is a need to educate farmers on cultural practices that can contribute to successful pest reduction within the IPM framework. Most panicle insect pests were mechanically controlled. It seems that economic and effective insect pest control methods for sorghum and millet are not yet available at the farm level (Schulten 1989, Nwanze 1991). Due to the high labor demands of physical plucking and destruction of insects, there is a need for rapid development and introduction of less laborious yet simple and affordable IPM strategies.

Based on the findings in this study and gaps in knowledge and research focus we suggest: (a) more in-depth studies with greater spatial and temporal coverage, (b) comparative assessments of perceptions of farmers and scientists with regard to insect pest and damage linkage and bioecology, (c) determination of relationships between pest densities and crop yield losses in farmers' fields, and (d) development of handbooks showing color photographs of insects and their local names.

Synthèse

Perceptions par les paysans des insectes ravageurs, stratégies de lutte et leur importance pour une lutte intégrée au niveau du mil. Les pertes causées par les insectes ravageurs du mil constituent un obstacle important à l'augmentation de la production agricole. La valeur économique des pertes de rendement dues aux insectes ravageurs justifie amplement que des études soient menées sur la bioécologie des principaux insectes ravageurs, la reconnaissance des dégâts causés par chacun et la mise au point de méthodes de lutte effectives. La complexité des interactions entre les opérations culturales et les dégâts des ravageurs sur les cultures mixtes des petites exploitations qui prédominent en Afrique sub-saharienne, exige la mise au point de stratégies de lutte intégrée (IPM). Les connaissances indigènes contenues dans les pratiques paysannes, les perceptions sur le comportement des ravageurs et l'identification des dégâts ainsi que le niveau d'efficacité des méthodes actuelles de lutte constituent des éléments essentiels pour le développement d'une stratégie de lutte intégrée appropriée pour chaque ravageur.

Cette contribution rapporte les résultats d'enquêtes menées dans des villages à l'ouest du Niger pour vérifier l'identification des ravageurs et leurs dégâts et évaluer les méthodes indigènes de lutte et leurs implications pour le développement d'un système de lutte intégrée contre les principaux ravageurs des panicules du mil.

Des échantillons de 26 et 40 paysans sélectionnés au hasard ont été interviewés selon un questionnaire structuré, durant la saison sèche et la saison des pluies en 1992. Il a été demandé aux paysans interviewés pendant la saison sèche d'identifier des insectes épinglés sur un panneau de collection ou immergés dans de l'alcool, dépendant du stade de développement de l'insecte. Puis, on leur a demandé d'identifier les dégâts causés par chaque insecte et le stade de la croissance de la plante auquel interviennent ces dégâts. Lors des enquêtes menées pendant la saison des pluies, on a demandé aux paysans d'énumérer et de faire le classement des ravageurs par ordre d'importance et d'indiquer la méthode de lutte qu'ils pratiquent.

En générale, les paysans connaissent les ravageurs de l'épi du mil et les dégâts qu'ils causent. Mais, les paysans diffèrent dans leur capacité à identifier les insectes ravageurs à partir d'échantillons en boîtes de collection. Cependant, parmi ceux-là même qui n'ont pas pu identifier les ravageurs en boîtes, il y avait des paysans qui ont pu parfaitement décrire les dégâts et les stades de croissance du mil auquels les dégâts interviennent. Les résultats des enquêtes montrent que l'on peut profiter de l'expérience des paysans dans le développement des méthodes de lutte intégrée. Aussi, il y a un besoin pour l'amélioration des connaissances dans l'identification des ravageurs par des paysans. La lutte mécanique a été le moyen de lutte le plus utilisé contre les ravageurs des panicules du mil. Aucune méthode culturale n'a été utilisée délibérément par les paysans contre les ravageurs. Donc, il y a lieu de sensibiliser et d'éduquer les paysans sur l'importance des méthodes culturales comme composantes de lutte intégrée dans la réduction de l'incidence et des dégâts dus aux ravageurs.

Compte tenu des résultats obtenus lors de la présente étude et des lacunes existantes du point de vue connaissance au niveau de la recherche actuelle, nous suggèrons: (a) des études beaucoup plus approfondies dans le temps et sur de plus vastes étendues, (b) une évaluation comparative de la perception des paysans et des chercheurs sur la notion d'insecte nuisible, les dégâts, et la bioécologie des ravageurs, (c) la détermination des relations entre la densité des nuisibles et les pertes de récoltes, et (d) le développement de manuels didactiques de référence montrant les insectes en couleur et leurs noms transcrits en langues locales afin d'améliorer le développement des enquêtes et la lutte intégrée.

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Summary of Discussion

Session 5

Sample size, reconnaissance questionnaires, and interpretation of results are key aspects of farm-level surveys. The choice of six villages in the study of farmers' perceptions of pests and pest control strategies was constrained by the time factor. For more precise results, a larger sample size would be necessary. Scientists should be aware of the local names of insect pests in order to avoid mis-information during interactions with farmers. Unfortunately, scientists generally underestimate farmers' knowledge of insect pests and crop damage. This sector is a vital store house of empirical information which should be exploited in the development of integrated pest management strategies targeted to farmers' needs.

The primary purpose of plowing at the end of the season is to reduce the population of soil diapausing larvae by exposing them to predation and desiccation. If done properly, incorporation of crop residues has an added advantage of enriching the soil organic matter.

There are several local traditional practices that farmers employ to control insect pests. For example, onion skins burnt in the field serve as a repellent against certain insect pest species such as the blister beetles. This could be a subject for research within the context of plant-derived pesticides.

