SICNA

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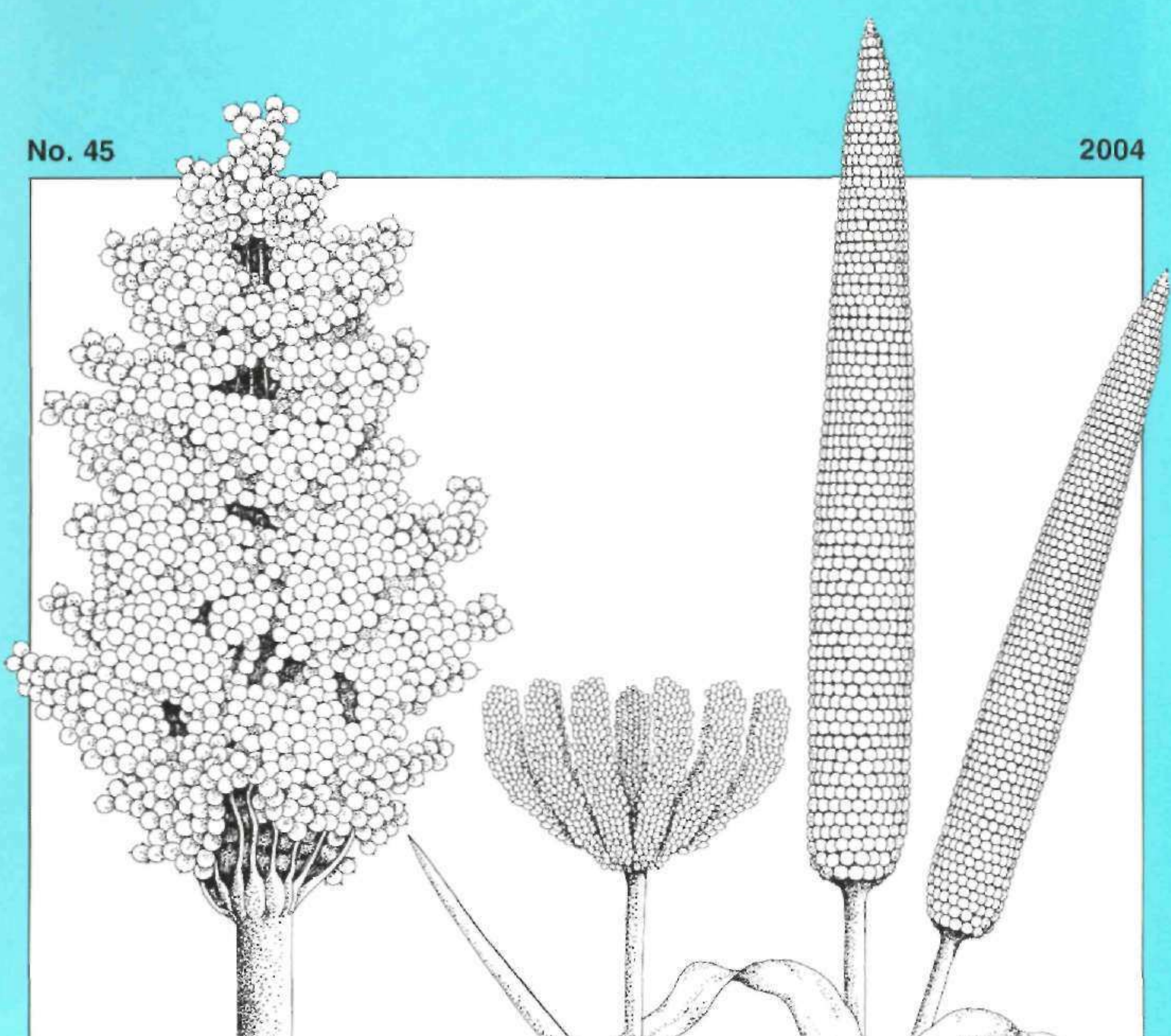

International Sorghum and Millets Newsletter

Co-publishers

SICNA
Sorghum Improvement Conference of North America
(www.sorghumgrowers.com)

ICRISAT
International Crops Research Institute for the Semi-Arid Tropics
(www.icrisat.org)

About SICNA

In 1947, sorghum breeders formed an informal working group to meet and review items of interest in sorghum breeding and genetics. This organization was named "Sorghum Research Committee". In the 1960s, with the advent of a number of severe disease and insect problems, special half-day sessions, particularly on diseases, became a part of the Sorghum Research Committee. In 1973, a concept was put forward that all sorghum workers, irrespective of discipline and employer, should meet twice a year to discuss mutual concerns with sorghum research and development. The Sorghum Improvement Conference of North America (SICNA) was that new organization. It is composed of eight disciplinary committees, dealing with genetics and breeding, pathology, entomology, chemistry and nutrition, physiology and agronomy, biotechnology, utilization and marketing, and agribusiness and commerce. SICNA meets formally once a year in conjuction with the National Grain Sorghum Producers Board. A general program of research, education, and developmental activities is prepared by the disciplinary committees. Funding is through membership participation and contributions from commercial donors. Essentially, SICNA represents the United States sorghum activities but accepts reports and encourages memberships from sorghum and millet researchers worldwide.

About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political, international organization for science-based agricultural development. ICRISAT conducts research on sorghum, pearl millet, chickpea, pigeonpea and groundnut - crops that support the livelihoods of the poorest of the poor in the semi-arid tropics encompassing 48 countries. ICRISAT also shares information and knowledge through capacity building, publications and ICTs. Established in 1972, it is one of 15 Centers supported by the Consultative Group on International Agricultural Research (CGIAR).

The opinions in this publication are those of the authors and not necessarily those of ICRISAT or SICNA. The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of ICRISAT or SICNA concerning the legal status of any country, territory, city, or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries. Where trade names are used this does not constitute endorsement of or discrimination against any product by ICRISAT or SICNA.

ISMN Scientific Editors 2004

JA Dahlberg **RP Thakur**

Contents

Editorial

News

Sorghum Research Reports

Genetic Enhancement and Breeding

Agronomy

Pathology

Entomology

Utilization

Socioeconomics

Millet Research Reports

Genetic Enhancement and Breeding

Biotechnology

Agronomy

Pathology

Entomology

Socioeconomics

ICRISAT Publications

Selected Bibliography

Editorial

Dear Reader,

Our efforts to bring this volume of the International Sorghum and Millets Newsletter (ISMN) 2004 in time have been successful. This volume contains valuable information on news items and preliminary research findings contained in 24 articles covering genetic enhancement and breeding, biotechnology, agronomy, pathology, entomology, utilization and socioeconomics on sorghum (12) and millets (12) from different parts of the world. We hope you enjoy reading these articles and find the information useful.

We would like to thank the reviewers of these articles for their time and efforts in getting back the reviews in time to facilitate the publication of this volume. They include: PM Gaur, L Krishnamurthy, K Krishnappa, VN Kulkarni, P Lavakumar, S Pande, KN Rai, S Ramesh, GV Ranga Rao, BVS Reddy, TJ Rego, KL Sahrawat and HC Sharma (ICRISAT, Patancheru, India); S Audi Lakshmi, B Dayakar Rao, S Indira and CV Ratnavathi [National Research Centre for Sorghum (NRCS), Hyderabad, India]. We would also like to acknowledge the contributions of our SICNA reviewers. They include B Bean (Texas Agricultural Experiment Station), S Goldman (University of Toledo), S Bean and J Burd (USDA-ARS), T Isakiet and B Rooney (Texas A & M University) and R Kochenower (Oklahoma State University).

This has been possible due to full cooperation and support of the authors, reviewers, technical editor and SICNA members. SICNA would like to especially thank Garrison and Townsend, Inc., Richardson Seeds, Inc., NC+ Hybrids, Crosbyton Seed Company and Sorghum Partners, Inc. for their continued support of SICNA and the newsletter.

We request the authors, who wish to submit articles, to read carefully the "Information for ISMN Contributors" on the inside back cover of this volume. We encourage each author to follow these suggestions while preparing manuscripts. Following these guidelines will accelerate the acceptability of your submission and save time and efforts in getting the Newsletter printed in a timely manner. Please remember that **the due date of your submission for ISMN 46 is 15 August 2005.**

We have enclosed a survey form for updating the mailing list. Please take a few minutes to complete the form and return to us either electronically or by post.

There is another survey form inserted in this volume seeking feedback on your impression about and interest in ISMN. Your timely feedback will help ICRISAT develop a suitable and sustainable strategy for the publication of the three newsletters currently published. Your prompt response either electronically or by post would be greatly appreciated.

We encourage scientists, particularly from Africa and South America, to contribute research articles, news and views on sorghum and millets - me highly nutritious cereals of the dryland ecosystems. We would also like to encourage private industries, seed companies and administrators to provide their comments and feedback to enhance the profile of ISMN towards better service to sorghum and millets researchers and other users.

We would like to thank Sheila Vijayakumar, Technical Editor for her continued interest and enhanced editing standard, and to VS Reddy, Senior Newsletter Officer, ICRISAT for his efficient coordination and handling of manuscripts, processing and typesetting for printing. We also acknowledge ICRISAT Library for timely compiling the SATCRIS listing included in this volume.

We wish you all the best for your contributions to research, development and promotion of sorghum and millets in the New Year 2005.

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News

Pearl Millet Scientists Honored

IS Khairwal, Pearl Millet Breeder at CCS Haryana Agricultural University (CCSHAU), Hisar, Haryana, India accepted the position of Project Coordinator, All India Coordinated Pearl Millet Improvement Project (AICPMIP), [Indian Council of Agricultural Research (ICAR)] in 2003. After obtaining PhD in Plant Breeding from CCSHAU in 1984, Khairwal worked in various capacities and was instrumental in the development of an extra-early maturing hybrid HHB 67 and other hybrids like HHB 50, HHB 60, HHB 68, HHB 117 and HHB 146, and open-pollinated varieties like HC 4 and HC 20 at CCSHAU.

Khairwal is a Fellow of the Indian Society of Genetics and Plant Breeding and received the ICAR Best Team Research Award on Pearl Millet Improvement in 2003. He is co-author of the book 'Pearl Millet Seed Production and Technology' and has co-edited another book 'Pearl Millet Breeding'. He is author and co-author of more than 150 booklets/bulletins, research papers and articles.

As a Professor of Plant Breeding, Khairwal taught advance courses in Biometrics, Plant Genetic Resources and Principles of Plant Breeding, and guided eight postgraduate students. Two of his students received the Jawaharlal Nehru Best Thesis Award. He has been closely associated with ICRISAT since 1976 and completed several assignments and projects on pearl millet improvement. The AICMPIP under the leadership of Khairwal received the Chowdhary Devi Lal Outstanding All India Coordinated Research Project Award 2003.

KN Rai, Pearl Millet Breeder, ICRISAT, Patancheru, India was honored for his lifetime achievements in pearl millet improvement with an 'Outstanding Scientist Award'. The honor came from the Society of Millets Research and Rajasthan Agricultural University, Bikaner, at its annual pearl millet group meeting held on 11-12 April 2004 at Jaipur, Rajasthan, India. Apart from his contributions made to strategic pearl millet research and training, specific mention was made of his contributions to seed parents' development and its impact on pearl millet seed industry in India. The citation in this respect says: "Dr Rai's main contribution has been with regard to the development of an open-pollinated variety, three hybrids, 80 male sterile lines and several populations and genetic stocks of pearl millet."

ICAR Recognition for Pearl Millet Improvement

The Indian Council of Agricultural Research (ICAR) held its Annual Award Ceremony on 19 October 2004 in New Delhi, India with Honorable Shared Pawar, the Indian Minister of Agriculture, as the chief guest. In all, 52 awards were given in 13 different categories that included individuals, institutions, research teams and coordinated projects. The Chowdhary Devi Lal Outstanding All India Coordinated Research Project (AICRP) Award for 2003 was jointly won by AICRP on Home Science and AICRP on Pearl Millet.

The research centers/scientists from diverse disciplines making significant contributions to pearl millet improvement under the umbrella of AICPMIP who were identified for receiving the AICRP Award on Pearl Millet were: IS Khairwal, AICPMIP Coordinator and leader of the awardee group; Srikant from the Rajasthan Agricultural University - Agricultural Research Station, Durgapura, Rajasthan; Balzor Singh from the Indian Agricultural Research Institute, New Delhi; RS Hooda from the CCS Haryana Agricultural University, Hisar, Haryana; HS Shetty from the University of Mysore; and KN Rai from ICRISAT.

The inclusion of ICRISAT for this award is an indicator of the strong and productive research partnership with AICPMIP that has led to substantial genetic diversification in the genetic base of NARS pearl millet programs, especially in the area of seed parents research and development, resulting in commendable on-farm impact.

Field Days at ICRISAT, Patancheru

It was an excellent opportunity for scientists from the national agricultural research institutes and the private sector to look at the best pearl millet and sorghum resources at ICRISAT. While the pearl millet scientists' field days were held on 20 and 21 September, the sorghum scientists' field days were on 22 and 23 September 2004.

The main purpose of the field days was to provide an opportunity for the visiting scientists from the public and private sector to select improved breeding materials for use in their programs, to exchange research information and to receive feedback on the on-going research agenda and the impact of the materials received by them previously.

The field days for both the crops were held after a gap of four years. Both field days attracted excellent participation. The pearl millet event attracted 41 scientists from 18 public sector research organizations, 22 private seed companies and from the Sehgal Family Foundation.

The sorghum event, on the other hand, attracted a total of 67 scientists, including 16 from the private sector, 22 from the public sector and 29 from ICRISAT. The scientists were from India, Indonesia and Egypt. Mary A Mgonja from ICRISAT-Nairobi participated in both the crop events. Tanned but happy, the scientist visitors returned with praises for ICRISAT's breeding work.

Speaking at the inauguration of the pearl millet field days, ICRISAT's Director General William Dar said that while scientists at ICRISAT have been convinced of the power of conventional plant breeding in delivering the goods, they are also convinced about the new science tools that can make significant contributions in "enhancing the pace and precision of plant breeding. These new tools are increasingly becoming an integral part of plant breeding. Dar emphasized the need for partnership research in diversifying the product value of sorghum and challenged the scientists to solve the unresolved issues of enhancing resistance to shoot fly and grain mold in breeding materials. He said that in ICRISAT the thrust is to do science that improves the livelihood of the poor farmers in the semi-arid tropics.

As IS Khairwal, the most experienced pearl millet breeder in India and also Coordinator of the AICPMIP said, there was such a vast range and amount of promising materials in the field that the most difficult decision for the participants was what to take and what to leave out.

G Harinarayana, Research Director of Ganga Kaveri Seeds was highly appreciative of the materials and mentioned that more than 90% of the hybrids from private seed companies are based on breeding materials and parental lines developed at ICRISAT. He said that the private sector was always ready to fund any project in which they could see a commercially useful product in a short time frame of 2-3 years.

The private sector's appreciation of pearl millet breeding lines was obvious from the fact that the number of seed companies that are members of the Pearl Millet Hybrid Parents Research Consortium increased from 9 in 2000 to 22 in 2004.

Representatives of public and private sectors, while appreciating the efforts of sorghum scientists in developing diversified materials and organizing the field day, indicated that they have selected several hybrid parents and other breeding material, and that there was considerable impact on the farmers' fields from the previously selected material. They also echoed the need to focus more on breeding for resistance to grain mold/shoot fly and *rabi* (postrainy) season adaptation.

N Seetharama, Director, National Research Centre for Sorghum, Hyderabad indicated that the rainy season sorghum market value is low because of grain molds.

The other comments included: "fabulous", "very useful", "Mecca of germplasm, breeding materials and research", "wonderful diversity", and so on about the program and materials.

More Straw from Pearl Millet

A two-day stakeholders workshop was held at ICRISAT, Patancheru on 11-12 August 2004 for a recently initiated project to genetically improve the quality of pearl millet crop residues for use as feed for ruminant livestock in northwestern India. Representatives from several public- and private-sector pearl millet breeding programs serving northwestern India joined forage and livestock production specialists from Rajasthan and Gujarat, representatives from major cooperatives involved in seed and dairy production in Gujarat (GUCOMASOL and NDDB), and an NGO interested in policy related to fodder for livestock in Gujarat, to meet with ICRISAT and International Livestock Research Institute (ILRI) scientists at Patancheru on 11-12 August 2004. This ICAR-ICRISAT-ILRI collaborative project is supported with a grant from the Australian Centre for International Agricultural Research (ACIAR) of A$1.2 million over five years (2004-08). It will attempt to use recurrent selection for predicted livestock feeding value within top-cross pollinator populations, and marker-assisted backcrossing of genomic regions associated with improved straw yield and straw nutritional quality into elite hybrid seed parents, to breed pearl millet cultivars for Gujarat, Rajasthan and Haryana that combine improved straw yield and straw quality with disease resistance and adaptation to the pearl millet production systems of that region. Thus the project's overall objective is to improve the yield and fodder quality of straw produced from high-yielding, disease resistant dual-purpose (grain and straw) pearl millet hybrids for arid and semi-arid regions of northwestern India.

Sorghum Research Reports

Genetic Enhancement and Breeding

Sorghum Breeding Research at ICRISAT - Goals, Strategies, Methods and Accomplishments

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Introduction

Sorghum *(Sorghum bicolor)* is the fifth most important cereal crop grown in the world. It is grown over 42 million ha as a rainfed crop mostly by subsistence farmers in the semi-arid tropics (SAT) of Africa, Asia and Latin America. Sorghum grain is used mainly for human consumption in Asia and Africa while it is used as animal feed in the Americas, China and Australia. In India, the rainy season sorghum grain is used mostly for animal/poultry feed while the postrainy season sorghum grain is used primarily for human consumption. The crop residue (stover) after grain harvest is a valuable source of fodder and fuel in India and Africa. Sorghum also has great potential to supplement fodder resources in India because of its wide adaptation, rapid growth, high green and dry fodder yields with high ratoonability and drought tolerance.

Sorghum is mostly grown by resource-limited farmers with minimal inputs which is one of the reasons for its low productivity. The yield and quality of sorghum produce is affected by a wide array of biotic (insect pests and diseases) and abiotic (drought and problematic soils) constraints. The important productivity-limiting constraints are: shoot fly (*Atherigona soccata)* (India and Eastern Africa), stem borer (*Chilo partellus*) (India and Africa), midge (*Contarinia sorghicola*) (Eastern Africa and Australia) and head bug (*Calocoris angustatus*) [India and Western and Central Africa (WCA)] among pests; grain mold (complex of fungi predominantly *Fusarium* spp, *Curvularia* spp, *Aspergillus* spp, *Alternaria* spp) (all regions) and anthracnose (*Colletotrichum graminicola*) (WCA and northern India) among diseases; *Striga* (*Striga asiatica, S. densiflora, S. hermonthica*) (all regions in Africa); drought (all regions); and problematic soils - saline (some parts of India and Middle East) and acidic (Latin America).

Breeding Goals and Strategies

The breeding goals (involving partners) have undergone significant changes since the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) was established in 1972 at Patancheru, India with sorghum as one of its five mandate crops for research aimed to improve its productivity for food use in SAT. External environments, perceptions of donors and national agricultural research systems (NARS), changing crop requirements and opportunities, and NARS capacity are the most important factors that influenced these changes. The identification of geographic functional regions with a set of constraints has resulted in the gradual shift in breeding strategy from initial wide adaptability to specific adaptations, and to trait-based breeding for threshold traits through the 1980s and 1990s. The ICRISAT-Patancheru-based wide adaptability approach was abandoned by early-1980s, and three research centers with regional hubs were established in Africa and one in Central America to take up breeding for region/production system-specific adaptations. Thus, five different phases in sorghum breeding goals could be recognized in ICRISAT's global sorghum breeding program. These are: (1) wide adaptability and high grain yield (1972-75); (2) wide adaptability and breeding for biotic and abiotic constraints(1976-79); (3) regional adaptations and resistance breeding (1980-84); (4) specific adaptations and resistance breeding (1985-89); and (5) trait-based breeding, sustainable productivity and upstream research (1990-present) (Reddy et al. 2004).

Breeding sorghum for high and stable yield with improved drought tolerance has received top priority at ICRISAT. Besides these, traits that are required for adaptation to different sorghum production systems have been considered. For example, improved postrainy season sorghums in India would require in addition to higher grain and fodder yields, tolerance to drought, shoot fly and lodging and grain quality (semi-corneous endosperm grains) suitable for making *'roti'* (unleavened bread). On the other hand, in the northern Guinea zone of WCA, improved sorghum lines should have longer maturity, and hard grains with stable resistance to *S. hermonthica,* anthracnose, grain mold, stem borer and head bug. Also, grain quality-evident traits such as soft endosperm grains preferred in Eastern Africa for food product preparations such as *injera* and *kisra* and hard endosperm grains preferred in Western Africa for *to* preparation were given due importance (Reddy and Stenhouse 1994).

Initially, major emphasis was given on developing improved varieties in collaboration with NARS for all SAT areas from ICRISAT-Patancheru. Later, hybrids as the target materials were given considerable importance at ICRISAT-Patancheru. Since 1995, emphasis was laid on developing improved hybrid parents at ICRISAT-Patancheru for Asia, and finished products (varieties and hybrids) at other ICRISAT locations in Africa, through partnership research.

Breeding Methods and Techniques

Initially, population improvement program with S_1/S_2 selection schemes involving ms_3/ms_7 male-sterile genes was used extensively in the 1970s to improve several broad-based populations like US/R, US/B, Fast Lane, etc. The lines derived from these populations through head-to-row selection were tested widely across several locations in Asia and Africa in an effort to select for wide adaptability for a range of traits, including red and white grain. Later, pedigree and backcross breeding methods also received some emphasis to transfer relatively small sets of genes into improved white-grained backgrounds. Grain yield was the main selection criterion in population, pedigree and backcross breeding methods. However, from 1980s onwards, major emphasis was placed on breeding for resistance to various biotic and abiotic stresses in each of the regions. In the later part of the 1980s, pedigree and backcross methods were deployed extensively for specific adaptations within each region. A trait-based pedigree breeding approach in which families were used as the selection units for resistance response, and individuals within the resistant families as selection units for grain yield was followed from 1990 onwards. Also, since 1990, simple mass selection is being used to improve the populations to develop trait-based gene pools; eg, ICSP-high tillering population. Simultaneous testcrossing and backcrossing the selected maintainer plants along with the selection for resistance trait and grain yield in the trait-based breeding programs were carried out to improve male-sterile lines for specific resistance traits and high grain yield (Reddy et al. 2004).

More recently, SSR (simple sequence repeat) markers associated with resistance to shoot fly and *Striga,* and stay-green were identified by evaluating the parents and recombinant inbred lines (RILs) derived from resistant x susceptible crosses. The RILs were developed through head-to-row generation advance. Further, genetic transformation for stem borer resistance is being used for deploying Bt-genes and T_1 tansgenics are currently being tested in the greenhouse.

Accomplishments

Breeding Products

ICRISAT's partnership efforts with NARS from SAT countries led to the release of 194 improved cultivars over the years (Table 1); Southern and Eastern Africa (SEA) (60), WCA (50), Asia (50) and Latin America (34).

Apart from these, over 54 hybrids that are being marketed by private seed companies in India were developed from ICRISAT-bred hybrid parents or their derivatives. Besides these, breeding efforts at ICRISAT have led to the development of various types of elite lines and gene pools. The lines include: high-yielding male-sterile lines (160), trait-specific male-sterile lines (567), restorer lines (873) and varieties (1451). The demand and diversity of male-sterile and restorer lines were demonstrated by the number of research seed samples supplied by ICRISAT-Patancheru upon request by different national programs. A total of 194,356 sorghum seed samples have been supplied to 107 countries during 1986-2003: Africa - 34,764; Asia - 14,351; Americas - 15,036; Europe - 1,305 seed samples. The ICRISAT web page (http://www.icrisat.org/text/research/grep/homepage/sorghum/breeding/pedigree.htm) provides complete information on the characteristic features of these materials including their pedigrees. Some of the most important improved cultivars and elite hybrid parents resistant to biotic and abiotic stresses are described below.

Striga **resistance.** *Striga,* an abnoxious obligate parasitic weed, is one of the most important biotic yield constraint in Africa, although less important in Asia. ICRISAT's African sorghum improvement program has developed a *Striga* resistant variety 'Framida' that has been released in Burkina Faso and Ghana. Similarly, a *Striga* resistant variety SAR 1 has been released for cultivation in *Striga* endemic areas in India. Several *Striga* resistant seed

Table 1. Number of ICRISAT-derived released sorghum varieties over the years in Asia, Africa and Latin America.

Region	1972-80	1981-90	1991-2000	2001-04	Total
Asia	2	15	32	1	50
Western and Central Africa	2	12	27	9	50
Southern and Eastern Africa	7	21	23	9	60
Latin America	4	16	14	0	34
Total	15	64	96	19	194

parents (eg, ICSA 579, ICSA 583, ICSA 584, ICSA 588 and ICSA 592) were also developed for use by national programs in Asia.

Disease and insect tolerance. Grain mold, shoot fly, stem borer and midge are important biotic constraints in Asia and Africa. ICRISAT in partnership with national programs in Asia has developed many grain mold resistant varieties. PVK 801, besides being grain mold resistant, is a dual-purpose variety with good quality stover.

Varieties such as ICSV 112 and ICSV 745 which are high yielding are also foliar disease resistant (ICSV 745 is also midge resistant). By using a trait-based breeding approach, ICRISAT has developed several grain mold resistant (eg, ICSA 300, ICSA 369, ICSA 400, ICSA 403 and ICSA 404) and shoot fly tolerant (eg, ICSA 419 and ICSA 435 for rainy season and ICSA 445 and ICSA 452 for postrainy season) cytoplasmic-nuclear male sterility-based seed parents. These seed parents have good potential for developing hybrids resistant to these biotic constraints and thus stabilizing yield gains obtainable from these hybrids.

Resistance to soil mineral toxicities. Of all the soil mineral stresses or chemical toxicities, acidity and associated Al^{3+} toxicity and salinity are probably the most important constraints to sorghum productivity in tropical environments. Although sorghum is known to be relatively more tolerant to soil salinity and acidity than other comparable crops such as maize (*Zea mays*), further enhancement of its genetic potential through plant breeding would be an eco-friendly and a more sustainable approach than just management options for increased productivity in such soils. Of more than 6000 sorghum genotypes from the world collection screened at Quilichao, Colombia, approximately 8% was found to tolerate 65% Al^{3+} saturation. Besides these, several high-yielding male-sterile lines, restorer lines and forage sorghum lines were found to be tolerant to Al^{3+} toxicity and have been supplied to NARS scientists. These are: grain sorghum A/B-lines: ICSB 93, ICSB 89002, SPMD 94004, SPB2 94013 and SPB2 94029; grain sorghum R-lines: ICSR 110, ICSR 91008, ICSR 91012, ICSR 93033 and GD 27669; and forage sorghum lines: ICSR 93024-2 and IS 31496.

Similarly, some of the elite sorghum varieties, hybrids and improved lines with better tolerance to salinity (at 250 μM NaCl solution; EC 23.4 dS cm^{1}) are: grain sorghum A/B-lines: ICSB 766, ICSB 676 and ICSB 300; grain sorghum R-lines: ICSR 1 % , ICSR 91005, ICSR 89010 and ICSR 93034; and grain sorghum varieties: ICSV 112, CSV 15, S 35, NTJ 2 and ICSV 145.

Sweet-stalked sorghum. In recognition of the increasing demand created for ethanol due to the Indian government's policy to mix 5% ethanol in petrol and likely and gradual increase of this proportion up to 10%, ICRISAT renewed its sweet sorghum research (which was initiated in 1980 and discontinued in early 1990s) for the identification and development of sweet-stalked and high biomass sorghum lines Starting in 2002. Sweet sorghums have a great potential for ethanol production by virtue of their high stem sugar concentrations, with a brix value up to 24%.

Several promising lines such as ICSB 38, ICSB 631 and ICSB 264 among the B-lines, SSV 84, Seredo, ICSR 93034, S 35, ICSV 700, ICSV 93046, E 36-1, CSV 15, NTJ 2 and Entry# 64 DTN among the varieties/R-lines with over 19% stalk sugar content were identified. Recently, a sweet stalk sorghum hybrid, NSSH 104, has been developed by crossing ICSA 38, an ICRISAT-bred female parent with an improved and released sweet stalk variety SSV 84 and it is being recommended for release by the National Research Centre for Sorghum (NRCS), Hyderabad as special purpose sorghum for cultivation in India.

Forage sorghum. Forage sorghum cultivars are commonly grown in northern India and West Africa. It is fed to animals as a green chop, silage or hay. Improvement of forage sorghum in India focuses on breeding varieties and hybrids with high forage yield, better quality fhigh sugar, high crude protein, low hydrocyanic acid (HCN), other nutritional and digestibility parameters], good seed yields, ratoonability and resistance to pests and diseases.

At ICRISAT, a strong program on forage sorghum improvement has developed a diversified set of hybrid parents, and grain and dual-purpose varieties. Evaluation of a large number of sorghum lines developed earlier under the Genetic Resources and Enhancement Program at ICRISAT and the lines selected from high tillering population resulted in the identification of tillering lines useful for developing forage varieties and hybrids. Some of them with high fresh fodder yield are: ICSR 93024-1, IS 33941, ICSR 93022, ICSR 93025-1-1, HT Pop-F_3-18-2, HT Pop-F_3-28-1, HT Pop-F_3 -42, HT Pop-F_3 -47, HT Pop-F_3- 51-I, HT Pop-F_3-51-2 and HT Pop-F_3-53-3. Besides these, IS 1059, IS 2944, IS 324, IS 4776 and IS 6090 for low HCN and IS 3247 and PJ 7R for low tannin content have been identified at ICRISAT.

Adoption and Impact

The adoption of improved cultivars along with natural resources management technologies resulted in an increase in sorghum grain productivity by 150 kg ha^{-1} (0.9% annually) in Africa, by 450 kg ha^{-1} (3.1% annually) in whole Asia and by 280 kg ha^{-1} (2.9% annually) in India during 1972 to 2002. The increased sorghum area in Africa (by 9 million ha) coupled with improved productivity resulted in enhanced production by 10 million t during 1972 to 2002, signifying its contribution to regional/ national food security. The higher increase in sorghum productivity in whole Asia and India compared to Africa could be attributed to the adoption of hybrids. Because of increases in sorghum productivity during 1972 to 2002, nearly 6 million ha (35% of the 1972 sorghum area) in India and 7.4 million ha (31% of the 1972 sorghum area) in Asia has been made available to farmers to diversify into high-income cash crops. Figures 1 and 2 show the patterns in area, production and productivity of sorghum over the years as well as the timing of ICRISAT-derived releases in Asia and Africa. Besides increasing grain productivity, the improved cultivars with enhanced resistance to yield constraints have not only stabilized the yield levels but also led to cultivar diversity, and thus contributed to sustainable production systems.

Amongst the varieties released in various countries, ICSV 112 is very popular among farmers in Africa and has been released in five countries (Zimbabwe, Kenya, Swaziland, Malawi and Mozambique). Another variety ICSV 111, released in Cameroon, Chad and Nigeria, has shown high impact on reducing the cost of production and improving productivity. The improved cultivars developed by ICRISAT in Southern Africa currently occupy 15-50% of the area in eight Southern African Development Community (SADC) member states. Macia, is an open-pollinated, early-maturing and high-yielding variety developed at ICRISAT-Bulawayo, Zimbabwe in 1989. It was released in Mozambique (as Macia in 1987), Botswana (as Phofu in 1994), Namibia (as Macia in 1998), Zimbabwe (as Macia in 1998 by SEED Co Ltd, a private seed company) and Tanzania (as Macia in 1999). Farmers are benefiting from rapid and extensive adoption of this variety in Botswana and Mozambique. It is being cultivated in an area of 0.1 million ha in Botswana, Namibia, Zimbabwe, Mozambique and Tanzania, which represent the SADC region of Southern Africa (Table 2).

There has been a yield advantage of 10-20% (up to 200 kg ha^{-1}) and the total benefits accrued from this has been US$7.3 million at US$0.1 kg^{-1}. In Kenya, the variety *Gadam el Hamam* was adopted for early maturity and good taste. The sorghum variety Pato is adopted in approximately 36% of the area under improved varieties in Tanzania.

In Sub-Saharan Africa, the variety, S 35 (ICSV 111) gave 25% more grain yield and its adoption rate was 10-15% in Nigeria and Ghana. Likewise, the sales of the variety ICSV 400 increased substantially to a value of 4.5 million

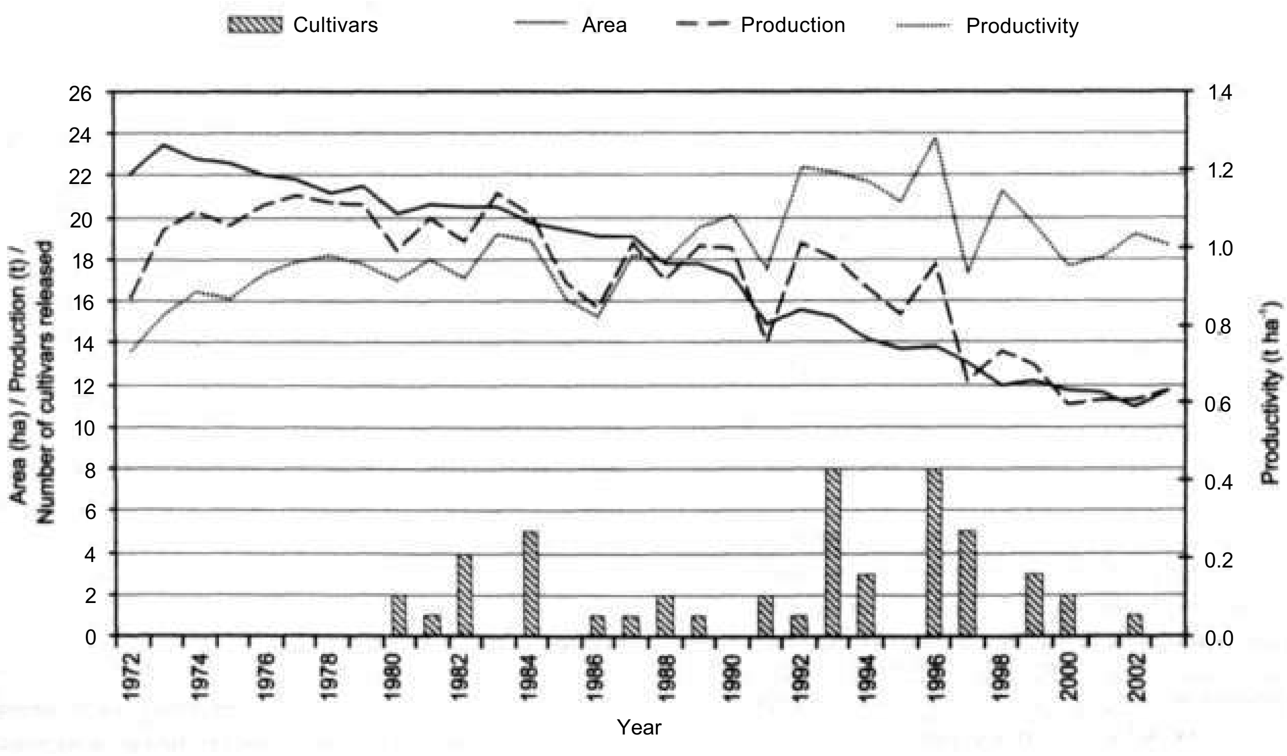

Figure 1. Sorghum area, production and productivity and number of cultivars released in Asia during 1972 to 2002.

Naira (US$40,000) in 2001 because the variety was used by the agro-industry. The extra-early maturing variety CSM 63 E or "Diacumbe" is highly accepted by farmers in WCA and the area of CSM 63 E cultivation has been continuously increasing in past many years. Seven new varieties have been released in Mali mostly belonging to the *guinea* race - Tieble (CSM 335), Kossa (CSM 485), Ngolofing (CSM 660), Marakanio (CGM 9-9-1-1), Padi (ICSV 901), Nazomble (Nazangola anthocyané) and Nazondje (Nazangola tan). Tieble and Ngolofing are spreading rapidly among farmers in the 800-1000 mm zone of Mali due to their good yield, relative earliness and excellent grain qualities. A hybrid (NAD 1) has been released in Niger for which seed production and adoption

Table 2. Estimated adoption and spread of SDS 3220 (Macia) in the SADC region of Southern Africa.

Country	Released name	Year of release	Approximate adoption area (ha)	Percentage of total area under sorghum
Botswana	Phofu	1994	37500	25
Namibia	Macia	1998	3000	10
Zimbabwe	Macia	1998	26300	15
Mozambique	Macia	1987	22000	7
Tanzania	Macia	1999	20000	3

Source: Shiferaw et al. (2004).

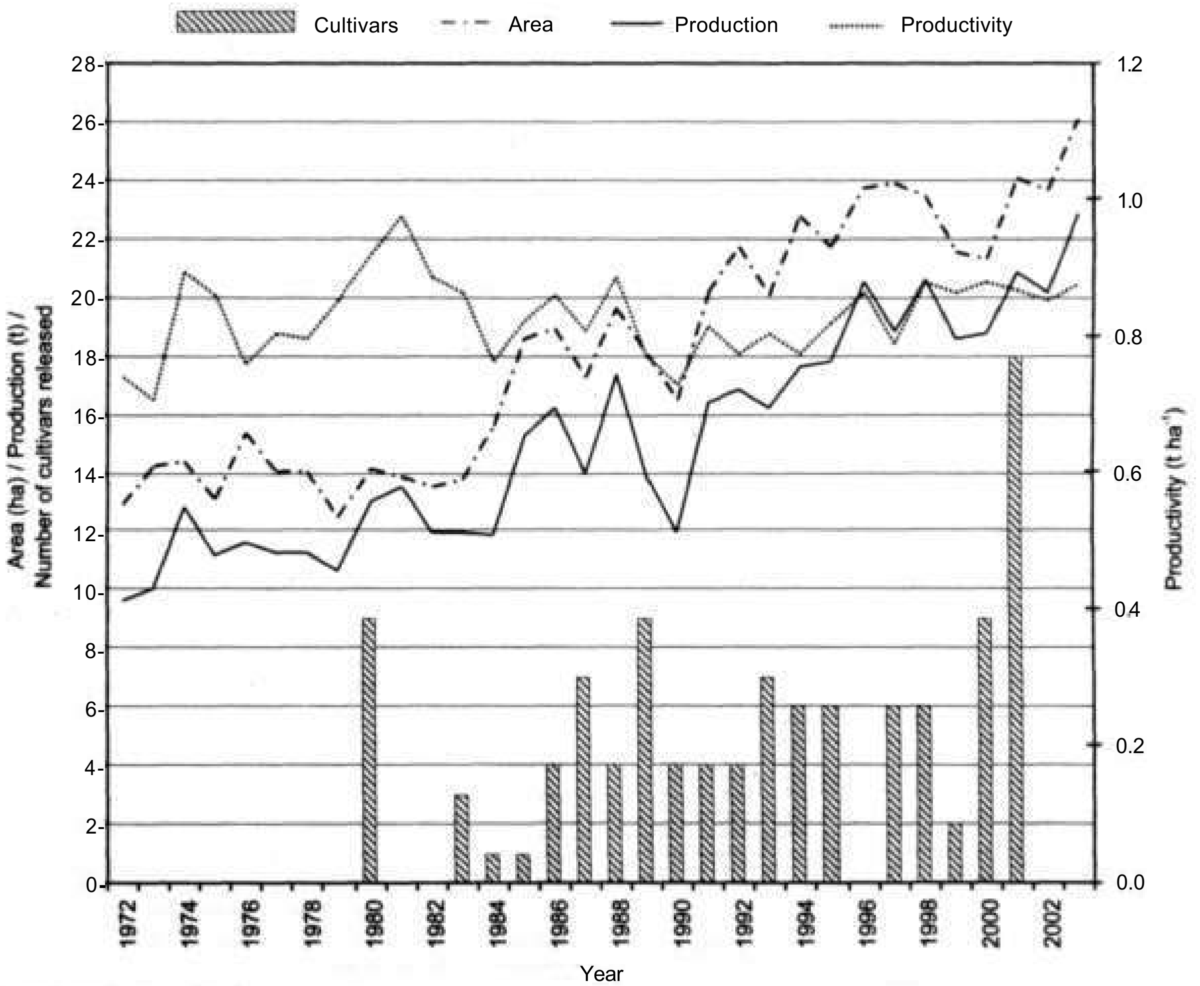

Figure 2. Sorghum area, production and productivity and number of cultivars released in Africa during 1972 to 2002.

are increasing in Niger and Nigeria. The hybrid ICSH 88902 has been released in Nigeria.

Similarly, several varieties released in Asian countries such as India, Myanmar, Pakistan, Philippines and Thailand have become very popular. A variety NTJ 2 is highly popular for its roti-making quality with terminal drought tolerance in the postrainy season sorghum growing areas in Andhra Pradesh, India. The varieties bred for specific adaptation, eg, ICSV 112 and ICSV 745, which are relatively early, dual-purpose (grain and stover) and foliar disease resistant (ICSV 745 is also resistant to midge) and introduced in Warangal district of Andhra Pradesh showed yield advantages ranging from 29% in monoculture and 56% in intercropping systems and enabled farmers to earn 13% higher income with ICSV 112 and 58% with ICSV 745. These varieties gave 20% higher grain yield and 35% higher fodder yield than locally adopted cultivars in Melghat region of Maharashtra state in India.

Nine sorghum varieties (including germplasm accessions) were released in Myanmar from 1980 to 1996. Two sorghum varieties, ICSV 107 (PARC-SSI) and IRAT 408 (PARC-SS2), introduced from ICRISAT-Patancheru were released in Pakistan in 1991. Two sorghum varieties, IES Sor 1 and IES Sor 4, developed using ICRISAT germplasm were released in the Philippines in 1993 and 1994, respectively. Suphanburi 1 derived from ICRISAT germplasm was released in Thailand in 1996 (Deb et al. 2004).