Synthèse de discussion

Session 5

La taille de l'échantillon, les questionnaires de reconnaissance et l'interprétation des résultats constituent des aspects clé des enquêtes menées en milieu réel. Faute de temps, on était obligé de limiter la taille de l'échantillon à six villages dans l'étude sur les perceptions par les paysans des insectes ravageurs et stratégies de lutte. Pour obtenir des résultats plus précis, il faudrait se baser sur un échantillon plus important. Les chercheurs doivent se familiariser davantage avec les noms communs des insectes ravageurs afin d'éviter des erreurs d'information au cours des interactions avec les paysans.

Malheureusement, les chercheurs sous-estiment souvent les connaissances des paysans à propos des insectes et des dégâts qu'ils causent aux cultures. Le paysan constitue une véritable source d'informations empiriques qui doivent être exploitées au bénéfice du développement des stratégies de lutte intégrée adaptées à ses besoins.

Le but essentiel du labour à la fin de la saison est de réduire la population des larves diapausantes au niveau du sol en les exposant à la prédation et à la dessiccation. L'intégration des résidus de culture, si fait correctement, a l'avantage d'enrichir la matière organique du sol.

Il existe plusieurs pratiques traditionnelles locales employées par les paysans pour lutter contre les insectes ravageurs. Par exemple, le brûlage de pelures d'oignons dans le champ sert de répulsif contre certaines espèces d'insectes. Cela pourrait faire l'objet d'étude dans le cadre des pesticides dérivées des plantes.

Session 6

Group Discussion

Discussion en groupe

Group Discussion: Summary of Statements

Research Priorities

In setting research priorities, we should be guided by a rigorous assessment of priority needs, research opportunities, and the probabilities of success. Priority needs should be defined using information derived from diagnostic on-farm studies on pest incidence, crop damage, and losses; as well as farmers' perceptions of pest problems and control options/investments. We could further refine our research priorities by defining what type of activity is required, i.e., whether diagnostic, basic, strategic, applied, or adaptive research should receive emphasis. This implies a comprehensive review and awareness of existing knowledge and the comparative advantage of the various partners in a research area. We should also ensure that we work within the framework of the human and financial resources available. And above all, research should be targeted to achieve maximum impact at farm level, and this should be our measure of success. This workshop should summarize these issues by developing a matrix assessing the panicle insect pests in each region against each of the following:

- The relative ranking (1–5) of the pest in terms of importance within particular regions and on a worldwide basis.
- Rank research needs by priority (1–5) and indicate relevance.
- Should research be undertaken or is there existing relevant information elsewhere that can be transferred and used effectively? (Yes/No)
- Are there existing control options? If so, have they been tried? And if yes, why are they not effective or being used in pest management?
- What type of research is needed—diagnostic, basic, strategic, applied, or adaptive? Where can it best be done, and by whom? In what time frame, and what are the expected outputs and probabilities of success?
- What resources (manpower and financial) are available, and for how long?

International Collaboration

Collaboration describes an approach that capitalizes on partnerships; and on joint efforts towards a common goal. This workshop is a good example. There is a distinction between collaboration and networking, and it is one which this workshop should explore. In the context of this workshop, the type of collaboration we are involved in is research oriented. All of us here today are in this arena of international collaboration: USAID Title XII International Sorghum/Millet Collaborative Research Support Program (INTSORMIL), ICRISAT, Natural Resources Institute (NRI), Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), our NARS partners and NGOs. We share ideas, theories, approaches, and results in a mutually beneficial peer-to-peer relationship. This is a key ingredient in collaboration, and together with equality, forms the cornerstone of a successful collaborative relationship: equal partners in the effort to resolve a problem or deal with an issue.

Research Networks

There are similarities in the objectives of networks and international collaboration; and in many ways, they are complementary. Networking and/or regionalization reduces costs, minimizes duplication, boosts efficiency, and favors the creation of a critical mass of professionals working in the same project. Networks encourage collaborative research, particularly in those initiatives which encourage the integrated use of indigenous resources. Examples of networks include the West and Central African Millet Research Network (WCAMRN), the West and Central African Sorghum Research Network (WECASORN), the West African Fertilizer Management and Evaluation Network (WAFMEN), the Eastern Africa Regional Sorghum and Millets Network (EARSAM), and the Cereals and Legumes Asia Network (CLAN). These networks contribute towards better cooperation among scientists and institutions in regional and subregional programs, and foster the development of human and institutional capacities through workshops, seminars, and monitoring tours. They also facilitate technology transfer to farmers through both on-station and on-farm verification trials and various farmer-participatory approaches. Several countries in Africa and Asia do not have adequate financial, institutional, and human resources to mount efficient and effective research programs. However, by participating in research networks, such countries can gain access to the global scientific community and adapt technologies that are suitable for their own needs and resources.

Technology Exchange

Technology exchange (TE) involves a communication process which is bi-directional. It implies not only the transfer of a technology but also a reciprocal feedback of information resulting from the use or non-use of that technology. TE is embedded in the concepts of international collaboration and networks, which also embody the communication process. In scientific terms, 'technology' implies various types of material: information, research methodology and techniques, research results, farming techniques, genetic material, etc. The means of delivery range from newsletters, journal articles, workshops, seminars, and conferences to training, field days, monitoring tours, on-farm trials, adaptation and farmer-participatory activities. However, there are weaknesses in the exchange of information even among ourselves. For example, many organizations at the sharp end of pest control have weak library facilities and even fail to maintain what they have. After these many years, our research should now be more adaptive if we are to succeed in communicating with the end-user. But this is further weakened by the reduced extension service for the transmission of technical information. The low staffing levels in government pest control services means that TE must take place through other channels such as NGOs and farmer-to-farmer interchange. To what extent would the climate of commercial interest restrict the transfer of new high-technology products such as genetically engineered plants? Fortunately, there are organizations that are already in the forefront of guarding against highly restrictive private interests.

Priorités de recherche

L'élaboration des priorités de recherche doit être guidée par une évaluation rigoureuse des besoins prioritaires, les opportunités de recherche et les probabilités de succès. Les besoins prioritaires doivent être définis sur la base des études diagnostiques en milieu réel sur l'incidence des ravageurs et les pertes dues à ceux-ci. Ils doivent également prendre en compte les perceptions par les paysans des problèmes liés aux ravageurs et des moyens/investissements de lutte relatifs.

Les priorités de recherche peuvent être définis avec une plus grande précision en détaillant le type d'activité nécessaire; autrement dit, quel type de recherche doit être accentuée davantage—la recherche diagnostique, fondamentale, stratégique, appliquée ou adaptative. Cela laisse entendre une revue globale et une sensibilisation approfondie des connaissances actuelles ainsi que de l'avantage comparatif des divers partenaires dans un domaine de recherche donné.

Par ailleurs, l'orientation de recherche choisie doit être en fonction de la disponibilité des ressources tant humaines que financières. Avant tout, la recherche doit être conduite de façon à réaliser l'impact maximum au niveau du champ paysan. C'est cet impact qui doit servir de mesure de notre succès. Cet Atelier doit fournir un compte rendu lié à toutes ces questions en élaborant une matrice qui permettrait d'apprécier les insectes nuisibles des panicules de sorgho et de mil de chaque région contre les suivants:

- Le classement relatif (sur une échelle de 1 à 5) de chaque insecte nuisible en terme de l'importance à l'intérieur des régions individuelles ou sur le plan mondial.
- La priorité des besoins en matière de recherche (1–5) et l'indication de leur pertinence.
- Faudrait-il entamer les travaux de recherche ou existe-t-il déjà des informations utiles disponibles ailleurs que l'on peut transférées et utilisées efficacement? (Oui/Non)
- Des options de lutte sont-elles disponibles? Si oui, ont-elles été testées? Si elles ont été testées, pourquoi ne sont-elles pas efficaces ou pas employées dans la lutte contre les ravageurs?
- Quel type de recherche est-il nécessaire? Recherche diagnostique, fondamentale, stratégique, appliquée ou adaptative? La recherche peut être le mieux réalisée par qui et où? Quels seraient les délais de temps et les résultats et les probabilités de succès escomptés?
- Quelles ressources (humaines et financières) sont disponibles et pour quelle durée de temps?

Collaboration internationale

La collaboration représente une approche qui met en valeur les partenariats, ou les efforts conjoints visant le même objectif. Cet Atelier sert d'un bon exemple. Il y a une distinction entre la collaboration et la mise en réseau, et c'est cette distinction que l'Atelier doit essayer d'examiner. Dans le cadre de cet Atelier, nous nous sommes engagés dans un type de collaboration qui est orienté vers la recherche. Nous nous sommes tous réunis aujourd'hui dans cette arène de collaboration internationale: le Programme Américain d'Appui à la Recherche Collaborative sur le Sorgho et le Mil (INTSORMIL), l'ICRISAT, l'Institut de Ressources Naturelles (NRI), Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), nos partenaires les systèmes nationaux de recherche agricole (SNRA) et les organisations non-gouvernementales (ONG). Nous partageons les idées, les théories, les approches et les résultats dans un rapport égal et mutuellement avantageux. Cela constitue un élément clé de la collaboration. La collaboration et l'égalité représentent ensemble la pierre angulaire d'un rapport fructueux de collaboration: les partenaires égaux dans l'effort de résoudre une question ou aborder un problème.

Réseaux de recherche

Il existe des similitudes entre les objectifs des réseaux et ceux de la collaboration internationale et, dans plusieurs sens, ils sont complémentaires. L'établissement des réseaux et/ou la régionalisation permet de réduire les coûts, de limiter la répétition, d'augmenter l'efficacité et de favoriser la création d'une masse critique de professionnels autour d'un même projet. Les réseaux encouragent la recherche collaborative, en particulier dans le cadre des initiatives qui favorisent l'utilisation intégrée des ressources indigènes.

Parmi les réseaux, on peut citer le Réseau Ouest et Centre Africain de Recherche sur le Mil (ROCAFREMI), le Réseau Ouest et Centre Africain de Recherche sur le Sorgho (ROCARS), le Réseau Ouest Africain pour l'Exploitation et l'Evaluation des Engrais (WAFMEN), le Réseau Régional Est-Africain sur le Sorgho et les Mils (EARSAM), ainsi que le Réseau

Asiatique pour les Céréales et les Légumineuses (CLAN). Ces réseaux contribuent à une meilleure coopération scientifique entre les chercheurs et les institutions au niveau régional et sous-régional et favorisent le développement des compétences tant humaines qu'institutionnelles par le biais des ateliers, des séminaires et des missions d'observation. Ils facilitent également le transfert de technologie aux paysans à travers les essais de vérification en station et en milieu réel ainsi que diverses approches avec la participation des paysans.

Plusieurs pays en Afrique et en Asie ne disposent pas de ressources financières, institutionnelles et humaines adéquates pour mettre en place des programmes de recherche efficaces. Cependant, en participant aux réseaux de recherche, de tels pays peuvent avoir accès à la communauté scientifique globale et adapter les technologies à leurs propres besoins et ressources.