Several ICRISAT-bred improved hybrid parents have been extensively used by both public and private sector research organizations to develop and market hybrids in Asia. In India alone, around 4 million ha is occupied by more than 54 hybrids developed from ICRISAT-bred parental lines or their derivatives. Notable among them is JKSH 22, a hybrid developed from ICRISAT-bred seed parent by a private sector based in India. It is known for its higher grain yield potential, bold grain and earliness (5-10 days compared to the most popular hybrid CSH 9) and showed remarkable adoption from 1500 ha in 1994 to 210,000 ha in 2002 (Fig. 3).

During 1994 to 2002, seed production of JKSH 22 earned farmers, on an average, over US$0. 31 million per year in Andhra Pradesh and Karnataka states and US$2.7 million per year from commercial cultivation in Maharashtra and other sorghum growing states in India. In the last three years (2001/02 to 2003/04), a total of 29,800 t of certified hybrid seed of ICRISAT-private sector hybrids (Table 3) was produced which gave a total income of US$18.8 million to farmers in Andhra Pradesh and Karnataka.

Similarly, several sorghum hybrids using ICRISAT hybrid parental material have been released in China during 1982-96. For example, hybrids such as Lio Za 4, Longsi 1, Jin Za No. 12 and Gilaza 80 have been developed from ICRISAT-bred parental lines and released in China.

Cost-benefit Ratio and Returns from Research

The productivity gain from improved cultivars has more than compensated the cost of additional inputs used for their cultivation. The cost-benefit ratio of production of improved cultivars ranged from 1:1.25 (in WCA) to 1:1.4 (in India). The net present value (NPV) of benefits from the cultivar S 35 was estimated at US$15 million in Chad and US$4.6 million in Cameroon, with an internal rate of return (IRR) of 95% in Chad and 75% in Cameroon. Improved sorghum cultivars in Mali are estimated to generate an NPV of US$16 million with an IRR of 69%. The adoption of improved cultivars in eight SADC member states contributed an additional US$19 million

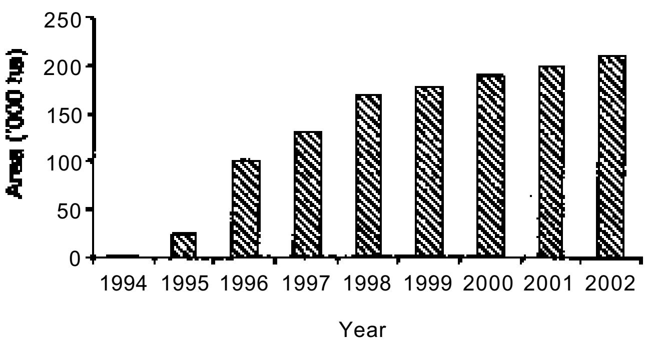

Figure 3. The area covered under JKSH 22, an ICRISAT-private sector partnership hybrid in India.

Table 3. Share of ICRISAT-private sector (PS) partnership sorghum certified hybrid seed production in total sorghum seed production in India.

Year	PS hybrid seed[1] (t)	Total certified seed (t)
2001/02	11600(71)	16410
2002/03	7200 (63)	11390
2003/04	11000(61)	18000
Total	29800 (65)	45800

1. Percentage values are given in parentheses.

Source: Yogeshwara Rao, Vikkis Agrotech Ltd., Hyderabad, India (personal communication).

per annum in income streams. In Zambia and Zimbabwe, IRR from the adoption of cultivar ICSV 88060 is estimated at 11-15% and 22%, respectively. The adoption of the improved cultivar SV 2 has yielded 27% in Zimbabwe and adoption of improved cultivars has fetched IRR of 10% to the investments in sorghum breeding (ICRISAT 1998). The adoption and the use of ICRISAT-bred midge resistant cultivars ICSV 745 and PM 13654 in Australia is expected to enhance grain productivity by 2.5% annually in midge-endemic areas that translates into a cost saving of US$4.7 million at the current average production levels (Deb and Bantilan 2003). Australia made net gains at an average of A$I .14 million per year from the impact of ICRISAT's sorghum research. These benefits are well in excess of Australia's financial contribution to ICRISAT (Brennan et al. 2004). This is an example of international research outputs aimed at improving productivity in developing countries and also having spillover benefits in developed countries.

Innovations in Science and Technology Sharing

Innovations in research and sharing of technologies so developed out of such innovations are the key factors for increased impact in fanners' fields. Innovative strategic and upstream research information developed at ICRISAT - ideas, concepts, methods and techniques that were inputs for further research - has contributed immensely to increased efficiency of breeding processes of ICRISAT and those of NARS partners. This research had a multiplier effect, with several public and private research organizations further developing finished products simultaneously for targeted production areas. Some of the important strategic research findings and application of new science tools and their impacts are described below.

Strategic research. ICRISAT has standardized large-scale, reliable, cost-effective and repeatable resistance-screening techniques such as interlard-fish meal technique for resistance to shoot fly, artificial infestation technique for resistance to stem borer and infestor-rows technique for resistance to midge among the insect pests, sprinkler irrigation with artificial inoculation technique for resistance to grain mold and infector-row field-screening techniques for resistance to downy mildew and anthracnose among the diseases, and chequer board method of field screening for resistance to *Striga;* and screening techniques for coleoptile and mesocotyl lengths for germination and emergence under deep-sowing areas in Africa, for seedling emergence under high surface soil temperature, for recovery from seedling drought and mid-season drought, for terminal drought stress tolerance and for resistance/tolerance to soil acidic and salinity toxicities. Sources of resistance to these biotic and abiotic stresses have been identified and these have been successfully transferred to NARS in India and Africa. The conceptualization and demonstration of landrace pollinators-based hybrids approach for terminal drought situations, particularly for postrainy situation in India led the private sector to develop and market hybrids for postrainy season for the first time in India. Development and transfer of methods of developing hybrid parents (Asia) and varieties (Africa) resistant to grain mold for rainy season and shoot fly for postrainy season in Asia and varieties resistant to drought, *Striga* and other biotic stresses in Africa and moving average concepts to increase the efficiency of selection for resistance to these stresses resulted in significant improvements in NARS resistance breeding programs (Reddy et al. 2004).

New science tools. Molecular markers and transgenic technologies, ingenuity of farmers and information technologies have been increasingly used. Major quantitative trait loci (QTLs) conferring resistance to several yield constraints have been identified. Molecular marker-assisted selection (MAS) is underway to introgress the QTLs governing *Striga* and shoot fly resistance, and stay-green, a proven trait conferring terminal drought resistance into farmer-accepted cultivars. ICRISAT is the first to develop sorghum transgenics for resistance to stem borer, which are currently under greenhouse testing. Farmer participatory varietal selection (FPVS)/plant breeding has started showing significant benefits for drought-prone areas both in Africa and Asia. FPVS facilitated the release of the variety SPV 1359 for postrainy season cultivation in Maharashtra and Karnataka states in India during 1999-2000. A high-yielding variety 'Tieble' was identified through FPVS trial in Gonsolo village in Mali in Africa during 2000. By 2002, nearly all the households in this village and the surrounding five villages had sown seeds of this variety. Farmer-participatory evaluation of ICRISAT-Patancheru-bred varieties (ICSV 111, ICSV 400 and ICSV 247) along with local cultivar in Nigeria in collaboration with the Institute for Agricultural Research (IAR), Zaria, Nigeria facilitated the acceptance and large-scale adoption of these improved varieties in Nigeria (Tabo et al. 1999). Computerization of seed dispatch and developing databases and websites (http://www.icrisat.org/text/research/grep/homepage/sorghum/breeding/main.htm) for all male-sterile lines, restorers, varieties and hybrids with pedigrees and characteristics has enabled NARS scientists to have better access to ICRISAT-bred breeding materials.

Table 4. Number of trainees from Asia, Africa and Latin America who were imparted training in sorghum improvement at ICRISAT[1].

Region	VS	PDF	RS	RF	In-service (six months)	In-service (short-term)	Apprentices
Southern and Eastern Africa	–	4	19	78	323	49	–
Asia (including India)	8	7	59	111	126	57	37
India	8	4	42	51	1	16	35
Western and Central Africa	-	2	23	17	312	9	-
Latin America	-	7	6	13	22	4	9
Total	8	20	107	219	783	119	46

1. VS = Visiting scientist ; PDF = Postdoctoral fellow; RS = Research scholar; RF = Research fellow.

Publications and Capacity Building

The publications of research findings (a total of 886 during 1977 to 2004) include 427 refereed journal articles, 291 conference papers, 49 book chapters and 119 other publications. A total of 1320 NARS scientists and research scholars were trained on various aspects of sorghum improvement during 1974 to 2003. Of these, eight were visiting scientists, 20 post-doctoral fellows, 107 research scholars, 219 research fellows, 783 in-service (six months) trainees, 119 in-service short-term trainees and 46 apprentices (Table 4). Besides training programs, workshops, conferences and scientists' field days have enabled researchers around the world to improve the efficiency of their sorghum improvement programs.

References

Brennan JP, MCS Bantilan, HC Sharma and **BVS Reddy. 2004.** Impact of ICRISAT research on sorghum midge on Australian agriculture. Impact Series no. 11. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 36 pp.

Deb UK and **Bantilan MCS. 2003.** Impacts of genetic improvement in sorghum. Pages 183-213 *in* Crop variety improvements and its effect on productivity - The impact of international agricultural research (Evenson RE and Gollin D, eds.). Wallingford, Oxon, UK: CAB International.

Deb UK, Bantilan MCS, Hash CT and **Ndjeunga J. 2004.** Adoption of improved sorghum cultivars. Pages 181-198 *in* Sorghum genetic enhancement: Research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

ICRISAT. 1998. New horizons for research partnerships: the SADC/ICRISAT Sorghum and Millet Improvement Program. PO Box 776, Bulawayo, Zimbabwe: international Crops Research Institute for the Semi-Arid Tropics. 16 pp.

Reddy BVS, Rao Prakasha, Deb UK, Stenhouse JW, Ramaiah B and **Ortiz R. 2004.** Global sorghum genetic enhancement processes at ICRISAT. Pages 65-102 *in* Sorghum genetic enhancement: Research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Reddy BVS and **Stenhouse JW. 1994.** Sorghum improvement for semi-arid tropics region: past, current and future research thrusts in Asia. Punjabrao Krishi Vidyapeeth (Akola) Research Journal 18:155-170.

Shiferaw B, Bantilan MCS, Gupta SC and **Shetty SVR. 2004.** Research spillover benefits and experiences in interregional technology transfer: An assessment and synthesis. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 140 pp.

Tabo R, Ogungible AO, Gupta SE and **Ajayi O. 1999.** Participatory evaluation of sorghum cultivars in northern Nigeria. International Sorghum and Millets Newsletter 40:36-38.

Nucleus and Breeder Seed Production in Sorghum

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Introduction

Of all the inputs, seed is the most basic and vital input for increased productivity of any crop variety. The actual impact of a variety on agricultural production depends on the extent of coverage and the level of performance on farmers' fields. Like any other industrial product, the originator of plant varieties, the plant breeder, has to make his variety available in required quantity and original quality for its wide adoption, popularity and real benefit to the farmer. Even an outstanding variety can fail to catch up because farmers do not get genuine seed with the stated purity and/or seed capable of reproducing the claimed performance of the variety. For example, one of the main reasons for the non-adoption of highly popular sorghum *(Sorghum bicolor)* cultivars in Africa, such as ICSV 111 and ICSV 400 in some regions of Nigeria (Ogungbile et al. 1999), and S 35 in some regions of Chad (Yapi et al. 1999) and Cameroon and Mali (Ndjomaha et al. 1998), have been attributed to non-availability of seed of these cultivars.

Classes of Seed

The breeder usually has a small quantity of seed of very high genetic purity, which only after successive multiplication in two or three stages provides required and good quality seed to farmers and producers. It is in this context that different classes of seed are recognized, whose production is planned and monitored under the process of seed certification by a governmental agency to make available required quantities of seed of targeted variety to farmers. In most countries, including India, three to four classes of seed, nucleus, breeder, foundation and certified seed, are recognized. While nucleus and breeder seed production do not require certification, foundation and certified seed production require a rigorous process of seed certification. Official/formal release of a variety is a prerequisite for its entrance into the seed production chain. However, private seed companies do not follow such rigorous release procedures and are allowed to market their products (mostly hybrids) as truthfully labeled seed in India. At the time of submitting a proposal for the release of any new variety, a breeder is required to have some quantity of seed for further multiplication and must supply sufficient quantities to the designated government agency to multiply for commercial cultivation. Each country has its own established well-defined seed production standards/systems governed by seed legislation. As nucleus and breeder seed are sources for further multiplication before reaching the farmers, utmost care has to be exercised during maintenance and production of these classes of seed. While procedures and techniques of foundation and certified seed production of pure-line varieties and hybrids are documented in several textbooks and/or seed production manuals, the same is not true in case of nucleus and breeder seed production. Such information is useful for all those (breeders and seed production specialists) who are engaged in maintenance and production of these classes of seed in sorghum to ensure adequateand timely supply of high quality seed of varieties and hybrids to the farmers. In this context, an attempt has been made in this article to describe a step-wise procedure for maintenance and production of nucleus and breeder seed in sorghum.

Nucleus seed. It is the initial handful of seed originated through selection/breeding by the breeder. It is the only class of seed, which is regenerated from itself and is produced in very small quantities under the supervision of the originating breeder or a designated qualified breeder. The varietal purity of subsequently multiplied breeder seed, foundation seed and certified seed depends on the purity of nucleus seed and therefore, it must be produced with utmost care. Sorghum is predominantly a self-pollinated crop, which suffers little inbreeding depression. However, outcrossing to an extent of 5 to 25% (House 1985) does occur depending on the climatic conditions and the genotype/panicle type (compact or loose). The availability of stable cytoplasmic-nuclear male-sterility (CMS) in sorghum (Stephens and Holland 1954) also makes it possible to develop hybrids for commercial cultivation. Three lines, seed parent/male-sterile line/A-line, maintainer/B-line (to maintain A-line) and restorer/R-line to restore fertility in the hybrids when the A-line is crossed with the R-line, are required. Both varieties and hybrid parental lines are theoretically pure lines and should be easy to maintain; however, sometimes due to factors beyond the breeder's control such as chance out-crossings, rare mutations and mechanical admixtures, a variety or parental line deteriorates and therefore, requires needed maintenance to conform to its designated characteristic features at least once every four to five years. Nucleus seed production procedures for pure-line variety and hybrid parents are described below.

Pure-line variety: For the maintenance and production of nucleus seed of a sorghum variety, head-to-row procedure is suggested. The seed from selected individual self-pollinated panicles (that are true to type of the designated variety) of the plants raised from the original/previous nucleus stock is grown in head-to-row progenies in subsequent season. The rows are carefully scrutinized for their conformity to the defined characteristics of the designated variety. Any progeny row(s) that show variation and deviation from the descriptors of the variety are discarded. Seed from only those selfed progeny rows that are uniform and conform to the characteristic features of the designated variety are bulked to constitute nucleus seed, which becomes a source for breeder seed production.

Hybrid parents: In case of hybrids, nucleus seed production involves the production of A-, B- and R-lines. The nucleus seed of A- or B-line is produced from paired plant-to-plant crossing of A- and B-lines. The A- and B-lines are grown in alternate rows and plants are carefully examined for their uniformity. Since A- and B-lines are isogenic lines except for male-sterility in A-lines, both A- and B-lines should conform to the same defined descriptors of the designated hybrid parents. Any off-types and those not conforming to the descriptors are discarded before anthesis. Apart from off-types, pollen shedders can be a problem in A-lines (a pollen shedder is a male-fertile plant in an A-line that results either from a breakdown of male-sterility or due to mechanical mixture during the previous harvest) and therefore, such plants should be rouged out and all the panicles before anthesis in A- and B-lines are bagged. The breakdown of male-sterility in A-lines may occur under high temperatures (>38°C) during flowering. Hence, it is recommended to avoid nucleus seed production of A-lines during summer season in the locations where temperature exceeds 38°C during flowering period. After rouging off-types and pollen shedders, only those plants in B-lines that conform to the defined characteristic features are used for pollinating similarly selected plants in A-lines in a paired plant-to-plant crossing system. Plants used as pollinators in B-lines as well as the plants that are pollinated in A-lines are bagged. Seeds harvested from bagged panicles from A- and B-lines are grown separately as head-to-row progenies in subsequent season. The progeny rows are examined for defined characteristics and seeds from only those progeny rows, which are uniform, are separately harvested in A- and B-lines and bulked to constitute nucleus seed of A- and B-lines. The nucleus seed production of R-lines is similar to that of a pure-line variety described earlier.

Breeder seed. Breeder seed is produced from nucleus seed in small quantities on experiment stations by the sponsoring breeder under his direct supervision. The organization sponsoring cultivar release has the responsibility for the supply and safe storage of breeder seed. Sponsored breeders can also produce breeder seed. In such cases, the originating breeder supplies the breeder seed to different institutions such as agricultural universities, central and state research institutions, and other recognized/sponsored organizations. The breeder seed required for national varieties in India is arranged through the Department of Agriculture and the National Seeds Corporation Limited, Government of India. The breeder seed for state varieties is produced by breeders of the states concerned. Breeder seed plots are monitored by a team consisting of breeders, representatives of the State Seed Certification Agency (SSCA) and the seed producing agency. Breeder seed production of hybrid sorghum involves the production of A-, B- and R-lines. Seed production of B- and R-lines is similar to that of any pure-line variety.

The production of breeder seed is expensive with an associated risk of contamination by repeated multiplication and of loss due to adverse production conditions. Therefore, the quantity of breeder seed required for about 3 to 4 years is produced by the breeder and deposited in cold storage. Highest standards of genetic purity must be maintained in the production of breeder seed since it is the base material for all further multiplication. Breeder seed might be produced under such controlled conditions as selfing by bagging if the requirement is small. Otherwise, it should be carried out under isolation. The minimum isolation distance to be maintained from any other sorghum crop is provided in Table 1. The breeder provides small quantities of breeder seed of the varieties and A-, B- and R-lines to foundation seed producers. The breeder also provides complete and accurate description of all distinguishing morphological and seed characters of the varieties, and A-, B- and R-lines, in case of hybrids, because the certification process depends upon these descriptions. The experiment station sponsoring the release of the hybrids trains the technical staff involved in the production and certification of hybrid seed and familiarizes them in the identification of distinguishing characters of the parents and the hybrid. The procedures for breeder seed production of hybrid parents and varieties are described below.

Male-sterile lines: Breeder seed production of A-lines is carried out by growing the A-line and its corresponding B-line together in an isolated plot. The isolation distance required for A-line x B-line production fields is >300 m. A row ratio of 4A:2B or 6A:2B is maintained and the borders of the field are sown with the B-line. The A-line and its B-line flower at about the same time and thus there are typically no problems of asynchronous flowering. Pollen produced by the B-line fertilizes the A-line plants thus maintaining the A-line.

Rouging in A-line seed production plots should be more stringent for pollen shedders because A-line and B-line plants cannot be distinguished after flowering. The pollen shedders in A-lines must be identified and uprooted each morning during the flowering period. Utmost caution must be exercised in labeling and harvesting A-line and B-line rows. The B-line rows are harvested first, followed by the A-line rows. Purity of the A-line is very important and any lapses can lead to huge losses of time and resources spent in rouging during hybrid seed (A x R) production plots in the next generation. Because of the reasons stated earlier while discussing nucleus seed production, it is recommended to avoid breeder seed production of A-lines during summer season in locations where temperature exceeds 38°C during flowering. Since the A- and B-lines exhibit synchronous flowering, seed yields of the A-line in the A/B seed production plots are relatively better than in the A-line x R-line (hybrid) production plots. Seed of the B-line harvested from the A-line and B-line production plots can be reused for the next generation, depending on the seed laws of the country.

Maintainer and restorer lines and varieties: Since varieties, B-lines and R-lines are pure-lines, their seed increase are somewhat similar. Seed multiplication plots of these types, particularly B- and R-lines are sown in an area isolated by a radius of >300 m distance (>200 m in case of varieties) from other sorghum cultivars (Table 1). If Johnson grass (*Sorghum halepense)* or any other forage or grassy sorghum types are growing in the vicinity, an isolation distance of 400 m is recommended (Reddy 1997). Any plant in these plots appearing different from the true to type (as described by the breeder) for any character (major or minor) should be uprooted, or rouged, before anthesis. Although the process of rouging, or removal of off-types, starts soon after the seedling stage, the boot leaf and the panicle emergence stages are most critical because detection of off-types is easier during these stages. If the off-types are allowed to flower, their pollen will cross with genuine type plants and contaminate seed in the next generation. Off-types that escape detection during the flowering stage should still be removed before harvest to minimize contamination. It is recommended that plants of doubtful status should also be removed. Purity of the hybrid parents (A/B- and R-lines) is very important because it affects the quality of hybrid seed that is generated.

Planning Nucleus and Breeder Seed Production

Nucleus and breeder seed should be produced under optimum production conditions. Plots endemic to serious diseases such as downy mildew *(Peronosclerospora sorghi)* and ergot *(Claviceps* spp), obnoxious weeds like 5. *halepense* and *Striga,* and areas prone to natural disasters such as floods, excessive bird damage or hailstorms should be avoided. Excessive rains or high humidity during the grain-filling stages of sorghum could cause grain molds, discoloration, weathering and pre-harvest sprouting, all of which affect germinability. Productivity *vs* cost, and climatic conditions, particularly during grain-filling stages, should be important considerations when selecting plots for seed production. If seed production is planned for the off-season, access to irrigation facilities is important.

The quantity of breeder seed required should be roughly estimated on an annual basis in advance, depending upon the projected demand for the commercial hybrid under cultivation (Table 2). It is desirable to maintain sufficient quantities of carry-over seed as an insurance against unforeseen seed crop losses. The progress of seed production and status of seed stocks should be reviewed annually in joint meetings among representatives of seed growers, foundation seed agencies and national seed agencies. The various activities of the multiplication chain of breeder seed, foundation seed and certified seed should be coordinated (Murty et al. 1994).

Table 1. Minimum isolation distance requirements for breeder seed production in sorghum.

Type of genetic-material	Isolation distance (m)	Isolated from the fields of
Hybrid parents	300	Parents of other grain or dual-purpose sorghum hybrids or varieties
	300	Same hybrid parents not conforming to purity requirements
	400	Johnson grass and forage sorghum
	400	Dual-purpose (both grain and fodder) sorghum but mainly meant for fodder
Variety (pure-line)	200	Other varieties of grain or dual-purpose sorghum or hybrid parents
	200	Same variety not conforming to varietal purity requirements
	400	Johnson grass and forage sorghum
	400	Dual-purpose (both grain and fodder) sorghum but mainly meant for fodder

Table 2. Annual estimates of land and seed requirements for various classes of hybrid parents and hybrid seed production in sorghum.

	Certified seed		Foundation seed[1]		Breeder seed[1]	
Projected area of commercial hybrid (ha)	Seed requirement (t)	Area to be sown (ha)	Seed required for certified seed production (kg)	Area to be sown (ha)	Seed required for foundation seed production (kg)	Area to be sown (ha)
100,000	1000	1000	6000 (A-line)[2]	6	60	0.01
			4000 (B-line)	4	40	0.07
			4000 (R-line)[3]	4	40	0.07
200,000	2000	2000	12000 (A-line)[2]	12	120	0.20
			8000 (B-line)	8	80	0.14
			8000 (R-line)[3]	8	80	0.14

1. A seed rate of 10 kg ha^{-1} and seed yield of 1000 kg ha^{-1} were assumed for certified and foundation seed production plots. Breeder seed production plot yields were estimated on the basis of 600 kg ha^{-1}.
2. A-line seed production.
3. R-line seed production.

Purity Test of Hybrids, Parental Lines and Pure-line Varieties

Purity of seed is a very important criterion for the acceptance of a variety. This is ensured through various technical methods involved in seed production. In spite of the best efforts in maintaining all the recommended standards from seed production to packaging, possibilities always exist for contamination of the original seed lots by unwanted seeds of other cultivars or other types. Contamination can occur due to several factors in the seed production plots such as natural crossing with another cultivar, mutation and unclean harvesting equipment, and during postharvest processing such as carelessness at the processing plant, and mistakes in bagging and tagging. There are chances that some impurities or mixture like seed of different color and size, immature seeds, weed seeds, etc may still be present in the harvested seed lot. Therefore, in addition to assessing genetic purity and inert material in the harvested seed, it needs to be assessed for its quality in terms of germination, moisture content, etc so that it is capable to raise a normal healthy crop, befitting the standard of the stated variety. Hence, the harvested seed is sent to the Seed Testing Laboratory notified by the State for purity, seed germination and moisture content tests. The minimum acceptable standards for genetic purity, germination and moisture content in nucleus and breeder seed in sorghum are furnished in Table 3.

Packaging and Labeling

Breeder seed of sorghum should be packaged in small quantities of 1-10 kg. This seed can be packaged in advance in standardized units, or prepared from bulk upon receipt of the request from a seed multiplication agency. It is important that the packaging should be clean, moisture

Table 3. Purity standards of nucleus and breeder seed of varieties and hybrid parents in sorghum.

Standards	Nucleus and breeder seed
Genetic purity (%)	100
Crop standards (%)	
Off-types	0
Pollen shedders	0
Diseased heads	0
Seed standards (%)	
Pure seed	100
Inert matter	0
Other crop seed	0
Weed seeds	0
Germination	>80
Moisture (in ordinary container)	<12
Moisture (in vapor proof container)	<8

proof, well labeled and not easily damaged in transit. The seed packet should have a breeder seed tag attached (preferably) or enclosed indicating the crop, label number, variety, quantity, seed lot number, seed class and actual data indicating inert matter, germination and genetic purity, with a date for the germination test. In addition, the producing institution should be indicated, along with the signature of the breeder responsible for multiplication of the seed lot. Different colors of tags are used for different classes of seeds. For nucleus seed and breeder seed, golden yellow tag is used.

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References

House LR. 1985. A guide to sorghum breeding. 2nd edition. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 206 pp.

Murty DS, Tabo R and **Ajayi O. 1994.** Sorghum hybrid seed production and management. Information Bulletin no. 41. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 72 pp.

Ndjomaha C, Yapi A and **Adamri A. 1998.** Impact of sorghum S 35 in extreme north Cameroon. Pages 26-27 *in* Assessing joint impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT, 2-4 Dec 19%, ICRISAT, Patancheru, India (Bantilan MCS and Joshi PK, eds.), Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Reddy BVS. 1997. Development, production, and maintenance of male-sterile lines in sorghum. Pages 22-27 *in* Development of cultivars and seed production techniques in sorghum and pearl millet (Faujdar Singh, Rai KN, Reddy BVS and Diwakar B, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Ogungbile AO, Tabo R, Gupta SC, Ajayi O and **Bantilan MCS. 1999.** Factors influencing awareness and adoption of ICSV 111 and ICSV 400 sorghum varieties. Patancheru 502 324, Andhra Pradesh, India: Socioeconomics and Policy Program, International Crops Research Institute for the Semi-Arid Tropics. (Mimeo.)

Stephens JC and **Holland RF. 1954.** Cytoplasmic male sterility for hybrid sorghum production. Agronomy Journal 46:20-23.

Yapi A, Debrah SK, Dehala G and **Ndjomaha C. 1999.** Impact of germplasm research spillovers: The case of sorghum variety S35 in Cameroon and Chad. Impact Series no. 3. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 30 pp.

Dominant Nuclear Male Sterility in Sorghum Induced by Hybridization of Two Fertile Lines

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Introduction

It is clearly established that in hybrids of genetically distant sorghum *(Sorghum bicolor)* accessions interaction of nuclear and cytoplasmic genes may cause cytoplasmic-genic male sterility. At the same time little is known on hybrid male sterility that results from interaction of different nuclear genes between themselves. This type of male sterility induced by specific crossing combinations has been revealed in some dicotyledonous species of higher plants (Kaul 1988).

Previously, by substitution backcrosses of male-sterile somaclones from the haploid and autodiploid plants of sorghum cv Milo-145 with the line SK-723, which is a fertility-restorer of *milo* cytoplasm, the analogues of SK-723 mat contained a dominant nuclear mutation of male sterility were obtained (Elkonin et al. 1994, Elkonin 2000, Tsvetova and Elkonin 2003). Assuming that initial male-sterile plants have been isolated among somaclones (R_0-R_2 generations) we supposed that this mutation has been induced in tissue culture. However, further investigations revealed a more complicated nature of this sterility. In this article we report on isolation of nuclear dominant mutation of male sterility, *Ms-h* (male sterile from hybridization), in the progeny of the Milo-145 x SK-723 hybrid obtained by common pollination of emasculated panicles of Milo-145 with the SK-723 pollen, without tissue culture stage.

Material and Methods

The autodiploid line used in this investigation was obtained by VS Tyrnov, Saratov State University, Saratov, Russia. It was derived from a spontaneously diploidized sorghum haploid, which was isolated among the seedlings of Milo-145. The line SK-723 is a selection from a hybrid population derived from an open-pollinated panicle of *Feterita.* Direct and reciprocal F_1 hybrids, F_2 and BC generations as well as the progenies from sib-crosses, selfed fertile siblings and the testcross hybrids were grown in an experimental field in 4-5 m rows. Fertility was determined by percentage seed set on panicles bagged before anthesis. The plants were classified as sterile (0% or 1-2 single seeds), partially sterile (1-50%, usually 5-15%) or fertile (>50%). The partially sterile plants were characterized by sectors of fertile flowers on one or few panicle branches usually located at the basal part of sterile panicle. The x^2-test was used to determine the fit of observed segregation ratios of sterile and fertile plants to the expected segregation ratios.

Results and Discussion

In the F_1 obtained by hybridization of the lines Milo-145 and SK-723, plants with partial or complete male sterility were observed. Remarkably, sterility was observed only on the panicle of the first tiller while the second and the third tillers had fertile panicles. Such plants with complete or partial male sterility appeared both in direct (Milo-145 x SK-723) and reciprocal (SK-723 x Milo-145) crossing combinations. This seems to indicate that this type of male sterility is controlled by interaction of nuclear genes rather than by interaction of nuclear and cytoplasmic genes.

In BC, obtained by pollination of sterile panicles of the Milo-145 x SK-723 hybrids with the pollen of SK-723, segregation for male-sterile and male-fertile plants corresponding to a 1:1 ratio was observed (Table 1). Male-fertile plants proved to be homozygous and did not segregate male-sterile plants in their self-pollinated progenies. At the same time, in the progenies obtained by crossing male-sterile to male-fertile siblings segregation of sterile and fertile plants was observed, thus suggesting heterozygosity of sterile plants for the nuclear gene-inductor of male sterility. In some progenies segregation corresponded to the ratio 1 fertile : 1 sterile. In BC_2 obtained by repeated crossing of sterile BC, plants to the line SK-723, there were families which segregated for sterile and fertile plants in the ratio 1:1, and families almost completely made up of male-sterile plants only. At the same time, after crossing sterile plants from BC, to the line KVV-181, another fertility restorer of the *milo* cytoplasm, complete restoration of male fertility was observed (Table 1).

These data could be explained by two different hypotheses. One of them assumes that isolated type of male sterility is conditioned by the action of one dominant gene. To search for this supposed dominant gene-inductor of male sterility, both lines SK-723 and Milo-145 have been testcrossed to a number of fertile and male-sterile sorghum lines (Table 2). No plants with male sterility were observed in the F_1 of these crosses with SK-723. Additionally, these testcrosses showed the ability to restore male fertility in the *milo* cytoplasm, ie, it contained dominant genes in the nuclear loci controlling expression of this type of cytoplasmic male sterility (CMS). This indicates that this type of male sterility does not result from interaction of nuclear gene of SK-723 in the locus controlling CMS, and sterile cytoplasm of the maternal line (Milo-145).

Table 1. Inheritance of male sterility arising after crossing of two fertile sorghum lines, Milo-145 and SK-723.

Hybrid combination	Generation	Number of plants[1]			Ratio of (f+ps) to s	X^2	P
		f	ps	s			
Milo-145 x SK-723	F_1	5	2[2]	3[2]			
SK-723 x Milo-145	F_1	11	7	3			
(Milo-145 x SK-723) x SK-723 (cross N1)	BC_1	8	2	14	1:1	0.667	0.25-0.50
(Milo-145 x SK-723) x SK-723 (cross N2)	BC_1	11	6	10	1:1	1.815	0.10-0.25
BC_1 sterile x fertile (sib-cross N1)	F_1	1	8	10	1:1	0.053	0.75-0.90
Fertile (from sib-cross NI) selfed	F_2BC_1	21	-	-	-		
BC, sterile x fertile (sib-cross N2)	F_1	11	3	6	1:1	2.000	0.10-0.25
Fertile (from sib-cross N2) selfed	F_2BC_1	18	-	-	-		
BC_1 sterile x fertile (sib-cross N3)	F_1	4	2	7	1:1	0.077	0.75-0.90
Fertile (from sib-cross N3) selfed	F_2BC_1	18	-	-	-		
BC_1 plant N1 x SK-723	BC_2	11	5	9	1:1	1.960	0.10-0.25
BC, plant N2 x SK-723	BC_2	7	4	10	1:1	0.048	0.75-0.90
BC, plant N3 x SK-723	BC_2	17	7	6	1:1	10.800	<0.05
BC, plant N4 x SK-723	BC_2	1	-	23	-		
BC_1 sterile x KVV-181	F_1	17	2	1	-		

1. f = Fertile; PS = Partially sterile; s = Sterile.
2. Panicles on the second and third tillers of these plants were fertile.

Table 2. Results of the testcrosses of SK-723 and Milo-145 with different male-fertile and male-sterile sorghum lines.

Hybrid combination	Generation	Number of plants[1] f	ps	s
A1 Saratovskoye-3 x SK-723	F_1	21	_	-
Efremovskoye-2B x SK-723	F_1	3	-	–
Negrityanskoye K-3366 x SK-723	F_1	21	-	–
Belenkyi x SK-723	F_1	12	-	-
SK-723 x Pishchevoye-615	F_1	30	-	-
Milo-I()x SK-723	F_1	7	-	–
A1 Efremovskoye-2 x Milo-145	F_1	5	9	3
Milo-145 x Efremovskoye-2B	F_1	3	-	–
Milo-145 x Pishchevoye-615	F_1	7	_	–

1. f = Fertile; ps = Partially sterile; s = Sterile.

At the same time, in the F_t hybrids obtained by crossing Milo-145 to the CMS-line A1 Efremovskoye-2, which also possesses milo cytoplasm, we observed both fertile and partially and completely male-sterile plants (Table 2). This indicates heterozygosity of Milo-145 at the locus controlling CMS expression. However, no sterile plants could be found in this line. Perhaps, Milo-145 is heterozygous for mutable allele in this locus that mutates to relatively stable sterility-maintaining condition only in some hybrid combinations. Indirect evidence in favor of the existence of such a mutable allele is the presence of the sectors with sterile branches in some panicles of Milo-145. Perhaps, in the hybrid genome of Milo-145 x SK-723 there exists in this locus genetic changes that result in the formation of a relatively stable dominant allele inducing male sterility. It should be noted that appearance of a dominant male sterility in the cross Milo-145 x SK-723 is a regular phenomenon because three lines with similar inheritance of male sterility were obtained previously in two independent experiments after crossing male-sterile Milo-145 somaclones to SK-723 (Elkonin et al. 1994). Hence, this type of male sterility is unlikely to be a result of random gene recombination.

Similar examples of induction of heritable genetic changes as a result of interaction of alleles located in one and the same locus or other loci between themselves are referred to as paramutations; they have been extensively studied in maize (Zea mays) and in some other plant species (Chandler et al. 2000). However, until now this phenomenon has not been described for loci controlling male fertility.

Additional data in favor of this hypothesis is the appearance of almost sterile non-segregating families (see Table 1, BC_2 progeny from BC, plant N4). Such families were observed early in tissue culture-derived material (Elkonin et al. 1994) and in this investigation. The absence of segregation in progenies of some male-sterile plants could be observed if these plants were homozygous for dominant male sterility-inducing gene. Such a homozygous condition may occur as a result of either the paramutagenic nature of this gene, or if these plants arise from seed, which were set as a result of self-pollination by a few pollen grains that could develop on heterozygous maternal plant.

Another hypothesis, which could also possibly explain the inheritance pattern of an isolated type of male sterility is complementary or epistatic interaction of a set of genes from different loci, some of these genes coming from Milo-145, while others from SK-723. Remarkably, the segregation ratios in the BC generations and sib-crosses also correspond to the two-gene model of inheritance with interacting dominant genes. At present, we are continuing to study this phenomenon to verify either the single dominant gene or multiple genes hypothesis.

References

Chandler VL, Eggleston WB and **Dorweiler JE. 2000.** Paramutation in maize. Plant Molecular Biology 43:121—145.

Elkonin LA. 2000. Dominant male sterility mutation of sorghum induced in tissue culture and its inhibition. International Sorghum and Millets Newsletter 41:28-30.

Elkonin LA, Gudova TN and **Ishin AG. 1994.** Inheritance of male sterility mutations induced in haploid sorghum tissue culture. Euphytica 80:111-118.

Kaul MLH. 1988. Male sterility in higher plants. Vol. 10 of Monographs on Theoretical and Applied Genetics. Berlin, Germany: Springer-Verlag. 991 pp.

Tsvetova MI and **Elkonin LA. 2003.** Cytological investigation of male sterility in sorghum caused by a dominant mutation Ms_{ti} derived from tissue culture. Sexual Plant Reproduction 16:43-49.

Improvement of Harvest Index in Sorghum Through Use of Exotic Germplasm

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Introduction

One of the main objectives to improving grain yield in hybrid sorghum is achieving higher harvest index (HI), the ratio of grain yield over above ground plant biomass. Harvest index is one of the major components for grain yield in crop improvement. Donald (1968) contended that greater wheat *(Triticum aestivium)* grain yields could only be achieved by either increasing biological yield with a sustained HI or by increasing HI alone. Harvest index is thus an important aspect of differential partitioning of photosynthate and improved HI represents an increased physiological capacity of the crop to mobilize photosynthate and nutrients and translocate them to organs of economic value (Wallace et al. 1972). SC170-14E, a converted exotic germplasm, was used to enhance the HI of Tx2783, an adapted parental R-line. The objectives of this study were to: (1) improve the HI of Tx2783 derived hybrids; and (2) determine the grain yield components responsible for HI variation.

Materials and Methods

Experimental entries were hybrids of the BC_2 derived pollinators with the female tester ATx645, the hybrid of the recurrent parent (HRP), the hybrid of the donor parent (HDP) and the standard commercial hybrid (SCH) ATx2752 x RTx430. BC_2 pollinators were developed between Tx2783, the recurrent parent, and SC170-14E, the donor parent. Tx2783 is a widely used pollinator resistant to biotype C and E greenbug *(Schizaphis graminum)* that produces hybrids with high grain yield potential. SC170-14E is a temperately adapted (fully-converted) version of the Ethiopian cultivar IS 12661.

A random sample of 28 hybrids, out of 200 possible hybrids, including three checks was studied. A randomized complete block design with three replications at two locations, Lubbock (L) and Halfway (H), in Texas, USA was used to collect agronomic data under fully irrigated conditions in 2001. At maturity five random plants were cut at ground level, where the plant population was uniform, wrapped, labeled and sun-dried for total dry biomass and grain mass. Traits measured were number of days to 50% flowering (FD), plant height (PH) (cm), panicle length (PL) (cm), number of whorls per panicle (WP), 1000-grain mass (TGM) (g), grain mass (GM) (g), number of seeds per panicle (SP), number of seeds per whorl (SW), total above ground dry biomass (TB) (g) and HI. Traits measured were subjected to simple and combined (location random) ANOVA and to linear correlations with HI. Normal distribution of experimental error between treatments was verified using Shapiro-Wilk test and F test was used for homogeneity of variance between locations. Significance level was at $P = 0.05$.

Table 1. Means of traits measured at Lubbock and Halfway, Texas, USA, coefficient of variation (CV), critical differences (*P* = 0.05) and probability of significance (PV) for sample hybrids in 2001[1].

Particulars	FD	PH	PL	WP	TGM	GM	SP	SW	TB	HI
Lubbock										
Mean	59	136	27.69	6.66	27.31	314.46	2315	272	588.88	53.40
CV (%)	2.22	4.90	5.77	7.65	5.70	15.17	15.62	20.64	14.76	5.21
LSD (0.05)	1.80	9.12	2.19	0.91	2.13	65.20	495.00	76.64	118.80	3.75
PV	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.04	0.01
Halfway										
Mean	66	138	29.69	8.91	29.80	437.69	2943	333	786.91	55.70
CV(%)	1.65	7.17	5.93	7.31	5.73	14.52	14.52	17.10	12.67	7.72
LSD (0.05)	1.48	13.50	2.41	0.89	2.34	86.81	584	78.85	136.22	5.89
PV	0.02	0.47	0.00	0.23	0.02	0.00	0.00	0.01	0.00	0.09

1. FD = Number of days to 50% flowering; PH = Plant height (cm); PL = Panicle length (cm); WP = Number of whorls per panicle; TGM = 1000-grain mass (g); GM = Grain mass (g); SP - Number of seeds per panicle; SW = Number of seeds per whorl; TB = Total above ground dry biomass (g); HI = Harvest index.