L'échange de technologie

L'échange de technologie est un processus de communication bi-directionnelle. Il comprend non seulement le transfert d'une technologie, mais aussi une réponse réciproque des informations émanant de l'emploi ou le non-emploi de cette technologie. L'échange de technologie se retrouve dans les concepts de la collaboration internationale et des réseaux qui représentent eux aussi le processus de communication. En termes scientifiques, le mot 'technologie' signifie divers types de matériel, par exemple, les informations, la méthode et les techniques de recherche, les résultats de recherche, les techniques de culture, le matériel génétique, etc. Les voies de transmission peuvent varier de bulletins d'information, articles de revue, ateliers, séminaires et conférences, à la formation, journées porte ouverte, missions d'observation, essais en milieu réel, essais d'adaptation, activités avec la participation paysanne, etc. Cependant, on constate aussi des faiblesses dans l'échange d'informations même parmi nous-mêmes. Par exemple, plusieurs organisations activement engagées dans la lutte contre les insectes ont des bibliothèques peu évoluées et n'arrivent même pas à maintenir les installations qu'elles possèdent.

A la fin de toutes ces années, notre recherche doit s'avérer plus adaptée afin de pouvoir réussir la communication avec l'utilisateur final. Malheureusement, ce processus se voit d'autant plus affaibli par le service de vulgarisation limité pour la transmission des informations techniques. Le nombre très réduit de personnel au niveau des services gouvernementaux de lutte contre les ravageurs oblige l'opération de l'échange de technologie par d'autres moyens telles les ONGs et les échanges entre paysans. Dans quelle mesure le climat d'intérêt commercial contraindrait-il le transfert de nouveaux produits de technologie de pointe telles les plantes créées par l'ingénierie génétique? Heureusement, il existe des organisations qui se trouvent déjà à l'avant garde de la protection contre les intérêts privés très restrictifs.

Recommendations

Sorghum midge and head bugs are recognized as the most widespread insect pests of sorghum, threatening increased and sustainable sorghum production in Africa, Asia, Australia, and the Americas (Appendix 1). Likewise, the millet head miner is the most important insect pest of pearl millet in Africa. Other insect pests are recognized as major local and subregional problems. For example, meloids and grasshoppers are recognized as sporadic panicle insect pests of millet in sub-Saharan Africa.

There is a lack of understanding of the severity of crop damage by insect pests in farmers' fields. Sound ecological studies of sorghum and millet panicle insect pests are needed to provide a basis for sustainable management strategies.

The participants recommend that:

- On-farm assessments of losses and evaluation of IPM technologies in agroecosystems be done with farmer participation as an essential prerequisite to resolving panicle insect pest problems.
- The existing knowledge in research institutions, published and unpublished information, and other sources be inventoried, reviewed, and used to identify knowledge gaps, plan strategies, and develop research opportunities and priorities. Appendix 2 is a list of research needs and priorities developed by the Workshop participants.
- New cultivars introduced into traditional farming systems should reduce, rather than intensify, problems of panicle insect pests.
- Sound ecologically-based IPM strategies be implemented that minimize the tendency to use insecticides.
- Research be conducted to increase the understanding of panicle insect pests in relation to their alternate hosts and the role these play in the development of management strategies.
- The common name "millet head miner" (MHM) be adopted for *Heliocheilus albipunctella* de Joannis (= *Raghuva albipunctella*).
- Damage ratings for assessing insect pest damage to sorghum/millet plants should be based on a 1–9 scale, where 1 = least damaged (<10%), and 9 = most damaged (>80%).
- Taxonomic research be undertaken to resolve the current confusion in identification of the complex of panicle-infesting bugs and meloids on sorghum and pearl millet in Africa.
- Free exchange of research information and publication of finalized data in refereed journals be encouraged; unpublished preliminary research results should be credited as such.
- Free exchange of sorghum and pearl millet genetic material be encouraged because it is important in the development of sustainable production systems. However, it is recognized that exchange may be limited by policy considerations beyond the control of scientists.
- Collaboration between national agricultural research systems (NARS), international agricultural research institutions, and universities be strengthened to promote research activities. Building on the strength of NARS is critical to achieve this goal.

Appendix 1

Relative ranking of panicle insect pests of sorghum and pearl millet[1].

Crop	Insect pest	Africa Western	Africa Eastern	Africa Southern	Asia India	Asia Southeast	USA	Australia
Sorghum	Sorghum midge	4	3	2	4	2	5	4
	Head bugs	5	2	2	4	2	1	1
	Meloids (blister beetles)	1	-	-	1	-	-	-
	Grasshoppers	1	-	-	1	-	-	-
	Head caterpillars	2	3	3	2	2	4	3
Pearl millet	Millet head miner	4	-	-	-	-	-	-
	Meloids (blister beetles)	4	-	-	-	-	-	-
	Grasshoppers	4	2	1	2	3	2	2
	Scarabaeid beetle	2	-	-	-	-	-	-
	Midge	1	-	-	-	-	-	-
	Head bugs	1	-	-	1	-	-	-

1. Ranking on a 1-5 scale, where 1 = low, and 5 = high.

Appendix 2

Research Needs and Priorities Identified by Working Groups

1. Bioecology and Crop Loss

The main requirements for further work in taxonomy/nomenclature, biology, ecology and crop loss assessment, for the major insect pests of sorghum and pearl millet are:

Sorghum midge (West Africa/Asia)

- Determine the effectiveness of the use of midge pheromones in population monitoring and mating disruption.
- Construct life tables to identify natural mortality factors and determine ways to enhance the effects of these factors in the development of IPM strategies.
- Conduct surveys to determine yield losses in farmers' fields.

Head bugs (West Africa/Asia)

- Clarify the identity and identification of the complex of head bugs on sorghum and millet in Africa.
- Further describe the biology and ecology of *Eurystylus* spp in West Africa and the ecology (off-season survival, migration) of *Calocoris* in India.
- Conduct surveys to assess crop losses and the natural enemy composition in farmers' fields in West Africa and India.

Helicoverpa (Asia)

- Assess the potential for using nuclear polyhedrosis virus, insecticides and/or biological control agents against *Helicoverpa armigera* on sorghum in India.

Blister beetles (West Africa)

- Clarify the identification of insect pest genera and species on millet and sorghum.
- Further elucidate the biology and ecology of the major pest species of sorghum and millet.
- Develop methods to assess losses by these insect pests in farmers' fields.

Scarabaeids (West Africa)

- Further clarify the identification of adults and immature stages of the most abundant scarabaeid pest species.
- Expand knowledge of biology and ecology of scarabaeid species infesting panicles of sorghum and millet.
- Simplify methods of crop loss assessment to determine the magnitude of losses caused by scarabaeids in farmers' fields.

Grasshoppers (West Africa)

- Determine ways to more accurately identify grasshopper eggs and egg pods.
- Elucidate diapause mechanisms to assist forecasting of outbreaks.
- Develop and apply methodologies to assess losses on farmers' fields.

Millet head miner (West Africa)

- Recommendation and adoption of "millet head miner" as a standardized common name.
- Assist forecasting of outbreaks by studying the diapause mechanism and factors breaking diapause.
- Study mating behavior and mechanisms of communication.
- Determine alternate wild hosts.
- Develop methods to assess yield loss in farmers' fields.

2. Plant Resistance

- Standardize techniques to screen for resistance to millet head miner in pearl millet and head bugs in sorghum.
- Identify and develop sources of resistance to millet head miner and sorghum head bugs; transfer stable resistance to these pests and to sorghum midge into high-yielding cultivars in Africa and hybrids and seed parents in India, Australia, and the Americas.
- Improve the agronomic desirability and yield potential of local adapted cultivars in West Africa.
- Increase and sustain resistance and diversify the genetic base, including cytoplasms, further elucidate in different sources, the mechanisms and genetics of resistance to sorghum midge and sorghum head bugs.
- Explore the potential of applying biotechnology to elucidate the genetic nature of resistance to specific insect pests and interactions with the host.
- Develop a better understanding of insect–host plant–environment interactions.

3. Crop Management and Biological Control

In general, standardized sampling and crop loss assessment methods are required for all panicle-infesting insect pests of sorghum and millet. Other specific needs and priorities are listed as follows:

Sorghum midge

- The magnitude of the sorghum midge problem in farmers' fields in West Africa requires better definition and understanding of the population dynamics and mortality factors in alternate hosts and on the sorghum crop.
- Research on crop management techniques, especially in Africa, should focus on the effects of flowering uniformity, uniform sowing date and genetic diversity.
- The potential for success in biological control is high in West Africa compared to the other parts of the world because sorghum and sorghum midge originated in Africa. Understanding the ecology of sorghum midge parasites and predators, especially on non-crop plants, has potential spillover effects in the management of this pest in developed countries.

Head bugs

- Assess the non-crop plant sources of head bugs and the ecology of the pest on these plants. From where do they migrate into sorghum? Can the size of the initial population from non-crop plants be forecasted?
- Study mortality on all stages of head bugs on sorghum and on alternate hosts.

Millet head miner

- Further study the relationship between rainfall and moth emergence, especially in explaining local and temporal differences in abundance.
- Determine sources of mortality and the impact of specific mortality factors on population dynamics.
- Improve understanding of the incidence of the millet head miner (i.e., in relation to time of flowering, cultivar, and seasons).

4. Integrated Pest Management

In general, research priorities should address areas and components of IPM that relate to the sorghum midge in West Africa, India, Australia, and the Americas; and to the sorghum head bug and the millet head miner as the most important panicle insect pests in West Africa. Research should focus on:

- On-farm research and evaluation of existing pest management technologies.
- Surveys conducted jointly by socioeconomists, agronomists, and entomologists on farmers' preferences and constraints to technology adoption.
- Identification and evaluation of the compatibility of potential IPM components for the major insect pests by using the following priority guidelines:

Sorghum midge	plant resistance, sowing date, cultivar maturity
Sorghum head bugs	plant resistance and sowing date, alternate hosts, off-season survival
Head caterpillars	sowing date, panicle type, cultivar maturity cycle
Millet head miner	cultivar maturity cycle, soil tillage, plant resistance

To enhance IPM technology development and technology/information exchange: a) an inventory of research results already available on different IPM components and systems, and b) the identification of knowledge gaps and research opportunities should receive high priority. To achieve this objective, closer collaboration between the following institutions is encouraged: ICRISAT, other international agricultural research centers (IARCs), USAID Title XII International Sorghum/Millet Collaborative Research Support Program (INTSORMIL), the International Centre of Insect Physiology and Ecology (ICIPE), CAB International, Natural Resources Institute (NRI), NARS, and nongovernmental organizations (NGOs) in Africa, Australia, and India, and associated mentor institutions and universities.

The comparative advantages of all collaborating partners in conducting research on specific pest problems should be identified in order to avoid duplication of effort.

Recommandations

La cécidomyie et les punaises des panicules sont reconnues comme des insectes nuisibles les plus répandus, présentant une contrainte majeure à la production durable du sorgho amélioré en Afrique, en Asie, en Australie et aux Amériques (Annexe 1). De même, la mineuse de l'épi du mil s'avère l'insecte ravageur le plus important du mil en Afrique. D'autre insectes représentent des contraintes majeures aux niveaux local et sous-régional. Par exemple, les méloïdes et les sauteriaux sont reconnus comme des ennemis occasionnels sur le mil en Afrique subsaharienne.

La sévérité des dégâts aux cultures par les insectes ravageurs au niveau du champ paysan est souvent mal connue. D'où le besoin de mettre en place des études écologiques valables sur les insectes nuisibles des panicules du sorgho et du mil afin de prévoir une base efficace pour l'élaboration des stratégies de lutte durable.