Results and Discussion

There were highly significant differences among hybrids for several traits measured (Table 1). One hybrid produced significantly higher HI than the HRP at L, while 6 hybrids at L, 1 at H and 5 between L+H combined produced significantly higher HI than the SCH. Figures 1 and 2 indicate HI fluctuation across environments. One hybrid at L and 7 hybrids at H and L+H produced significantly higher GM than the HRP. Additionally 16, 6 and 7 hybrids produced significantly higher grain than the SCH at L, H and L+H, respectively. There was no particular trait that positively impacted HI at P = 0.05 (Table 2). However, there was a tendency for HI to improve with GM (Fig. 3) and SP (Table 2), while PH had no noticeable impact on HI (Table 2). FD and PL at H and between L+H

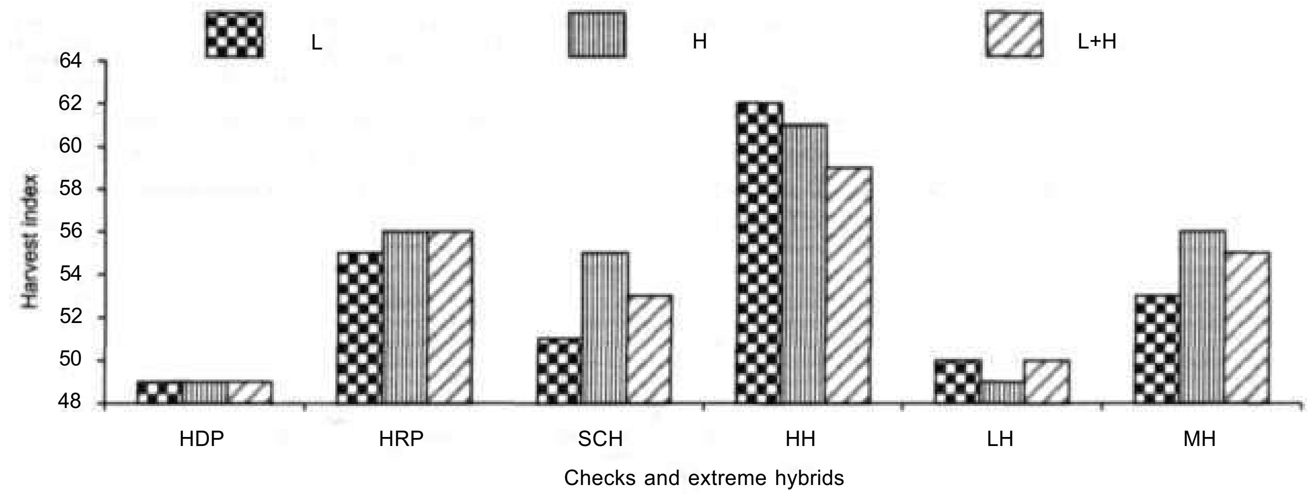

Figure 1. Mean harvest index for the hybrid of the donor parent (HDP), hybrid of the recurrent parent (HRP), standard commercial hybrid (SCH), highest yielding hybrid (HH), lowest yielding hybrid (LH) and mean hybrid (MH) at Lubbock (L), Halfway (H) and combined between Lubbock and Halfway (L+H) in 2001.

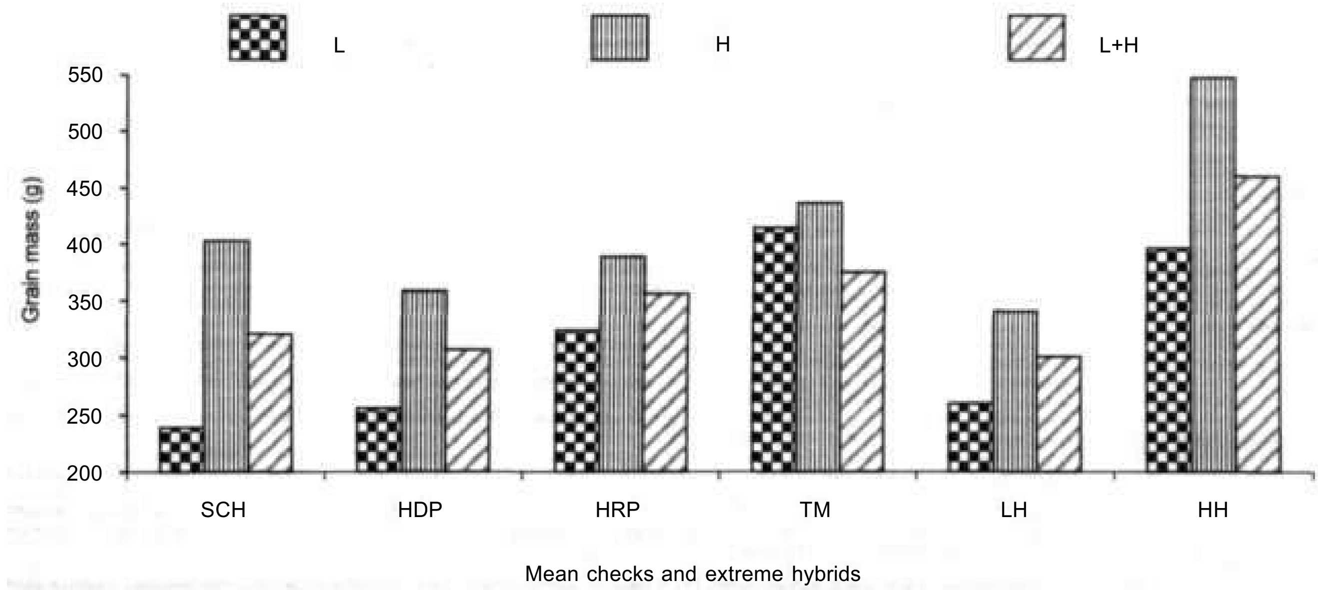

Figure 2. Mean grain mass of the standard commercial hybrid (SCH), hybrid of the donor parent (HDP), hybrid of the recurrent parent (HRP), test mean (TM), lowest yielding hybrid (LH) and highest yielding hybrid (HH) at Lubbock (L), Halfway (H) and combined between Lubbock and Halfway (L+H) in 2001.

were negatively and significantly correlated with HI (Table 2).

Harvest index is a complex parameter defined by several yield components and environmental interactions. No specific traits (Table 2) predicted positive increase in HI at $P = 0.05$. Allen (1983) reported that HI was positively and significantly correlated with GM, which is at a certain level consistent with this study (Fig. 3). Correlation between mean HI and GM across environments is indicated in Figure 4. Hybrids with higher HI had more SP, higher GM in some cases, shorter PL and fewer WP in general. This indicates that PL and WP may be produced at the expense of HI and GM. Blum (1970) claimed that SP was one of the major factors contributing to grain yield. The negative correlation between H1 and FD reported in this article is in agreement with the finding of Broad and Hammer (2001). Increase in HI and GM could predict higher water- and nutrient-use efficiency, and increased translocation of nutrients to the seeds. Table 3 shows highest lowest values of parental and extreme hybrids.

One hybrid produced significantly higher H1 than the HRP and SCH at L. Several hybrids produced significantly higher grain yield than the HRP and SCH at L and H and L+H combined. Breeders (Singh and Stoskopf 1971, Nass 1973) have reported that HI was positively and significantly correlated with grain yield.

No yield components studied had a positive and significant correlation with HI at $P = 0.05$. FD and PL were negatively and significantly correlated with HI at H. GM showed a positive and significant correlation with HI at $P<0.20$ at L and L+H. Broad sense heritability, estimated from the experimental error, was 71.3% for GM and 56.1% for HI. Exotic germplasm seemed to improve the H1 of Tx2783 derived hybrids over the HRP at L and over the SCH at L, L+H and H.

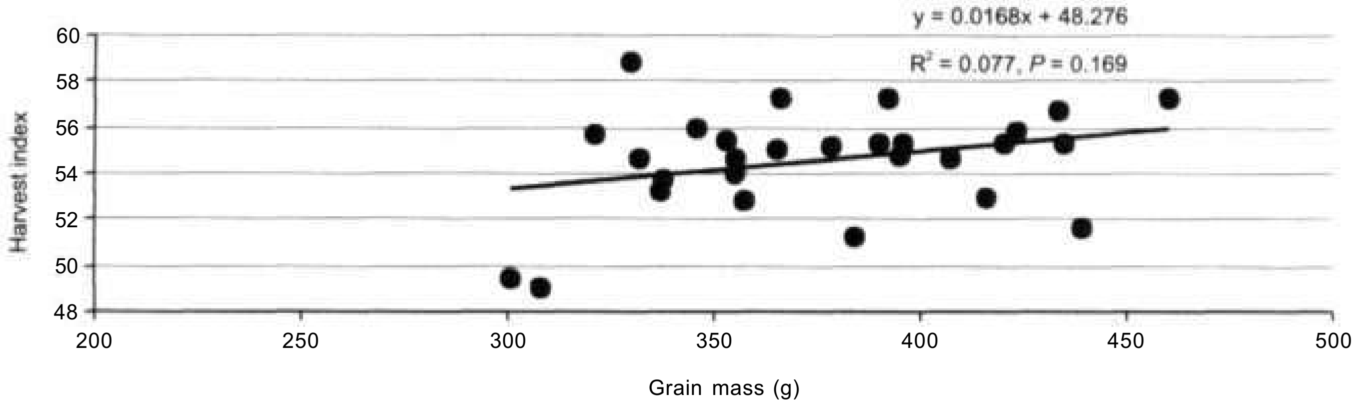

Figure 3. Correlation between harvest index and grain mass of hybrids from the mean of the combined L+H (Lubbock + Halfway) in 2001.

Table 2. Correlation between harvest index and selected agronomic traits (N=28) on hybrid yield components at Lubbock and Halfway and for Halfway and Lubbock combined in 2001[1].

Particulars	FD	PH	PL	WP	TGM	GM	SP	SW	TB
Lubbock									
R	-0.3519	-0.0298	-0.3241	-0.3308	0.1716	0.3218	0.1901	0.2416	0.0291
PV	0.0779	0.8850	0.1063	0.0988	0.4019	0.1089	0.3522	0.2345	0.8879
R^2	0.1238	0.0009	0.1050	0.1094	0.0295	0.1036	0.0361	0.0583	0.0008
Halfway									
R	-0.4161	-0.1484	-0.4527	0.1025	-0.3782	0.2367	0.3751	0.3058	-0.1885
PV	0.0345	0.4694	0.0202	0.6183	0.0568	0.2443	0.0590	0.1287	0.3565
R^2	0.1731	0.0220	0.2049	0.0105	0.1430	0.0560	0.1407	0.0935	0.0355
Lubbock + Halfway									
R	-0.2390	-0.1682	-0.4577	-0.0545	-0.1342	0.2779	0.2608	0.2117	-0.0528
PV	0.2396	0.4114	0.0187	0.7915	0.5135	0.1692	0.1981	0.2992	0.7980
R^2	0.0571	0.0283	0.2095	0.0030	0.0180	0.0772	0.0680	0.0448	0.0028

1. FD = Number of days to 50% flowering; PH = Plant height (cm); PL = Panicle length (cm); WP = Number of whorls per panicle; TGM - 1000-grain mass (g); GM = Grain mass (g); SP = Number of seeds per panicle; SW = Number of seeds per whorl; TB = Total above ground dry biomass (g).
Correlations are on means basis. R ▪ Coefficient of correlation; R^2 = Coefficient of determination; PV = Probability of significance.

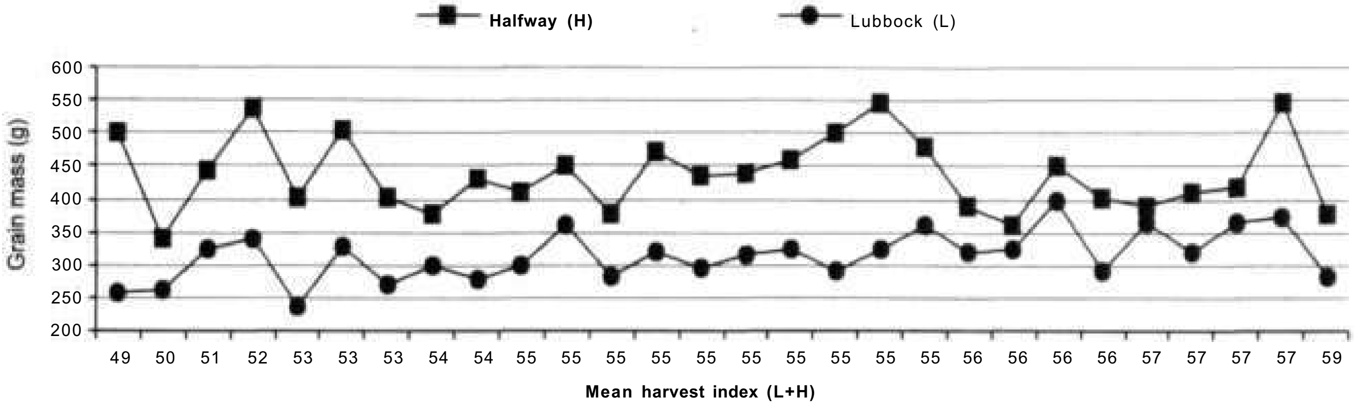

Figure 4. Correlation between mean harvest index (L+H) and mean grain mass for hybrids at L and H in 2001.

Table 3. Harvest index (HI) and selected agronomic traits measured for 25 sample hybrids and 3 checks of Tx2783 derived population hybrids at Lubbock (L) and Halfway (H) in 2001[1].

Traits	HRPL	HRPH	HDPL	HDPH	SCHL	SCHH	HHL	HHH	LHL	LHH
FD	57	66	59	66	61	67	61	67	57	63
PH	133	142	127	125	123	108	152	150	120	I2X
PL	26	29	2X	31	26	29	33	34	24.67	27
WP	8.4	4	9.2	8	10.8	9	9.80	10	7.7	X
TGM	27.2	28.8	30.1	30.4	28.5	33.4	30. 1	32.9	24.7	26.7
GM	325	390	256	359	239	246	396	539	239	377
SP	2193	2470	1570	2144	1537	1555	3020	3434	1854	2143
SW	262	264	171	270	142	174	348	344	196	240
TB	584	689	524	726	469	517	742	10X4	467	673
HI	55.0	56.6	49.1	48.8	50.9	54.6	61.6	60.4	50 4	48.6

1. HRP = Hybrid of the recurrent parent; HDP = Hybrid of the donor parent; SCH = Standard commercial hybrid; HH = Highest yielding hybrid; LH = Lowest yielding hybrid.
FD = Number of days to 50% flowering; PH = Plant height (cm); PL = Panicle length (cm); WP = Number of whorls per panicle; TGM - 1000-grain mass (g); GM = Grain mass (g); SP = Number of seeds per panicle; SW = Number of seeds per whorl; TB - Total above ground dry biomass (g).

Conclusions

Hybrids were identified that produced higher HI and significantly higher GM than the HRP and SCH. The use of exotic germplasm and HI in breeding could be a useful tool to select pollinators for higher yielding hybrids.

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References

Allen RE. 1983. Harvest index of backcrossed-derived wheat lines differing in culm height. Crop Science 23:1029-1032.

Blum A. 1970. Nature of heterosis in grain production by the sorghum panicle. Crop Science 10:28-31.

Broad IJ and **Hammer GL. 2001.** Genotype and environmental effects on harvest index of sorghum. *In* Proceedings of the 10th Australian Agronomy Conference, Hobart, 2001. (http://www.regional.org.au/au/asa/2001/p/4/broad.htm)

Donald CM. 1968. The design of a wheat ideotype. Pages 377-387 *in* Proceedings of the 3rd International Wheat Genetic Symposium, Canberra, New South Wales, Australia, 5-9 August 1968 (Finlay KW and Shepherd KW, eds). Australia: Butterworth and Co.

Nass HJ. 1973. Determination of characters for yield selection in spring wheat. Canadian Journal of Plant Science 53:755-762.

Singh ID and **Stoskopf NC. 1971.** Harvest index in cereals. Agronomy Journal 63:224-226.

Wallace JR, Ozbun JL and **Munger HM. 1972.** Physiological genetics of crop yield. Advances in Agronomy 24:97-146.

Agronomy

Suitable Sorghum Varieties for Postrainy Season in Vertisols in Bellary, India

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Introduction

Among the cereals grown during the postrainy (winter) season, sorghum *(Sorghum bicolor)* is an important staple food grown in the Northern Dry Zone of Karnataka in the semi-arid tropics of South India. Both sorghum grain and stover contribute to the livelihoods of the poor in India (Hall and Yoganand 2000). Stover utilization as fodder can provide up to 50% of the income from cropping systems in India (Rama Devi et al. 2000). Winter sorghum is mainly grown on the residual soil moisture stored in situ during the rainy season (June to September). Winter sorghum must have some drought tolerance, especially during the post-flowering growth stage. There is a need for dual-purpose (both grain and stover) improved varieties, which can thrive under postrainy season conditions. This study reports the performance of improved sorghum varieties in the Advanced Varietal Trials (AVTs) within the All India Coordinated Sorghum Improvement Project (AICSIP).

Materials and Methods

A total of 20 sorghum varieties along with the check M 35-1 that were in various stages of evaluation in A VTs within AICSIP were evaluated for their performance in medium to deep black soils during the winter season of 2000/01 at the Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Research Farm, Bellary, Karnataka. The field experiment was conducted in a complete randomized block design. The trial was sown on 15 October 2000 and harvested on 14 February 2001. Sorghum varieties were planted in

Table 1. Mean performance of sorghum varieties for yield and yield components during postrainy season 2000/01 in Vertisols **of Bellary, Karnataka, India.**

Variety	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Plant height at harvest (m)	Panicle mass (g $plant^{-1}$)	Grain mass (g $plant^{-1}$)	1000-grain mass (g)	Panicle length (cm)	Panicle diameter (cm)
SPV 1380	1.07	1.74	1.5	28.00	22.98	25.90	15.7	12.7
SPV 1411	1.48	2.48	1.8	32.00	24.92	26.53	16.5	13.5
CSV 8R	1.43	1.76	1.4	31.67	24.25	26.77	16.2	13.1
SPV 1413	1.78	2.36	1.7	36.67	30.87	27.57	17.7	14.5
SPV 1423	1.10	1.68	1.6	28.67	23.07	24.33	15.4	12.6
SPV 1452	1.53	2.11	1.7	35.67	29.07	28.77	15.5	12.7
CSV 14R	1.51	2.11	1.6	34.00	27.16	27.90	15.6	13.0
SPV 1457	1.67	2.19	1.8	35.67	29.21	28.23	16.7	14.5
SPV 1491	1.39	2.43	1.8	30.00	23.47	28.23	15.3	12.4
SPV 1499	1.69	2.04	1.5	36.33	30.03	29.90	16.9	14.7
SPV 1359 (CSV 216R)	1.73	2.34	1.8	39.00	31.36	29.77	17.6	15.0
SPV 1500	1.27	1.68	1.5	31.33	23.96	26.60	15.4	14.1
SPV 1501	0.92	1.56	1.6	28.67	22.47	26.53	14.4	12.4
SPV 1502	1.53	2.21	1.6	35.67	28.21	28.07	14.7	12.3
SPV 1503	1.52	2.21	1.6	33.67	26.42	26.00	16.0	12.3
SPV 1504	1.66	2.24	1.7	35.33	28.11	27.03	16.7	12.3
SPV 1505	1.54	2.04	1.7	36.00	29.10	27.27	15.1	13.4
Swathi	1.33	1.96	1.5	33.00	26.01	26.87	14.9	12.5
Mouli (RSLG 262)	1.76	2.44	1.8	38.67	32.90	28.33	17.5	14.9
M 35-1	1.80	2.69	1.9	40.00	31.44	29.40	17.8	15.1
SEm±	0.17	0.16	0.08	2.713	2.371	0.912	0.64	0.61
CD at 5%	0.47	0.46	0.24	NS[1]	6.789	2.612	1.84	1.73

1. NS = Not significant.

Table 2. Correlation coefficients among growth and yield components and grain yield of sorghum varieties during postrainy season 2000/01 in Bellary, Karnataka, India[1].

Component	Stover yield (t ha^{-1})	Plant height at harvest (m)	Panicle mass (g plant^{-1})	Grain mass (g plant^{-1})	1000-grain mass (g)	Panicle length (cm)	Panicle diameter (cm)	Grain yield (t ha^{-1})
Stover yield (t ha^{-1})	1.000	0.837**	0.703**	0.668**	0.582*	0.636**	0.421	0.803**
Plant height at harvest (m)		1.000	0.529*	0.509*	0.440	0.460	0.354	0.541*
Panicle mass (g plant^{-1})			1.000	0.974**	0.764**	0.674**	0.663**	0.923**
Grain mass (g plant^{-1})				1.000	0.740**	0.698**	0.685**	0.903**
1000-grain mass (g)					1.000	0.484*	0.598**	0.714**
Panicle length (cm)						1.000	0.791**	0.768**
Panicle diameter (cm)							1.000	0.630**
Grain yield (t ha^{-1})								1.000

1. * = Significant at 5% level; ** = Significant at 1% level.

three replications, each consisting of six rows of 6.75 m length with spacing of 45 cm between rows and 15 cm between plants; seed was sown at a depth of 5 cm. Sorghum was fertilized at the time of sowing with 30 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1} with urea and single super phosphate, respectively Total rainfall recorded during the cropping season was 33.2 mm in 3 rainy days. Standard agronomic practices and plant protection measures were followed throughout the growing season. Grain and fodder were harvested, sun-dried and weighed to obtain net plot yield.

Results and Discussion

The crop experienced water stress especially during reproductive stages of plant growth. Those varieties with reported drought tolerance performed better than the other varieties within the trial. M 35-1, SPV 1413, Mouli and SPV 1359 had significantly higher grain yields than other entries (Table 1). Greater grain yields in the above varieties was attributed to better plant growth with higher biomass accumulation in the panicle at harvest. These varieties had higher panicle length, panicle diameter, panicle mass plant^{-1} and grain mass plant^{-1} than other test varieties (Table 1).

Correlation studies indicated a strong relationship between grain yield and plant height (0.541), stover yield (0.803), grain mass (0.903), panicle mass (0.923), 1000-grain mass (0.714), panicle length (0.768) and panicle diameter (0.630) (Table 2). Significantly greater correlations were observed in panicle length (0.768) and panicle diameter (0.630) with grain yield. These results are similar to those reported by Veerabadhiran and Kennedy (2001) and Patil (2002) for sorghum. These results clearly indicate good prospects for combining grain and stover yields in sorghum varieties adapted to postrainy season in Bellary region.

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References

Hall AH and **Yoganand B. (eds.) 2000.** Sorghum utilization and the livelihoods of the poor in India: summary proceedings of a workshop, 4-5 February 1999, ICRISAT, Patancheru, India. Patancheru 502 324, Andhra Pradesh, India: Socio-economics and Policy Program, International Crops Research Institute for the Semi-Arid Tropics. 92 pp.

Patil SL. 2002. Sorghum hybrids and varieties suitable for postrainy season cultivation in northern Karnataka, India. International Sorghum and Millets Newsletter 43:46-48.

Rama Devi K, Bandyopadhyay R, Hall AJ, Indira S, Pande S and **Jaiswal P. 2000.** Farmers' perceptions of the effects of plant diseases on the yield and nutritive value of crop residues used for peri-urban dairy production on the Deccan Plateau: Findings from participatory rural appraisals. Information Bulletin no. 60. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 39 pp.

Veerabadhiran P and **Kennedy VJF. 2001.** Correlation and path analysis studies in selected germplasms of sorghum. Madras Agricultural Journal 88:309-310.

Suitable Sorghum Hybrids for the Postrainy Season in Vertisols in Bellary, India

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Introduction

The postrainy season (winter) sorghum *(Sorghum bicolor)* in Bellary region, Northern Dry Zone of Karnataka, India is mainly grown on medium to deep Vertisols on moisture stored in situ during the rainy season (June to September). The low productivity of sorghum in the deep black soils of northern Karnataka, southern Maharashtra and Andhra Pradesh is attributed to poor adaptation of improved cultivars in these drought-prone areas (Salunke et al. 2003). Correlation analysis among crop growth and yield components is one of the techniques used to understand the influence of yield components on the productivity potential of a crop. This research was conducted to evaluate and identify sorghum hybrids with suitable drought tolerance, which could be grown during the postrainy season in Vertisols in the semi-arid tropics of South India.

Materials and Methods

A field study was conducted with 21 hybrids, which were developed from the parents that were mostly adapted to the postrainy season environment, and a check (M 35-1) in a randomized block design with three replications on medium to deep black soils during the postrainy season in 2000/01 at the Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Research Farm, Bellary. The crop was sown on 13 October 2000

Table 1. Mean performance of sorghum hybrids during the postrainy season 2000/01 in Vertisols in Bellary, Karnataka, India.

Hybrid	Grain yield ($t\ ha^{-1}$)	Stover yield ($t\ ha^{-1}$)	Plant height at harvest (m)	Panicle mass ($g\ plant^{-1}$)	Grain mass ($g\ plant^{-1}$)	1000-grain mass (g)	Panicle length (cm)	Panicle diameter (cm)
SPH 1077	1.32	1.76	1.5	25.00	21.33	23.53	13.0	11.0
SPH 1078	1.09	1.56	1.4	24.00	20.00	24.63	12.3	10.2
SPH 1079	1.38	1.86	1.5	22.67	22.27	23.28	14.1	11.3
CSH 15R	1.10	1.52	1.4	25.67	19.17	25.80	12.9	10.7
SPH 1089	1.14	1.63	1.5	23.83	20.43	23.33	13.1	11.5
SPH 1174	1.52	2.02	1.6	29.00	24.67	26.03	14.0	12.5
SPH 1219	1.03	1.39	1.6	24.00	19.33	21.73	13.3	10.8
SPH 1221	1.14	1.54	1.4	23.00	18.83	22.20	12.5	10.5
SPH 1225	1.41	1.88	1.5	25.33	22.17	23.73	13.7	11.1
SPH 1226	1.24	1.68	1.5	24.67	19.87	23.41	13.4	11.4
SPH 1227	1.17	1.60	1.5	24.00	19.63	25.17	12.5	10.5
CSH 19R	1.76	2.33	1.6	32.33	28.00	29.69	15.7	12.3
SPH 1229	1.02	1.53	1.5	23.67	19.50	23.07	13.8	11.1
SPH 1230	1.69	2.18	1.6	31.67	26.67	28.22	13.9	11.4
SPH 1231	1.56	1.80	1.5	29.00	24.69	27.45	13.7	11.4
SPH 1233	1.29	1.70	1.5	26.33	21.07	24.27	13.2	11.0
SPH 1234	1.48	2.06	1.5	27.33	22.83	25.50	12.5	11.0
SPH 1235	1.34	1.81	1.4	24.67	21.17	22.73	13.8	10.8
SPH 1236	1.45	1.97	1.5	27.67	23.90	23.77	13.5	10.6
SPH 1237	1.22	1.65	1.5	24.33	20.83	22.81	13.6	10.9
SPH 1238	0.96	1.65	1.4	23.67	19.90	24.70	13.6	11.3
M 35-1 (check)	1.23	1.76	1.5	24.00	20.43	25.20	13.7	11.0
SEm±	0.18	0.19	0.09	2.47	2.12	1.30	0.85	0.64
CD at 5%	NS[1]	NS	NS	NS	NS	3.72	NS	NS

1. NS = Not significant.

Table 2. Estimates of correlation coefficient among yield and yield components in sorghum hybrids during the postrainy season 2000/01 in Vertisols in Bellary, Karnataka, India[1].

Component	Stover yield ($t\ ha^{-1}$)	Plant height at harvest (m)	Panicle mass ($g\ plant^{-1}$)	Grain mass ($g\ plant^{-1}$)	1000-grain mass (g)	Panicle length (cm)	Panicle diameter (cm)	Grain yield (t ha-')
Stover yield ($t\ ha^{-1}$)	1.000	0.481*	0.814**	0.926**	0.690**	0.612**	0.606**	0.927**
Plant height at harvest (m)		1.000	0.509*	0.559*	0.337	0.482*	0.568**	0.523*
Panicle mass ($g\ plant^{-1}$)			1.000	0.913**	0.840**	0.531*	0.576**	0.858**
Grain mass (g plant')				1.000	0.761**	0.672**	0.646**	0.944**
1000-grain mass (g)					1.000	0.455*	0.522*	0.683**
Panicle length (cm)						1.000	0.738**	0.559**
Panicle diameter (cm)							1.000	0.555**
Grain yield ($t\ ha^{-1}$)								1.000

1. * = Significant at 5% level; ** = Significant at 1% level.

and harvested on 13 February 2001. Sorghum hybrids were planted in three replications, each consisting of six rows of 6.75 m length with 45 cm x 15 cm plant spacing; seed was sown at a depth of 5 cm. The test plot was fertilized with urea at 30 kg N ha^{-1} and single super phosphate at 30 kg P_2O_5 ha^{-1} at planting. The crop experienced severe water stress during reproductive growth stages that adversely affected crop yields. Total rainfall recorded during the cropping season was 45.6 mm in 4 days. Standard agronomic practices and plant protection measures were followed during the growing season. Grain and fodder yields were recorded for analysis.

Results and Discussion

The drought tolerant hybrids were statistically similar in yield components. Even though the hybrids evaluated did not vary significantly among themselves for grain yield, there was a large variation under adverse weather conditions in Bellary and the grain yield ranged from 0.96 to 1.691 ha^{-1}. Among the different hybrids evaluated, the performance of CSH 19R was better with higher grain (1.76 t ha^{-1}) and stover yield (2.33 t ha^{-1}), followed by SPH 1230 and SPH 1231 (Table 1). Greater grain and straw yield in these hybrids could be attributed to better physiological efficiency as evidenced by the higher dry matter accumulation within panicles (Table 1). These results were similar to those reported earlier in sorghum by Pawar and Jadav (1996). The performance of CSH 15R and SPH 1079 in our study was disappointing compared to results reported in a previous postrainy season study in 1999/2000, which experienced normal rainfall (Patil 2000). This clearly indicates that CSH 15R (despite being a short-duration hybrid) and SPH 1079 are sensitive to water stress. The performance of SPH 1238 indicated its extreme sensitivity to water stress and therefore may not be suitable for this region.

Correlation coefficients indicated that grain yield was positively and significantly correlated with plant height (0.523), stover yield (0.927) and all other yield components, ie, grain mass (0.944), panicle mass (0.858), 1000-grain mass (0.683), panicle length (0.559) and panicle diameter (0.555) (Table 2). These results confirm earlier observations by Navale et al. (2000) and Veerabadhiran and Kennedy (2001) with sorghum grown under similar situations. A significant positive relationship between grain and stover yields indicates good prospects for enhancing both grain and stover yields simultaneously even under terminal water stress situations typically observed under postrainy seasons.

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References

Navale PA, Nimbalkar CA and **Gandhi HT.** 2000. Correlation and regression analysis in *rabi* sorghum. Journal of Maharashtra Agricultural Universities 25:320-321.

Patil SL. 2000. Evaluation of sorghum hybrids and varieties. Pages 42-44 *in* Annual progress report. Bellary, Karnataka, India: CSWCRTI, Research Centre.

Pawar KP and **Jadav AS.** 1996. Correlation and path analysis in *rabi* sorghum. Journal of Maharashtra Agricultural Universities 21:344-347.

Salunke VD, Deshmukh RV, Aglave BN and **Borikar** ST. 2003. Evaluation of sorghum genotypes for drought tolerance. International Sorghum and Millets Newsletter 44:88-90.

Veerabadhiran P and **Kennedy VJF.** 2001. Correlation and path analysis studies in selected germplasms of sorghum. Madras Agricultural Journal 88:309-310.

Colonization of Sorghum Peduncles by *Fusarium thapsinum* and *Curvularia lunata:* Subsequent Pigment Accumulation

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Introduction

Several species of fungi can infect sorghum *(Sorghum bicolor)* panicles at developmental stages that precede, occur during, and after flowering. Two of the most important pathogens that contribute towards grain mold and associated panicle diseases include *Fusarium thapsinum* (F. *moniliforme* mating group F) (FT) and *Curvularia lunata* (CL) (Bandyopadhyay et al. 2002, Prom et al. 2003). These two fungi have been found in association with early infection events of sorghum, especially at anthesis, in every geography and environment in which they have been sought. In the greenhouse, early infections of sorghum spikelets misted at anthesis with either FT or CL can cause significant disease in susceptible genotypes.

FT and CL infect and colonize developing caryopses and also colonize tissues that are associated with and support the spikelets, such as the peduncle and rachis branches. Head blight of sorghum is a disease complex that is closely related to grain mold. In this case, infection of the peduncle and adjacent supportive tissues could lead to significant losses in terms of seed set and seed weight. Colonization of supportive tissues in the panicle by FT and CL appear to lead to the accumulation of pigmented phytoalexin compounds; this response may or may not significantly impact resistance to head blight or grain mold.

Materials and Methods

Four sorghum lines were tested in the greenhouse to determine the effect of panicle inoculations at anthesis on levels of peduncle colonization and subsequent accumulation of pigmented phytoalexins. Sureno is a white-tan, zerazera variety that is resistant to grain mold. Tx2911 is highly grain mold resistant and is a bright-red pericarp, *kafir-caudatum* plant type. SCI70 is a white-grained, *caudatum* line which is moderately resistant to grain weathering and moderately susceptible to grain mold (personal observation). Tx430 is very susceptible to grain mold and is derived from a cross between SC 170 and RTx2536.

Sorghum panicles were randomly chosen and treated when anthers had emerged from at least 50% of the spikelets. Treatments consisted of: (1) FT; (2) CL; or (3) sterile distilled water as control (CONT). Inoculum was sprayed at all angles onto the flowering panicles until the suspension began to drip from individual spikelets. Peduncles were then wiped down with a piece of sterile cheesecloth (5 cm x 5 cm) soaked in 0.53% NaOCl after inoculum had stopped dripping from the panicle. Panicles were immediately covered with paper pollinating bags in order to maintain a high relative humidity and favor

Table 1. Re-isolation of *Fusarium thapsinum* (FT) and *Curvularia lunata* (CL) from peduncle sections of sorghum anthetic inoculations three days post-plating.

Cultivar	Treatment	Recovery[1]
Sureno	CONT-FT[2]	0.10 c
Sureno	CONT-CL[2]	0.05 b
Sureno	FT	0.32 e
Sureno	CL[4]	0.55 f
SC 170	CONT-FT	0.01 ab
SC 170	CONT-CL	0.02 ab
SC 170	FT	0.95 i
SC 170	CL	0.83 h
Tx2911	CONT-FT	0.00 a
Tx2911	CONT-CL	0.00 a
Tx2911	FT	0.27 e
Tx2911	CL	0.15 d
Tx430	CONT-FT	0.03 ab
Tx430	CONT-CL	0.00 a
Tx430	FT	0.65 g
Tx430	CL	0.70 g

1. Recovery of isolates from 100 peduncle sections from ten panicles (10 sections each).
Values are significantly different at P * 0.05 if followed by different letters. Comparisons were made by ANOVA and Fisher's Least Significant Difference test.
2. Panicles were sprayed with sterile distilled water as control (CONT) and assayed for re-isolation of FT (CONT-FT) or CL (CONT-CL).
3. Panicles were inoculated with FT and assayed for re-isolation of FT from peduncle tissue.
4. Panicles were inoculated with CL and assayed for re-isolation of CL from peduncle tissue.

initial infection and colonization of the spikelets and supporting tissues.

Cross-sections of sorghum peduncles were collected at harvest (~60 days post-inoculation). Ten 1-mm thick peduncle sections beginning at 2.5 cm below the lowest rachis branch were collected from each of ten panicles (for a total of 100 peduncle sections per treatment-cultivar combination). Peduncle cross-sections were then incubated in 0.53% NaOC1 for a period of 10 min to surface sterilize the external portion of the tissue. This was done in order to avoid confusion with saprophytic contaminants upon re-isolation of fungi. The sections were plated on potato dextrose agar (PDA) and observed three days later for the re-isolation of FT or CL isolates. Comparisons of overall means were made using ANOVA and Fisher's Least Significant Difference test at $P = 0.05$ (Table 1).

Results and Discussion

Peduncle cross-sections yielded both FT and CL even after incubation in 0.53% NaOCl for 10 min, but not if originally inoculated at anthesis with sterile distilled water. Re-isolation levels of FT from Sureno and Tx2911 (both are resistant varieties) were not different from one another but were both significantly less than levels from SC 170 (moderately susceptible) and Tx430 (very susceptible). Re-isolation of CL from Tx2911 was significantly less than the other cultivar-treatment combinations. Peduncle sections from CL treatments yielded relatively high amounts of the fungus. This was surprising since CL is not typically associated with extensive colonization of the peduncle, although extensive colonization by CL is possible under greenhouse conditions when high humidity is maintained on the panicle.

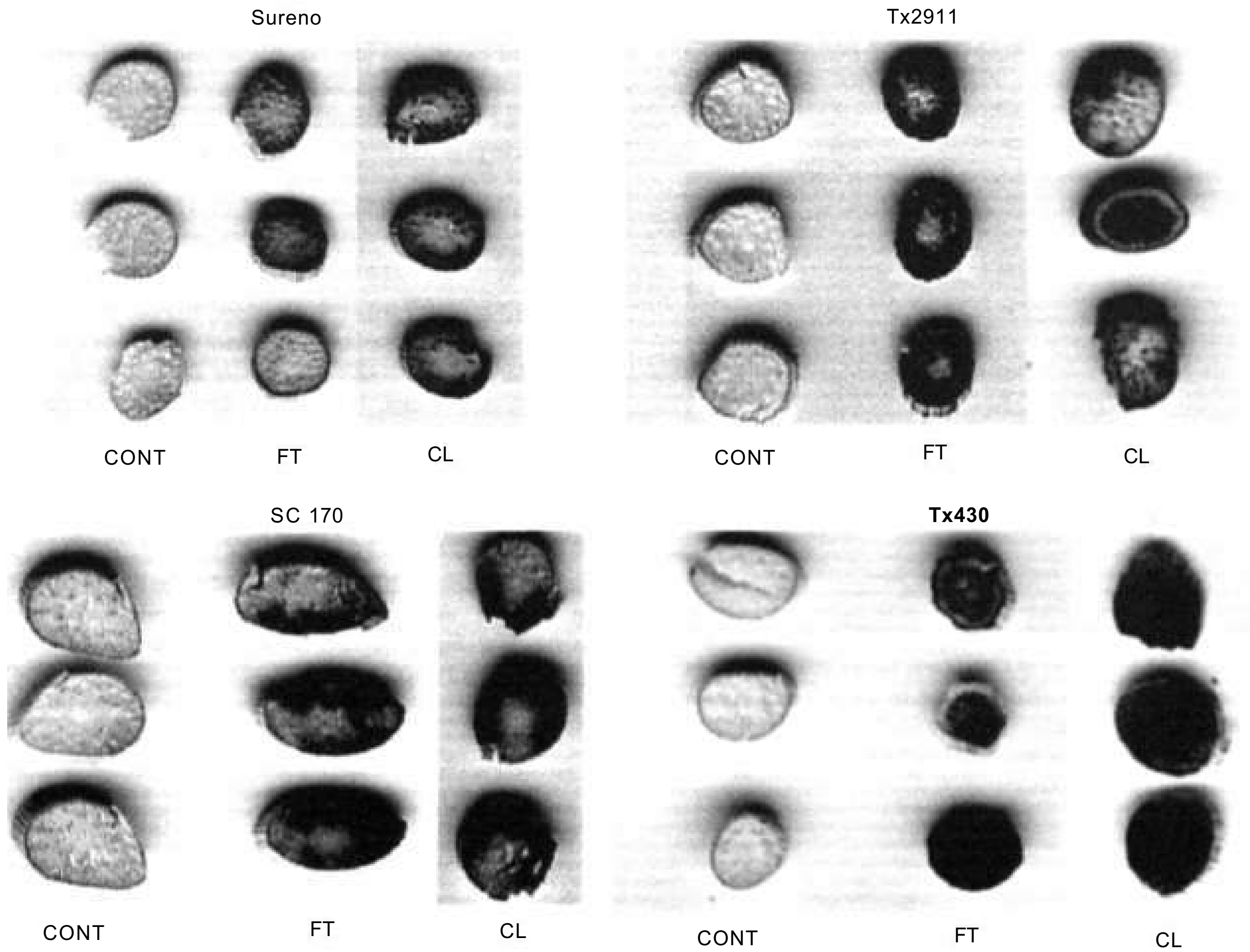

Figure 1. Peduncle cross-sections from Sureno, Tx2911, SC 170 and Tx430. [Note: These cross-sections were taken from peduncles obtained at 60 days post-inoculation/post-anthesis. Flowering panicles were inoculated with *Fusarium thapsinum* (FT), *Curvularia lunata* (CL) or sterile distilled water (CONT).]

As has been observed in the past, significant accumulations of red-pigmented compounds occur in sorghum tissues that are actively being colonized by fungal hyphae. The peduncle is no exception in this case. Various stalk rots and head blights, caused by *Colletotrichum* spp, for example, have often been associated with pigment accumulation in sorghum (Nicholson and Wood 2001). The examples shown here demonstrate that facultative grain mold pathogens, such as FT and CL, may also induce pigment accumulations (Fig. 1) and potentially infect the parenchymal and vascular bundle cells of the sorghum peduncle (Fig.2). These pigments represent the 3'-deoxyanthocyanin compounds that are generally associated with stress and pathogenesis in red and purple genotypes (Nicholson and Wood 2001). However, Sureno, a tan plant type, does not accrue significant amounts of these pigments in the peduncle in response to FT or CL (Fig.1). This suggests that Sureno, which is highly resistant to grain mold and other panicle diseases, uses a mechanism other than phytoalexins to defend itself against these facultative pathogens. Accumulation of a high amount of pigment phytoalexins in Tx430 (susceptible) indicates that these compounds cannot be relied upon for resistance alone (Fig.1).

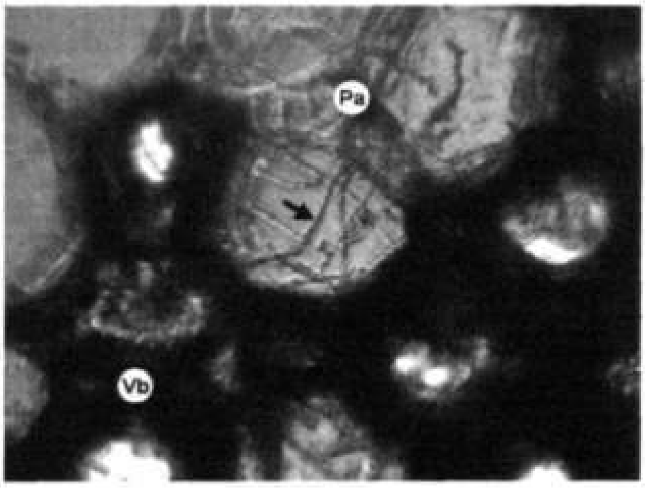

Figure 2. Hyphae (arrow) of *Curvularia lunata* (CL) as seen in the parenchymal region (Pa) adjacent to the vascular bundle region (Vb) of the peduncle. This cross-section is derived from a panicle of SC 170 that was inoculated with CL at anthesis. (Note: Total magnification = 100x.)

Both resistant and susceptible cultivars are capable of inducing pigmented phytoalexin compounds. However, the data show that this physiological trait is not necessarily related to the plant's ability to defend itself against grain mold fungi. For example, Tx2911, a grain mold resistant line, produces high levels of pigments. Low levels of *F. thapsinum* and *C. lunata* are re-isolated from peduncle sections (Table1). Both *F. thapsinum* and C. *lunata* were found to induce deoxyanthocyanin production in inoculated Tx2911 peduncle tissue (Table1). Even so, the fungi could ramify through the responding tissue and therefore be demonstrably recovered by the re-isolation of viable cultures from peduncles (Table1). Figure 2 shows fungal hyphae growing within parenchymal cells located near the vascular bundles of a SC 170 peduncle 60 days after the flowering panicle was inoculated at anthesis with CL.

The pathways (phenylpropanoid and flavonoid) leading to the production of these compounds are highly inducible by infection with facultative pathogens. This is indicative that the genes in this pathway are also highly inducible and highly regulated (Nicholson and Wood 2001, Bandyopadhyay et al. 2002). It is likely that multiple grain mold pathogens arc capable of causing significant damage to the sorghum panicle structure when contributing to a "head blight" complex even in the presence of phytoalexin pigments.

References

Bandyopadhyay R, Little CR, Waniska RD and **Butler DR. 2002.** Sorghum grain mold: through the 1990s into the new millennium. Pages 172-183 *in* Sorghum and millets diseases (Leslie JF, ed.). Ames, Iowa, USA: Iowa State University Press.

Nicholson R and **Wood K. 2001.** Phytoalexins and secondary products, where are they and how can we measure them? Physiological and Molecular Plant Pathology 59:63-69.

Prom LK, Waniska RD, Kollo AI and **Roomy WL. 2003.** Responses of eight sorghum cultivars inoculated with *Fusarium thapsinum, Curvularia lunata,* and a mixture of the two fungi. Crop Protection 22:623-628.

Detection of Seedborne Grain Mold Fungi in Sorghum and their Control with Fungicidal Seed Treatment

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Introduction

Grain mold, caused by a complex of fungi, is a serious problem of sorghum *{Sorghum bicolor)* that affects its grain yield, quality and market value. The annual economic loss in Asia and Africa as a result of grain mold is more than US$130 million (Chandrashekar et al. 2000). Early-maturing, short-statured, high-yielding hybrids that flower and mature during wet weather are particularly vulnerable to attack by mold fungi. Among the fungi involved in the mold complex, species of *Fusarium, Curvularia* and *Alternaria* are more abundant than others (Girish et al. 2004). The risk of introducing new species or strains of a pathogen could be minimized if we have sound knowledge of their seedborne nature and the treatment to reduce the possibility of seed transmitted inoculum. Efforts to produce sorghum genotypes with tolerance to grain mold by conventional breeding have been only partially successful (Thakur et al. 2003). This study was undertaken to investigate the seedborne nature of predominant mold fungi and to identify a fungicide as seed treatment to minimize the seed infection of these fungi.

Materials and Methods

Seedborne nature of mold fungi. Seed of mold resistant (IS 8545 and PVK 801) and susceptible (Bulk Y, SPV 104 and CSH 9) genotypes from the crop grown during the rainy season in 2002 was used. Twenty-five seeds from each of five genotypes were surface sterilized in 2% Clorox® for 2 min and thoroughly washed with sterile distilled water (SDW), and soaked in 4% potassium hydroxide (KOH) for 15 min and then transferred into SDW. Each seed was dissected to separate its seed coat, endosperm and embryo. These were plated separately on potato carrot agar (PCA) medium, and incubated at 22±2°C with 12 h near-ultraviolet light (NUV) for 5 days. Data were recorded on the number of seed components infected by individual fungi in each genotype. The experiment was repeated once.

Seed treatment with fungicide. Three treatments, Bavistin (carbendazim) (2.5 g kg^{-1}) seed as dry seed dressing (SD), thiram (3 g kg^{-1} seed) as SD and soaking seed in Bavistin solution (2%) for 4 h as seed steeping (ST), were used (Munghate and Raut 1982). From each genotype 300 seeds were used with 100 seeds in each of three replications. Seed were surface sterilized in *2%* Clorox® for 2 min, washed with SDW and air-dried before treating with fungicides. Seed without fungicidal treatment served as control. The seed were evaluated for fungal colonization using the standard blotter method at 22±2°C with 12 h NUV for 7 days (ISTA 1992). Overall mold colonization and seed germination were recorded and subjected to analysis of variance to determine significant differences among the treatments. The experiment was repeated once.

Table 1. Infection by *Curvularia lunata* and *Fusarium verticillioides* on seed components of five sorghum genotypes plated on potato carrot agar medium.

	Infection[1] (%)					
	C. lunata			*F. verticillioides*		
Genotype[2]	Seed coat	Endosperm	Embryo	Seed coat	Endosperm	Embryo
Bulk Y (S)	20	32	38	74	56	34
CSH 9 (S)	84	78 '	62	36	24	12
SPV 104 (S)	54	50	30	18	18	14
PVK 801 (R)	30	30	6	20	18	0
IS 8545 (R)	0	8	2	38	34	4
Mean	38	40	28	37	30	13
SEm±	5.2	6.0	5.1	**10.6**	4.3	2.8

1. Data are means of two experiments. In each experiment, 25 seeds per genotype were tested.
2. S = Susceptible; R = Resistant.

Table 2. Effect of fungicide treatment on grain colonization by mold fungi in five sorghum genotypes.

Treatment[2]	Grain colonization (%) by mold fungi[1]				
	Bulk Y (S)	CSH 9 (S)	SPV 104 (S)	IS 8545 (R)	PVK 801 (R)
Thiram SD	20 (74)[3]	15 (85)	0 (100)	3 (96)	17 (80)
Bavistin SD	54 (30)	96 (4)	63 (29)	54 (27)	53 (37)
Bavistin ST	64 (18)	100 (0)	55 (38)	50 (32)	77 (8)
Control	78	100	89	74	84
SEm±	9.6	0.7	9.5	13.5	6.5
Mean reduction	43	30	52	42	56

1. Data are means of two experiments with three replications in each experiment; 100 seeds per replication were tested. S = Susceptible: R = Resistant.
2. SD = Seed dressing; ST = Seed steeping.
3. Figures in parentheses indicate reduction percentage compared to control.

Results and Discussion

Fungal infection in seed components. Infection of seed components (seed coat, endosperm and embryo) occurred only by *Fusarium verticillioides* and *Curvularia lunula* and not by *Alternaria alternata.* The incidence of infection varied significantly among the component tissues and among the sorghum genotypes (Table1). Infection of tissues was significantly lowered in resistant (IS 8545 and PVK 801) than in susceptible genotypes (Bulk Y, SPV 104 and CSH 9). In the susceptible genotypes, the component tissue infection ranged from 20 to 84% by *C. lunata* and 12 to 74% by *F. verticillioides.* In an earlier study (Girish et al. 2004), we found six fungi *(A. alternata, Bipolaris sorghicola, C. lunata, F. verticillioides, Exserohilum rostratum* and *Phoma sorghina)* commonly associated with sorghum grain mold complex and these caused seed rot and reduced seed germination to a considerable extent. In this investigation, of these six fungi only *C. lunata* and *F. verticillioides* were found to be seedborne and highly infectious as infection was detected in seed coat, endosperm and embryo in most sorghum genotypes.

Effect of fungicides on grain mold colonization. Seed treatment with thiram SD significantly reduced grain mold colonization in all the five sorghum genotypes (Table 2). Compared with thiram SD, Bavistin SD or Bavistin ST was less effective in reducing grain colonization. Among the methods of fungicide application, SD was more effective in controlling the mold colonization than ST.

Effect of fungicides on grain infection by seedborne fungi. Seed treatment with thiram significantly reduced

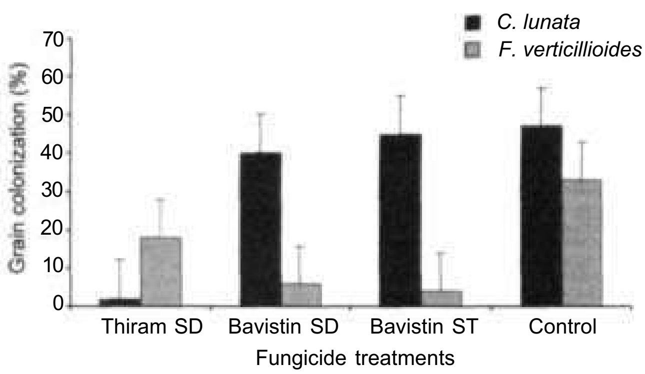

Figure **1.** Effect of fungicide treatments on grain mold colonizaion by *Curvularia lunata* and *Fusarium verticillioides* across five sorghum genotypes. (Note: SD = Seed dressing; ST = Seed steeping.)

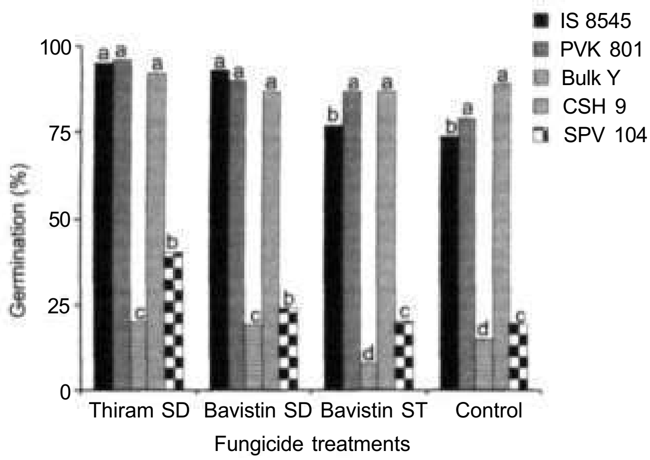

Figure 2. Effect of fungicide treatments of moldy grain on germination of five sorghum genotypes. (Note: The values of bars with common letters in each treatment group are not significantly different at P<0.05. SD = Seed dressing; ST = Seed steeping.)

infection by *C. lunata,* while Bavistin treatments significantly reduced infection by *F. verticillioides* across sorghum genotypes (Fig. 1). With reduction in grain mold infection (by 30-56%), there was a subsequent increase in seed germination by 4-47% over the control across sorghum genotypes (Fig. 2). In this study, out of the two SD fungicides, thiram proved superior to Bavistin in eliminating infection by A *alternata* and *C. lunata* and Bavistin was superior to thiram in eliminating infection by *F. verticillioides.* Thus, it is suggested that seed treatment with a mixture of thiram and Bavistin (1:1) could be routinely used to eliminate the seedborne infection by C. *lunata* and *F. verticillioides* during sorghum germplasm exchange.

References

Chandrashekar A, Bandyopadhyay R and **Hall AJ. (eds.) 2000.** Technical and institutional options for sorghum grain mold management: proceedings of an international consultation, 18-19 May 2000, ICRISAT, Patancheru, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 229 pp.

Girish AG, Rao VP and **Thakur RP. 2004.** Diversity of grain mold fungi on selected sorghum genotypes. Indian Phyto-pathology 57(1): 84-87.

ISTA. 1992. International rules for seed testing. Seed Science and Technology, Vol. 20, Supplement. 203 pp.

Munghate AG and **Raut JG. 1982.** Efficacy of nine different fungicides against fungi associated with sorghum seed. Journal of Pesticides 16(8): 16-18.

Thakur RP, Reddy BVS, Rao VP, Garud TB, Agarkar GD and **Bharathi Bhat. 2003.** Sorghum grain mold: Resistance stability in advanced B-lines. International Sorghum and Millets Newsletter 44:108-112.

Effect of Two Mold Causing Fungi on Physical and Nutritional Properties of *Kharif* Sorghum Grains

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Introduction

Sorghum *(Sorghum bicolor)* was the second largest grain crop in India until the Green Revolution and presently ranks third in area sown and fifth in production among the food grains in the country. The principal grain mold fungi in India are *Fusarium* spp and *Curvularia lunata* and both cause severe yield losses. In severely affected grains nutritional quality can be seriously impacted (Williams and Rao 1980). Bhatnagar (1971) reported marked reduction in the size and weight of sorghum grains artificially infected with *C. lunata.* Considering the gravity of grain quality deterioration in terms of physical and nutritional properties, the present investigations were undertaken to study the impact of grain mold on physical and nutritional properties of sorghum grains.

Materials and Methods

Field experiments were carried out to obtain grains with different mold intensities during the *kharif (*rainy) season in 2002. A split plot design was used with eight sorghum lines (CSH 9, CSH 14, CSH 16, CSH 17, CSH 18, CSV 13, CSV 15 and PVK 801) as main treatments and three harvest situations as sub-treatments with three replications. Sorghum lines were inoculated with *Fusarium moniliforme* and C. *lunata* in the field. The observations for each treatment and sub-treatments were taken in three replications under laboratory conditions.

A correlation of fungi associated with grains to the pathological, physical and nutritional parameters was recorded. A simple statistical correlation technique was used to study the relationship between fungal infection and physico-chemical properties of sorghum grains.

Grain quality parameters related to fungal infection were threshed grain mold rating (TGMR), germination and physical properties such as test weight, grain volume and density, floaters and grain hardness. Nutritional parameters measured included moisture, crude protein, crude fat, crude fiber, soluble sugars, starch, ash and appropriate calorific value.

Results and Discussion

The correlation study between physical and nutritional parameters with fungi are summarized below.

The fungi *F. moniliforme* and *C. lunata* showed significant positive or negative correlations with pathological, physical and nutritional properties. *Fusarium moniliforme* and *C. lunata* showed positive correlations to TGMR with mean increases in TGMR when infection of *F. moniliforme* (r - 0.878) and C. *lunata* (r = 0.874) increased and vice-versa. Germination was found to be negatively correlated with *F. moniliforme* (-0.833) and *C. lunata* (-0.716). Germination percentage was maximum when association of *F. moniliforme* and C. *lunata* was lowest and germination was minimum when there was highest fungal infection with seed. Garud et al. (2000) have reported similar findings.

Floaters (0.687 and 0.673) and water absorption (0.540 and 0.522) were positively correlated with both ***F. moniliforme*** and ***C.*** *lunata,* respectively. This indicates that floaters and water absorption were highest when infection by these fungi was highest and minimum when infection was lowest Test weight (-0.827 and -0.807), grain volume (-0.842 and -0.699), grain density (-0.549 and -0.540) and grain hardness (-0.712 and -0.679) were negatively correlated with *F. moniliforme* and *C. lunata.*

The results for nutritional qualities such as crude fiber (0.829 and 0.769) and ash (0.746 and 0.654) were positively correlated with fungal infection. Moisture (-0.579 and -0.376), crude protein (-0.827 and -0.791), soluble sugars (-0.732 and -0.748) and starch (-0.542 and -0.543) were negatively correlated with *F. moniliforme* and *C. lunata,* respectively. These parameters were maximum at lowest infection and minimum at highest fungal infection (Table 1). Correlation studies clearly indicated that as the infection of *F. moniliforme* and *C. lunata* increases, the physical and nutritional (biochemical) parameters of seed significantly deteriorated. Similar work, on variation in physical seed characters such as grain mold grade, 100-grain mass, grain hardness, grain volume, density, floaters and percentage germination among hybrids and parental lines was conducted by Indira and Rana (1996). We report for the first time physical and nutritional parameters of sorghum grains infected with grain mold.

Table 1. Correlation coefficient between different physical and nutritional parameters and fungal infected sorghum grains.

	Correlation coefficient of fungal infected grains[1]	
Parameters	*Fusarium moniliforme*	*Curvularia lunata*
TGMR[2]	0.878*	0.874*
Germination (%)	-0.833*	-0.716*
Test weight (g)	-0.827*	-0.807*
Grain volume (ml)	-0.842*	-0.699*
Grain density (g ml^{-1})	-0.549*	-0.540*
Floaters (%)	0.687*	0.673*
Grain hardness (kg)	-0.712*	-0.679*
Water absorption (%)	0.540*	0.522*
Moisture (%)	-0.579*	-0.376
Crude protein (%)	-0.827*	-0.791*
Crude fat (%)	-0.738*	-0.722*
Crude fiber (%)	0.829*	0.769*
Soluble sugars (%)	-0.732*	-0.748*
Ash (%)	0.746*	0.654*
Starch (%)	-0.542*	-0.543*
Approx. calorific value (%)	-0.864*	-0.822*

1. * = Significant at 5% level.
2. TGMR = Threshed grain mold rating.

References

Bhatnagar GC. 1971. Discolouration of great millet grains in earheads due to *Curvularia lunata (Cochliobolous lunatus)* on sorghum. Rajasthan Journal of Agricultural Sciences 2:113—115.

Garud TB, Shinde BM, Syed I and **Aglave BN. 2000.** Effect of two mold causing fungi on germination of sorghum seed. International Sorghum and Millets Newsletter 41:54.

Indira S and **Rana BS. 1996.** Variation in physical seed characters significant in grain mold resistance of sorghum. *In* Proceedings of the International Conference on Genetic Improvement of Sorghum and Pearl Millet, 23-27 September 1996, Lubbock, Texas, USA. USA: INTSORMIL.

Williams RJ and **Rao KN. 1980.** A review of sorghum grain mold. Pages 79-92 *in* Sorghum diseases, world review: proceedings of the International Workshop on Sorghum Diseases, 11-15 December 1978, ICRISAT, Hyderabad, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Entomology

Resistance of Stored Sorghum Grain to Maize Weevil

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Introduction

The maize weevil *(Sitophilus zeamais)* is one of the most destructive and widely distributed insect pests of stored grain (Teetes et al. 1981, Teetes and Pendleton 2000). This 4-mm long weevil is a common pest of maize (*Zea mays*) and sorghum (*Sorghum bicolor*). The maize weevil is abundant in warm, humid regions of the world. Maize weevils infest developing kernels in the field and are inadvertently taken into storage. A female deposits a total of 300 to 400 eggs, about five eggs each day, in the cavities formed when it chews the kernels. The larva feeds internally and damages the kernel. Six generations may occur per year, with an average of 39 days per generation (Morrison 1963, Wilbur and Mills 1985). Maize weevils live for 2 to 5 months.

Use of sorghum cultivars that resist damage in the field and in storage is an alternative to the use of insecticide. But resistance to maize weevils in stored grain of different genotypes of sorghum has not been evaluated for more than 20 years (Teetes et al. 1981). The goal of this research was to evaluate resistance of stored grain of 20 sorghum genotypes to maize weevil and relate resistance to such factors as grain size, hardness and protein content.

Materials and Methods

Resistance of 20 sorghum genotypes to maize weevil was evaluated from 25 October 2003 to 5 February 2004 at the insect pest management laboratory at West Texas

Table 1. Total number of maize weevil adults, damage score and grain weight loss at 105 days after infestation of sorghum grain[1].

Sorghum	Maize weevils (Total number g^{-1} grain)	Damage score[2] (1-5)	Grain weight loss (%)
Sureno	3.1 ±0.50 g	1.5 ±0.10 i	0.8 ±0.07 j
Sima	1.7 ±0.66 g	1.6±0.19i	3.8 ±0.09 ij
Macia	2.8 ± 1.17 g	1.8 ±0.26 hi	5.4±0.18 hij
Malisor-84-7-167	3.9±0.81 fg	1.7 ±0.14 hi	6.6± 0.12 hi
Tegemeo	3.5 ± 1.02 fg	2.0 ± 0.20 ghi	8.2 ±0.14 h
ATx635	6.4±0.81 ef	2.3 ±0.15 fgh	13.8 ±0.12 gh
Malisor-84-7-476	7.4± 1..11 de	2.5 ±0.20 fg	5.2±0.16g
Kuyuma	7.3 ± 1.75 de	2.7 ±0.24 ef	6.8 ±0.24 g
Tx2882	7.5 ± 1.35 de	2.7 ±0.21 def	17.4 ±0.18 fg
Segaolane	8.6 ±0.94 de	2.8 ±0.27 cdef	1.8±0.21 f
B1	10.6 ± 1.11 bcd	3.1 ±0.18 cde	27.2 ±0.16 efg
RTx430-5451	10.1 ±0.81 bed	3.3 ±0.12 bed	27.4 ±0.17 def
Tx2737	10.0 ±2.08 bcd	3.2 ±0.37 bcde	30.2 ±0.31 def
RTx430-5362	10.5 ±1.31 bcd	3.4 ±0.24 abc	32.0 ±0.25 cde
ATx623	10.4 ±1.31 bed	3.2 ±0.20 bcde	32.2 ±0.23 bcde
T x 2911	9.5 ± 1.39 cde	3.4 ±0.33 abc	33.8 ±0.29 abcd
SRN39	12.9 ± 1.49 ab	3.7 ±0.24 ab	35.8 ±0.22 abcd
ATx631	12.0 ± 1.50 abc	3.9 ±0.21 a	37.2 ±0.25 abc
CE151	14.2 ±0.95 a	4.0±0.15 a	43.4 ±0.14 ab
SC630-11E11	12.1 ±1.01 abc	3.9 ±0.21 a	46.8 ±0.21 a
LSD	3.351	0.615	0.547

1. Means followed by the same letter in a column are not significantly different (P<0.0001).
2. Grain damaged by weevils on a 1-5 scale, where 1 = no evidence of damage and 5 = 76-100% damage.

A & M University, Canyon, Texas, USA. Experiments were conducted in a controlled environment at 25-27°C and 65-70% relative humidity. Three female and two male newly emerged maize weevils were put with 5 g of sorghum grain in each of ten 25-ml plastic vials (Vial Scint Pet). The gender of each weevil was determined based on its physical appearance, ie, the snout is shorter, thicker and rougher for a male than a female and the tip of the abdomen curves downward for a male whereas it extends straight back in a female (Wilbur and Mills 1985). Each vial of grain and weevils was covered by a small piece of organdy cloth attached over the top of the vial with a rubber band. Ten vials of each sorghum genotype were sequentially set up and evaluated every three weeks during a total of 105 days. Daily, each grain in the 10 vials of each genotype was evaluated for damage, numbers of live and dead weevil adults were counted, and the grain in each vial was weighed. A scale of 1-5 was used to score damage, where 1 = no evidence of damage, 2 = some feeding on the surface, involving 1-25% or one shallow hole in a kernel, 3 = two tunnels, causing 26-50% damage to a kernel, 4 = 51-75% damage or more than two holes in a kernel and 5 = 76-100% damage and many tunnels in a kernel.

Results and Discussion

The cumulative total number of maize weevil adults produced g^{-1} grain differed significantly among the genotypes of sorghum. Few maize weevil adults emerged from Sima, Macia and Sureno - 1.7, 2.8 and 3.1 weevils g^{-1} of grain at 105 days after infestation, respectively (Table 1). Most adults emerged from CE151, SRN39, SC630-11E11 and ATx631 - 14.2, 12.9, 12.1, and 12.0 maize weevils g^{-1} of grain at 105 days after infestation, respectively.

The score of damage caused by maize weevils to sorghum grain differed significantly among the genotypes of sorghum. Sureno, Sima, Malisor-84-7-167 and Macia were least damaged, with scores of 1.5, 1.6, 1.7 and 1.8 at 105 days after infestation, respectively (Table 1). The genotypes CE 151, SC630-11 E11 and ATx631 were most damaged, with scores of 4.0, 3.9 and 3.9 at 105 days after infestation, respectively.

Weight loss of grain differed significantly among the genotypes of sorghum. Of the original 5 g of grain per vial, grain in vials of Sureno, Sima, Macia, Malisor-84-7-167 and Tegemeo weighed most at 105 days after infestation with maize weevils - 5.0, 4.8, 4.7, 4.7 and 4.6 g per vial, respectively. Relative percentage weight loss of grain of Sureno, Sima, Macia and Malisor-84-7-167 ranged from 0.8 to 6.6% (Table 1). Grain of SC630-11E11, CE 151 and ATx631 weighed the least at 105 days after infestation with maize weevils, with 2.7, 2.8 and 3.1 g remaining of the original 5 g of grain per vial. Relative percentage weight loss of grain of ATx631, CE 151 and SC630-11 E11 was 37.2 to 46.8%.

Grain weight loss was correlated with the cumulative total number of maize weevil adults produced g^{-1} grain and with the score of damage to the sorghum grain, but not with grain size, hardness or protein content. Overall, grains of sorghums from Central America and Africa, especially Sureno, Sima, Macia and Malisor, were very resistant to maize weevils.

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References

Morrison EO. 1963. Effect of environmental factors on population dynamics of the rice weevil, *Sitophilus zeamais* Motsch. PhD disssertation, Texas A & M University, College Station, Texas, USA. 154 pp.

Teetes GL, Chantrasorn W, Johnson JW, Granovsky TA and **Rooney LW. 1981.** Maize weevil: a search for resistance in converted exotic sorghum kernels. College Station, Texas, USA: Texas Agricultural Experiment Station. 38 pp.

Teetes GL and Pendleton BB. 2000. Insect pests of sorghum. Pages 443-495 *in* Sorghum: Origin, history, technology, and production (Smith CW and Frederiksen RA, eds.). New York, USA: John Wiley and Sons, Inc.

Wilbur DA and Mills RB. 1985. Stored grain insects. Pages 552-568 *in* Fundamentals of applied entomology, 4th edition (Pfadt RE, ed.). New York, USA: Macmillan Publishing Co.

Utilization

Performance of Broilers on Sorghum-based Diets

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Introduction

In India, sorghum *(Sorghum bicolor)* is grown in both the rainy and postrainy seasons. The postrainy season grain is generally of good quality and used for human consumption. The rainy season sorghum is often vulnerable to grain deterioration due to grain mold attack, making it unfit for food. Normal as well as moldy grain has enormous demand for industrial uses such as animal/poultry feed, alcoholic beverages, etc. However, the lack of an assured supply of the rainy season produced sorghum grain limits its use to only about 10% of the industrial demand. By 2010, the demand for rainy season sorghum for industrial use is estimated to increase by 10 to 30%; the major demand is expected to be from the poultry industry, which is growing at a rate of 15-20% per annum (Kleih et al. 2000). Consequently, the estimated feed requirement is about 18 million t by 2005 as against current production levels of 16 million t, leaving a gap of 2 million t. Maize *(Zea mays)* is the principal energy source in poultry feed. The demand and supply of maize reveals a large gap that can be filled by sorghum, the next best alternate cereal. At present, normal as well as moldy sorghum grain is used in poultry feed rations to a limited extent whenever maize supply is low or its price is too high. The apprehensions of some poultry producers/feed manufacturers about the energy levels of sorghum-based poultry feed rations in relation to maize rations is one of the major reasons for its limited use.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (Patancheru, India), along with Acharya NG Ranga Agricultural University (ANGRAU) (Hyderabad, India) and in collaboration with the non-governmental organizations (NGOs), Federation of Farmers' Associations (FFA) and Andhra Pradesh Poultry Federation (APPF), and Janaki Feeds (Hyderabad), a private partner, has implemented a project funded by **the** Department for International Development (DFID), UK. The project aimed at enhancing the use of rainy season sorghum in poultry feed rations as a potential alternative to maize and to create sustainable marketing linkages between sorghum growers and the poultry industry through innovative institutional systems. We report here the performance of broilers fed with sorghum-based feeds replacing maize in different proportions.

Materials and Methods

The grain from four improved sorghum cultivars, CSH 16, CSV 15, PSV 16 and S 35, and one traditional (yellow) sorghum variety planted in the rainy season 2002, were harvested. The grains were used in poultry feed trials (PFTs), which were conducted at the Poultry Experimental Station, ANGRAU, Rajendranagar, Hyderabad. Yellow (hybrid) maize procured from the market was used as control in the PFTs. The grain lots were analyzed for proximate composition, calcium and phosphorus (AOAC 1984); amino acids (Degussa Laboratory, Germany) and metabolizable energy; tannins and phenolic compounds by the Folin Denis method; aflatoxins, fumonisin (Feng-Yin and Furi 1996) and grain mold severity (AICSIP 2003) (Table 1). A broiler PFT was conducted by formulating starter (1-4 weeks) as well as finisher (5-6 weeks) diets by replacing maize (control diet) with sorghum at 50%, 75% and 100% levels and adjusting with oil and saw dust to make the diets iso-nitrogenous and iso-caloric. All the diets were made homogenous in lysine, methionine and cystine levels. One-day old 512 commercial (Cobb) female broilers were randomly distributed to 64 groups and housed in battery brooders with a floor space of 1.1 ft^2 $bird^{-1}$. A total of 16 dietary treatments (Table 2) were evaluated in four replications, each comprising eight birds. In the second trial, part-by-part replacement of maize with sorghum was conducted without homogenizing the diets for nitrogen and energy. Eight treatments (four each for mash and pellet forms) were evaluated in four replications (Table 3). Feed and water was offered ad libitum and standard management practices with routine vaccination schedule were adopted. Body weight gains and feed consumption were recorded weekly. Shank and breast skin color was scored by visual method (using Roche fan color equipment) to assess the carcass yellow pigmentation. The carcass weight, length of intestine and caecum, and weight of certain visceral organs, the liver, spleen, pancreas and bursa of fabricus, were measured. The data on these measurements were subjected to one-way analysis of variance to test statistical significance of the treatments and a t-test was used to assess pair-wise treatment significance. Cost of feed was calculated for each of the diets and feed efficiency (feed kg^{-1} live weight gain) was assessed.

Results and Discussion

Sorghum cultivars contained more protein (9.56 to 11.79%) than maize (hybrid yellow) (9.3%). However, metabolizable energy was greater in maize (3700 kcal kg^{-1}) than in sorghum cultivars (3 1 % to 3422 kcal kg^{-1}) (Table1). Similar results were also reported by Rama Rao et al. (1995). Amino acid profile was almost similar except tryptophan content, which was higher in sorghum (0.09-0.12%) than maize (0.07%). Tannins, phenolic compounds as tannic acid equivalent and catechin equivalent, were found low in all the sorghum cultivars (0.023 to 0.045%). The chemical analysis conducted at ICRISAT indicated that all the sorghum cultivars had low levels of grain mold and mycotoxins.

Performance data of 6-week-old birds showed that body weight gains and feed consumption of broilers were statistically similar on sorghum diets at all inclusion levels compared to the control diet (Table 2). However, the feed efficiency of broilers with sorghum-based diets at 100% inclusion level was found to be significantly higher than the maize-based diet (*P* = 0.05). Among the sorghum cultivars, better feed efficiency was found with CSV 15, CSH 16, PSV 16 and local variety at 100% inclusion level. However, yellow pigmentation of skin and carcass of broilers were better with maize-based diet compared to sorghum-based diets. Cost of feed for live broiler weight gain was similar for most of the feed rations. The cost varied among sorghum cultivars as well as within the cultivar among the different inclusion levels. The cost of feed kg"[1] live weight gain was significantly lower with CSV 15, PSV 16, S 35 and local sorghum-based diets than that with maize. It is interesting to note that the cost reduction is much lower with 100% inclusion level of CSV 15, PSV 16 and local sorghum cultivars in place of maize in the broiler feed rations.

Table 1. Chemical composition and nutritive value of maize and sorghum grain.

Parameter	Yellow maize	Sorghum cultivars				
		CSV 15	CSH 16	PSV 16	S 35	Local
Dry matter (%)	92.00	92.57	92.13	92.98	93.44	92.00
Metabolizable energy (kcal kg^{-1})	3700	3422	3196	3402	3238	3196
Crude protein (%)	9.30	9.56	10.13	10.96	11.79	10.40
Ether extract (%)	3.80	3.01	2.85	2.40	3.73	2.63
Crude fiber (%)	2.19	3.20	2.48	2.81	4.02	2.00
Ash (%)	1.31	1.13	1.29	1.37	1.53	1.46
Nitrogen-firee extract (%)	83.40	83.10	83.25	82.46	78.93	83.51
Calcium (%)	0.052	0.051	0.047	0.050	0.052	0.036
Phosphorus (%)	0.300	0.226	0.270	0.260	0.304	0.200
Grain mold scale[1]	Nil	2	2	2	3	2
Tannins (%) (catechin equivalent)	Nil	0.038	0.023	0.030	0.023	0.045
Aflatoxins (ppm)	Nil	0.0025	0.011	0.054	0.036	NA[2]
Fumonisin (ppm)	Nil	0.160	1.132	0.277	0.157	NA
Methionine (%)	0.18	0.15	0.16	0.17	0.17	NA
Cystine (%)	0.19	0.17	0.18	0.18	0.19	NA
Methionine (%) + cystine (%)	0.37	0.32	0.34	0.35	0.36	NA
Lysine (%)	0.27	0.20	0.20	0.20	0.22	NA
Threonine (%)	0.32	0.27	0.29	0.30	0.33	NA
Tryptophan (%)	0.07	0.09	0.10	0.11	0.12	NA
Arginine(%)	0.44	0.33	0.34	0.36	0.40	NA
Isoleucine(%)	0.31	0.31	0.35	0.36	0.40	NA
Leucine (%)	1.07	0.99	1.16	1.19	1.31	NA
Valine (%)	0.42	0.40	0.45	0.47	0.51	NA

1. Threshed grain mold rating (TGMR) on a 1-5 scale, where 1 = no mold, 2 = 1 to 10% grains molded, 3 = 11 to 25% grains molded, 4 = 26 to 50% grains molded and 5 = > 50% grains molded.
2. NA = Data not available.

Dixit and Baghel (1997) observed lower feed cost kg^{-1} body weight gain on sorghum diets than maize diets.

The second trial on part-by-part replacement (maize with sorghum) also indicated that sorghum could totally replace maize (56 parts in starter and 60 parts in finisher diets) without affecting broiler performance. The feed cost per kg live weight gain was lower with CSV 15 (Rs 17.16) and PSV 16 (Rs 17.62) than with maize (Rs 18.02) (Table 2). Further, pelletization improved the broiler performance over the mash feed in the sorghum diets (Table 3). Despite the increased feed cost (by Rs 0.25 kg^{-1}) on pellet feeds, the efficiency of broiler production was better on sorghum pellets than on mash (Table 3). Inclusion of Stylosanthes leaf meal at 3% in 100% sorghum-based

Table 2. Relative performance of broilers fed on sorghum-based and maize-based feed rations.

Cultivar	Grain inclusion level (%)	Body weight gain[1] (g)	Feed consumption[2] (g)	Feed efficiency[3]	Cost of feed kg^{-1} live weight gain[4] (Rs)
Yellow maize	100	1779	3298	1.854 ab	18.02 bc
CSV 15	50	1757	3302	1.879 a	18.40 abc
	75	1816	3279	1.805 abcd	17.75 bcd
	100	1845	3220	1.745 cde	17.16 d
CSH 16	50	1781	3195	1.794 bcd	18.24 abc
	75	1888	3214	1.702 e	18.05 bc
	100	1833	3217	1.755 cde	18.47 ab
PSV 16	50	1755	3163	1.803 abcd	17.93 bcd
	75	1841	3261	1.771 cde	17.66 bcd
	100	1799	3171	1.762 cde	17.62 cd
S 35	50	1863	3282	1.762 cde	17.92 bcd
	75	1793	3275	1.826 abc	19.02 a
	100	1821	3283	1.802 abcd	19.03 a
Local sorghum	50	1812	3242	1.790 bcd	17.97 bed
	75	1800	3153	1.751 cde	18.25 abc
	100	1795	3098	1.726 de	17.89 bcd

1. Birds were 6 weeks old. Values are not significant.
2. Values are not significant.
3. Feed kg^{-1} live weight gain; values followed by the same letter are not significantly different at 5% level.
4. Values followed by the same letter are not significantly different at 5% level.

Table 3. Relative performance and economics of sorghum-based and maize-based feed rations (pellet and mash forms) on broilers[1].

Treatment	Body weight gain[1] (g)		Feed intake (g)		Feed conversion ratio		Feed cost (Rs kg^{-1} feed)		Feed cost (Rs kg^{-1} live weight gain)	
	Mash	Pellet	Mash	Pellet	Mash	Pellet	Mash	Pellet	Mash	Pellet
Maize 100% (control)	1961 bc	1942 bcd	3495	3500	1.81	1.80	11.54	11.79	21.01	21.37
Sorghum 50%	2000 cde	2081 e	3589	3533	1.79	1.70	11.36	11.61	20.17	19.36
Sorghum 75%	1871 ab	2033 de	3442	3651	1.84	1.80	11.18	11.43	20.46	20.31
Sorghum 100% + Stylosanthes 3%	1784 a	1974 cd	3512	3608	1.97	1.83	11.09	11.34	22.39	20.65
SEm±		33.9		0.023		49.7		–		–

1. Cost of maize and sorghum was Rs 6.00 kg^{-1} and Rs 5.40 kg^{-1}, respectively. Birds were 6 weeks old. Data are means of two trials. The grain used in the second trial is not cultivar specific.
2. Values followed by the same letter in a column are not significantly different at 5% level.

broiler diets improved the shank and skin color of carcass to a desired level. Carcass yields and abdominal fat on all sorghum diets as well as sorghum diet fortified with *Stylosanthes* meal were comparable to that of maize. Thus, it appears that pelletization of 100% sorghum-based diets with *Stylosanthes* leaf meal at 3%, besides improving the skin and carcass color, improved the feed conversion ratio and lowered the total feed cost for production of live broilers.

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References

AICSIP. 2003. Grain mould scaling. Annual report 2003. Hyderabad, Andhra Pradesh, India: AICSIP. 77 pp.

AOAC. 1984. Official methods of analysis. Arlington, USA: AOAC. pp. 187-188.

Feng-Yih YU and Furi-S Chu. 1996. Production and characterization of antibody against fumonisin B1. Jounal of Food Protection 59:992-997.

Dixit Rekha and Baghel RPS. 1997. Effect of feeding sorghum instead of maize on the performance of broilers. Indian Journal of Poultry Science 32:343-344.

Klein Ulrich, Bala Ravi S, Dayakar Rao B and **Yoganand B. 2000.** Industrial utilization of sorghum in India. Working Paper Series no. 4. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 38 pp.

Rama Rao SV, Praharaj NK, Raju MVLN, Mahapatra SC, Chawak MM and **Mishra SK. 1995.** Replacement of yellow maize with tannin free sorghum in white leghorn layer diet. Indian Journal of Poultry Science 30:76-78.

Socioeconomics

Economics of Improved Sorghum Cultivars in Farmers' Fields in Andhra Pradesh, India

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Introduction

India is the second largest producer of sorghum *(Sorghum bicolor)* in the world, producing 7.8 million t in 2001-02 (CMIE 2004). Sorghum in India is grown in the rainy season (June-October) on around 4.5 million ha and in the postrainy season (September-January) on around 5.4 million ha. In the state of Andhra Pradesh, rainy season sorghum is grown on 0.3 million ha, producing 0.29 million t of grain while the postrainy season sorghum accounts for 0.34 million ha producing 0.35 million t of grain (Government of Andhra Pradesh 2003). Generally, resource-poor small farmers in the semi-arid regions of Andhra Pradesh with less than 1 ha of land grow sorghum. The crop is mainly cultivated under semi-subsistence farming to meet household requirements of food and fodder with a small marketable surplus. While postrainy season sorghum is almost completely used for human consumption, rainy season sorghum, which is used for food, is also used for non-food purposes such as poultry and livestock feed, and alcohol and starch manufacturing (Klein et al. 2000). Lack of availability of rainy season sorghum in bulk quantities and assured supplies is one of the main reasons constraining its usage in industry. High per unit cost of production of local sorghum and unremunerative grain price reduce its profitability to farmers. Although about 35% of marketable surplus is available, these are often scattered and hence non-economical to procure in sufficient bulk quantities by industrial users (Marsland and Parthasarathy Rao 2000).

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, along with Acharya NG Ranga Agricultural University (ANGRAU), Hyderabad, India has been implementing a project, funded by the Department for International Development (DFID), UK, in collaboration with the non-governmental organizations (NGOs), Federation of Farmers' Associations (FFA) and Andhra Pradesh Poultry Federation (APPF), and Janaki Feeds, a private poultry feed manufacturer.

The objective of the project is to enhance the access and availability of rainy season sorghum grain for poultry feed rations. Under this project, improved sorghum cultivars were identified and were distributed to selected farmers in target villages in Andhra Pradesh during the rainy season in 2003. Subsequently, attempts were made by the coalition partners to create a sustainable marketing linkage between sorghum growers and the poultry industry through innovative institutional systems. This article briefly highlights the economic returns of the improved sorghum cultivars compared to traditional varieties.

Materials and Methods

The Mahbubnagar and Ranga Reddy districts of Andhra Pradesh, where rainy season sorghum cultivation is predominant, were selected for the implementation of project activities at the field level. After a thorough study of district profiles, four mandals (two from each district) were selected. Based on the response from farmers to participate in project activities, proximity of villages to regulated market yards, existence of farmers' clubs and associations, and accessibility of these villages in all seasons, four villages (one from each mandal) were

Table 1. Economic structure and performance of improved and local sorghum cultivars in two selected districts in Andhra Pradesh, India during rainy season 2003[1].