Les participants à cet Atelier recommandent:

- L'évaluation des pertes de récolte en milieu réel, ainsi que l'évaluation des technologies de lutte intégrée au sein des agroécosystèmes doit être effectuées avec la participation des paysans, participation nécessaire au préalable pour résoudre les problèmes liés aux ravageurs des panicules.
- Les connaissances actuelles au sein des institutions de recherche, les informations publiées, non-publiées et personnelles, ainsi que d'autres sources utiles doivent être inventoriées, examinées et utilisées pour l'identification des lacunes d'information, la planification des stratégies et l'élaboration des opportunités et priorités de recherche. L'annexe 2 donne une liste des besoins et priorités de recherche développés par les participants à cet Atelier.
- De nouveaux cultivars introduits dans les systèmes d'exploitation traditionnels doivent réduire, et non pas intensifier, les problèmes des insectes nuisibles des panicules.
- Des stratégies écologiquement efficaces de lutte intégrée doivent être mises en oeuvre afin de limiter les tendances à employer les insecticides.
- Les travaux de recherche doivent viser une meilleure connaissance des insectes nuisibles aux panicules vis-à-vis de leurs hôtes et du rôle de ceux-ci afin de pouvoir développer des stratégies de lutte efficaces.
- Le nom commun 'mineuse de l'épi du mil' ('millet head miner' en anglais) doit être employé pour *Heilocheilus albipunctella* de Joannis (=*Raghuva albipunctella*).
- La notation pour l'évaluation des dégâts causés par les insectes nuisibles aux plantes de sorgho et de mil doit se baser sur une échelle 1–9, où 1 = minimum de dégâts, et 9 = maximum de dégâts.
- La recherche taxonomique doit être entreprise pour résoudre la confusion actuelle dans l'identification du complexe des punaises des panicules et des méloïdes sur le sorgho et le mil en Afrique.
- Le libre échange des informations de recherche et la publication de données finales dans les revues formelles doit être encouragé. Des résultats préliminaires de recherche non-publiées doivent être mentionnés en tant que tels, en reconnaissant la source de données.
- Le libre échange de matériel génétique du sorgho et du mil doit être encouragé étant donné son importance dans le développement des systèmes de production durables. Cependant, on reconnaît que l'échange peut être limité par les considérations de la politique qui sont indépendantes de la volonté des chercheurs.
- La collaboration entre les systèmes nationaux de recherche agricole (SNRA), les institutions internationales de recherche agricole, ainsi que les universités doit être renforcée afin de promouvoir les activités de recherche. Le renforcement des compétences des SNRA est crucial à la réalisation des objectifs essentiels.

Annexe 1

L'importance relative des insectes nuisibles des panicules de sorgho et de mil.[1]

Culture	Insecte ravageur	Afrique occi-dentale	Afrique orien-tale	Afrique australe	Asie Inde	Asie Sud-Ouest	Etats-Unis	Australie
Sorgho	Cécidomyie	4	3	2	4	2	5	4
	Punaise des panicules	5	2	2	4	2	1	1
	Méloïdes	1	-	-	1	-	-	-
	Sauteriaux	1	-	-	1	-	-	-
	Chenilles des chandelles	2	3	3	2	2	4	3
Mil	Mineuse de l'épi	4	-	-	-	-	-	-
	Méloïdes	4	-	-	-	-	-	-
	Sauteriaux	4	2	1	2	3	2	2
	Scarabée	2	-	-	-	-	-	-
	Cécidomyie	1	-	-	-	-	-	-
	Punaises des panicules	1	-	-	1	-	-	-

1. Notation sur une échelle de 1–5, où 1 = bas, et 5 = élevé.

Annexe 2

Besoins et priorités de recherche identifiés par les groupes de travail

1. Bioécologie et pertes de rendement

Les principaux besoins en études plus approfondies en matière de la taxonomie/nomenclature, la biologie, l'écologie et l'évaluation des pertes de rendement, pour les importants insectes ravageurs de sorgho et de mil, sont les suivants:

Cécidomyie du sorgho (Afrique de l'Ouest/Asie)

- Détermination de l'efficacité de l'emploi des phéromones de la cécidomyie dans le suivi des populations et la perturbation de l'accouplement.
- Construction des tables de vie afin de pouvoir identifier les facteurs naturels de mortalité et détermination des moyens d'améliorer les effets de ces facteurs dans la mise au point des stratégies de lutte intégrée.
- Conduite des enquêtes pour déterminer les pertes de rendement au niveau des champs paysans.

Punaises des panicules (Afrique de l'Ouest/Asie)

- Eclaircissement de l'identité ainsi que l'identification du complexe des punaises des panicules de sorgho et de mil en Afrique.
- Description détaillée de la biologie et l'écologie de *Eurystylus* spp en Afrique de l'Ouest et celle de l'écologie (survie hors-saison, migration) de *Calocoris* en Inde.
- Conduite des enquêtes pour l'évaluation des pertes de rendement et de la composition des ennemis naturels en milieu réel en Afrique de l'Ouest et en Inde.

Helicoverpa (Asie)

- Evaluation du potentiel pour l'utilisation du virus de polyhédrose nucléaire, des insecticides et/ou des agents de lutte biologique contre *Helicoverpa armigera* sur le sorgho en Inde.

Méloïdes (Afrique de l'Ouest)

- Eclaircissement de l'identification des genres et des espèces d'insectes ravageurs qui attaquent le mil et le sorgho.
- Approfondissement des études sur la biologie et l'écologie des principales espèces de ravageurs du sorgho et du mil.
- Elaboration des méthodes d'évaluation des pertes de rendement dues à ces ravageurs au niveau des champs paysans.

Scarabéidés (Afrique de l'Ouest)

- Etude détaillée de l'identification des adultes et des stades immatures des espèces nuisibles les plus abondantes.
- Elargissement des connaissances sur la biologie et l'écologie des espèces qui infestent les panicules de sorgho et de mil.
- Mise au point de méthodes plus simples d'évaluation des pertes de rendement afin de déterminer l'importance des dégâts causés par les scarabées dans les champs paysans.