	Mahbubnagar		Ranga Reddy	
Cost / Income measure	Improved sorghum + pigeonpea	Local sorghum + pigeonpea	Improved sorghum + pigeonpea	Local sorghum + pigeonpea
Variable costs (Rs ha^{-1})				
Human labor[2]	2021.70	1238.20	1563.70	924.70
Bullock labor	1138.90	1327.10	1024.80	1292.00
Machine labor	458.60	-	175.10	-
Farmyard manure	481.60	410.30	201.00	183.70
Seed of main crop	125.90	57.70	128.40	52.60
Seed of intercrop	120.00	76.60	41.20	81.50
Fertilizer	772.10	712.10	523.70	508.00
Pesticides	182.30	323.80	316.80	260.60
Interest on working expenses	171.20	139.30	106.90	108.90
Subtotal	5472.30	4285.10	4081.60	3412.00
Fixed costs[3] (Rs ha^{-1})	1331.30	1337.90	1182.80	1166.30
Total cost (Subtotal + Fixed costs) (Rs ha^{-1})	6803.60	5623.00	5264.40	4578.30
Main crop (sorghum)				
Grain yield (kg ha^{-1})	1210	270	540	120
Price of grain (Rs 100kg^{-1})	419.20	428.00	428.00	412.00
Total value of grain (Rs)	5072.32	1155.60	2311.20	494.40
Fodder yield (kg ha^{-1})	2297	1900	1560	1260
Price of fodder (Rs 100kg^{-1})	21.10	22.30	20.10	22.80
Total value of fodder (Rs)	484.66	423.70	313.56	287.28
Intercrop (pigeonpea)				
Grain yield (kg ha^{-1})	520	380	330	250
Price of grain (Rs 100 kg^{-1})	1585.00	1585.00	1493.00	1493.00
Total value of grain (Rs)	8242.00	6023.00	4926.90	3732.50
Gross returns	13798.98	7602.30	7551.66	4514.18
Net returns	6995.38	1979.30	2287.26	-64.12
Output/input ratio	2.02	1.35	1.44	0.98

1. Total sample farmers surveyed: 69.
   Study area: two villages each from Mahbubnagar and Ranga Reddy districts.
2. Includes the wages paid for the hired casual labor and family labor.
3. Include the cost imputed for owned land rent and the expenditure made towards the land revenue, depreciation and interest on fixed costs excluding land rent.

Source: Survey **data** from Project villages.

selected for the study. Almost all the sorghum farmers in the selected villages were cultivating a traditional yellow sorghum variety, locally called *'patcha jonna'* which was intercropped with pigeonpea *(Cajanus cajan).* Sixty-nine sorghum growers spread over the four villages were selected randomly for this study.

Four improved high-yiekiing sorghum cultivars, CSH 16, CSV 15, PSV 16 and S 35, suitable for the agroclimatic area and known to be less susceptible to grain mold attack were supplied to the selected farmers for sowing in 2003. All farmers grew pigeonpea (local variety) as an intercrop along with sorghum with a row arrangement of 5:1 (sorghum : pigeonpea). The seed was treated with Endosulfan dust and packed in cloth bags. Each bag of 3.5 kg seed is sufficient for sowing 0.4 ha as a sole crop. An information brochure printed in the local language was supplied along with the seed bag to enable the farmers to follow the recommended cultivation practices. A postharvest survey was conducted through structured schedules by direct interview methods to assess the cost-return profile of improved sorghum cultivars supplied under me project.

Results and Discussion

Around 26% of me project farmers grew the traditional sorghum variety during me rainy season in 2003. The crop was harvested between me last week of November and the first week of December. Because of early season drought, the crop was exposed to long dry spells during bodi the vegetative growth and flowering stages and was also exposed to continuous rains during grain development which resulted in grain mold attack. Since improved as well as local sorghum cultivars were grown in similar agroclimatic conditions, the crop yields of both were comparable. The yield of improved sorghum cultivars (weighted average of all four) was higher than local cultivars by about 348% in Mahbubnagar district and 350% in Ranga Reddy district (Table 1). The cost of cultivation of improved cultivars was Rs 6803 ha^{-1} and Rs 5264 ha^{-1} compared to Rs 5623 ha^{-1} and Rs 4578 ha^{-1} for traditional cultivars in Mahbubnagar and Ranga Reddy districts, respectively. Despite higher cost of cultivation, the net returns/benefit-cost ratio obtained for the improved sorghum + pigeonpea intercropping system were higher in both districts. Also, per unit cost of production was lower man mat of traditional varieties in both the districts, ensuring higher profitability to the farmers. Similar results were reported by Kiresur et al. (1999). In Ranga Reddy district, the cultivation of local sorghum intercropped with pigeonpea gave negative net returns with less than unity benefit-cost ratio. This may have resulted from severe pod borer *(Heliothis armigera)* attack which drastically reduced pigeonpea yields as well as the yields of me main crop.

During field visits, farmers perceived that *CSV* 15 and CSH 16 performed better than PSV 16 and S 35 as these cultivars met the criteria for good quality and yield of grain and stover. Encouraged by the enthusiasm and response of farmers, improved cultivars were supplied to 546 farmers in 12 villages for the 2004 rainy season to allow for the scale-up of the project. Farmers are also keen to participate in collective marketing, dealing directly with poultry feed manufacturers for the grain to be produced in the 2004 rainy season.

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References

CMIE. 2004, Economic intelligence service: Agriculture. Mumbai, India: CMIE. 364 pp.

Government of Andhra Pradesh. 2003. Season and crop report of Andhra Pradesh. Hyderabad, India: Directorate of Economics and Statistics, Government of Andhra Pradesh. 434 pp.

Kiresur V, Pandey R and Mruthyunjaya. 1999. Determinants of adoption of modern sorghum production technology - the experience of Karnataka state. Indian Journal of Agricultural Economics 54(2): 155-168.

Kleih Ulrich, Bala Ravi S, Dayakar Rao B and **Yoganand B. 2000.** Industrial utilization of sorghum in India. Working Paper Series no. 4. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 38 pp.

Marsland N and Parthasarathy Rao, P. 2000. Marketing of rainy and post-rainy season sorghum in Andhra Pradesh, Karnataka and Maharashtra. Working Paper Series no. 1. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 40 pp.

Millet Research Reports

Genetic Enhancement and Breeding

Performance of a Male-sterile F_1 and its Inbred Parental Lines in Pearl Millet

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Introduction

Seed yield potential, stability of resistance to downy mildew (DM) *(Sclerospora graminicola)* and combining ability are the three key attributes defining the utility of a male-sterile line for hybrid development in pearl millet *(Pennisetum glaucum).* The male-sterile line 843A is the inbred seed parent of several early-maturing commercial hybrids in India (Stegmeier et al. 1998). Considering the vulnerability of inbred seed parents and their single-cross hybrids to DM in India (Hash 1997) and the high value of 843A in hybrid breeding, the pearl millet research program at the International Crops Research Institute for the Semi-Arid Tropics (1CRISAT), Patancheru, India developed several DM resistant inbred seed parents as possible replacement for 843A. ICMA 95111 and ICMA 97444 are two such inbred seed parents. These lines as well as 843A are similar morphologically for basic features such as flowering time, plant height, panicle length, tillering ability and seed size. Seed yield of the seed parents is now gaining increasing importance in the seed production economy of hybrids. Earlier research showed that male-sterile F_1s may outyield their high-yielding inbred parental lines by 64-107% in hybrid seed production plots (Rai et al. 2000). These F_1s, however, were based on inbred lines having large morphological differences. The objective of this research was to examine the seed yield and DM resistance advantage of a male-sterile F_1 produced by crossing two morphologically similar inbred lines derived from substantially similar genetic backgrounds.

Materials and Methods

A yield trial, consisting of ICMB 97444, ICMB 95111, a male-sterile F_1 hybrid produced from a cross between ICMA 95111 x ICMB 97444 and 843B (check), was conducted in the Alfisols at ICRISAT-Patancheru during the 2001 rainy season and 2002 postrainy season in 4-row plots, each row of 4 m length, in a randomized complete block design with four replications. Plant spacing was 75 cm x 10 cm. The plots were fertilized with 46 kg N ha^{-1} and 18 kg P_2O_5 ha^{-1} as a basal dose, with an additional 35 kg N ha^{-1} topdressed twice at 20 and 30 days after planting. Time to 50% flowering was recorded on the plot basis. Panicles from all four rows were harvested, sun-dried and threshed to determine grain yields. Plant height was determined from a random sample of five plants. Main panicles of these plants were used to determine panicle length (cm) and panicle diameter (mm). Number of panicles per plant was determined from plant count and panicle count data. A random sample of 200 seeds was weighed to determine 1000-seed mass (g).

A greenhouse seedling inoculation technique (Singh and Gopinath 1985) was used to evaluate DM resistance for four diverse pathotypes (Jalna, Durgapura, Patancheru and Jamnagar) under high disease pressure. Seedlings grown in two pots (total of 50-60 seedlings) per entry constituted a plot. The experiment was conducted in a randomized complete block design with five replications.

Results and Discussion

The average seed yield of the trial in the 2001 rainy season was 2243 kg ha^{-1}, 16% more than that in the 2002 summer season (Table 1). The two inbred parental lines ICMB 95111 and ICMB 97444 had similar mean yields, which was 18% higher than that of 843B (Table 1). The male-sterile F_1 had 22% higher mean yield than the highest yielding inbred parental line ICMB 97444. The hybrid flowered two days later than 843B, while the parental inbred lines flowered 3-5 days later than 843B. These results of male-sterile F_1s are consistent with research reported earlier where male-sterile F_1s had been developed from inbred lines of diverse morphological traits and genetic backgrounds (Rai et al. 2000).

The likely phenotypic variability in three-way hybrids resulting from the use of male-sterile F_1s is generally expressed as a major concern. Flowering time, plant height, panicle length and panicle girth are the four most striking traits for which this variability concern may arise. Genetic difference of 2-3 days for earliness in seed parents, as observed in this study, is small in magnitude, but it is important from the viewpoint of synchronizing with the flowering of the restorer parent in seed production plots. Such a small magnitude of difference, however, is of no practical significance in commercial

Table 1. **Grain yield and agronomic traits[1] of a peart millet male-sterile F_1 (ICMA 95111 x ICMB 97444) and its parental inbred lines, rainy season 2001 (2001R) and summer season 2002 (2002S) at ICRISAT, Patancheru, India.**

Seed parent	Grain yield (kg ha^{-1})			Days to 50% flowering	Plant height (cm)	1000-seed mass (g)	Panicle length (cm)	Panicle diameter (mm)	Number of panicles plant^{-1}
	2001 R	2002S	Mean						
ICMA 95111 x ICMB 97444	2804	2241	2523	42	86	11.1	16	26	2.9
ICMB 95111	2266	1804	2035	43	82	10.6	15	26	2.7
ICMB 97444	2161	1968	2065	45	90	12.2	16	27	2.6
843B (check)	1742	1719	1731	40	78	11.6	16	24	2.7
Mean	2243	1933	2088	42	83	11.4	16	25.6	2.7
LSD (0.05)	297.4	87.1	153.6	0.5	3.2	0.6	0.6	0.6	0.3
CV(%)	8.8	3.0	7.0	1.2	3.7	5.2	3.9	2.4	8.7

1. Data are means of two seasons.

Table 2. Downy mildew incidence in a pearl millet male-sterile F_1 (ICMA 95111 x ICMB 97444) and its parental inbred lines against four pathotypes of *Sclerospora graminicola* under greenhouse condition at ICRISAT, Patancheru, India.

Seed parent	Downy mildew incidence (%)			
	Patancheru	Durgapura	Jalna	Jamnagar
ICMA 95111 X ICMB 97444	0.0	0.9	1.2	1.5
ICMB 95111	0.0	0.8	1.3	0.0
ICMB 97444	2.6	8.4	3.8	8.5
843B (check)	93.8	94.8	8.2	91.3
Mean	24.1	26.3	3.6	25.3
LSD (0.05)	1.4	1.5	1.9	1.4
CV(%)	4.6	4.6	37.9	4.3

crops of hybrids. Similarly, differences of 4-8 cm for plant height, 1 cm for panicle length and 1 mm for panicle diameter, though statistically significant, are of no practical significance in a commercial hybrid crop. Further, these differences are likely to be blurred to a considerable extent with the use of non-d_2 pollen parents having longer and thicker panicles (which behave as complete to partial dominant traits) as compared to these seed parents; this would mostly be the case, as these seed parents have characteristic features of dwarf height and short panicles of below average thickness. These aspects and the extent of heterosis in three-way hybrids as compared to those in single-cross hybrids need to be investigated.

Although the male-sterile F_1 and its parental lines were highly resistant to all four pathotypes of DM, the DM incidence levels among these lines varied, and the differences were statistically significant (Table 2). ICMB 95111 was the most DM resistant line with 0-1.3% DM incidence, followed by ICMB 97444 that had 2.6-8.5% DM incidence under high disease pressure (>90% DM incidence in 843B against three of the four pathotypes). The DM resistance of the male-sterile F_1 was similar to that of the more resistant parental line ICMB 95111. This supports previous findings (Rai et al. 2000) and indicates complete dominance of resistance over susceptibility, implying the usefulness of this approach in DM management. The F_1 seed parent approach is also useful in resistance gene deployment (Witcombe and Hash 2000) including enhancement of intra-locus genetic diversity and inter-locus combination of alleles for DM resistance at the hybrid seed production stage. Though such intra-locus diversity for DM resistance in F_1 seed parents will be lost in the three-way hybrids, its practical consequences are negligible if the restorer line involved in three-way hybrids is DM resistant.

References

Hash CT. 1997. Research on downy mildew of pearl millet. Pages 121-128 *in* Integrating research evaluation efforts: proceedings of an International Workshop, 14 -16 Dec 1994, ICRISAT, Patancheru, India (Bantilan MCS and Joshi PK, eds.).

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

Rai KN, Chandra S and **Rao AS. 2000.** Potential advantages of male-sterile F, hybrids for use as seed parents of three-way hybrids in pearl millet. Field Crops Research 68:173-181.

Singh SD and **Gopinath R. 1985.** A seedling inoculation technique for detecting downy mildew resistance in pearl millet. Plant Disease 69:582-584.

Stegmeier WD, Andrews DJ, Rai KN and **Hash CT. 1998.** Pearl millet parental lines 843 A and 843 B. International Sorghum and Millets Newsletter 39:129-130.

Witcombe JR and **Hash CT. 2000.** Resistance gene deployment strategies in cereal hybrids using marker-assisted selection gene pyramiding, three way hybrids, and synthetic parent population. Euphytica 112:175-186.

Effectiveness of Within-progeny Selection for Downy Mildew Resistance in Pearl Millet

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Introduction

Development of trait-specific breeding lines with high grain yield and resistance to downy mildew (DM) *(Sclerospora graminicola)* is a major research and development objective of the pearl millet improvement program at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India. While selecting for grain yield and agronomic traits during the course of inbreeding and generation advance, it is not uncommon to find progenies that have good combinations of these traits, but have unacceptable levels of DM susceptibility. The question, therefore, arises as to whether or not such progenies should be discarded from further selection, or can within-progeny selection be used to improve resistance to acceptable levels. A high-tillering and early-maturing Mandor Restorer Composite (MRC) has recently been jointly developed by ICRISAT and the All India Coordinated Pearl Millet Improvement Project (AICPMIP) Unit at Mandor, Rajasthan from diallel crosses among 10 diverse restorer lines selected for high tillering, early maturity and adaptation to dry environments of northwestern India. During the course of S_2 progeny selection in this composite, it was observed that several progenies with outstanding performance for grain yield potential, high tillering ability, and other agronomic traits were highly susceptible to DM assessed in unreplicated single pots (30-40 seedlings) under high disease pressure in the greenhouse. The objective of this study was to determine whether single-pot DM screening of a limited number of seedlings would be effective enough for mass evaluation of a large number of progenies in a breeding program, and whether within-progeny selection would be effective to improve the DM resistance to acceptable levels.

Materials and Methods

Based on the visual assessment of agronomic performance of 1200 S_2 progenies in an unreplicated observation nursery during summer 2002 at Patancheru and DM incidence against Durgapura pathotype (Sg 212) in a greenhouse seedling screening (Singh and Gopinath 1985) done in unreplicated single pots consisting of 30-40 seedlings (hereafter referred to as screen 1), a large proportion of the progenies in the test were selected for further selection and R-line development. Using remnant seed, 51 progenies with high agronomic scores were re-screened in unreplicated two pots with a total of 50-60 seedlings (hereafter referred to as screen 2). Eighteen of these progenies tracing to as many different S_1 progenies and with varying DM incidence levels were selected for conducting the DM resistance selection efficiency trial. The DM incidence in the inoculated seedlings was recorded and the DM-free seedlings of each progeny were transplanted. Selfed seeds from 8 to 10 plants from each progeny were bulked to generate selected S_3 progeny bulks. Using the remnant seed, these 18 S_2 progenies were also grown in the field under disease-free condition, and seeds of 8-10 selfed plants were bulked to produce unselected S_3 progeny bulks. These 36 progenies along with two susceptible checks (7042S and 843B) were evaluated in the greenhouse under high disease pressure (>90% DM incidence in 843B and 7042S) in a split-plot design with four replications. Progenies were treated as main plots, and selected and unselected bulks as sub-plots. A plot consisted of two pots, each with 30 seedlings. The experiment was repeated twice and the two experiments were analyzed as two environments. Since the genotype x environment interaction was not significant, pooled residual from combined analysis of the data from both experiments was used for statistical test of significance.

Results and Discussion

The disease pressure in all three tests was very high with >90% DM incidence in bom the susceptible checks 7042S and 843B (Table1). The DM incidence among the

Table 1. Downy mildew (DM) incidence in S_2 and S_3 progenies derived from Mandor Restorer Composite against Durgapura pathotype (Sg 212) under greenhouse conditions at ICRISAT, Patancheru, India.

	DM incidence (%) in S, progeny[1]		DM incidence (%) in S_2 progeny[2]	
Progeny	Unselected	Selected	Screen 1	Screen 2
MRC HS-82-2-1	9	15	10	29
MRC HS-84-2-2	48	24*	35	68
MRC HS-86-1-2	51	49	51	47
MRC HS-98-3-1	33	23	29	11
MRC HS-130-6-5	35	14*	36	54
MRC HS-139-4-2	22	17	41	45
MRC HS-142-3-6	28	22	46	34
MRC HS-161-3-2	29	38	19	30
MRC HS-167-4-2	36	29	26	21
MRC HS-176-5-1	31	20	24	19
MRC HS-178-1-3	48	29*	20	22
MRC HS-179-1-2	48	33*	57	64
MRC HS-183-2-2	13	20	14	13
MRC HS-192-2-1	6	2	15	7
MRC HS-198-1-1	8	4	17	0
MRC S1 - 1 - 1	69	61	53	68
MRC S1-122-1	48	19*	41	66
MRC S1-467-2	72	46*	30	78
Control (susceptible)				
7042S		96	93	100
843B		90	93	100
LSD (0.05)		13	-	-

1. Mean of 4 replications; * = Significant at 5% level.
2. Unreplicated data.

S_2 progenies varied from 10 to 57% in screen 1 and from 0 to 68% in screen 2, with a highly significant positive correlation (r = 0.75; *P<0.01)* between the DM incidence in the progenies in the two screens. This suggests that for mass screening of the breeding lines where rejection rather than selection at high intensity is the primary objective, single-pot DM screening is adequate to economize resources. There was only a marginal increase in the correlation for DM incidence in S_2 progenies in screen 2 and the unselected set of the S_3 progenies (r = 0.78; P<0.01). These strong relationships could be attributed to the high heritability of DM resistance under high disease pressure and uniform inoculum distribution under the controlled greenhouse screening.

There were significant differences (P<0.05) between the selected and unselected versions in the six S_3 progenies with the DM incidence levels in the selected versions reduced from half to one-third of those in the unselected versions (Table 1). The lack of response in other progenies could be because some of them were initially resistant (<8% DM incidence in two progenies), while the other susceptible ones could have less genetic variability for resistance, leading to poor phenotypic selection response. Also, the DM incidence in the six selected progenies varied from 14 to 46%, indicating that one-stage selection during the inbreeding process, even under very high disease pressure, was not effective in improving the resistance to acceptable levels, generally considered to be <10%. Two alternative options that might improve the DM resistance levels of these responsive progenies within the acceptable range are: (1) Further multi-stage phenotypic selection during the inbreeding process; and (2) Progeny-based selection. Exploitation of residual variability to select for DM resistance in the otherwise susceptible inbred lines using pedigree breeding has been shown to be effective (Singh et al. 1988, 1992). The most successful example of this selection approach is the development of resistance in ICMA 841 and ICMB 841 from their otherwise susceptible versions 5141A and 5141B (Singh et al. 1990), which are the seed parents of a most widely cultivated hybrid Pusa 23 in India. Progeny selection for DM resistance under high disease pressure in the greenhouse has been found to be effective in developing highly DM resistant versions of two commercially released maintainer lines and a restorer line (CT Hash, ICRISAT, Patancheru, India, personal communication). Thus, if a population progeny has been found to possess excellent combination of high yield potential and agronomic traits, but is moderately susceptible to DM, within-progeny selection for DM resistance may be pursued. However, the likelihood of its effectiveness in improving the resistance to an acceptable level will depend on the genetic variability for DM resistance in the progeny.

References

Singh SD and **Gopinath R. 1985.** A seedling inoculation technique for detecting downy mildew resistance in pearl millet. Plant Disease 69:582-584.

Singh SD, Singh P, Andrews DJ, Talukdar BS and **King SB. 1992.** Reselection of pearl millet cultivar utilizing residual variability for downy mildew reaction. Plant Breeding 109:54-59.

Singh SD, Singh P, Rai KN and **Andrews DJ. 1990.** Registration of ICMA 841 and ICMB 841 pearl millet parental lines with cytoplasmic-genic male sterility system. Crop Science 30:1978.

Singh SD, Williams RJ and **Malla Reddy P. 1988.** Isolation of downy mildew resistant lines from a highly susceptible cultivar of pearl millet, Indain Phytopathology 41:450-456.

Evaluation of New Grain Pearl Millet Hybrids in Australia

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Introduction

Sorghum *(Sorghum bicolor)* is the predominant dryland summer crop in northern Australia, grown as a feed grain for intensive livestock industries such as poultry, cattle and pigs. However, the dryland cropping environments of central and southwestern Queensland are highly variable and characterized by unpredictable rainfall and summer temperatures (>40°C). Increasingly the feed grain industry is looking for alternative crops to spread production risks and stabilize grain supply.

Pearl millet *(Pennisetum glaucum)* is a potential new crop for the Australian grains industry; it has a short crop duration and is grown widely across the semi-arid tropics of Africa and the Indian subcontinent in environments similar to those of northern Australia. As a high-protein coarse grain, pearl millet will find its key market as an alternative feed grain to sorghum in the intensive production of monogastric animals such as poultry and pigs (Singh and Perez-Maldonado 2003). High-yielding grain pearl millets developed in India and the United States retain the grain quality and' early maturity of traditional pearl millets but are of dwarf stature and well suited to mechanized farming systems. Since these new pearl millets have been successfully produced and marketed in the United States (Andrews et al. 1995), the challenge now is to develop a grain pearl millet industry in Australia.

Materials and Methods

Hybrid seed production. Eighty-six F_1 hybrids of grain pearl millet were produced in February 2002 (32 hybrids) and September 2002 (54 hybrids) in hand-pollinated nurseries at the Queensland Department of Primary Industries and Fisheries (QDPI&F) Biloela Research Station in central Queensland (24°22' S, 150°31' E). Nine male sterile lines in the A_4 cytoplasmic male sterility system (CMS) were crossed in all combinations with nine R_4 restorer lines. Four hybrids were produced from line 59135A4 and a single hybrid (293 A5 x NM-7R 1R5) was available in the A5 CMS.

Evaluation of hybrids. Pearl millet hybrids were evaluated against four check lines; open-pollinated pearl millet breeding lines, NPM-1 (Andrews and Rajewski 1995a) and NPM-3 (Andrews and Rajewski 1995b), and two early-maturing commercial sorghum hybrids (referred to as sorghum #1 and sorghum #2). Trials were planted in September 2002 (spring) and February 2003 (autumn) at Biloela Research Station under high fertility levels (69 kg N ha^{-1} in spring, 92 kg N ha^{-1} in autumn) and with supplementary irrigation. In both trials hybrids were planted in twin-row plots of 7 m length with 1 m row spacing. Trial design was a randomized complete block design with four replications. Established plants were hand-thinned to an effective plant population of 10 plants m^2. Phenology observations were recorded every second day from flag leaf emergence; anthesis was recorded as the day on which stigmas emerged on 50% of the main tiller panicles within each plot. Trial plots were cut to 5 m length and harvested with a small plot mechanical header. Grain mass was measured as the mass of one thousand seeds from a single sample taken from each replication in the autumn trial. No replicated data on grain size was available from the spring trial.

Results and Discussion

Grain yield. Significant differences between yields of pearl millet hybrids in the spring trial (P <0.001) were due to general combining ability of female and male parents (P <0.001) (Table1). Female lines 59041wA4 (mean grain yield 3.3 t ha^{-1}) and 183A4 (mean grain yield 3.1 t ha^{-1}) produced higher yielding hybrids than other female lines (iP<0.001). Hybrids using male line 4AmRm (mean grain yield 3.2 t ha^{-1}) performed significantly better than those of other male parents *(P <0.001)*. Grain yields of some of the elite pearl millet hybrids were comparable to those of sorghum hybrids (sorghum #1 3.9 t ha^{-1} and sorghum #2 3.6 t ha^{-1}); 59041wA4 x 4AmRm was the highest yielding pearl millet and the only hybrid to yield higher than open-pollinated pearl millet checks, NPM-1 (2.91 ha^{-1}) and NPM-3 (3.21 ha^{-1}) (P<0.001).

In the autumn trial significant differences between hybrid grain yields were explained by specific combining ability (P <0.01) and the general combining ability of female and male parents (P <0.001) (Table 2). Lines 183A4 (mean grain yield 4.3 t ha^{-1}) and 59041 wA4 (mean grain yield 3.91 ha^{-1}) were the best performing females (P <0.001); 4Rm (mean grain yield 3.9 t ha^{-1}) and 4AmRm (mean grain yield 3.9 t ha^{1}) were the best performing males. Elite pearl millet hybrids such as 183A4 x 4AmRm (4.8 t ha^{-1}), 183A4 x 1056-58016R4 (4.6 t ha^{-1}), 183A4 x 9Rm4Rm (4.5 t ha^{-1}), 293A5 x NM-7R1R5 (4.3 t ha^{-1}) and 59041wA4 x 4AmRm (4.3 t ha^{-1}) were higher yielding than open-pollinated NPM-3 (3.8 t ha^{-1}), the mean millet hybrid (3.6 t ha^{-1}) and both sorghum hybrids (sorghum #1 1.4 t ha^{-1} and sorghum #2 3.3 t ha^{-1}) (P<0.001). Sorghum treatments suffered a marked yield loss due to sorghum midge *(Stenodiplosis sorghicola)* and ergot *(Claviceps africana).*

Grain size. Significant differences between grain size of pearl millet hybrids (measured as mass of one thousand seeds) was evident in the autumn trial. Differences were due to specific combining ability (P <0.001) and the general combining ability of female and male parents (P <0.001) (Table 3). Hybrids 183A4 x 4Rm (16.4 g), 59041wA4 x 4Rm (15.6 g), 68wA4 x 4Rm (15.5 g) and 68wA4 x 1056-58016R4 (15.2 g) had higher grain mass than the mean hybrid and open-pollinated pearl millets (P<0.001). Sorghum grain was two to three times heavier than pearl millet grain.

Maturity. In the spring trial pearl millet hybrids were marginally quicker to anthesis and physiological maturity

Table 1. Grain yield (t ha^{1}) of 32 hybrids of pearl millet, two open-pollinated pearl millet breeding lines and two commercial sorghum hybrids in spring 2002 yield trial in Queensland, Australia.

	Male parent				
Female parent	4AmRm	59026R4	68wR4	1163wR4	Mean (female)
59041wA4	3.8	3.3	3.4	2.9	3.3
183A4	3.4	3.3	2.9	2.8	3.1
293A4	3.5	2.9	2.4	2.5	2.8
378-2A4	3.0	2.5	2.5	2.7	2.7
59022A4	2.8	2.6	2.6	2.4	2.6
59135A4	3.2	2.4	2.5	2.3	2.6
413A4	3.1	2.5	2.3	2.5	2.6
NM-5A4	3.0	2.1	2.3	2.4	2.5
Mean (male)	3.2	2.7	2.6	2.6	2.8
Checks					
NPM-1	2.9				
NPM-3	3.2				
Sorghum #1	3.9				
Sorghum #2	3.6				
	P	LSD (P <0.05)			
Genotypes	<0.001	0.44			
Female parent	<0.001	0.22			
Male parent	<0.001	0.15			
Female parent x Male parent	0.208				
CV =11.0%					

Table 2. Grain yield (t ha^{-1}) of 86 hybrids of pearl millet, two open-pollinated pearl millet breeding lines and two commercial sorghum hybrids in autumn 2003 yield trial in Queensland, Australia.

	Male parent									
Female parent	4Rm	4AmRm	9Rm4Rm	1056-58016R4	1163wR4	58012R4	68wR4	86R1R4	59026R4	Mean (female)
183A4	4.6	4.8	4.5	4.6	4.2	4.2	3.9	4.0	3.7	4.3
59041 wA4	4.0	4.3	4.1	3.5	4.1	3.8	3.7	3.7	3.5	3.9
59135A4		3.8	-	-	3.8	-	3.6	-	3.5	3.7
293A4	4.2	3.9	3.7	3.8	3.4	3.6	3.5	3.5	3.0	3.6
NM-5A4	4.0	4.0	3.7	3.6	4.1	3.5	3.3	3.1	3.1	3.6
413A4	4.1	3.8	3.7	3.8	3.4	3.3	3.6	3.2	3.2	3.6
68wA4	3.4	3.7	3.7	3.7	3.3	3.7	3.3	3.7	3.6	3.6
378-2 A4	3.7	3.8	3.7	3.8	3.6	3.4	3.3	3.2	3.1	3.5
59022 A4	3.9	3.6	3.7	3.7	3.3	3.2	3.3	3.2	3.5	3.5
95M59668A4	3.3	3.3	3.1	2.9	2.9	2.9	2.9	2.4	3.1	3.0
Mean (male)	3.9	3.9	3.8	3.7	3.6	3.5	3.4	3.3	3.3	3.6
293A5 X NM-7R1 R5	4.3									
NPM-1	3.7									
NPM-3	3.8									
Sorghum #1	1.4									
Sorghum #2	3.3									

	P	LSD (P<0.05)
Genotypes	<0.001	0.44
Female parent	<0.001	0.15
Male parent	<0.001	0.15
Female parent x Male parent	<0.01	0.44

CV - 8.8%

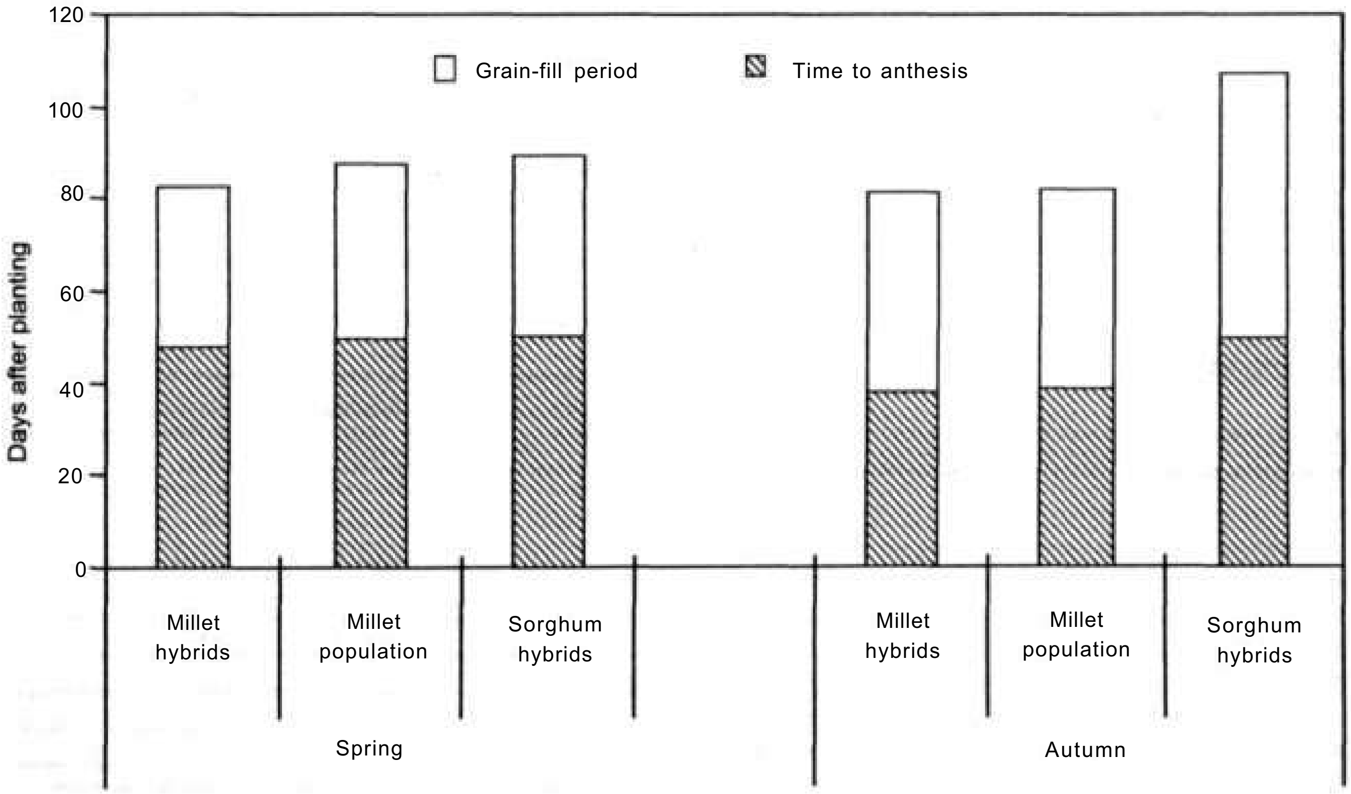

Figure 1. Phenology response of pearl millet and sorghum treatments in spring 2002 and autumn 2003 trials in Queensland, Australia.

Table 3. Mean 1000-seed mass of pearl millet and sorghum in autumn 2003 trial in Queensland, Australia.

Description		1000-seed mass (g)
Pearl millet hybrids		11.5
NPM-1		10.1
NPM-3		11.3
Sorghum #1		34.1
Sorghum #2		35.9
	P	LSD (P<0.05)
Genotypes	<0.001	1.3
Female parent	<0.001	0.4
Male parent	<0.001	0.4
Female parent x Male parent	<0.001	0.4
CV = 7.6%		

than sorghum treatments (83 days vs 87 days) (P<0.001, LSD = 3.3, CV = 2.9%) (Fig. 1). In the autumn trial pearl millet hybrids and open-pollinated lines flowered in less than 40 days and were significantly quicker maturing than sorghum hybrids (P <0.001, LSD = 1.6, CV = 2.9%). Pearl millet hybrids and open-pollinated populations were significantly quicker to physiological maturity than sorghum hybrids (82 days vs 107 days) in the autumn trial (P<0.001, LSD = 3.3, CV = 2.9%).

Accumulated thermal time to anthesis in pearl millet was 568°Cd in spring and 563°Cd in autumn (base temperature of 10°C). Physiological maturity occurred at 1135°Cd in spring and 1071°Cd in autumn. Since both experiments were conducted at daylengths close to or below the critical photoperiod of 12.9 h for pearl millet (van Oosterom et al. 2001), temperature was most likely the predominant factor in determining maturity in pearl millet.

Conclusions

In two yield trials completed in consecutive seasons at a single site, elite pearl millet hybrids produced grain yields **of up to 4.8 t ha^{-1} and took 83 days to reach physiological maturity. Yields were comparable to early-maturing grain sorghum hybrids and from an autumn planting pearl millets matured 25 days earlier than sorghums. Three parents exhibited high general combining ability for grain yield across both seasons. It is envisaged that female** lines **183A4 and 59041wA4 and male line 4AmRm will be** released to seed companies in **2004 and that** their hybrids will form the basis of a new commercial crop in Australia. Male lines such as **4Rm** and **9Rm4Rm** were evaluated in a single trial and also showed high general combining ability for grain yield; these and more recently released germplasm may warrant further research.

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References

Andrews DJ, Hanna WW, Rajewski JF and **Collins VP. 1995.** Advances in grain pearl millet: utilisation and production research. Presented at the Third National Symposium on New Crops: New Opportunities, New Technologies, October 22-25, 1995, Indianapolis, Indiana, USA.

Andrews DJ and **Rajewski JF. 1995a.** Registration of NPM-1 and NPM-2 grain pearl millet germplasms. Crop Science 35:597-599.

Andrews DJ and **Rajewski JF. 1995b.** Registration of NPM-3 grain pearl millet germplasm. Crop Science 35:1229.

Singh DN and **Perez-Maldonado R. 2003.** Pearl millet as an alternative feed grain for pigs and poultry. Asia-Pacific Journal of Clinical Nutrition 12:S40.

van Oosterom EJ, Carberry PS, Hargreaves JNG and **O'Leary GJ. 2001.** Simulating growth, development and yield of tillering in pearl millet. II. Simulation of canopy development. Field Crops Research 72:67-91.

Biotechnology

Linkage Groups Associated with Partial Rust Resistance in Pearl Millet

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Introduction

Partial rust resistance has been identified in pearl millet *(Pennisetum glaucum)* ICMP 501, and is expressed as longer latent period, reduced uredinium size, and lower area under the disease progress curve (AUDPC) in field epidemics (Wilson 1994). Quantitative genetic analysis conducted to determine the minimum number of loci conferring resistance in crosses with Tift 383 estimated that AUDPC was conferred by 2.5 genes (Wilson 1997). Confirming the inheritance of resistance and identifying markers associated with resistance will facilitate selection efforts. These studies were conducted to compare results of inheritance of resistance obtained from quantitative genetic analyses with segregation of molecular markers in a recombinant inbred population derived by single-seed descent from the cross Tift 383 x ICMP 501.

Materials and Methods

Fifty-one F_4: F_3 single-seed descent progenies, derived from multiple F_1s of the cross Tift 383 x ICMP 501 were evaluated for rust development in field epidemics at Tifton, Georgia, USA in 1994 and 1995. Four and three replications in 1994 and 1995 respectively, of single row plots were evaluated weekly for date of 50% anthesis. Rust severity was evaluated three times through the season. Severities were transformed to logits and regressed against days from anthesis by linear regression. Severities at 5-day intervals from anthesis to 30 days after anthesis were estimated from regression equations. AUDPC for the 30-day interval for each plot was calculated as described previously (Wilson 1997). The apparent infection rate in each plot was determined as the slope of the logit regression line against days from anthesis.

Progeny were also assessed in the greenhouse for whole plant latent period (T50, ie, time for 50% uredinium eruption on the entire plant after inoculation) and uredinium dimensions on the flag-1 leaf. Five replications (pots) with 3 plants per pot were inoculated with a bulk rust inoculum collected from a susceptible hybrid in the field in 1995. Plants were inoculated when panicles were half emerged from the boot. Percentage of infection sites with erupted uredinia were estimated over all three plants per pot and evaluated at one- to two-day intervals. Whole plant T50s were calculated as previously described (Wilson 1994). When pustule eruption was complete, the length and width of five random uredinia on the flag-1 leaves within a replication were measured.

Methods for DNA extraction, restriction enzyme digestion, gel electrophoresis, Southern transfer, probe labeling and hybridization were as described in Devos et al. (1992). Forty-four restriction fragment length polymorphism (RFLP) probes, spread over the seven pearl millet linkage groups (LGs), were mapped in a Tift 383 x ICMP 501 recombinant inbred line (RIL) population. To determine associations between traits and individual markers, trait means for the different alleles at each locus were calculated. A t-test was applied on the sample means to test whether differences between means were statistically significant.

Results and Discussion

The 44 probes detected 47 loci in the Tift 383 x ICMP 501 R1L population. In addition to residual heterozygosity in the F_4: F_5 RILs, some alleles were identified in the progeny that appeared to be unrelated to either parent. This may be explained by residual heterogeneity present in the 'inbred ' parents which can lead to different allele combinations being present in subsets of the population derived from different F_1S, or it may have occurred through outcrossing. The means of the different assessments and components of partial rust resistance associated with the alleles present in the population were calculated at each of the 47 RFLP loci. A t-test on the sample means demonstrated that differences ($P<0.01$) in expression of resistance among the progeny were associated with markers on LGs 1,3,5,6 and 7.

Three chromosome regions appeared to be conferring rust resistance in the field as measured by AUDPC. Significant differences ($P<0.01$) in AUDPC were associated with a distally located marker on LG 1, with three markers on LG 3 and two markers on LG 7. At all loci, low AUDPCs were associated with the alleles from ICMP 501, the resistant parent. None of these markers were associated with components of partial resistance measured in the greenhouse.

Eight markers from LG 5 were associated with differences in apparent infection rate ($P<0.01$) (Table 1). Three of these markers were also associated with latent

Table 1. Probabilities[1] associated with allelic segregation and measurements of partial rust resistance in F_4: F_5 single-seed descent pearl millet progenies derived from a cross of Tift 383 x ICMP 501. (Note: Markers for which associations were obtained only at the 5% significance level have not been listed.)

		AUDPC[2]			AIR[3]			Uredinium dimension				Heading date	
Locus	LG	1994	1995	Mean	1994	1995	Mean	Length	Width	Area	T50[4]	1994	1995
Xpsm347.2	1	*	*		NS	NS	NS	NS	NS	NS	NS	NS	NS
Xpsm592	2	NS	NS	NS	NS	*	NS	NS	NS	NS	*	NS	**
Xpsm73.3	2	NS	NS	NS	NS	*	NS	NS	NS	NS	*	NS	**
Xpsm443	2	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	••
Xpsm662.1	2	NS	*	NS	•	**	*	*	NS	*	*	*	***
Xpsm 850	3	**	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
Xpsm74	3	**	*	***	NS	NS	NS	NS	NS	NS	NS	NS	NS
Xpsm63	3	*	**	***	NS	NS	NS	NS	NS	NS	NS	NS	NS
Xpsm815	5	NS	NS	NS	***	***	***	NS	NS	NS	*	***	***
Xpsm318	5	NS	NS	NS	***	***	***	NS	NS	NS	NS	***	***
Xpsm345	5	NS	NS	NS	**	***	*#	NS	NS	NS	NS	*	*
Xpsm73.1	5	NS	NS	NS	**	*	**	*	NS	NS	NS	**	***
Xpsm653	5	NS	NS	NS	**	**	**	NS	NS	NS	NS	**	**
Xpsm47	5	NS	*	NS	**	**	**	NS	NS	NS	*	*	***
Xpsm607.2	5	NS	NS	NS	***	***	***	*	NS	NS	*	***	**•
Xpsm735.1	5	NS	NS	NS	***	+**	***	NS	NS	NS	NS	***	***
Xpsm870	6	NS	NS	NS	NS	NS	NS	NS	**	*	NS	NS	NS
Xpsm618	7	**	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS
Xpsm416.4	7	**	NS	**	NS	NS	*	NS	NS	NS	NS	NS	NS

1. * = Significant at 5% level; ** = Significant at 1% level; *** = Significant at 0.1% level; NS = Not significant.
2. AUDPC = Area under the disease progress curve.
3. AIR = Apparent infection rate.
4. TSO - Latent period, time for 50% uredinium eruption on the entire plant after inoculation in the greenhouse.

period (0.01<P<0.05). Lower apparent infection rates and longer latent periods were associated with the alleles from Tift 383. However, it should be noted that at these same loci, alleles from Tift 383 delayed flowering by an average of 10 days. The lower apparent infection rate conferred by these loci may thus represent an increased resistance associated with physiological maturity that was not fully corrected after adjusting the apparent infection rate for heading date. Supporting evidence for this is that alleles from Tift 383 on LG 5 were not significantly associated with lower AUDPC among the progeny. Tift 383 alleles conferring earlier flowering were identified on LG 2 in the 1995 trial. Similarly as on LG 5, the later flowering genotypes showed a reduced apparent infection rate.

Several loci were identified that showed an association with the length and width of the uredinia. However, most of these associations were significant only at the 5% level. At one locus located distally on LG 6, the presence of Tift 383 alleles significantly (P<0.001) reduced the width of the uredinia.

These results were obtained in only a small population and it is clear that they need to be confirmed. However, the identification of LG 1, LG 3 and LG7 associated with low AUDPC values agrees with the previous estimate of 2.5 loci determined earlier (Wilson 1997). The expression of resistance is greatest in ICMP 501, though Tift 383 was also found to possess a small but measurable level of resistance (Wilson 1994). This study identified markers on LG 1, LG 3 and LG 7 derived from ICMP 501, and markers on LG 5 derived from Tift 383 that were associated with greater levels of resistance among the single-seed descent progeny. The alleles from ICMP 501 likely confer true resistance while the alleles from Tift 383 most likely provide a maturity-related physiological resistance. Larger progeny sizes and greater precision in measuring the components and expression of partial rust resistance will be required to more accurately locate the alleles for resistance within these LGs.

References

Devos KM, Atkinson MD, Chinoy CN, Liu C and **Gale MD. 1992.** RFLP based genetic map of the homoeologous group 3 chromosomes of wheat and rye. Theoretical and Applied Genetics 83:931-939.

Wilson JP. 1994. Field and greenhouse evaluations of pearl millet for partial resistance to *Puccinia substriata* var. *indica.* Plant Disease 78:1202-1205.

Wilson JP. 1997. Inheritance of partial rust resistance in pearl millet. Plant Breeding 116:239-243.

Agronomy

Research Highlights of Millet-based Rainfed Nutritious Cereals Production System Under NATP

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Introduction

Millets are small-grained cereals and forage grasses used for food, feed or forage. Commonly cultivated millets are great millet or sorghum *(Sorghum bicolor; jowar),* pearl millet *(Pennisetum glaucum; bajra),* finger millet *(Eleusine coracana),* foxtail millet *(Setaria italica)* and kodo millet *(Paspalum scrobiculatum).* These are principal crops of rainfed agriculture which provide staple human diet and also feed and fodder for livestock. In India, millets are cultivated on approximately 22 million ha with a production of about 18 million t annually. Millets contain essential minerals such as iron and calcium besides adequate quantities of protein (7.3-12.5%), fat (3-5%) and more importantly a good amount of roughage. Owing to the presence of roughage, millets are well known for providing energy over a period of time after consumption. This feature is valuable for the working class (physical work) and glycemic-sensitive (diabetic)/gluten-sensitive persons as well as in the preparation of weaning foods. Due to these unique nutritional qualities they have been termed as "nutritious cereals".

In response to the emerging needs and future challenges facing the country's agricultural sector, the Government of India, with financial assistance from the World Bank, has implemented the National Agricultural Technology Project (NATP) to support agroecosystem-based research to enhance agricultural system efficiencies. Keeping in view the extent of diversity across agroclimatic regions of India, the programs under NATP were classified into different production systems. The priority setting process considered the potential contribution of improvements in productivity, stability or sustainability of each production system in order to address a range of national objectives such as national food security, household food security and poverty alleviation; environmental quality and conservation of biodiversity; sustainability in the use of natural resources; product diversification to enhance rural income; welfare of tribal people, women or other less advantaged groups; exploitation of commercially viable technologies; and enhancement of export potential.

The Indian Council of Agricultural Research (ICAR) group, the principal implementing organization of the NATP, has focused research on the rainfed agroecosystem. The Rainfed Nutritious Cereals-based Production System (RNPS) has greater importance in dryland farming systems which predominate the area. Under the RNPS, there were 25 projects involving 18 ICAR institutes and 20 state agricultural universities which geographically covered nearly two-thirds of the country. Experiments were conducted at different locations across the country during 2000/01 to 2002/03 and have given encouraging results. The research highlights encompassing six major thematic areas are presented in this report.

Improved Crop Management, Cropping System, Integrated Pest Management and Integrated Nutrient Management

Simple cost-effective practices such as seed treatment with Carbendazim (2 g kg^{-1} seed) to manage blast disease of finger millet, intercropping millets with pulses or vegetable crops and moisture conservation practice like

Table 1. Effect of seed treatment on grain yield (kg ha^{1}) of finger millet in different trials in India.

	Karnataka				Tamil Nadu	
Treatment[1]	Kolar	Chitradurga	Chamarajanagar	Hassan	(Dharmapuri)	Mean
T_1	1615	1390	1360	2360	1553	1656
T_2	1657	1588	1540	2753	1618	1831
T_3	3005	2035	1753	3586	2907	2657
T_4	3055	2275	1803	4200	3036	2874
CD at 5%	275.7	220.8	176.7	524.3	419.6	

1. T_1 = Local variety + untreated seed; T_2 = Local variety + Carbendazim seed treatment; T_3 = Variety GPU-28 + untreated seed; T_4 = Variety GPU -28 + Carbendazim seed treatment.

compartmental bunding (CB) improved yield substantially. Fourteen trials in Tamil Nadu, 46 trials in Karnataka and 23 trials in Uttaranchal revealed that an improved finger millet variety + seed treatment with Carbendazim had the highest grain yield of 2874 kg ha^{-1} compared to farmer's practice with local variety + untreated seed which yielded a maximum of 1656 kg ha^{-1} (Table 1).

In the On-Farm Adaptive Research (OFAR) trials, intercropping finger millet with pigeonpea *(Cajanus cajan)* in a ratio of 8:2 rows resulted in gross monetary returns of Rs 14,787 ha^{1} as compared to Rs 6,978 ha^{-1} with farmer's practice of sole cropping (Table 2). The results implied mat intercropping of medium- and short-duration varieties of base crop (finger millet) and medium-duration variety of pigeonpea (TTB-7) is a better choice as an insurance against drought conditions and enhances production over a sole crop.

Integration of moisture conservation practices such as CB with other components like nutrient management and intercropping improved not only soil health and water-use efficiency but also the yield. Adoption of CB + integrated nutrient management (INM) increased productivity in *rabi* (postrainy season) sorghum by 33 to 38% over farmer's practice. When this technology was combined with the best variety (CSV 216R), the yield increases were 72, 51, 30, 75, 64, 46 and 49% in Bellary, Bijapur, Raichur (Karnataka), Kurnool (Andhra Pradesh), Sangli, Satara and Solapur (Maharashtra), respectively with a mean increase of 55.2%. The corresponding yield gain with variety CSH 15R was 63, 44, 10, 63, 42, 29 and 40% (mean increase of 41.5%) over farmer's practice. A combination of CB + INM + CSV 216R recorded net returns of Rs 5,131 ha^{-1} in Bellary and Rs 5,049 ha^{1} in Kurnool compared to Rs 2,108

Table 2. Gross monetary returns from finger millet as influenced by intercrop management in On-Farm Adaptive Research (OFAR) trials in India[1].

	Gross monetary returns (Rs ha^{-1})			
Treatment	2001	2002	2003	Mean
Farmer's practice (sole crop)	7,270	7,365	6,300	6,978
Sole crop with recommended spacing	8,755	9,160	7,530	8,482
Finger millet + field bean intercrop	6,430	6,475	6,235	6,380
Finger millet + pigeonpea intercrop	17,925	16,995	9,440	14,787

1. Data are means obtained from 63 farmers across 15 villages in Karnataka, Tamil Nadu, Andhra Pradesh and Orissa.

Table 3. Influence of moisture conservation practices and nutrient management systems on gross monetary returns (Rs ha^{-1}) of pearl millet[1].

	Nutrient management systems[3]				
Moisture conservation practices[2]	N1	N2	N3	N4	Mean
M1	11449	11423	10312	11973	11289
M2	12364	12393	11546	13488	12448
M3	13891	14030	12892	16058	14218
M4	11925	12640	11842	13252	12414
Mean	12407	12622	11648	13692	
Treatments				CD at 5%	
Moisture conservation (M)				806.7	
Nutrient management (N)				806.7	
Interaction (M x N)				NS[4]	

1. Trials were conducted at the research stations located at Aurangabad, Dhule (Maharashtra), Bijapur (Karnataka) and Kovilpatti (Tamil Nadu).
2. M1 = Sowing across the slope; M2 = Ridges and furrows with tied ridging; M3 = Paired row planting at 30/60 cm and opening of furrows in wider rows at 35 days after sowing; M4 = intercropping of pearl millet with short growing legume in a ratio of 2:1 rows.
3. N1 = 100% recommended dose of fertilizer (RDF); N2 = 50% RDF + farmyard manure (FYM) at 2.S t ha^{-1} ; N3 = 50% RDF + bio - fertilizer *(Azospirillum)* seed treatment; N4 - 50% RDF + FYM at 2.5 t ha^{-1} + bio-fertilizer seed treatment.
4. NS = Not significant.

ha-[1] and Rs 2,589 ha^{-1}, respectively with no CB + farmer's practice.

A simple change of geometry from normal rows to paired rows has a dramatic increase in yield and improves moisture utilization as well as gross monetary returns in finger millet cultivation. It also provides sufficient space for intercropping. The performance of moisture conservation practices, paired row planting at 30/60 cm, opening of furrows in wider gap at 35 days after sowing (DAS) and INM system of 50% recommended dose of fertilizers (RDF) + farmyard manure (FYM) at 2.51 ha^{-1} + *Azospirillum* seed treatment recorded good grain yield of pearl millet and gross monetary returns of Rs 16,058 ha^{-1} compared to Rs 6,040 ha^{-1} obtained with farmer's practice (Table 3).

Rain Water Management and Watershed Development

Action plans for land and water resource development for different production systems in various watersheds/ micro-watersheds were pursued. Demonstrations of remote sensing techniques for characterization of watersheds and identification of critical areas based on soil limitations were also undertaken. Construction of water harvesting structures and use of mechanical or vegetative barriers for soil and water conservation were popularized.

Watershed development for rain water management in seven villages of Bihar, four villages in Uttar Pradesh, one village each in Himachal Pradesh, Haryana, Jammu and Kashmir and Punjab has shown that runoff during monsoon, which causes soil and nutrient losses and damage crops during *kharif* (rainy season), can be diverted safely to renovated village ponds. This harvested rain water can be recycled for supplemental irrigation to *rabi* crops and orchards. Increase in yield of wheat *(Triticum aestivum)* (from 1.35 to 3.82 t ha^{-1}) was recorded after providing critical irrigation from harvested rain water (Table 4). After implementation of the project, mean annual agricultural income in the watershed area increased from Rs 7,448 ha^{-1} to Rs 24,590 ha^{-1}.

Postharvest Technology and Value-addition

Millet crops also offer excellent feed/fodder to meet the needs of milch/draft and other domestic animals. Sweet sorghum fodder increases milk yields of milch animals as its green cane juice brix value matches that of sugarcane *(Saccharum officinarum)*. It can compete with sugarcane molasses in producing industrial grade alcohol without significant modifications of the sugar milling equipment.

Table 4. Comparison of yield of wheat and net annual agricultural income before and after implementation of watershed activities[1].

Yield / Net returns[1]	Before implementation (2001)	After implementation 2002	After implementation 2003
Average grain yield (t ha^{-1})	1.35	2.01	3.82
Average straw yield (t ha^{-1})	2.72	3.51	6.11
Net annual agricultural income (Rs ha^{-1})	7448	16210	24590

1. Data are means obtained from 15 farmers in the watershed command area in Uttar Pradesh and Bihar, India.

Table 5. Comparison of market value (Rs t^{-1}) realized from *kharif* sorghum harvested at different stages of maturity at different locations in India[1].

Treatment	Akola	Coimbatore	Parbhani	Mahbubnagar	Mean
Harvest at physiological maturity followed by artificial drying	3990	8070	4050	5510	5410
Harvest at normal maturity	2420	5830	2700	3010	3490
Increase (%)	65	66	50	83	55

1. Data are means obtained from five farmers in each location.

Many sugar industries have shown interest in this technology of sweet sorghum, which is not only of short duration but also less demanding of irrigation compared to sugarcane. It is also versatile in producing diversified raw material like grain and fodder, besides juice for biofuel (alcohol). The recommended sweet sorghum variety SSV 84 on an average produces 25 t ha^{-1} of cane yield with a brix of 18% as well as grain yield of 2 t ha^{-1}.

Kharif sorghum is invariably affected by molds. A relatively simple technology of harvesting panicles at physiological maturity and drying them artificially using a ventilating drier improves the quality of the grain. It also preserves the nutritional value and avoids molds/ mycotoxins. More importantly this technology significantly improves the market value and acceptability of the grain. Farmers were shown this technology and there was an increase of 65, 66, 50 and 83% of market value in Akola, Coimbatore, Parbhani and Mahbubnagar, respectively (Table 5). Since the ventilating driers cost Rs 175,000, a system of community-based ventilating driers was initiated in the project.

Diversification in Sorghum-based Production System

Under the RNPS program, farmers were encouraged to intercultivate millets or vegetables [tomato *(Lycopersicon esculentum),* brinjal *(Solanum melongena',* eggplant), chili *(Capsicum annuum),* beans *(Phaseolus vulgaris),* gourds *(Lagenaria* spp), drumstick *(Moringa oleifera),* curry leaf *(Murraya koenigii)* and other leafy vegetables] in the silvi-pasture system. It was observed that farmers preferred tree species (other than fruit trees) like teak *(Tectona grandis),* neem *(Azadirachta indica),* and *subabul (Leucaena leucocephala)* mainly on the farm bunds and in some cases as plantations.

Based on a survey, 12 **mango** *(Mangifera indica)* orchards in age groups of 2 years, 5-7 years and >10 years were selected in each district for conducting the on-farm trials in Karnataka. In each group, five intercrops [sorghum, cowpea *(Vigna unguiculata),* horse gram *(Dolichos uniflorus), Stylosanthes* and *Cenchrus]* were sown in all the targeted districts. At Dharwad, additional income was obtained by growing intercrops in mango orchards; eg, groundnut *(Arachis hypogaea)* (Rs 9,313 ha^{-1}) and sunflower *(Helianthus annuus)* (Table 6).

Dual-purpose and Product Utilization of Millets

Experiments were conducted to evaluate broiler feed using coarse cereals. Replacement of 50% of dietary maize *(Zea mays)* with pearl millet, and soybean *(Glycine max)* meal with combination of rape seed *(Brassica napus)* meal and sunflower seed meal, each at 5 or 10% level of diet supported optimum growth, feed-utilization efficiency and meat production in broiler chicks. Inclusion of 30% pearl millet, 5% rape seed meal and 5-10% sunflower seed meal replacing maize and soybean meal can be economical in broiler production without affecting feed utilization and growth rate. Alternatively foxtail millet can be incorporated by replacing 50% of dietary maize in broiler diets. It is significant to note that the concentration of serum lethal dosage level cholesterol can be decreased by incorporation of alternate energy sources in *Vanaraja* chick diet.

Low digestibility and deficiency of nutrients are the major constraints for achieving optimum milk production from livestock fed on millet crop residue rations. To supply the limiting nutrients, feed experiments were conducted and observed that the milk yield of cows increased by 1 to 1.2 L, the feed cost per animal reduced by Rs 3.60 to 2.70 and the farmer's income increased by

Table 6. Net monetary returns (Rs ha*[1]) obtained in mango-based production system at Dharwad, Karnataka, India.

Treatment	Gross returns of intercrop	Gross returns of main crop	Expenditure	Net income	Additional income
Sorghum in mango orchard	5712	71520	17000	63232	1492
Sunflower in mango orchard	7836	77940	17500	68276	6536
Groundnut in mango orchard	9268	79785	19500	71053	9313
Sole mango		76740	15000	61740	
CD at *5%*				7875.3	

Rs 13 to 15 cow^{-1} day^{-1} by adopting either maize kernel or wheat bran with groundnut cake in addition to finger millet straw as supplement.

Socioeconomic and Database Development

The RNPS has enabled introduction of new genotypes in farmers' fields whose productivity levels are higher than the existing ones as indicated in the results of OFAR.

There is increasing competition from competing crops especially in Maharashtra where sorghum area has been declining. The project outlined the importance of inter-cropping with higher targeted levels of sorghum productivity, so that the overall income would offset the decline of sorghum acreage. It assumes importance mainly because sorghum and other millets are the only staple food crops grown in these areas, thus assuring household food security and means of livelihood.

Looking Ahead

The NATP with focused programs has been proposed to continue beyond 2004. Many of the results summarized in this article have been implemented on a large-scale in adjunct programs, viz, Technology Assessment and Refinement through Institution Village Linkage Programme (TAR-IVLP) and Agricultural Technology Management Agency (ATMA). Encouraging results helped to improve the socioeconomic conditions of the poor and marginal farmers through mitigating the drought effect in dryland farming. It is hoped that millet-based rainfed nutritious cereal production system gains momentum for greater improvement in increasing productivity and in overall development of the region.

Pathology

Downy Mildew Incidence and Oospore Production by *Sclerospora graminicola* in Pearl Millet Hybrids in Maharashtra and Rajasthan

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Introduction

Downy mildew (DM), caused by *Sclerospora graminicola,* is a serious and widespread disease of pearl millet *(Pennisetum glaucum)* in India. Pearl millet F_1 hybrids are relatively more susceptible to DM than open-pollinated varieties. Because of increased cultivation of a number of genetically diverse F_1 hybrids in India, there has been corresponding shifts in virulence in the pathogen population. Currently at least five host-specific/ region-specific pathogen populations (pathotypes) are known to exist (Sivararnakrishnan et al. 2003). We monitor downy mildew resistance of hybrids and virulence of 5. *graminicola* through field surveys of farmers' crops and collect infected leaf samples containing oospores (sexual spores) for pathogenic characterization of the isolates in the greenhouse (Thakur et al. 2003). Oospores formed in the infected leaf tissues get mixed with field soil or seed and help in survival of the pathogen from one season to another, and thus serve as initial inoculum source for the next crop. During the DM surveys in Maharashtra and Rajasthan, India we recorded DM incidence and collected oospore samples (infected leaf samples) from some of the highly susceptible hybrids to study the relationship between disease incidence and oospore production on different hybrids.

Materials and Methods

Downy mildew surveys of pearl millet crops in fanners' fields were conducted during the rainy season 1993-2001 in eight districts (Ahmadnagar, Aurangabad, Beed, Dhule, Jalgaon, Jalna, Nashik and Pune) of Maharashtra and during the rainy season 1999 and 2001 in six districts (Ajmer, Alwar, Bharatpur, Dausa, Jaipur and Tonk) of Rajasthan for the prevalence of DM. A total of 115 fields grown with 14 hybrids in eight districts of Maharashtra and 20 fields grown with seven hybrids in six districts of Rajasthan were surveyed and data were recorded for DM incidence (Fig. 1 and Table 1). The DM incidence was recorded from five random subplots (with at least 50 plants in each subplot) in each field. Heavily infected leaf tissues (brown colored), likely source of oospores, were collected from each subplot and samples from all subplots in a field were pooled and considered as one isolate. The samples were sun-dried and ground into a fine powder using a mill with 0.2S mm sieve (Thomas-Willey Laboratory Mill, Thomas Scientific Co., Philadelphia, Pennsylvania, USA). Five mg of leaf powder from each isolate was suspended in 10 ml sterile distilled water and vortexed for a few minutes. One ml of the suspension was observed under a compound microscope for the presence of oospores. Oospores are round, brownish-yellow to dark brown with thick wall consisting of distinct layers of exosporium, mesosporium and endosporium. The number of oospores was counted, and total number of oospores mg^{1} leaf powder was calculated.

Results and Discussion .

DM incidence on hybrids. In Maharashtra, the number of fields for each cultivar varied from one in ICMH 451 to 26 in MLBH 26 and the mean DM incidence varied from 27% in Proagro 9330 to 55% in Eknath 201 (Table 1). The DM incidence across cultivars among districts varied from 4% in Beed to 30-79% in Nashik (Fig. 1). In Rajasthan, the number of fields for each hybrid varied from one each for GK 1004, Proagro 7701 and Proagro 9330 to six for ICMH 451 and the mean DM incidence varied from 16% in Proagro 9330 to 80% in BK 560 (Table1). The DM incidence across cultivars was 13% in Ajmer, 8-68% in Alwar, 16-80% in Bharatpur, 64% in Dausa, 39-71% in Tonk and 52-80% in Jaipur (Fig. 1).

Oospore production on hybrids. In Maharashtra, the mean number of oospores produced on hybrids varied from 37 in MLBH 308 to 9736 mg^{-1} leaf powder of ICMH 451 (Table1 and Fig.2). Similarly, the range of oospore production across cultivars also varied from 34-52

Table 1. Variation in downy mildew (DM) incidence and oospore production on pearl millet hybrids in Maharashtra and Rajasthan, India.

Hybrid cultivar	Isolate (field no.)	DM incidence (%)		No. of oospore mg^{-1} leaf powder	
		Mean ± SEm	Range	Mean ± SEm	Range
Maharashtra					
BK 560	4	33 ± 13.1	2-58	456 ± 41	4512-4688
Eknath 201	9	55 ± 7.2	20-82	2888 ± 671	6-5080
GK 1004	12	50 ± 7.4	5-95	2707 ± 952	44-8668
GK 1014	2	39 ± 9.5	29-48	653 ± 339	314-992
ICMH 451	1	34 ± 0	34	9736 ± 0	-
MLBH 104	25	35 ± 5.6	1-86	2460 ± 1009	4-25384
MLBH 267	26	44 ±4.8	5-86	910 ± 347	4-5952
MLBH 287	5	38 ± 4.6	20-45	1758 ± 991	60-4840
MLBH 308	2	32 ± 4.0	28-36	37 ± 21	16-58
Pioneer 7686	2	44 ± 12.5	31-56	45 ± 37	8-82
Proagro 7501	9	34 ± 6.8	3-72	1068 ± 619	8-5712
Proagro 7701	8	38 ± 10.1	1-80	1699 ± 839	12-6100
Proagro 9330	6	27 ± 8.9	4-53	38 ± 14	4-90
Vijay 4	4	30 ± 4.3	20-39	146 ± 90	12-408
Rajasthan					
Bioseed 8421	4	41 ± 16.3	8-86	2250 ± 1091	20-4146
BK 560	3	80 ± 1.9	76-82	437 ± 407	22-1250
GK 1004	1	68 ± 0	0	16 ± 0	-
ICMH 451	6	48 ±9.1	13-76	68 ±32	4-218
Pioneer 7686	4	55 ± 3.1	22-80	4464 ± 1102	• 1490-6268
Proagro 7701	1	37 ± 0	0	4092 ±0	-
Proagro 9330	1	16 ± 0	0	180 ± 0	-

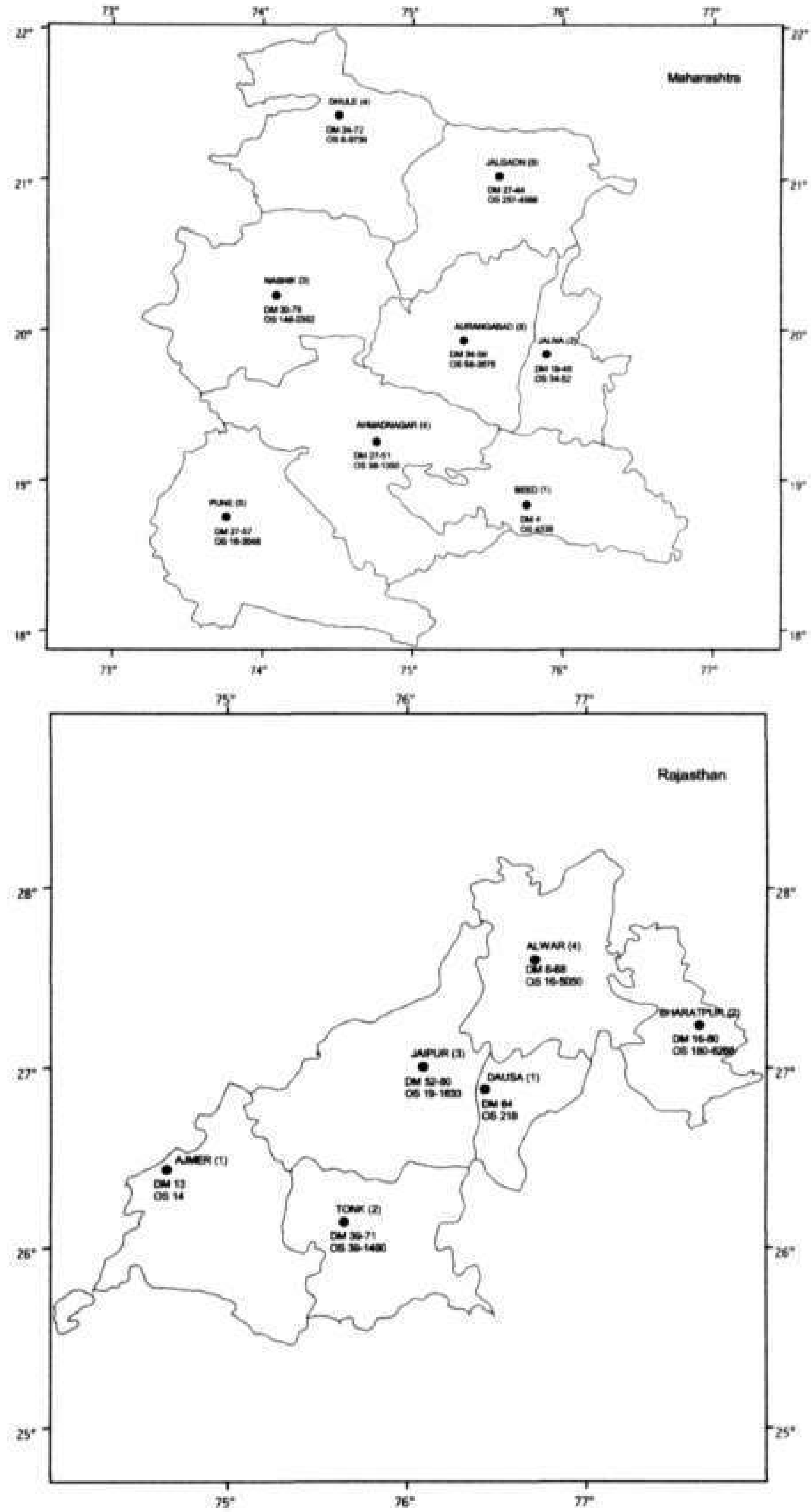
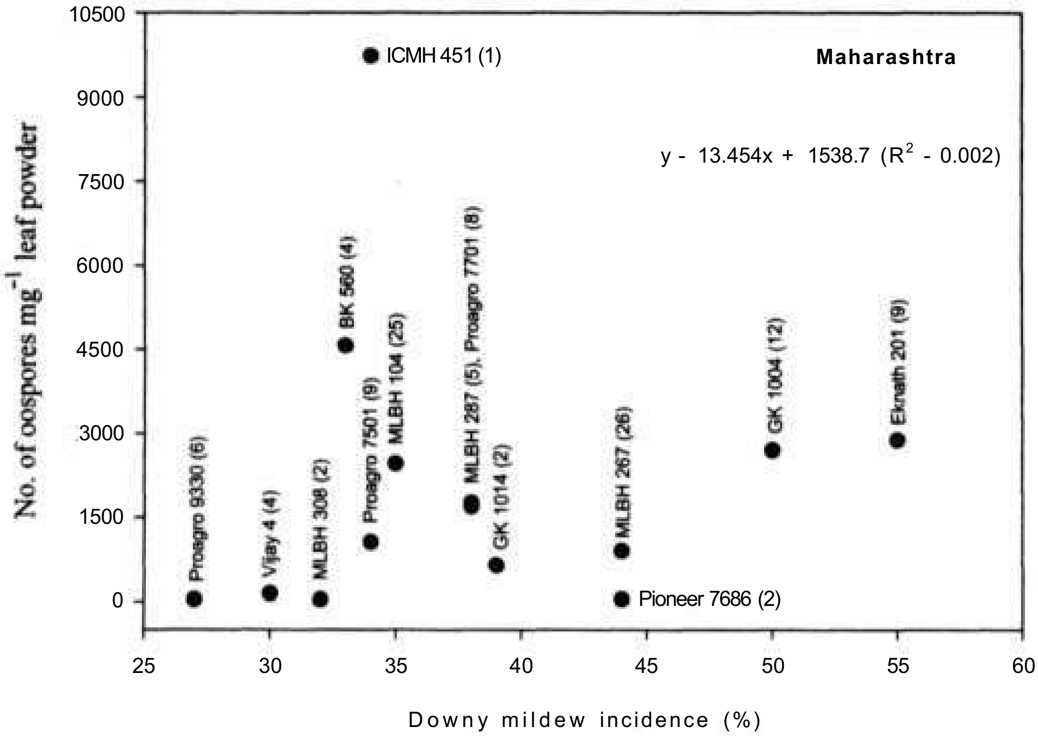


Figure 1. Pearl millet downy mildew surveys conducted in different districts of Maharashtra and Rajasthan, India. (Note: Number of cultivars surveyed is given in parentheses; DM = Downy mildew incidence (%); OS = Number of oospores mg^{-1} leaf powder.)



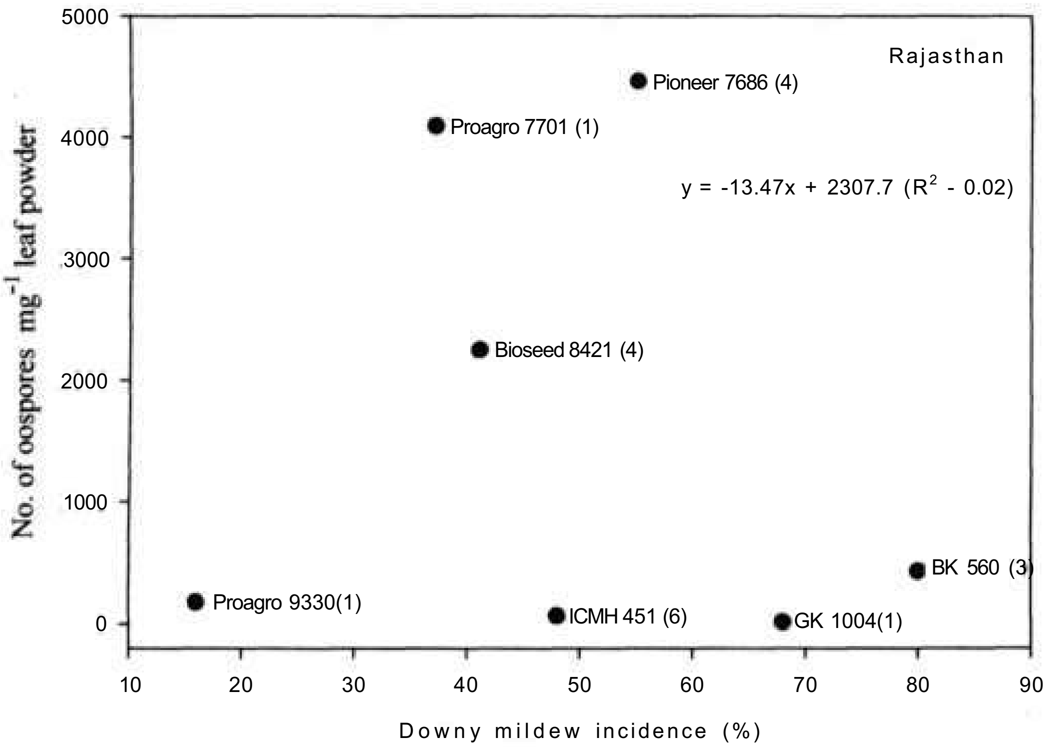


Figure 2. Relationship between downy mildew incidence and oospore production in pearl millet hybrids in Maharashtra and Rajasthan, India. (Note: Number of isolates are given in parentheses.)

in Jalna to 6-9736 mg^{-1} leaf powder in Dhule (Fig. 1). In Rajasthan, the mean number of oospores varied from 16 in GK 1004 to 4464 mg^{-1} leaf powder on Pioneer 7686 (Table 1 and Fig. 2). The number of oospores mg"[1] leaf powder was 14 in Ajmer, 16-5050 in Alwar, 19-1633 in Jaipur, 39-1490 in Tonk, 180-6268 in Bharatpur and 218 in Dausa(Fig. 1).

Relationship between DM incidence and oospore production. Six hybrids grown commonly in both Maharashtra and Rajasthan showed variations in both disease incidence and oospore production (Table 1). BK 560 showed 80% incidence, produced 437 oospores in Rajasthan compared to 4568 oospores mg^{-1} leaf powder in Maharashtra. Similar trends were also observed in GK 1004 and ICMH 451, whereas reverse trends were observed in case of Pioneer 7686, Proagro 7701 and Proagro 9330.

Regression analysis indicated that there was no significant relation between DM incidence and oospore production by different cultivars within a state. Several hybrids that showed high DM incidence did not show corresponding high oospore production and vice versa at different locations. For example, hybrids ICMH 451 recorded 34% DM incidence and 9736 oospores mg^{-1} leaf powder in Maharashtra compared to 48% DM incidence and 68 oospores mg-[1] leaf powder in Rajasthan (Table 1 and Fig. 2). Similarly, Pioneer 7686 recorded 44% DM incidence and 45 oospores mg^{-1} leaf powder in Maharashtra compared to 55% DM incidence and 4464 oospores mg^{-1} leaf powder in Rajasthan (Table 1 and Fig. 2). The amount of oospore production in a cultivar will depend on its level of susceptibility, existence of opposite mating types of spores in the right frequency (Pushpavathi 2003), environmental conditions and age of infected tissue. Generally, mature necrotic tissues support more oospore production than younger tissues. The hybrids that show high disease incidence and support high oospore production would allow the establishment of S. *graminicola* isolate much faster than those that show low disease incidence and low oospore production. In this study some of the hybrids supported high oospore production. This would lead to buildup of initial inoculum in the fields and would allow rapid establishment of DM on new crop during the next season. It would be useful to investigate the influence of oospore density on DM incidence in the next season crop and this information might contribute to the development of a disease forecast model.

References

Pushpavathi B. 2003. Pathogenic and genetic diversity in populations of *Sclerospora graminicola,* the incitant of downy mildew in pearl millet. PhD thesis, Acharya NG Ranga Agricultural University, Rajendranagar, Hyderabad, Andhra Pradesh, India. 110 pp.

Sivaramakrishnan S, Thakur RP, Kannan S and **Rao VP. 2003.** Pathogenic and genetic diversity among Indian isolates of *Sclerospora graminicola.* Indian Phytopathology 56:392-397.

Thakur RP, Rao VP, Amruthesh KN, Shetty HS and **Datar VV. 2003.** Field surveys of pearl millet downy mildew - effects of hybrids, fungicide and cropping sequence. Journal of Mycology and Plant Pathology 33:387-394.

Using Weather Information to Identify Pearl Millet Downy Mildew Risk Environments in India

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Introduction

Downy mildew, caused by *Scleropsora graminicola,* is widely prevalent and the most destructive disease of pearl millet *(Pennisetum glaucum)* hybrids in India. Incidence of downy mildew has been quite variable depending on cultivar, season and location (Thakur et al. 2002). Downy mildew, like several other plant diseases, is heavily influenced by weather variables. *Sclerospora graminicola,* an oomycete fungus, is an obligate biotroph and reproduces both by sexual and asexual means. The process of spore germination, infection and disease development is directly influenced by relative humidity (RH) and temperature, and indirectly by rainfall, radiation and wind speed. The asexual zoospores are motile and require a thin film of water on the leaf surface to swim and encyst before they cause infection.

Among the weather factors, RH and temperature during the early vegetative growth of the crop are critical for infection and disease development. The purpose of this study was to understand the relationship between weather parameters such as RH and temperature, and downy mildew incidence for identifying disease risk environments with an ultimate objective of developing decision-making tools for disease management. The most vulnerable crop stage for downy mildew infection is up to 30 days after emergence. The relationship between prevalent weather (temperature and **RH)** and disease incidence (DI), recorded at 30 days after emergence, formed the basis for identifying the disease risk environment.

Materials and Methods

Downy mildew incidence data and weather data collected from a collaborative Pearl Millet Downy Mildew Virulence Nursery (PMDMVN) at several locations in India were used for the study. The nursery consisted of a set of pearl millet genotypes, resistant and susceptible to downy mildew. Each genotype was grown in 2 rows of 4 m and replicated 2-3 times in a randomized block design. Downy mildew disease pressure was created using an infector-row system at each location (Singh et al. 1997). Data were recorded on downy mildew incidence at 30 and 60 days after seedling emergence. Data for temperature and RH were collected from the meteorological observatory of the research station where the nursery was conducted.

The DI data and weather data were used for a period of 3 to 5 years from five locations, Durgapura (Rajasthan), Jamnagar (Gujarat), Mysore (Karnataka), Patancheru (Andhra Pradesh) and Jalna (Maharashtra). These locations are situated between 12 and 21° N, and 70 and 78° E, with mean annual rainfall ranging from 762 to 1000 mm representing major pearl millet hybrid growing environments. Of the 12 pearl millet genotypes in the PMDMVN, DI data were used for the four susceptible genotypes, BJ 104 (hybrid), NHB 3 (hybrid), 5141B (inbred) and J 104S (inbred).

Simple correlation analyses were performed to find relationships between RH, temperature and DI at each location. There were 16 environments for BJ 104 and 18 environments for each of the other three genotypes. This

Table 1. Weather data and downy mildew disease incidence (DI) in four susceptible pearl millet genotypes at five locations in India during 1994-97[1].

	Relative humidity (%)				Mean temperature (°C)					
	Minimum		Maximum		Minimum		Maximum		D1[2] (%)	
Location	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Patancheru	66 ± 2.4	61-71	91 ± 1.1	88-93	22 ± 0.4	21-23	30 ± 0.4	29-31	67 ± 5.2	19-100
Mysore	62 ± 0.0	62-62	84 ± 0.5	83-84	22 ± 2.0	20-24	28 ± 0.5	27-28	74 ± 3.4	35-97
Durgapura	62 ± 1.5	60-63	87 ± 2.0	84-93	24 ± 0.0	24	33 ± 0.3	32-33	40 ±4.1	0-78
Jamnagar	69 ± 4.4	61-76	90 ±1.8	87-93	24 ± 1.0	22-25	32 ± 0.6	31-33	80 ± 4.0	28-99
Jalna	54 ± 2.4	51-59	92 ± 2.3	90-97	22 ± 0.6	21-23	31 ± 0.3	30-31	82 ± 3.4	43-100

1. Data are means of four years.
2. Data for four genotypes: BJ 104, NHB 3, 5141B and J104S.

discrepancy resulted because of non-inclusion of any of these genotypes in certain years in the nursery.

Results and Discussion

There was considerable variation in RH across locations and years. The mean minimum RH (RHmin) ranged from 54% (Jalna) to 69% (Jamnagar), and the mean maximum RH (RHmax) ranged from 84% (Mysore) to 92% (Jalna) across four crop seasons (Table1). However, the range of RHmin was 51-76% and that of RHmax was 83-97%. Relative to RH, there was less variation in temperatures across locations and years. The mean minimum temperature (Tmin) ranged from 22 to 24°C and the mean maximum temperature (Tmax) ranged from 28 to 33°C. The range of Tmin was 20-25°C and that of Tmax was 27-33°C (Table 1).

The mean DI on four pearl millet genotypes varied from 40 to 82% across locations and years (Table 1). Considerable year-to-year variations at and across locations were found on these genotypes. Based on the distribution of downy mildew incidence on four genotypes across years and locations, we designated a 70% DI to classify the environments as high disease risk or low disease risk.

BJ 104 showed high mean DI (>70%) in 7 of the 16 environments, NHB 3 in 14 of the 18 environments, 5141B in 10 of the 18 environments and J 104S in 11 of the 18 environments (Table 2). Depending on the DI on individual genotypes during different years at a location, the year x location combinations were classified as high disease risk or low disease risk environment. However, this was not consistent in all the four genotypes even for a single year at a particular location because of variable DI in the genotypes. It would be desirable to consider two equally susceptible genotypes across locations for future study.

Table 2. Frequency of high downy mildew disease incidence on four pearl millet genotypes across environments at five locations in India during 1994-97.

Genotype	Total environments	High disease risk environments (>70% incidence)	Percentage of high disease risk
BJ 104	16	7	44
NHB 3	18	14	77
5141B	18	10	55
J 104S	18	11	61

Positive relationships were found between RHmax and DI at 30 days after seedling emergence for some locations; eg, for BJ 104 at Mysore and Durgapura in some years. However, the relationship was not consistent across genotypes over environments and years. This could be due to variable rainfall pattern during the experimental years at these locations. The relationships between temperature (both maximum and minimum) and DI were not significantly correlated for any location and year.