Sauteriaux (Afrique de l'Ouest)

- Etablissement des moyens permettant d'identifier plus précisément les oeufs et les oothèques des sauteriaux.
- Description des mécanismes de diapause pour faciliter la prévision des invasions d'insectes.
- Elaboration et application des méthodologies pour l'évaluation des pertes en milieu réel.

Mineuse de l'épi du mil (Afrique de l'Ouest)

- Normalisation et l'adoption du nom commun "mineuse de l'épi du mil".
- Renforcement de la prévision des invasions par l'étude du mécanisme de la diapause ainsi que des facteurs interrompant la diapause.
- Etude du comportement lors des accouplements et les mécanismes.
- Détermination des hôtes sauvages qui peuvent soutenir l'insecte.
- Mise au point des méthodes pour la détermination des pertes de rendement.

2. Résistance variétale

- Normalisation des techniques de criblage pour la résistance à la mineuse de l'épi du mil et aux punaises des panicules du sorgho.
- Identification et mise au point des sources de résistance à la mineuse de l'épi du mil et aux punaises des panicules du sorgho. Transfert de la résistance stable à ces ravageurs et à la cécidomyie du sorgho dans les cultivars à haut rendement en Afrique et dans les hybrides et les parents femelles en Australie, aux Etats-Unis et en Inde.
- Amélioration des caractères agronomiquement désirables ainsi que du potentiel de rendement des

cultivars localement adaptés en Afrique de l'Ouest.
- Amélioration de la résistance durable à la cécidomyie et aux punaises des panicules de sorgho et diversification de la base génétique, y compris les cytoplasmes. Description approfondie des mécanismes et de la génétique de résistance à ces ravageurs dans les sources différentes.
- Exploration du potentiel des méthodes biotechnologiques pour mettre en évidence la nature génétique de la résistance aux insectes ravageurs spécifiques et de leurs interactions avec leurs hôtes.
- Développement d'une meilleure connaissance des interactions insecte–plante hôte–environnement.

3. Exploitation des cultures et lutte biologique

En général, des méthodes normalisées d'échantillonnage et d'évaluation des pertes de rendement sont nécessaires pour tous les insectes nuisibles des panicules de sorgho et de mil. D'autres besoins et priorités spécifiques sont détaillés ci-dessous:

Cécidomyie du sorgho
- Une meilleure définition de l'étendue du problème de la cécidomyie du sorgho au niveau des champs paysans en Afrique de l'Ouest nécessiterait une connaissance approfondie de la dynamique des populations et des facteurs de mortalité au niveau des plantes hôtes sauvages et le sorgho.
- La recherche sur les techniques d'exploitation des cultures, particulièrement en Afrique, doit insister sur les effets de l'uniformité de floraison, les dates de semis uniformes et la diversité génétique.
- Le potentiel du succès en matière de lutte biologique est élevé en Afrique par rapport aux autres parties du monde, étant donné que le sorgho et la cécidomyie sont originaires de l'Afrique. L'étude de l'écologie des parasites et des prédateurs de la cécidomyie du sorgho, surtout sur les plantes non-cultivées, peut avoir des effets dérivés potentiellement utiles pour la lutte contre cet insecte dans les pays développés.

Punaises des panicules
- Evaluation des plantes non-cultivées sources de punaises ainsi que l'écologie du ravageur sur ces plantes. A partir de quelles plantes les punaises migrent-elles vers le sorgho? Peut-on prévoir la taille de la population d'origine sur les plantes non-cultivées?
- Etude de la mortalité portant sur tous les stades des punaises des panicules sur le sorgho et sur les hôtes obligatoires.

Mineuse de l'épi du mil
- Etude plus approfondie des relations entre la pluviométrie et l'émergence des papillons, en particulier pour expliquer les différences locales et temporelles de l'abondance.
- Détermination des sources de la mortalité et l'impact des facteurs spécifiques de mortalité sur la dynamique des populations.
- Connaissance améliorée de la distribution de la mineuse sur les panicules (c'est-à-dire, la distribution par rapport à la variété ou au moment précis de la saison).

4. Lutte intégrée

En général, les priorités de recherche doivent aborder les aspects et les composantes de la lutte intégrée relatifs, premièrement, à la cécidomyie en Afrique de l'Ouest, en Inde, en Australie et aux Etats-Unis, et deuxièmement, à la punaise des panicules du sorgho et à la mineuse de l'épi du mil, celles-ci étant les insectes nuisibles des panicules les plus importantes en Afrique de l'Ouest.

Les priorités de recherche doivent porter particulièrement sur:
- Recherche et évaluation en milieu réel des technologies actuelles de lutte contre les ravageurs.
- Enquêtes menées conjointement par les socio-économistes, les agronomes et les entomologistes sur les préférences des paysans et les contraintes à l'adoption de technologies.
- Identification et évaluation de la comptabilité des composantes potentielles de lutte intégrée contre les principaux insectes ravageurs en appliquant les critères suivants de priorité:

Cécidomyie	résistance variétale, date de semis, cycle de maturation des cultivars
Punaises des panicules du sorgho	résistance variétale et date de semis, hôtes obligatoires, survie hors-saison
Chenilles des chandelles	date de semis, type de panicule, cycle de maturation du cultivar
Mineuse de l'épi du mil	cycle de maturation du cultivar, labour du sol, résistance variétale

Pour améliorer le développement de la technologie de lutte intégrée et favoriser l'échange de technologies/informations, il faut accorder une attention prioritaire à 1) l'établissement d'une inventaire des résultats de recherche déjà disponibles sur les composantes et les systèmes différents de lutte intégrée; et 2) l'identification des lacunes dans les connaissances et les opportunités de recherche.