While the year-to-year and location-to-location variations in DI were noticed, the causes for such variations were not well understood. We believe the main reason for such insignificant correlations between weather variables and DI could be the lack of weather data from the experimental plots. Because all weather data reported here were collected from the meteorological observatory of the research stations, these may not be representative of the field microclimate data. We suggest that for all such future studies, microclimate data on RH, temperature, leaf wetness and radiation be collected from the experimental plots at the crop canopy level. For wider application of weather data-based disease forecasting, it would be necessary to obtain the data both from the meteorological observatory and microclimate conditions in the field, and determine correlations of these with the DI data. It is often not easy to obtain microclimate data, so it would be necessary to understand the correlation between meteorological observatory data and microclimate data and then with DI data.

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References

Singh SD, Wilson JP, Navi SS, Talukdar BS, Hess DE and **Reddy KN. 1997.** Screening techniques and sources of resistance to downy mildew and rust in pearl millet. Information Bulletin no. 48. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 104 pp.

Thakur RP, Magill CW, Sivaramakrishnan S, Hash CT, Shetty HS and **Hess DE. 2002.** Variability in *Sclerospora graminicola,* the pearl millet downy mildew pathogen. Pages 51-56 *in* Sorghum and millets diseases (Leslie JF, ed.). Iowa, USA: Iowa State Press.

Raw Cow's Milk and *Gliocladium virens* Induced Protection Against Downy Mildew of Pearl Millet

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Introduction

The emerging paradigm of sustainability in agriculture strives to amalgamate modern technology with traditional farming wisdom. The relevance of indigenous knowledge of plant protection to sustainability is often questioned for want of validation. Integration of bio-agents with indigenous knowledge is a logical strategy to manage plant diseases (Arun Kumar 2001). Bio-agents such as *Trichoderma* spp reduce fungal diseases in many plant species through various mechanisms (Howell 2003). In India, the farmers in the state of Gujarat use milk to control plant diseases. Milk has been demonstrated to effectively control powdery mildew (Bettiol 1999).

Pearl millet *(Pennisetum glaucum)* is the principal staple food crop grown in arid Rajasthan, India. Downy mildew (DM) is the major limiting factor of pearl millet production in Rajasthan and all other millet-cultivating tracts in India. Farmers generally grow only traditional landraces, which are highly susceptible to the disease. Modern technological interventions such as fertilizers and pesticides are not cost feasible in arid peasant agriculture. Therefore, studies were undertaken to manage DM in rainfed crop of pearl millet using raw cow's milk (RCM) together with *Gliocladium virens* (biocontrol agent) as seed and soil treatments.

Materials and Methods

A field experiment was conducted during the rainy season in 2003 in a DM sick plot at the Central Arid Zone Research Institute (CAZRI), Jodhpur, Rajasthan. 'Nokha-local', a DM-susceptible pearl millet cultivar was used. The experiment was conducted with five treatments in a randomized block design (RBD) with three replications: (1) Seed treatment with RCM (50%, diluted with water) for 18 h at room temperature (30±2°C); (2) Seed treatment with *G. virens* (6 g kg^{-1} seed); (3) Soil treatment with *G. virens* (10 g nr^{2}); (4) Seed treatment with RCM + *G. virens* and soil treatment with *G. virens ;* and (5) Control (no soil and seed treatment). Each plot measured 3 m x 2 m, with 4 rows and each row had 20 plants. The crop was fertilized with diammonium phosphate (40 kg ha^{-1}) as basal dose. No insecticides or herbicides were applied. Downy mildew incidence was recorded twice, 30 days after sowing (DAS) and at soft dough stage (ie, 60 DAS). Fresh weight/dry weight ratio of 50 plants and 1000-grain mass were analyzed for all the treatments.

Results and Discussion

Downy mildew management requires reduction of primary inoculum from seed and soil and secondary infections in plants later during crop growth. *Gliocladium virens* appeared to be more effective man RCM in reducing the DM incidence (Table 1). *Gliocladium* spp, applied as soil or seed treatments, grow readily along with the developing root system of the treated plant and protect the roots from initial infection (Howell 2003). This fact is also corroborated by reduced DM incidence. In terms of disease incidence and protection over control, seed treatment with RCM seems to be similar to soil treatment with *G. virens* (Table 1). However, a combination of all three treatments (ie, seed treatment with RCM + *G. virens* and soil treatment with *G. virens)* did not show significant difference from seed treatment with *G. virens* for disease incidence and control. Results indicated some additive effect of RCM probably through induced resistance (Arun Kumar et al. 2002). Proline and potassium phosphate in RCM are known to boost immune system in plants (Bettiol 1999). Irrespective of the treatments almost all yield attributes showed little change. Plant height was maximum in the treatment where *G. virens* was added to me soil, followed by seed treatment with *G. virens.* Highest root length was recorded in seed treatments with RCM and *G. virens* whereas about 7.3% increase in plant height was recorded in soil treatment with *G. virens.* The fresh weight/dry weight ratio of 50 plants decreased by 12% in the combination of all three treatments followed by soil and seed treatments with G. *virens.* This indicated that biocontrol treated plants curtailed the process of rapid necrosis and drying. Maximum 1000-grain mass was observed in RCM seed treatment (21.3 g) followed by *G. virens* applied to soil (19.3 g) and *G. virens* seed treatment (18.6 g). The combination of all three treatments had lowest (17.0 g) 1000-grain mass.

Since pearl millet is a crop of low economic value grown by resource-poor farmers, seed treatment is a more viable and less expensive option than spraying of fungicides for control of DM. There is a high risk of the pathogen developing resistance that is associated with the use of chemical fungicides unlike biocontrol agents. Therefore, seed treatments with RCM and *G. virens* along with soil applications of the latter can be an

Table 1. Effect of biocontrol agents on downy mildew incidence and pearl millet growth during the rainy season in 2003 at CAZRI, Jodhpur, Rajasthan, India.

Treatment	Disease incidence[1] (%)	Protection over control (%)	Root length[2] (cm)	Plant height[2] (cm)	No. of tillers[2]
Seed treatment with raw cow's milk (50% dilution with water) for 18 h	12.6 (14.3)[3]	57.4 (36.4)	10.5	75.1	12.1
Seed treatment with *Gliocladium virens* (6 g kg^{-1} seed)	8.8 (13.0)	70.2 (42.2)	10.5	90.0	13.2
Soil treatment with *Gliocladium virens* (10 g m^{-2})	12.6 (13.8)	57.4 (38.6)	10.2	92.0	14.5
Combination of the above three treatments	8.0 (11.6)	72.9 (48.4)	10.2	85.9	15.6
Control	29.6 (22.5)		10.4	84.2	15.6
CD at 5%	8.28		2.52	18.32	8.81
CV(%)	28.64		13.38	11.78	27.4

1. Recorded at 30 days after sowing (DAS) and at 60 DAS.
2. Recorded at 60 DAS.
3. Figures in parentheses are arcsine-transformed values.

important component in an integrated disease management strategy for resource-poor farmers.

References

Arun Kumar. 2001. Environment-friendly approaches for management of plant diseases in arid zone. Pages 257-263 *in* Environmental protection (Choudhary V, Singh K and Kakralya MK, eds.). Jaipur. Rajasthan, India: Pointer Publications.

Aran Kumar, Raj Bhansali R and **Mali PC. 2002.** Response of bio-control agents in relation to acquired resistance against leaf curl virus in chilli (Abstract). Page 167 *in* Proceedings of Asian Congress of Mycology and Plant Pathology, 1-4 October 2002, Mysore, India.

Bettiol W. 1999. Effectiveness of cow's milk against zucchini squash powdery mildew *(Sphaerotheca fuliginea)* in greenhouse conditions. Crop Protection 18:489-492.

Howell CR. 2003. Mechanisms employed by *Trichoderma* species in the biological control of plant diseases: The history and evolution of current concepts. Plant Disease 8:4-10.

Finger Millet Blast Pathogen Diversity and Management in East Africa: A Summary of Project Activities and Outputs

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Background and Objectives

In the semi-arid tropics of East Africa, finger millet *(Eleusine coracana)* is a staple food for millions of people. This cereal plays an important role in the diets and economy of subsistence farmers and is especially important for pregnant women, nursing mothers and children (National Research Council 1996). Blast caused by *Magnaporthe grisea* (anamorph *Pyricularia grisea)* is a major constraint to finger millet production in the region. Blast affects finger millet at all stages of growth and most of the landraces and a number of other genotypes are highly susceptible. The major objectives of the project R8030 [UK Department for International Development (DFID) - Crop Protection Programme] were to: (1) characterize the pathogen populations; (2) use this information as a basis for epidemiological studies; (3) gain an understanding of the cropping practices and the farmers' perception of the disease problems and management through socioeconomic and disease surveys; and (4) identify sources of resistance.

Genetic Diversity of Pathogen Populations

A baseline collection of nearly 300 *M. grisea* isolates was established at Warwick HRI, UK for molecular and pathogenicity characterization utilizing more than 450 finger millet and weed blast samples collected from Uganda and Kenya. The PCR (polymerase chain reaction)-based analyses were carried out to generate SSR (simple sequence repeat) and AFLP (amplified fragment length polymorphism) profiles. AFLPs revealed a higher degree of diversity and up to eight pathogen genotypes (genetic groups) were observed. Some pathogen genotypes were common to both Uganda and Kenya while others were restricted to one country (Fig.1).

A repetitive DNA element *grasshopper (grh)* has been observed only in populations of *M. grisea* from finger millet in Japan, Nepal and India as well as some West African countries (Dobinson et al. 1993). Following a PCR screen of finger millet and weed *M. grisea* collections from East Africa, 13 isolates containing the *grh* element were identified. Finger millet originated in the area that now is Uganda, and the results suggest that the indigenous blast populations did not contain this element and the *M. grisea* isolates with *grh* were recent introductions.

Isolates causing leaf, neck and panicle blast on finger millet compared by AFLP analysis were genetically similar indicating that the same strains were capable of causing different expressions of blast under suitable conditions. This suggests that host resistance in general should be effective against all expressions of blast.

Reproduction of *M. grisea* is predominantly asexual. However, high fertility of isolates from finger millet in laboratory crosses has previously been observed (Yaegashi and Nishihara 1976). Based on the *M. grisea* mating type gene sequences, a near equal distribution of MAT1-1 (47%) and MAT1-2 (53%) alleles among blast populations in Uganda and Kenya was observed. Cross-compatability assays have shown the high fertility status of these isolates with the formation of perithecia bearing asci with ascospores.

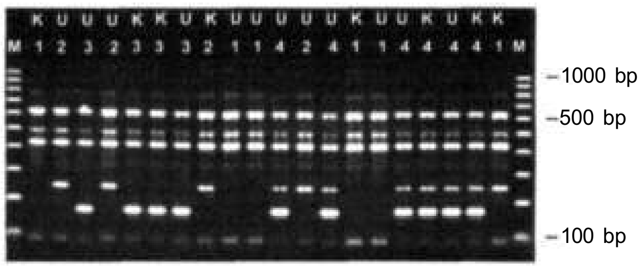

Figure 1. AFLP profiles of a set *of Magnaporthe grisea* isolates from finger millet from Uganda and Kenya. (Note: These isolates are represented by four genotypes present in both countries; U = Uganda; K = Kenya; 1-4 = Pathogen genotypes; M = Molecular marker.)

Pathogen Aggressiveness and Epidemiology

Pathogenicity tests were performed with a representative set of characterized isolates by spray inoculation (30 ml conidial suspension at 10^5 conidia ml^{-1} amended with 0.1 % gelatin) of 6-week-old finger millet seedlings (SEREMI 1, SEREMI 2, SEREMI 3, PESE 1, Gulu E, 1NDAF 5, OK/3, P665, HPB-83-4 and E 11). The experiment was carried out in three replications. Plants were incubated at 25-27°C and 7-8 days after inoculation the number of lesions per leaf and the percentage of infected area were scored.

In general, variation in pathogenicity was recorded among the *M. grisea* isolates analyzed both on a particular variety as well as in infecting different varieties. For example, in a set of 35 blast isolates, most isolates showed the highest disease score on E 11, but four of the isolates gave the highest disease score on PESE 1. None of the isolates tested so far, however, showed clearly different compatibility and incompatibility reactions.

Pathogenicity tests were also carried out on seed heads of mature finger millet plants of varieties E 11, SEREMI 1, SEREMI 2, SEREMI 3, PESE 1 and P665 using a set of eight *M. grisea* isolates. The apparent susceptibility of the finger millet varieties to seed head infection, with the exception of E 11, appeared to differ from that in the seedling assays. For example, SEREMI 1, which was relatively resistant in the seedling experiments, appealed more susceptible with regard to seed head infection especially when inoculated with isolates from neck and seeds and P665 was the least infected (Fig. 2).

Magnaporthe grisea isolates from weed hosts compared with isolates from finger millet were in general not genetically distinct and in most cases belonged to the same genetic groups as isolates from finger millet, underlining the potential of weeds to serve as inoculum sources. Pathogenicity tests revealed that the isolates from weeds were pathogenic to finger millet, with some weed isolates being as aggressive as some of the finger millet isolates. Field experiments carried out in Uganda suggest that seedborne inoculum contributes to initial blast development, as higher disease incidence was observed with seeds containing higher proportion of inoculum.

Disease and Socioeconomic Surveys

Disease surveys in Kenya identified blast as the most important and widespread disease in Busia, Teso and Kisii districts. Grain yield losses attributed to blast were estimated to be between 10 and 50%. In Uganda, blast incidence (13 to 50%) and severity (24 to 68%) varied considerably across main finger millet cultivated areas in the north and east. In both countries, the disease incidence and severity were higher during the first season (February-July) than in second season (August-December). Varieties

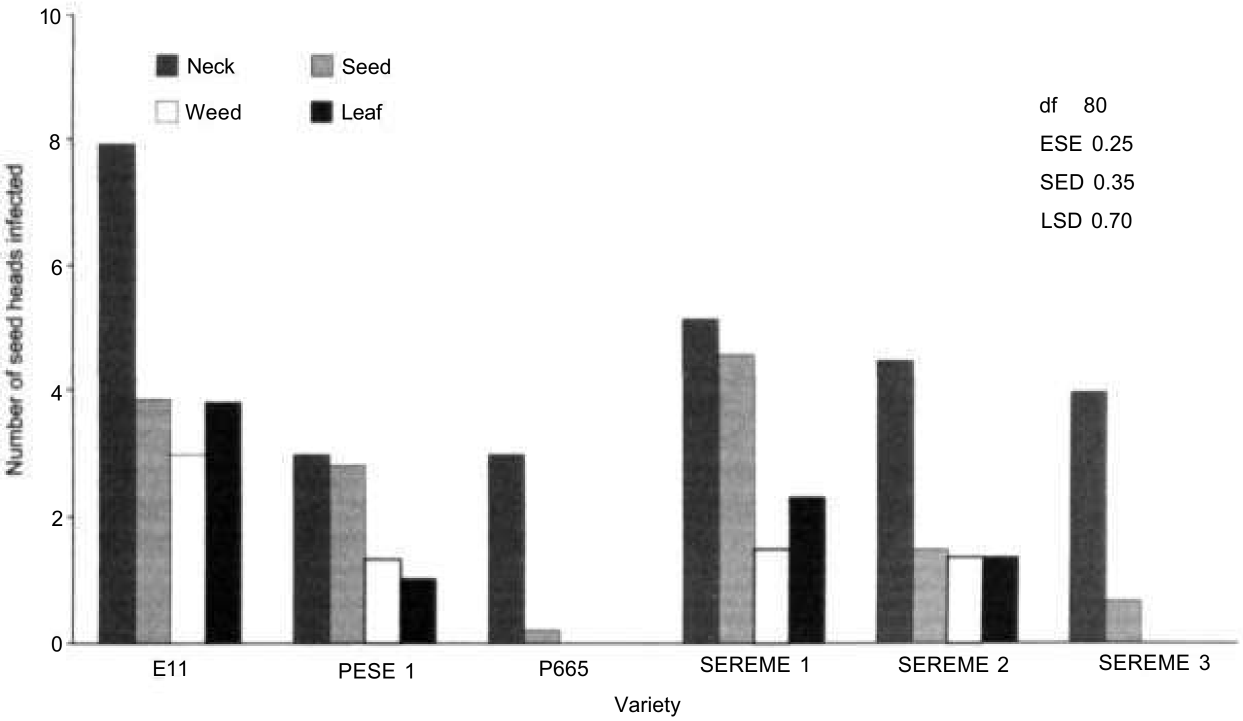

Figure 2. Variation among six different finger millet varieties in blast infection by four different *Magnaporthe grisea* isolates from finger millet neck, seed and leaf, and a weed based on the number of seed heads infected per 10 inoculated heads.

producing dark colored seeds and compact heads were more blast resistant compared to white-seeded and open-headed varieties. Blast was commonly observed on weeds such as *Eleusine indica* (most common), *Digitaria* spp, *Dactyloctenium* sp and *Cyperus* sp occurring in finger millet fields.

A participatory rural appraisal (PRA) conducted in western Kenya revealed that finger millet production was most commercialized in Kisii and least in Teso. *Enaikuru* in Kisi, *Emumware* in Teso and *Ikhulule* in Busia were the most popular local varieties. The improved varieties Gulu E and P224, liked for their early maturity, were common in Busia although farmers rated them as moderately susceptible to blast. Farmers in Kisii rated *Marege* and *Enyakundi* as having some level of resistance to blast. In Busia, farmers have adopted row planting to reduce labor intensive weeding.

In Uganda, five to eight varieties were grown depending on the location in the first season (February-July) whilst fewer varieties were grown in the second season (August-December) and some of the previously common varieties are no longer grown due to poor attributes. The majority of farmers saved their own seed and very few farmers purchased seed from stockists. Millet is commonly grown in mixed cropping, and the order of rotation varied, but some farmers, especially in Teso, were aware that millet should not follow sorghum *(Sorghum bicolor)* because of *Striga.*

Most farmers were aware of blast symptoms (in Uganda described as *Ebwetelele, Obapu* and *Kalajajwa* - generally meaning 'dry heads' and known as *egetabo* in Kisii, Kenya) but were not aware of the cause, modes of transmission and control measures. Both Kenyan and Ugandan farmers in general reported a lack of crop pest and disease management information. This needs to be addressed urgently and it is also important to develop blast resistant varieties with farmer preferred qualities in order to overcome production constraints. Based on PRA carried out in Kenya and Uganda, the characteristics of finger millet (and ranking) preferred by farmers are: early maturing (1); drought tolerance (2); uniformity in height (3); high tillering (4); large heads, non-shattering and high yielding (5); widely adaptable (6); easy to dry, clean and market (7); resistance to diseases especially blast, lodging and pests (8); white seeded (9); good palatability (10); good brewing qualities (11); and good storability and viability (12).

Varietal Screening for Blast Resistance

A wide range of varieties including 65 farmer varieties and 30 germplasm accessions from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Nairobi, Kenya were screened for their reaction to blast under natural infection in repeated trials during the February-July and August-December seasons in 2002 at Alupe, Teso district. The trials were planted in three replications, in two-row plots, each row 3 m long. Susceptible variety KNE 479 was used as infector rows while KNE 620 and KNE 1034 were used as resistant checks and KNE 479 and KAT/FM1 as susceptible checks. Leaf, neck and finger blasts were scored separately using a scale of 1 (no disease) to 9 (more than 75% disease). Early-maturing varieties had higher finger blast incidence and severity and there was a significant negative correlation between finger blast severity and grain yield during the long rainy season. Among the ICRISAT germplasm lines, KNE 620, KNE 629, KNE 688, KNE 814 and KNE 1149 and farmer variety accessions 14, 29, 32 and 44 were identified with low blast levels and good agronomic performance. The identified varieties/lines can be utilized in breeding programs whilst some could be promoted for commercial production.

Conclusions and Perspectives

A baseline collection of characterized pathogen isolates showed limited diversity for AFLPs. Some of the pathogen genotypes were common to Uganda and Kenya whilst others were restricted to one country. Considerable variation in pathogen aggressiveness but no differential reaction to host varieties was observed. Isolates from weeds were capable of infecting finger millet and seedborne pathogen appears to contribute to initial disease development. Varieties with resistance to blast have been identified and a database on East African finger millet cropping systems and prevalence of blast, constraints to production and farmers' perception of blast and its management has been generated. Current finger millet production practices demand extreme hard work; consequently new production technologies need to be identified and developed. The knowledge and resources generated from this project lay the basis for improved disease intervention and efficient utilization of host resistance.

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References

Dobinson KF, Harris RE and **Hamer JE. 1993.** Grasshopper, a long terminal repeat (LTR) retroelement in the phytopathogenic fungus *Magnaporthe grisea.* Molecular Plant Microbe Interactions 6:114-126.

National Research Council. 1996. Finger millet. Pages 39-58 *in* Lost crops in Africa. Vol. I, Grains. USA: Board on Science and Technology for International Development, National Research Council.

Yaegashi H and **Nishihara N. 1976.** Production of the perfect stage in *Pyricularia* from cereals and grasses. Annals of the Phytopathological Society of Japan 42:511-515.

Entomology

Methods for Rearing *Heliocheilus albipunctella* in the Laboratory and Eliminating the Pupal Diapause

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Introduction

The millet head miner *Heliocheilus albipunctella* is one of the most damaging pests of pearl millet in the Sahel. During the past 15 years, considerable progress in the development of pest control measures has been achieved through increased knowledge of the ecology of this heliothine moth (Nwanze and Youm 1995, Kadi Kadi et al. 1998, Youm and Owusu 1998a, 1998b). Future research to improve control of the millet head miner could be enhanced through the development of reliable artificial rearing techniques. Moreover, the improved rearing techniques could be used for the assessment of biological control agents and for supporting millet breeding programs to advance head miner integrated pest management (IPM).

Breeding populations of *H. albipunctella* were established at the Natural Resources Institute (NRI), University of Greenwich, UK from eggs collected from Niger at the end of the 1996, 1997 and 1998 field seasons. Previous authors have reported difficulty in rearing *H. albipunctella* (Gahukar et al. 1986), and the process has remained problematic. However, from 1996 to 1998 we effectively increased the number of generations reared in each successive year, and the 1998 population was sustained until the end of the project, which was terminated after 15 months.

Methods and Results

Heliocheilus albipunctella cultures were maintained under environmentally controlled conditions. Relative humidity was kept at a constant 60%. A photoperiod of 14 h light and 10 h dark, with photophase light intensity changes, was used, and temperatures were maintained at 31°C and 27°C, respectively. Under this temperature regime few pupae entered diapause. The information related to the life cycle and successful rearing methodology is summarized.

Adults to eggs. In the field, *H. albipunctella* females fly directly to buzzing males and mating takes place at the buzzing site, typically on the lower portions of the stem/ leaves of pearl millet *(Pennisetum glaucum)* or other suitable vegetation. In the laboratory, virgin adults of *H. albipunctella* mate readily, even in confined conditions. At NRI, adults were maintained in mating cages consisting of a perspex cylinder (15cm diameter, 30 cm height) with a perforated metal lid. Up to 5 pairs of moths were placed in a single mating cage. Strips of fabric (disposable nappy liner) were suspended from the walls of mating cages to provide males with buzzing perches, and suitable mating sites. A layer of water-absorbent filter paper on the cage floor was moistened before the onset of scotophase to simulate the natural increase in relative humidity that occurs at dusk. It was estimated that 80% of moths mated under these conditions, provided a healthy partner was available. Successful matings were obtained with females for up to three nights after emergence, and with males for up to 5 nights post-emergence.

Access to free-water extends adult survival. In the field, *H. albipunctella* adults have been observed drinking from dew or rain drops on millet stems, and in our rearing culture water was provided in the form of water-soaked pieces of cotton wool that were placed in the cages, and also by the moistened filter paper used to increase the relative humidity. Moths also drank honey-water when provided.

Heliocheilus albipunctella is monophagous in the wild, with larvae mostly found on pearl millet panicles. This relates to the females' strict host specificity during oviposition, and this factor must be accommodated when rearing the moth. Cotton wool pieces provided for oviposition in the early stages of rearing were rarely observed with eggs. The only reliable method for obtaining eggs was to provide mated females with an erect millet panicle for oviposition on the nights following mating. Early stages of panicle development (up to flowering) are preferred for egg laying. Pearl millet was grown for this purpose in glasshouses at NRI during 1997-99. The supply of young panicles tended to be erratic; however, females readily oviposited on thawed panicles that had been stored frozen. Thus, a large stockpile of frozen panicles was kept for oviposition.

Typically, eggs are laid singly or in small clusters on the panicle and are attached to the base of the florets or to the peduncles (Vercambre 1978). They can readily be detached using a soft-bristled paintbrush or flexible forceps, after which they can easily be transferred onto larval diet for hatching. In this case the eggs should be placed on fresh diet 2 days after oviposition, and the surface of the diet block should be scratched to promote larval access into the media. Eggs that hatched on the cut panicles within the sealed plastic containers were similarly transferred onto the larval diet using a soft sable paintbrush. It is critical that the larvae are transferred soon after hatching, preferably within 6-8 h, otherwise high mortality can occur.

Larvae. Larvae were reared on a solid medium, based on chickpea *(Cicer arietinum)* flour, yeast and agar, which is the laboratory standard for rearing *Heliothis/ Helicoverpa.* At the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Niamey, Niger larvae were reared individually on medium contained in 35 ml plastic pots with cardboard lids that are permeable to water vapor and hence provide a safeguard against

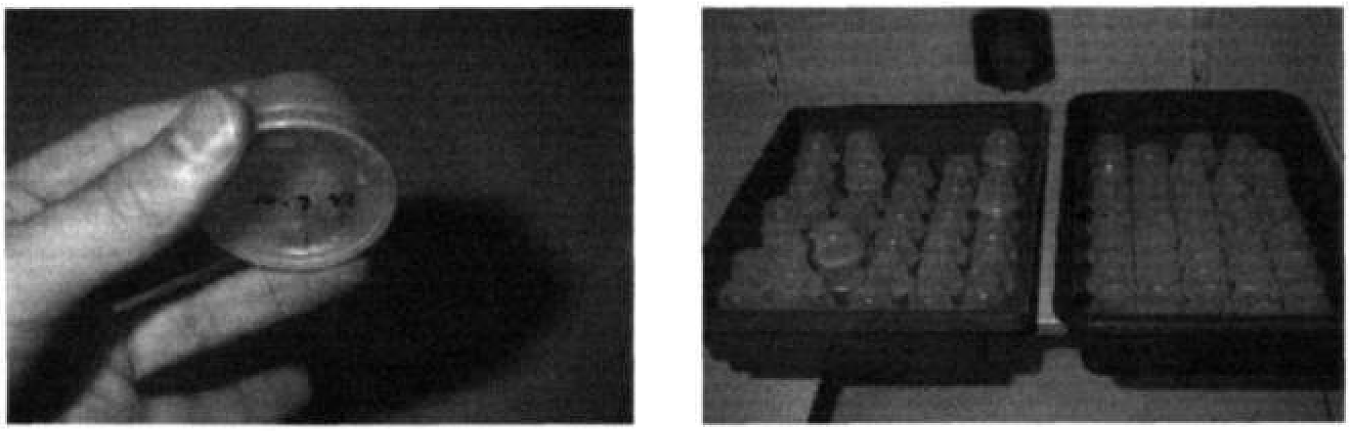

Figure1, Rearing of *Heliocheilus albipunctella:* (left) rearing pot containing larval medium and first instar caterpillars; and (right) hulk rearing in pots and each pot contained 5 larvae initially.

excessive moisture and risk of fungal growth. At NRI a slightly different system was developed in which, initially up to 5 larvae were maintained per 35-ml pot, which saved a substantial amount of time and effort. These pots had plastic snap-on lids, pierced 4 times using an entomological pin to allow ventilation. By maintaining the pots in an inverted position (ie, lid down, see Fig. 1), escapes by the tiny first instar larvae were negligible. A new dice-sized piece of diet was added to the pot every 4 days. The old piece of diet, which typically contains the developing larvae, was left inside the pot. There is little larval cannibalism in *H. albipunctella,* except that full-grown larvae may eat freshly formed pupae, particularly if fresh medium is overdue. Hence, it is a good practice to reduce the larval number to 1 or 2 per pot when the final larval instar stage occurs. Bulk rearing of larvae was also tried, maintaining up to 25 larvae in 250 ml plastic tubs. But the productivity of this method was found to be inferior to the use of small pots, possibly because of larval-pupal cannibalism and higher pathogen transmission rates.

Hygiene is critical for the successful culture of *H. albipunctella,* especially during larval rearing. Bacterial and viral pathogens appeared to contribute substantially to the decline of the NRI culture in 1996 and to a lesser extent in 1997, and low-level incidence of infection was evident even when the culture was thriving. Consequently, all forceps and artists' brushes used to handle larvae were repeatedly dipped in *Virkon* ® (a bleach-based disinfectant solution), and then rinsed and dried before re-use, during feeding sessions.

Larval development passed through 5 instars and took approximately 25 days under the conditions specified above. Final instar larvae turn green and then pink prior to pupation. In the field, the pre-pupal larva emerges from the panicle, drops to the ground and then burrows to a depth of about 25 cm before pupation occurs. In culture, at this stage the larval burrowing activities cause the medium to disintegrate and pupation occurs on the base of the pot, inside a silk-lined cavity within the particulate substrate.

Pupa and diapause. In the field, a pupal diapause suspends development for approximately 10 months, until the onset of the next season's rains. The pupa then returns to the soil surface where the pupal case splits and the adult emerges. In the laboratory cultures, pupae were collected every six days, and maintained resting on dry filter paper inside petri dishes. The pupae were observed daily for adult emergence.

Under the regime employed (31°C under 14 h light, 27°C under 10 h dark), few pupae entered diapause and these emerged 9-10 months after pupation. Earlier efforts to culture *H. albipunctella* at NRI, in which larvae were maintained at 26°C, had been unsuccessful because the majority of pupae entered diapause (J Colvin, NRI, UK, personal communication). It seems that there is a threshold rearing temperature during larval development at which diapause becomes inevitable, but this was not sought here, since the adopted regime inhibited diapause effectively. The non-diapausing pupal stage typically lasted 18-30 days under the present cultural conditions (see Fig. 2).

The sex ratio of emergent adults did not differ significantly from 1:1. There is potential for improving the likelihood of successful emergence. Even in the most successful rearing regime (1998-99) almost one-third of all emerging adults had either badly deformed wings or failed to emerge from the pupal case. Successful emergence might be enhanced if the pupae were buried in moist

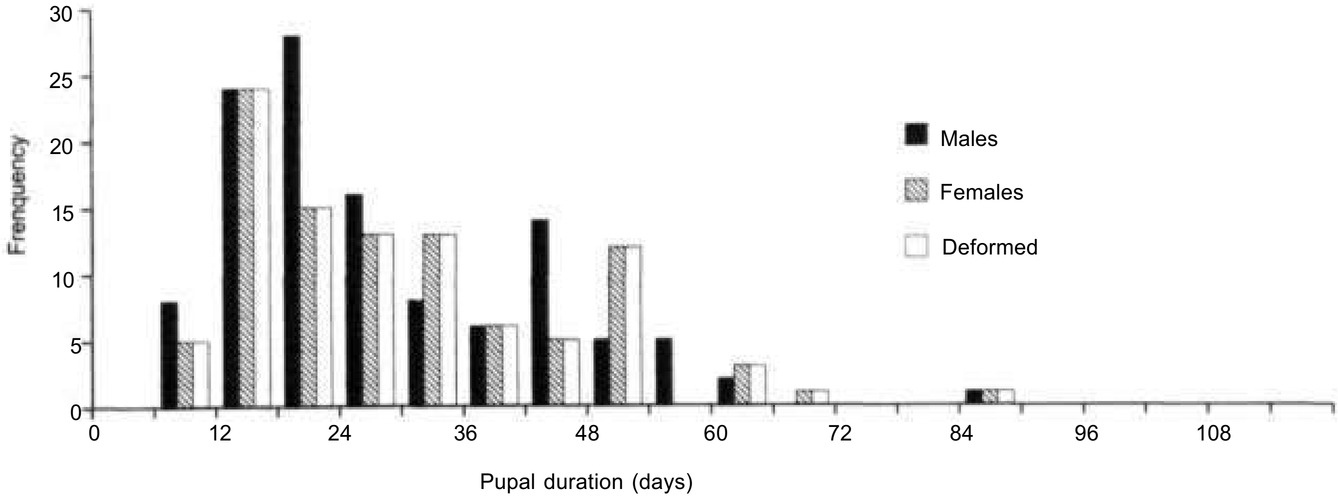

Figure 2. *Heliocheilus albipunctella* pupal duration under culture (31°C under 14 h light and 27°C under 10 h dark) during 1998.

sand, thereby simulating natural emergence conditions more closely.

Findings of these studies will be helpful in enhancing the rearing of the millet head miner in the laboratory and improve its management in the Sahel.

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References

Gahukar RT, Guevremont H, Bhatnagar VS, Doumbia YO, Ndoye M and **Pierrard G. 1986.** A review of the pest status of the millet spike worm, *Raghuva albipunctella* (De Joannis) (Noctuidae: Lepidoptera) and its management in the Sahel. Insect Science and its Application 7:457-463.

Kadi Kadi HA, Gilstrap FE, Teetes GL, Youm O and **Pendleton BB. 1998.** Field evaluation, longevity, and oviposition period of millet head miner (Lepidoptera: Noctuidae) in Niger. International Sorghum and Millets Newsletter 39:143-144.

Nwanze KF and **Youm O. 1995.** Panicle insect pests of sorghum and pearl millet: proceedings of an International Consultative Workshop, 4-7 Oct 1993, ICRISAT Sahelian Center, Niamey, Niger. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 320 pp.

Vercambre B. 1978. *Raghuva* spp. et *Masalia* sp. (Lep.: Noctuidae), chenilles des chandelles du mil en zones sahelienne. Agronomic Tropicale 33:62-79.

Youm O and **Owusu EO**. **1998a.** Assesssment of yield loss due to the millet head miner, *Heliocheilus albipunctella* (Lepidoptera: Noctuidae) using a damage rating scale and regression analysis in Niger. International Journal of Pest Management 44(2): 119-121.

Youm O and **Owusu EO. 1998b.** Farmers' perceptions of yield losses due to insect pests and methods for assessment in pearl millet. International Journal of Pest Management 44(2): 123-125.

Observations on Factors Affecting Attraction and Oviposition Preferences of the Millet Head Miner *Heliocheilus albipunctella* to Pearl Millet Panicles

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Introduction

The millet head miner *Heliocheilus albipunctella* is a serious insect pest of pearl millet *(Pennisetum glaucum)* in the Sahelian zone of West Africa. Females lay 20-50 batches of about 300-400 eggs on millet heads (Bernardi et al. 1989, Nwanze and Harris 1992). Eggs normally hatch in 3-5 days and the developing larvae feed on floral glumes and flower stems thus causing yield decrease.

Even though millet panicles serve as oviposition sites for the head miner, the mechanisms underlying this choice remain unknown. This article reports on laboratory experiments to investigate factors affecting host plant and head miner oviposition interactions.

Materials and Methods

Insects. Gravid female head miners were obtained from light traps (Robinson traps equipped with photosentivie cells with 125W mercury vapor bulbs) located at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center, Niamey, Niger.

Panicle stages tests. The most suitable panicle stage for oviposition by the millet head miner was assessed using five plant growth stages, ie, 30% panicle extension, 50% panicle extension, 100% panicle extension, flowering stage and dough-filling stage. Panicle stages were arranged evenly in paper containers (27 cm height, 25 cm diameter) covered with nylon gauze. Ten adult females were used for a multi-choice test condition in the dark. The number of eggs laid on each panicle stage was counted the following morning. Five millet varieties were used in three replications. Positions of three pearl millet panicles in the cages were randomly assigned for each experiment.

Whole substrate tests. Four freshly cut sorghum *(Sorghum bicolor)* panicles and pearl millet panicles, leaves and stems were tested under multi-choice and no-choice test conditions. Substrates were arranged in cages as described above and 10 gravid females were released into the cages between 1800 and 1900 h. Cages were left in the dark for oviposition. The number of eggs on each substrate was counted the following morning. There were five replications.

Methanol extracts tests. Extracts from fresh sorghum panicles and pearl millet panicles, leaves and stems were tested for oviposition stimulation under multi-choice and no-choice test conditions. Extracts were obtained by immersing the plant material (10 g each) in 100 ml of 80% methanol for 3 days in the dark. After removal of solid material, filter papers were soaked in the respective extracts. The filter papers were vacuum-dried in a hood and then were fixed around wooden rolling pins (20 cm length, 2 cm diameter). The rolling pins were then set up in cages as described in the preceding experiments. Ten gravid females were released into the cages between 1800 and 1900 h. Cages were left overnight in the dark for oviposition. The number of eggs on each treatment was counted the following morning. There were five replications. Control trials (ie, filter paper dipped in methanol only) were initially set up but later ignored because the methanol alone did not stimulate oviposition.

Results and Discussion

Female head miner oviposition preferences for four pearl millet varieties under multi-choice and no-choice situations are presented in Table 1. In a multi-choice situation, irrespective of the plant variety studied, 30% panicle extension gave the highest mean percentage of eggs, followed by 50% panicle head extension, full extension, flowering stage and dough-filling stage. There were no eggs laid on the flowering and dough-filling stage panicles. However, in a no-choice situation some eggs were laid albeit far lower than for 30% panicle stage. At 30% panicle extension, the pearl millet variety Chalakh had the highest number of eggs, followed by ICMV IS 89305.

The mean number of eggs oviposited on different substrates and their respective methanol extracts are presented in Table 2. Among all the test treatments, pearl millet panicles and their extracts were preferred for egg laying. However, the number of eggs laid on filter paper impregnated with methanol extract of pearl millet panicles was lower than for intact panicles. In no-choice situations, eggs were not laid on the whole plant or methanol extracts of the sorghum panicles, pearl millet

Table **1.** Oviposition preference by millet head miner among different stages of pearl millet panicles under multi-choice **and** no-choice test conditions.

	Mean total eggs (%) ± SE				
Variety	30% panicle extension	50% panicle extension	100% panicle extension	Flowering	Dough filling
Multi-choice test					
3/4HK	57.2 ± 2.48	30.3 ± 1.26	12.5 ±3.73	0.0	0.0
MBH110	70.7 ± 8.94	22.8 ±11.85	5.8 ±2.18	0.75	0.0
ICMV IS 89305	75.7 ± 0.83	16.3 ± 2.68	7.4 ±1.31	0.0	0.0
Chalakh	85.8 ± 0.71	13.9 ± 1.08	0.4	0.0	0.0
No-choice test					
3/4HK	46.0 ± 8.52	21.0 ± 2.94	10.3 ± 1.25	3.3 ±1.70	3.0 ±1.41
MBH110	60.7 ± 9.39	27.0 ± 4.32	12.3 ±3.09	5.7 ±2.06	4.0 ±2.16
ICMV IS 89305	61.3 ± 12.82	26.7 ± 6.24	14.7 ± 3.68	4.0 ±2.45	5.3 ±2.06
Chalakh	74.0 ± 7.48	25.7 ± 4.64	17.3 ±2.86	3.3 ±1.25	3.0 ±0.82

Table 2. Numbers of eggs (mean ± SE) deposited by *Heliocheilus albipunctella* female moths on whole plant substrates or filter paper impregnated with methanole extract under multi-choice and no choice test conditions.

	Multi-choice test		No-choice test	
Substrate	Plant	Filter paper	Plant	Filter paper
Sorghum panicles	0.2 ±0.18	0.0	0.0	0.0
Pearl millet panicles	44.4 ± 7.38	5.4 ± 0.92	32.0 ± 2.9	16.8 ±1.9
Pearl millet leaves	0.2 ±0.18	0.0	0.0	0.0
Pearl millet stems	0.4 ± 0.36	0.0	0.5 ± 0.5	0.5 ± 0.5

leaves or pearl millet stems (Table 2). This suggests the absence of ovipositional preference signals in sorghum panicles, pearl millet leaves and pearl millet stems.

Factors responsible for the ovipositional behavior of the pearl millet head miner have not been studied in depth. Generally, it is understood that there is a complex interaction between insects and their host plants that governs host finding for feeding, mating and oviposition (Brattsen and Ahmad 1986, Metcalf and Metcalf 1992, Hirano et al. 1994, Owusu et al. 1996). Significant ovipositional preference for immature pearl millet panicles suggests the presence of plant chemicals that stimulate oviposition, which are most attractive at 30% panicle extension and decline with panicle age.

We have observed in the field that on a night with a moderate breeze, more females invade millet fields than during a night of still air (especially after rain) or very strong wind. These observations suggest that anemotaxis may compliment spectral reflectance and millet panicle volatiles and serve in combination as the agents responsible for host finding, while contact chemoreception combined with plant nutrient composition may be responsible for discriminative probing and oviposition site searching behavior. After landing on millet panicles, females can spend 15-20 minutes probing with the ovipositor before oviposition. In some cases, they fly to other panicles after long periods of probing without laying eggs. This behavior remains unexplained; however, we suspect deposition of chemicals by females after oviposition, which may deter other females from ovipositing on the same panicle.

Rererences

Bernardi M, **Mishoe JW** and **Jones JW. 1989.** Raghuva: A computer simulation of *Raghuva albipunctella* population dynamics and *Pennisetum americanum* and *P. typhoides* phenology. Ecological Modelling 44:275-298.

Brattsen LB and **Ahmad S. (eds.) 1986.** Molecular aspects of insect-plant associations. New York, USA: Plenum Press. 346 pp.

Hirano C, Yasumi K, Itoh E, Kim C-S and **Horiike M. 1994.** A feeding deterrent for *Thrips palmi* Karny (Thysanoptera: Thripidae) found in tomato leaves: isolation and identification. Japanese Journal of Applied Entomology and Zoology 38:109-120.

Metcalf RL and **Metcalf ER. 1992.** Plant kairomones in insect ecology and control. London, UK: Chapman and Hall. 168 pp.

Nwanze KF and **Harris KM. 1992.** Insect pests of pearl millet in West Africa. Review of Agricultural Entomology 80:1133-1155.