Pour ce faire, on doit favoriser une collaboration plus étroite entre les institutions suivantes: l'ICRISAT et les autres Centres internationaux de recherche agricole, le Programme Américain d'Appui à la Recherche Collaborative sur le Sorgho et le Mil (INTSORMIL), le Centre International sur la Physiologie et l'Ecologie des Insectes (ICIPE), le CAB International, l'Institut de Ressources Naturelles (NRI), les systèmes nationaux de recherche agricole (SNRA), les organisations nongouvernementales (ONG) de l'Afrique, de l'Australie, et de l'Inde, ainsi que les instituts guides associés et les universités.

Enfin, les avantages comparatifs de tous les partenaires collaborateurs en ce qui concerne la conduite de la recherche sur des problèmes de ravageurs doit être identifié afin d'éviter la duplication de travaux.

List of Participants/*Liste des participants*

S Abdou
Institut National de Recherches
Agronomiques du Niger (INRAN)
Station de Kollo
BP 60, Kollo
Niger

M Adamou
Institut National de Recherches
Agronomiques du Niger (INRAN)
BP 429, Niamey
Niger

A Ndiaye
Institut National de Recherches
Agronomiques du Niger (INRAN)
BP 429, Niamey
Niger

A B Bal
Département de Formation en
Protection de Végétaux (DFPV)
BP 12625, Niamey
Niger

M Baldé
Centre National de Recherches
Agronomiques (CNRA)/
Institut Senegalais de
Recherches Agricoles (ISRA)
BP 53, Bambey
Senegal

P S Beevor
Natural Resources Institute (NRI)
Central Avenue, Chatham Maritime
Kent ME4 4TB
UK

M K Diagne (Interpreter)
BP 5138 Fann, Dakar
Senegal

M C Dike
Department of Crop Protection
Institute for Agricultural Research
Ahmadu Bello University (IAR/ABU)
PMB 1044, Zaria
Nigeria

Y O Doumbia
Institut d'Economie Rurale (IER)
Station de Recherche Agronomique de
Sotuba
BP 438, Sotuba
Mali

F E Gilstrap
Department of Entomology
Texas A&M University
College Station
Texas 77843-2475
USA

K M Harris
81 Linden Way
Ripley, Woking
Surrey GU23 6LP
UK

I G Hiremath
Department of Agrobiology
Seoul National University
Suwon 441 744
South Korea

N D Jago
Natural Resources Institute (NRI)
Central Avenue, Chatham Maritime
Kent ME4 4TB
UK

H A Kadi Kadi
Institut National de Recherches
Agronomiques du Niger (INRAN/CERRA)
BP 240, Maradi
Niger

S A Kogo
Direction de la Protection des Végétaux (DPV)
BP 323, Niamey
Niger

S Krall
Deutsche Gesellschaft für
Technische Zusammenarbeit (GTZ)
GmbH Postfach 5180
65 726 Eschborn
Germany

O Lea (Interpreter)
BP 4204, Ouagadougou
Burkina Faso

C C Nwasike
Department of Plant Science
Institute for Agricultural Research
Ahmadu Bello University (IAR/ABU)
PMB 1044, Zaria
Nigeria

J E Ohabuike
Commission du Bassin du Lac Tchad (CBLT)
BP 272, N'Djamena
Chad

M Ouattara
Institut National de Recherches Agronomiques du Niger (INRAN)
BP 429, Niamey
Niger

G C Peterson
Texas Agricultural Experiment Station
Route 3, Box 219
Lubbock, Texas 79401-9757
USA

H N Pitre
Department of Entomology
Mississippi State University
Mississippi State, MS 39762
USA

B S Rana
All India Coordinated Sorghum Improvement Project (AICSIP)
National Research Centre for Sorghum
Rajendranagar, Hyderabad 500 030
Andhra Pradesh
India

G L Teetes
Department of Entomology
Texas A&M University
College Station
Texas 77843-2475
USA

K Touré
Institut d'Economie Rurale (IER)
Station de Recherche Agronomique de Sotuba
BP 258, Bamako
Mali

A Yehouénou
Institut National Agronomique–Station de Recherches sur les Cultures Vivrières (SRCV-INA)
BP 3, N'Dali
Benin

J O Zongo
Laboratoire de Recherches–Protection des Végétaux
BP 403, Bobo-Dioulasso
Burkina Faso

ICRISAT Asia Center
Patancheru 502 324, Andhra Pradesh, India

K F Nwanze
B V S Reddy
H C Sharma

SADC/ICRISAT Regional Sorghum and Millet Improvement Program
PO Box 776, Bulawayo, Zimbabwe

K Leuschner

ICRISAT Sahelian Center
BP 12404, Niamey, Niger

Z Amadou
J Baidu-Forson
A Bationo
I Bayoun
M C Klaij
K Anand Kumar
C Renard
M V K Sivakumar
Z Somda
O Youm

ICRISAT West African Sorghum Improvement Program (WASIP)—Mali
BP 320, Bamako, Mali

A Ratnadass (CIRAD/CA)

ICRISAT West African Sorghum Improvement Program (WASIP)—Nigeria
IITA Office, Sabo Bakin Zuwo Road, PMB 3491, Kano, Nigeria

O Ajayi

About ICRISAT

The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, finger millet, chickpea, pigeonpea, and groundnut; these six crops are vital to life for the ever-increasing populations of the semi-arid tropics. ICRISAT's mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

ICRISAT was established in 1972. It is one of 16 nonprofit, research and training centers funded through the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank.

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International Crops Research Institute for the Semi-Arid Tropics
Patancheru 502 324, Andhra Pradesh, India

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