Owusu EO, Kim C-S, Horiike M and **Hirano C. 1996.** Comparative biological and enzymatic studies on some host-adapted populations of melon and cotton aphid, *Aphis gossypii* (Homoptera: Aphididae). Journal of Agricultural Science, Cambridge 126:449-453.

Socioeconomics

Economic Impact of Improved Pearl Millet Production Technology in Resource-poor Rainfed Areas of Kurnool District of Andhra Pradesh

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Introduction

Pearl millet *(Pennisetum glaucum)* is the most drought tolerant domesticated cereal, and is the fourth most important cereal food crop in India. Being an arid and semi-arid crop, it is traditionally a component of dryland cropping systems (Harinarayana 1987). Traditional farming practices include the use of locally adapted varieties with poor yield potential and little application of manures and chemical fertilizers. The production potential of pearl millet needs to be commercially exploited in such areas. Given quality seed, optimum amounts of fertilizer, and good cultural and water management practices, it is possible to increase millet productivity and attain stabilized yield levels.

The drought-prone districts of Andhra Pradesh, India include Kurnool, Mahbubnagar, Nalgonda, Anantapur and Prakasam and are characterized by low soil fertility, inappropriate soil and water management practices causing land degradation, lack of improved varieties, pest and disease incidence, declining land: man ratio, and resource-poor farmers, which contributes to the burgeoning problem of rural poverty. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the Government of Andhra Pradesh have initiated a project with the Andhra Pradesh Rural Livelihoods Programme (APRLP) to help reduce poverty through increased agricultural productivity and improved livelihood opportunities through technical backstopping and convergence through a consortium of institutions. Watersheds are used as an entry point for these activities.

Materials and Methods

Watersheds for undertaking on-farm research were selected in Karivemula and Devanakonda villages in Kurnool district, based on representative typology of the watershed, extent of rainfed area, current crop productivity and willingness of community to participate in on-farm research activities. The strategy adopted was a knowledge-based, bottom-up and participatory approach, which involved close interactions with the project implementation agencies (PIAs) and farmers. The detailed socioeconomic surveys using participatory rural appraisal (PRA) in each watershed helped us to understand the constraints to reduced crop productivity. From this analysis, we were able to better understand how to achieve increased productivity from the farmer's perspective.

Soil samples were collected from thirty farmers' fields in Karivemula and Devanakonda watersheds of Kurnool district on a toposequence and were analyzed for physical and biological parameters and various nutrients. The results indicated that all the fields were low in N (599 mg kg^{-1} soil), low to medium in available P (9.8 mg kg^{-1} soil) (Olsen's P), high in exchangeable K (133 mg kg^{-1} soil), and low in available Zn (0.4 mg kg^{-1} soil), S (3.2 mg kg^{-1} soil) and B (0.3 mg kg^{-1} soil). The information from soil analysis along with historical rainfall and minimum and maximum temperature data enabled us to calculate the length of the growing period (LGP). This critical information assisted in identifying better options to improve yield levels and for sustaining natural resources.

Five on-farm trials in Karivemula as well as in Devanakonda were conducted during the rainy season in 2003 to demonstrate the beneficial effects of improved production technologies in pearl millet. The package included improved cultivar (ICTP 8203), seed rate of 4.0 kg ha^{-1}, seed treatment with thiram (3 g kg^{-1} seed) and fertilizer dose of 60 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1}. Full application of P and 50% of N were applied as a basal dose and the remaining 50% of N as topdressing at 30 days after sowing. Basal application of micronutrients included a mixture of 5 kg borax (0.5 kg B) ha', 50 kg zinc sulfate (10 kg Zn) ha^{-1} and 200 kg gypsum (30 kg S) ha^{-1}. Two intercultivations at 25 and 50 days after sowing were used to control weeds. The crop was free from pests and diseases. Improved production technology was compared with the farmers' method in an area of 1000 m^2 in each of the farmers' fields. The farmers' method included a seed rate of 3 kg ha^{-1} and a fertilizer dose of 32 kg N ha^{-1} and 23 kg P_2O_5 ha^{-1}. Full application of P and 9 kg N ha^{-1} were applied as basal and 23 kg N ha^{-1} applied as topdressing at the panicle initiation stage. The seasonal rainfall was 307 mm in Karivemula and 470 mm in Devanakonda, much below the previous normal rainfall (572 mm).

Results and Discussion

The improved production technologies gave higher yields in both locations and recorded a mean grain yield of 2.11 ha^{-1} which was 164% higher than that obtained with farmers' practice (0.80 t ha^{-1}) (Table1). In addition to increased grain yields, improved technology also resulted in a higher fodder yield of 1.81 t ha^{-1}. Fodder yield is very important in this area, as the major crops grown are groundnut *(Arachis hypogaea),* tomato *(Lycopersicon esculentum),* sunflower *(Helianthus annuus)* and castor *(Ricinis communis).* Only groundnut is used as a source of fodder. Severe scarcity of fodder is being experienced in Kurnool district due to continuous droughts, which is leading to yearly reductions in cattle population.

The increased grain and fodder yields with improved production practice were due mainly to higher plant populations, increased total dry matter, increased heads weight, higher threshing percentage, higher 100-grain mass and higher harvest index (Table2). Traditional dryland cropping systems are characterized by low risk and low yield. It must be recognized that low risk will continue to be the guiding principle in view of socio-economic conditions of dryland farmers. The problem would be how to combine low risk and high yield. For realizing full yield potential, optimum plant population per unit area is very important. Selecting suitable variety will not only help increase production of a single crop but also help increase cropping intensity. Plant population depends not only on seeding rate but also on the time and method of sowing which are low monetary inputs. The rainy season crops should be planted with the first "soaking" rains to enable the crops to make use of early season rains which should allow them to complete their life cycle before the cessation of rains. Split application of fertilizers in relation to crop needs and moisture availability also helps increase fertilizer-use efficiency. Robust plants with yield contributing factors like higher threshing percentage, bold grain and uniform maturity are encouraged. Yield increases in response to balanced fertilization have been reported by Bationo et al. (1993).

The economic viability of improved technologies over traditional farmers' practice was calculated using prevailing prices of input and output costs. The additional cost of US\$29 ha^{-1} (Table1) incurred in the improved technology as compared to farmers' practice was mainly due to balanced fertilization (micronutrients and additional N and P) and one additional weeding by intercultivation. However, the improved technology resulted in increased mean income of US\$146 with a cost-benefit ratio of 2.6 (Table1). This additional income could substantially

Table 1. Yields and economics of pearl millet in ten on-farm trials conducted at Karivemula and Devanakonda watersheds in Kurnool district of Andhra Pradesh, India.

Cultivation method	Grain yield (tha[1])	Fodder yield (t ha^{-1})	Cost of cultivation (Rs ha')	Net return (Rs ha-')	Benefit-cost ratio
Improved production technology	2.11	1.81	3500 (78)[1]	9148 (203)	2.6
Farmers' practice	0.80	1.13	2200 (49)	2581 (57)	1.2
SE±	0.14	0.18	91	764	
CV(%)	21.0	27.2	7.1	29.1	

1. Figures in parenthesis are in US$.

Table 2. Yield components of pearl millet in ten on-farm trials conducted at Karivemula and Devanakonda watersheds in Kurnool district of Andhra Pradesh, India.

Cultivation method	Plant population (number ha^{-1})	Total dry matter (t ha')	Heads weight (t ha^{-1})	Threshing (%)	100-grain mass (g)	Harvest index
Improved production technology	129212	4.34	2.53	83	1.07	0.48
Farmers' practice	127282	2.17	1.04	76	0.64	0.37
SE±	3335	0.32	0.16	0.72	0.10	0.02
CV (%)	5.8	21.7	19.8	2.0	25.0	9.9

benefit resource-poor fanners and improve their livelihoods in the dry regions of Kurnool district. Significant increases in grain yields of sorghum *(Sorghum bicolor)* by 120% and maize *(Zea mays)* by 76% were observed due to balanced fertilization (TJ Rego, ICRISAT, personal communication). Arromratana et al. (1993) reported that applications of micronutrients like gypsum and B significantly increased test weight. Similar results were also reported by Joshi (1997) and the response to micronutrients was more evident during a drought year than in normal years. Rajat De and Gautam (1987) reported that with scientific management practices, crop yields could be increased at least three-fold. The results from our study clearly bring out the potential benefits of improved production technology in enhancing pearl millet yields and net returns in the dry ecoregions of Andhra Pradesh.

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References

Arromratana U, Nagara TN, Ratawarat S and **Paisancharoen K. 1993.** Relationship of soil water status, gypsum and boron management on yield and quality of peanut in the wet season. Page 34 *in* Abstract on Agricultural Development Research Center in Northeast Thailand (11) 1988-1993, Moe Din Daeng, Khon Kaen, Thailand.

Bationo A, Christianson CB and **Klaij MC. 1993.** The effect of crop residue and fertilizer use on pearl millet yields in Niger. Fertilizer Research 34:251-258.

Harinarayana G. 1987. Pearl millet in Indian agriculture. Pages 5-17 *in* Proceedings of the International Pearl Millet Workshop, 7-11 April 1986, 1CRISAT Center, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Joshi NL. 1997. Response of pearl millet-based cropping systems to nitrogen in the arid region. Pages 5-23 *in* From research station to farmer's field: nutrient management research for millet-based cropping systems of western Rajasthan: proceedings of a planning workshop, 20-22 May 1996, Jodhpur, India (Seeling B and Joshi NL, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Jodhpur 342 003, Rajasthan, India: Central Arid Zone Research Institue.

Rajat De and Gautam RC. 1987. Management practices to increase and stabilize pearl millet production in India. Pages 247-253 *in* Proceedings of the International Pearl Millet Workshop, 7-11 April 1986,ICRISAT Center, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

ICRISAT Publications

Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and **Evenson RE. (eds.) 2004.** Sorghum genetic enhancement: research process, dissemination and impacts. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 320 pp. ISBN 92-9066-470-3. Order code BOE 033. HDC US$25.00, LDC US$10.00, India Rs 450.00.

This volume covers 32 years of sorghum research across ICRISAT in partnership with NARS in Asia, Africa and Latin America and gives insights on the many facets of the research process, dissemination and impacts. The volume was completed through close collaboration among biological, natural and social scientists. The chapters document the flow of ICRISAT sorghum germplasm across regions and the genetic enhancement research process in partnership with NARS. It elaborates on ICRISAT's contribution to NARS breeding programs through capacity building and the supply of useful germplasm, breeding materials, hybrid parents and cultivars. It assesses the impacts of ICRISAT-NARS partnerships in genetic enhancement research on sorghum. The contents include an introduction to the crop; trends in global sorghum production; conservation, utilization and distribution of sorghum germplasm; research-for-development targets; research processes and strategies in Asia, Africa and Latin America, its outputs and contributions to public and private sector institutions; applications of new tools; regional breeding; and market-oriented needs of sorghum.

With the ultimate aim of increasing sorghum production worldwide, ICRISAT has readily made available its germplasm to NARS of developing and developed countries. Since NARS evaluation and selection of materials has led to the incorporation of ICRISAT germplasm into varieties released and grown in farmers' fields, this book assesses the value of the germplasm to NARS and the seed sector. A systematic documentation and analysis of the use of ICRISAT germplasm is undertaken for understanding the role of its germplasm products in varietal development worldwide. Mechanisms to increase the efficiency of genetic enhancement research are explored through a better understanding of past activities and their impact on the development of new cultivars by ICRISAT and its partners. This facilitates exploitation of the world germplasm base and helps identify means of achieving greater utility. Several chapters deal with research partnerships and technology exchange, adoption of improved cultivars and lessons learned from adoption studies as well as critical factors influencing the uptake process. Important dimensions of the impacts of sorghum research are highlighted. Research benefits were measured in terms of increase in yields, reduction in per unit cost of production, increase in stability in sorghum yield and improved food security. The nature, extent and determinants of sorghum research spillover effects across continents and agro-ecological zones were also examined and quantified. The concluding chapter presents future directions for partnership and a research strategy for sorghum research-for-development, suggesting new and innovative partnerships among all players (ICRISAT, NARS, public- and private-seed sectors and NGOs). This book serves as a valuable resource and will be of significant interest to those working in plant breeding, crop science and agricultural economics.

Brenan JP, Bantilan MCS, Sharma HC and **Reddy BVS. 2004.** Impact of ICRISAT research on sorghum midge on Australian agriculture. Impact Series no. 11. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 36 pp. ISBN 92-9066-467-3. Order code ISE 011. HDC US$18.00, LCD US$6.00, India Rs 282.00.

The most significant contribution from ICRISAT to Australian agriculture has been the introduction of improved sorghum midge *(Stenodiplosis sorghicola)* resistant lines combining desirable white grain and tan plant color through material such as ICSV 197, ICSV 745 and PM 13654. Overall, Australia has received significant benefits from ICRISAT's research on midge resistance in sorghum, at an average of A$ 1.14 million yr^{-1}. This is an example of international agricultural research output aimed at improving productivity in developing countries also having spillover benefits in developed countries. The spillover impacts in Australia from genetic materials developed and distributed through ICRISAT were analyzed in two levels. The first level is the identification of anticipated spillover benefits in terms of cost reduction for sorghum. The second level is the incorporation of price effects of international agricultural research for this crop. The price effects resulting from successful ICRISAT research were found to be significant. The lower prices for sorghum, as a result of increased production led to income reductions for Australian producers, and these were partly offset by the increased yields. The gains for the Australian consumers of these grains (ie, the Australian livestock sector) from the lower prices were significant, so that overall Australia made net gains from the impact of ICRISAT's sorghum research. These findings have important implications for international agricultural research, and recognition of these can assist in informed decision-making for research resources allocation and planning, and is likely to result in a more efficient and cooperative system worldwide.

Hall A. 2004. New patterns of partnership in agricultural research in Africa: Institutional lessons from SMIP. Working Paper Series no. 18. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 32 pp.

This report discusses new patterns of partnership in agricultural research and the possible emergence of a new model for the production, diffusion and use of agricultural technology. It provides an overview of recent experiences from the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP) in Southern Africa, a technology program in which an explicit attempt has been made to pursue a broad-based partnership approach. This report argues that SMIP's progress to date holds many lessons for both national and international agricultural research organizations in Southern Africa and associated regional bodies. Foremost amongst these lessons is that there is potentially great advantage to be gained from blurring the institutional and organizational distinction that usually exists between research and general development activities. Secondly, ways of achieving this inevitably involve working with partners from outside the formal research community, including those from the private and voluntary sectors. Thirdly, while there is growing acknowledgment that such patterns of partnership are of value, there is still a need to learn ways in which these relationships can be developed in practice. SMIP has much to offer with regard to lessons in this area. A general implication for ICRISAT is that much more time and effort need to be invested in institutional learning from past and current projects if the Institute wants to enhance its impact performance.

Monyo ES, Ngereza J, Mgonja MA, Rohrbach DD, Saadan HM and **Ngowi P. 2004.** Adoption of improved sorghum and pearl millet technologies in Tanzania. Bulawayo, Zimbabwe: International Crops Research Institute for the Semi-Arid Tropics. 23 pp.

Sorghum and pearl millet are important food crops in Tanzania, particularly in the drier areas. ICRISAT and the national research program have developed several improved varieties of both crops, of which five (3 sorghum, 2 pearl millet) have been released during the period 1986-1999. This publication describes on-station and on-farm performance of the new varieties, results from detailed adoption surveys conducted in 2001, and efforts to multiply and distribute seed through conventional as well as new, innovative means.

Improved varieties occupy approximately 36% of Tanzania's sorghum area and 29% of its pearl millet area. They are widely popular mainly for their early maturity (and thus drought tolerance) and high yield, 10 to 38% higher than local landraces. Adoption has been stimulated by interventions by ICRISAT, NGOs and other partners to strengthen local seed systems and community-based seed production; and by the efforts of the national extension service to make farmers aware of the new varieties.

The surveys also examined the variety evaluation criteria used by farmers. Farmers identified positive and negative traits in each variety, providing a valuable guide to setting priorities for plant breeding research.

Selected Bibliography

Sorghum -2004

Agarwal M, Singh R and **Shrotrla PK. 2004.** Classification of elite sorghum lines by principal component analysis. Indian Journal of Agricultural Research 38(l):55-59.

Aher RK and **Nair LN. 2004.** Post infection changes in sugar, organic acid and free amino acid contents of sorghum leaf anthracnose caused by *Colletotrichum graminicola.* Advances in Plant Sciences 17(l):85-88.

Ahmad N, Khan H, Saleem M, Khan SZ and **Bahrami AM. 2004.** Effect of urea treated sorghum stover with or without cattle manure on its intake and digestibility by the growing ruminants. Journal of Animal and Veterinary Advances 3(4): 198-201.

Ajayi AE and **Olufayo AA. 2004.** Evaluation of two temperature stress indices to estimate grain sorghum yield and evapotranspiration. Agronomy Journal 96(5): 1282-1287.

Amaducci S, **Monti A** and **Venturi G. 2004.** Non-structural carbohydrates and fibre components in sweet and fibre sorghum as affected by low and normal input techniques. Industrial Crops and Products 20(1): 111-118.

Amedie B, Hiremath SM, Chittapur BM, Halikatti SI and **Chimmad VP. 2004.** Intercropping of grain legumes in sorghum. Karnataka Journal of Agricultural Sciences 17(1):22-27.

Amzallag GN. 2004. Brassinosteroid: A modular of the development window for salt-adaptation in *Sorghum bicolor.* Israel Journal of Plant Sciences 52(1): 1-8.

An YJ. 2004. Toxicity of benzene, toluene, ethylbenzene, and xylene (BTEX) mixtures to *Sorghum bicolor* and *Cucumis sativus.* Bulletin of Environmental Contamination and Toxicology 72(5): 1006-1011.

Anonymous. 2004. AP to encourage ethanol plants based on sweet sorghum. Chemical Weekly (Bombay) 49(52): 122-123.

Anwar S, Shah WA, Bakht J and **Jabeen N. 2004.** Comparison of sorghum extracts, chemical and hand weeding for weed management in wheat *(Triticum aestivum* L.) crop. Journal of Agronomy 3(l):59-67.

Aruna C and **Audilakshmi S. 2004.** Genetic architecture of grain hardness - a durable resistance mechanism for grain moulds in sorghum *(Sorghum bicolor* (L.) Moench). Indian Journal of Genetics and Plant Breeding 64(l):35-38.

Awika JM and **Rooney LW. 2004.** Sorghum phytochemicals and their potential impact on human health. Phytochemistry 65(9):1199-1221.

Awika JM, Roomy LW and **Waniska RD. 2004.** Properties of 3-deoxyanthocyanins from sorghum. Journal of Agricultural and Food Chemistry 52(14):4388-4394.

Azooz MM. 2004. Proteins, sugars and ion leakage as a selection criterion for the salt tolerance of three sorghum cultivars at seedling stage grown under NaCl and nicotinamide. International Journal of Agriculture and Biology 6(l):27-35.

Azooz MM, Shaddad MA and **Abdel-Latef AA. 2004.** Accumulation and compartmentation of proline in relation to salt tolerance of three sorghum cultivars. Indian Journal of Plant Physiology (New Series) 9(1): 1-8.

Bandyopadhyay KK, Ghosh PK, Chaudhary RS, Hati KM, Mandal KG and **Misra AK. 2004.** Integrated nutrient management practices in soybean *(Glycine max)* and sorghum *(Sorghum bicolor)* in sole and intercropping systems in a Vertisol. Indian Journal of Agricultural Sciences 74(2):55-63.

Belton PS and **Taylor JRN. 2004.** Sorghum and millets: protein sources for Africa. Trends in Food Science and Technology 15(2):94-98.

Berenji J and **Dahlberg J. 2004.** Perspectives of sorghum in Europe. Journal of Agronomy and Crop Science 190(5):332-338.

Beta T and **Corke H. 2004.** Effect of ferulic acid and catechin on sorghum and maize starch pasting properties. Cereal Chemistry 81(3):418-422.

Bhargava S and **Paranjpe S. 2004.** Genotypic variation in the photosynthetic competence of *Sorghum bicolor* seedlings subjected to polyethylene glycol-mediated drought stress. Journal of Plant Physiology 161(1):125-129.

Bogo A, Mantle PG and **Harthmann OEL. 2004.** Screening of sweet sorghum accessions for inhibition of secondary sporulation and saccharide measurements in honeydew of *Claviceps africana.* Fitopatologia Brasileira 29(1):86-90.

Chaudhary SB, Pawar SV and **Patil SC. 2004.** Heterosis studies in *rati* sorghum. Advances in Plant Sciences 17(l):333-336.

Cheema ZA, Khaliq A and **Saeed S. 2004.** Weed control in maize *(Zea mays* L.) through sorghum allelopathy. Journal of Sustainable Agriculture 23(4):73-86.

Chenghai Yang, Everitt JH and **Bradford JM. 2004.** Airborne hyperspectral imagery and yield monitor data for estimating grain sorghum yield variability. Transactions of the ASAE 47(3):915-924.

Chittapur BM and **Kulkarni SS. 2004.** Response of pop sorghum cultivars to pre-sowing seed hardening treatments. Karnataka Journal of Agricultural Sciences 17(1):93-96.

Cho NK, Kang YK, Song CK, Jeun YC, Oh JS and **Cho YI. 2004.** Effects of planting density on growth, forage yield and chemical composition of *jeju* native sorghum *(Sorghum bicolor* L.). Journal - Korean Society of Grassland Science 24(3):225-230.

Cho NK, Kang YK, Song CK, Jeun YC, Oh JS and **Cho YI. 2004.** Effects of seeding date on ecological response, forage yield potential and chemical composition in *jeju* native sorghum *(Sorghum bicolor* L.). Journal - Korean Society of Grassland Science 24(3):231-236.

Cubuk MH and **Heperkan HA. 2004.** Investigation of pollutant formation of sweet sorghum-lignite (Orhaneli) mixtures in fluidised beds. Biomass and Bioenergy 27(3):277-287.

da Silva LS and **Taylor JRN. 2004.** Sorghum bran as a potential source of kafirin. Cereal Chemistry 81(3):322-327.

Das ND, Srivastava NN, Indira S and **Rani GS. 2004.** Weather-based forecasting on grain-mold disease of sorghum *{Sorghum bicolor)* in Palem, Andhra Pradesh. Indian Journal of Agricultural Sciences 74(3):159-161.

Del Pozo- Insfran D, Urias-Lugo D and **Hernandez-Brenes C. 2004. E**ffect of amyloglucosidase on wort composition and fermentable carbohydrate depletion in sorghum lager beers. Journal - Institute of Brewing 110(2): 124-132.

Doka O, Bicanic DD, Dicko MH and **Slingerland MA. 2004.** Photoacoustic approach to direct determination of the total phenolic content in red sorghum flours. Journal of Agricultural and Food Chemistry 52(8):2133-2136.

Du B, Bekele A and **Morrison JE Jr. 2004.** Drill furrow opener effects on wheat and sorghum establishment in no-till fields. Applied Engineering in Agriculture 20(2): 179-185.

Earp CF, McDonough CM, Awika J and **Rooney LW. 2004.** Testa development in the caryopsis of *Sorghum bicolor* (L.) Moench. Journal of Cereal Science 39(2):303-311.

Earp CF, McDonough CM and **Rooney LW. 2004.** Microscopy of pericarp development in the caryopsis *of Sorghum bicolor* (L.) Moench. Journal of Cereal Science 39(l):21-27.

Elkhalifa AEO, Schiffler B and **Bernhard R. 2004.** Effect of fermentation on the starch digestibility, resistant starch and some physicochemical properties of sorghum flour. Nahrung 48(2):91-94.

El-Sebsy AA. 2004. Effect of irrigation intervals and varieties of grain sorghum on growth, yield and consumptive use of water. Alexandria Science Exchange 25(1): 199-212.

Ercoli L, Mariotti M, Masoni A and **Arduini I.2004.** Growth responses of sorghum plants to chilling temperature and duration of exposure. European Journal of Agronomy 21(1):93-103.

Figueira LK. 2004. Predator: prey ratios of *Chrysoperla externa* (Hagen) (Neuroptera: Chrysopidae) for the control of greenbug in sorghum genotypes. Neotropical Entomology 33(4):447-450.

Filya I, Sucu E and **Karabulut A. 2004.** Effect of *Propionibacterium acidipropionici,* with or without *Lactobacillus plantarum,* on the fermentation and aerobic stability of wheat, sorghum and maize silages. Journal of Applied Microbiology 97(4):818-816.

Finlayson SA, Gohil HL and **Kato-Noguchi H. 2004.** Circadian ethylene synthesis in *Sorghum bicolor.* expression and control of the system at the whole plant level. Journal of Plant Growth Regulation 23(l):29-36.

Folliard A, Traore PCS, Vaksmann M and **Kouressy M. 2004.** Modeling of sorghum response to photoperiod: a threshold-hyperbolic approach. Field Crops Research 89(l):59-70.

Gaffa T, Yoshimoto Y, Hanashiro I, Honda O, Kawasaki S and **Takeda Y. 2004.** Physicochemical properties and molecular structures of starches from millet *(Pennisetum typhoides)* and sorghum *(Sorghum bicolor* L. Moench) cultivars in Nigeria. Cereal Chemistry 81(2):255-260.

Gerik TJ, Rosenthal WD and **Vanderlip RL. 2004.** Simulating seed number in grain sorghum from increases in plant dry weight. Agronomy Journal 96(5): 1222-1230.

Ghosh M and **Ulaganathan K. 2004.** Immunolocalization of sorghum antifungal protein in embryogenic seed tissues. Current Science (Bangalore) 86(1):24~25.

Girish AG, **Rao VP** and **Thakur RP. 2004.** Diversity of grain mold fungi on selected sorghum genotypes. Indian Phytopathology 57(l):84-87.

Goodwin PH, Oliver RP and **Hsiang T. 2004.** Comparative analysis of expressed sequence tags from *Malva pusilla. Sorghum bicolor,* and *Medicago truncatula* infected with *Colletotrichum* species. Plant Science 167(3):481-489.

Grenier C, Bramel PJ, Dahiberg JA, El-Ahmadi A, Mahmoud M, Peterson GC, Rosenow DT and **Ejeta G. 2004.** Sorghums *of* the Sudan: analysis of regional diversity and distribution. Genetic Resources and Crop Evolution 51(5):489-500.

Grichar WJ, Besler BA and **Brewer KD. 2004.** Effect of row spacing and herbicide dose on weed control and grain sorghum yield. Crop Protection 23(3):263-267.

Gupta S, Khanna VK, Singh R and **Garg GK. 2004.** Identification of in vitro-responsive immature embryo size for plant regeneration in sudan grass *(Sorghum sudanense* Piper). Indian Journal of Biotechnology 3(1): 124 -127.

Gwary DM, Rabo TD and **Anaso AB. 2004.** Development of anthracnose symptoms on sorghum genotypes in the Nigerian savanna. Journal of Plant Diseases and Protection 111(1):96-103.

Habyarimana E, Bonardi P, Laureti D, Di Bari V, Cosentino S and **Lorenzoni C. 2004.** Multilocational evaluation of biomass sorghum hybrids under two stand densities and variable water supply in Italy. Industrial Crops and Products 20(1):3-9.

Habyarimana E, Laureti D, De Ninno M and **Lorenzoni C. 2004.** Performances of biomass sorghum [*Sorghum bicolor* (L.) Moench] under different water regimes in Mediterranean region. Industrial Crops and Products 20(l):23-28.

Hall A, Blummel M, Thorpe W, Bidinger FR and **Hash CT. 2004.** Sorghum and pearl millet as food-feed-crops in India. Animal Nutrition and Feed Technology 4(1):1-15.

Hambiin MT, Mitchell SE, White GM, Galiego J, Kukatia R, Wing RA, Paterson AH and **Kresovich S. 2004.** Comparative population genetics of the panicoid grasses: sequence polymorphism, linkage disequilibrium and selection in a diverse sample of *Sorghum bicolor.* Genetics 167(1):471-483.

Hentz M and **Nuessly G. 2004.** Development, longevity, and fecundity of *Sipha flava* (Homoptera: Aphididae) feeding on *Sorghum bicolor.* Environmental Entomology 33(3):546-553.

Herrera A, Tellez-Luis SJ, Gonzalez-Cabriales JJ, Ramirez JA and **Vazquez M. 2004.** Effect of the hydrochloric acid concentration on the hydrolysis of sorghum straw at atmospheric pressure. Journal of Food Engineering 63(1): 103-109.

Hwang KT, Weller CL and **Cuppett SL. 2004.** Policosanol contents and composition of grain sorghum kernels and dried distillers grains. Cereal Chemistry 81(3):345-349.

Hwang KT, Weller CL, Cuppett SL and **Hanna MA.** 2004. Changes in composition and thermal transition temperatures of grain sorghum wax during storage. Industrial Crops and Products 19(2): 125-132.

Kader MA and **Jutzi SC. 2004.** Effects of thermal and salt treatments during imbibition on germination and seedling growth of sorghum at 42/19°C. Journal of Agronomy and Crop Science 190(l):35-38.

Kalra V and **Pundir CS. 2004.** Quantification of urinary oxalate by immobilized oxalate oxidase of forage sorghum leaf. Indian Journal of Biotechnology 3(l):52-57.

Kamalakannan A, Shanmugam V and **Maruthasalam S. 2004.** Evaluation of maize genotypes for resistance to sorghum downy mildew (SDM) caused by *Peronosclerospora sorghi* (Weston and Uppal) C.G. Shaw. Plant Disease Research (Ludhiana) 19(1):60-63.

Kamatar MY and **Chimmad VP. 2004.** Evaluation of released hybrids and varieties for physiological indices in *rabi* sorghum. Karnataka Journal of Agricultural Sciences 17(1): 97-99.

Kamatar MY and **Nayakar NY. 2004.** DSH-4R, drought tolerant post-rainy season sorghum hybrid for Karnataka. Karnataka Journal of Agricultural Sciences 17(1):46—51.

Kenga R, Alabi SO and **Gupta SC. 2004.** Combining ability studies in tropical sorghum *(Sorghum bicolor* (L.) Moench). Field Crops Research 88(2/3):251-260.

Khatri RS and **Lodhi GP. 2004.** Regeneration ability in sudan vis-a-vis sorghum type parent and their hybrids in sorghum *(Sorghum bicolor* (L.) Moench). Environment and Ecology 22(2):360-361.

Kishore N and **Singh LN. 2004**. Stability for forage yield influencing traits in sorghum *(Sorghum bicolor* (1.) Moench) in montane. Indian Journal of Genetics and Plant Breeding 64(l):71-72.

Kshirsagar RB, Kulkarni KD, Pawar YD, Machewad GM and **Agarkar BS. 2004.** Studies on the effect of improvers and sorghum malt on the quality of wheat bread. Indian Journal of Nutrition and Dietetics 41 (7):299-303.

Kumari M and **Pundir CS. 2004.** Measurement of urinary oxalate by grain sorghum leaf oxalate oxidase immobilized to affixed alkylamine glass beads. Indian Journal of Biochemistry and Biophysics 41(2/3): 102-106.

Kurdali F. 2004. Estimates of dry matter yield and nitrogen uptake in sorghum grown on saline and non-saline soils manured with *dhaincha* plant residues. Journal of Plant Nutrition 27(9):1611-1634.

Kwak CS, Lira SJ, Kim SA and **Park SC. 2004.** Antioxidative and antimutagenic effects of Korean buckwheat, sorghum, millet and job's tears. Journal - Korean Society of Food Science and Nutrition 33(6):921-929.

Kyarisiima CC, Okot MW and **Svihus B. 2004.** Use of wood ash in the treatment of high tannin sorghum for poultry feeding. South African Journal of Animal Science 34(2): 110-115.

Lee SM and **Pan BS. 2004.** Inhibitory effect of tannin in dietary sorghum distillery residue and preliminary treatment with polyethylene glycol on in vitro digestibility of grey mullet *(Mugil cephalus).* Journal of Food Biochemistry 27(6):485-500.

Magalhaes JV, Garvin DF, Wang Y, Sorrells ME, Klein PE, Schaffert RE, Li Li and **Kochian LV. 2004.** Comparative mapping of a major aluminum tolerance gene in sorghum and other species in the Poaceae. Genetics 167(4): 1905-1914.

Mahmood A and **Cheema ZA. 2004.** Influence of sorghum mulch on purple nutsedge *(Cyperus rotundas* L.). International Journal of Agriculture and Biology 6(l):86-88.

Marley PS, Aba DA, Shebayan JAY, Musa R and **Sanni A. 2004.** Integrated management of *Striga hermonthica* in sorghum using a mycoherbicide and host plant resistance in the Nigerian Sudano-Sahelian savanna. Weed Research 44(3): 157-162.

Marley PS, Marasas WFO and **Hester V. 2004.** Occurrence of *Fusarium andiyazi* associated with sorghum in Nigeria. Archives of Phytopathology and Plant Protection 37(3):177-181.

Marley PS, Shebayan J, Aba DA and **Idem N. 2004.** Possibilities for control of *Striga hermonthica* in sorghum *(Sorghum bicolor)* using neem *(Azadirachta indica)* and parkia *(Parkia biglobosa)-based* products. International Journal of Pest Management 50(4):291-296

Marley PS, Toure A, Shebayan JAY, Aba DA, Toure AO, Diatto AG and **Katile SO. 2004.** Variability in host plant resistance of sorghum to *Striga hermonthica* infestation in West Africa. Archives of Phytopathology and Plant Protection 37(l):29-34.

Mateus GP and **Crusciol CAC. 2004.** Gigantic guinea sorghum straw on the weed establishment in a no-tillage area. Pesquisa Agropecuaria Brasileira 39(6):539-542.

McDonough CM, Floyd CD, Waniska RD and Rooney LW. 2004. Effect of accelerated aging on maize, sorghum, and sorghum meal. Journal of Cereal Science 39(3):351-361.

Menz MA, Klein RR, Unruh NC, Rooney WL, Klein PE and **Mullet JE. 2004.** Genetic diversity of public inbreds of sorghum determined by mapped AFLP and SSR markers. Crop Science **44(4):** 1236-1244.

Moore JW, Murray DS and **Westerman RB. 2004.** Palmer amaranth *(Amaranthus palmeri)* effects on the harvest and yield of grain sorghum *(Sorghum bicolor).* Weed Technology 18(l):23-29.

Mosha TCE and Vicent MM. 2004. Nutritional value and acceptability of homemade maize/sorghum-based weaning mixtures supplemented with rojo bean flour, ground sardines and peanut paste. International Journal of Food Sciences and Nutrition 5(4):301-315.

Moustafa ZR, Omran SEH and **El Taweel FHA. 2004.** Response of sweet sorghum plants to zinc, phosphorus fertilization and seed inoculation with va mycorrhiza. Alexandria Science Exchange 25(l):59-74.

Moyer JL, Fritz JO and **Higgins JJ. 2004.** Trends in forage yield and nutritive value of hay-type sorghum spp. Agronomy Journal 96(5): 1453-1458.

Muthukumar B and **Bennetzen JL. 2004.** Isolation and characterization of genomic and transcribed retrotransposon sequences from sorghum. Molecular Genetics and Genomics 271(3):308-316.

Myer RO and **Gorbet DW.** 2004. Crystalline amino acid supplementation of grain sorghum-based low protein diets for growing-finishing pigs. Journal of Applied Animal Research 25(2):85-90.

Nair SK, Prasanna BM, Rathore RS, Setty TAS, Kumar R and **Singh NN. 2004.** Genetic analysis of resistance to sorghum downy mildew and Rajasthan downy mildew in maize *(Zea mays* L.). Field Crops Research 89(2/3):379-387.

Netondo GW, Onyango JC and **Beck E. 2004.** Sorghum and salinity: I. Response of growth, water relations, and ion accumulation to NaCl salinity. Crop Science 44(3):797-805.

Netondo GW, Onyango JC and **Beck E. 2004.** Sorghum and salinity: II. Gas exchange and chlorophyll fluorescence of sorghum under salt stress. Crop Science 44(3):806-811.

Neumann E and **George E. 2004.** Colonisation with the arbuscular mycorrhizal fungus *Glomus mosseae* (Nicol. & Gerd.) enhanced phosphorus uptake from dry soil in *Sorghum bicolor* (L.). Plant and Soil 261(l/2):245-255.

Nikkhah A and **Alikhani M. 2004.** Effects of feeding ground or steam-flaked broom sorghum and ground barley on performance of dairy cows in midlactation. Journal of Dairy Science 87(1): 122-130.

Nunes A, Correfa I, Barros A and **Delgadiilo I. 2004.** Sequential in vitro pepsin digestion of uncooked and cooked sorghum **and** maize samples. Journal of Agricultural and Food Chemistry 52(7):2052-2058.

Nunez-Gonzalez MA, Maiti RK and **Singh VP. 2004.** Differential responses of mineral acquisition by glossy and non-glossy sorghum *(Sorghum bicolor* (L.) Moench). Crop Research 27(1): 137-143.

Ogbonna AC, Obi SKC and **Okolo BN.** 2004. Optimization of proteolytic activities in malting sorghum. Process Biochemistry 39(6):713-718.

Ogbonna AC, Obi SKC, Okolo BN and **Odibo FJC. 2004.** Purification and some properties of a cysteine proteinase from sorghum malt variety SK5912. Journal of the Science of Food and Agriculture 84(2): 113-120.

Okori P, Rubaihayo PR, Ekwamu A and **Fahieson J. 2004.** Genetic characterization of *Cercospora sorghi* from cultivated and wild sorghum and its relationship to other *Cercospora* fungi. Phytopathology 94(7):743.

Oliver AL, Grant RJ, Pedersen JF and **O'Rear J. 2004.** Comparison of brown midrib -6 and -18 forage sorghum with conventional sorghum and corn silage in diets of lactating dairy cows. Journal of Dairy Science 87(3):637-644.

Olupona JA and **Balogun OO. 2004.** Nutrient utilization by rabbits fed brewers' dried grains from different proportions of barley, maize and sorghum. Nigerian Journal of Animal Production 31(1-2):189-193.

Omanya GO, Haussmann BIG, Hess DE, Reddy BVS, Kayentao M, Welz HG and **Geiger HH. 2004.** Utility of indirect and direct selection traits for improving *Striga* resistance in two sorghum recombinant inbred populations. Field Crops Research 89(2/3):237-252.

Ortas I and **Rowell DL. 2004.** Effect of ammonium and nitrate on indigenous mycorrhizal infection, rhizosphere pH change, and phosphorus uptake by sorghum. Communications in Soil Science and Plant Analysis 35(13/14): 1923-1944.

Ortas I, Rowell DL and **Harris PJ. 2004.** Effect of mycorrhizae and pH change at the root-soil interface on phosphorus uptake by sorghum using a rhizocylinder technique. Communications in Soil Science and Plant Analysis 35(7-8): 1061-1080.

Oyeniyi JO and **Bozimo DO. 2004.** Relationship between author collaboration and productivity: a study of sorghum literature in Nigeria. African Journal of Library Archives and Information Science 14(l):29-36.

Patil SL and **Sheelavantar MN. 2004.** Effect of cultural practices on soil properties, moisture conservation and grain yield of winter sorghum *(Sorghum bicolar* L. Moench) in semi-arid tropics of India. Agricultural Water Management 64(l):49-67.

Patil SL, Sheelvanter MN, Lamani VK and **Reddy R. 2004.** Nutrient availability and grain yield of winter sorghum *(Sorghum bicolor* (L.) Moench) as influenced by tillage practices and integrated nutrient management in Vertisols of semi-arid tropics of India. Acta Agronomica Hungarica 52(2): 173-182.

Pawar KB and **Chavan PD. 2004.** Influence of leaf leachates of some plant species on free proline content in germinating seeds of *Sorghum bicolor* (L.) Moench. Allelopathy Journal 13(l):89-92.

Pedersen JF, Bean SR, Funneil DL and **Graybosch RA. 2004.** Rapid iodine staining techniques for identifying the waxy phenotype in sorghum grain and waxy genotype in sorghum pollen. Crop Science 44(3):764~767.

Pholsen S and **Suksri A. 2004.** Effect of organic amendment and chemical fertiliser on growth, yield and fodder quality of a forage sorghum *(Sorghum bicolor* L. Moench). Pakistan Journal of Biological Sciences 7(4):651-657.

Ping JA, Zhang FY, Cui GM and **Cheng QJ. 2004.** Study on the properties of autonomous seed setting and embryology in sorghum apomictic line 2083. Acta Agronomica Sinica 30(7):714-718.

Pinto AP, Mota AM, de Varennes A and **Pinto FC. 2004.** Influence of organic matter on the uptake of cadmium, zinc, copper and iron by sorghum plants. Science of me Total Environment 326(1-3):239-247.

Prasifka JR, Heinz KM and **Sansone CG. 2004.** Timing, magnitude, rates, and putative causes of predator movement between cotton and grain sorghum fields. Environmental Entomology 33(2):282-290.

Pring DR and **Tang HV. 2004.** Transcript profiling of male-fertile and male-sterile sorghum indicates extensive alterations in gene expression during microgametogenesis. Sexual Plant Reproduction 16(6): 289-297.

Prom LK. 2004. Effects of *Fusarium thapsinum, Curvularia lunata,* and their combination on sorghum germination and seed mycoflora. Journal of New Seeds 6(l):39-50.

Pyare R and **Prasad K. 2004.** Response of nitrogen doses to fodder yield of sorghum under two methods of sowing. Plant Archives 4(1): 145-147.

Raghuwanshi RK, Gautam VS and **Kushwaha SS. 2004.** Effect of intercropping of soybean with sorghum on yield and N uptake and available N status in Vertisol of Madhya Pradesh. Crop Research 27(l):70-76.

Raikwar MK and **Nag SK. 2004.** Dissipation of carbendazim residues in fodder sorghum *(Sorghum bicolor).* Indian Journal of Agricultural Sciences 74(4):227-229.

Rangasamy A and **Chinnusamy C. 2004.** Nutrient uptake pattern of sorghum and redgram influenced by sorghum based intercropping system in rainfed Vertisols. Journal of Ecobiology 16(2): 137-142.

Ratnavathi CV and **Sashidhar RB. 2004.** Induction of chitinase in response to *Aspergillus* infection in sorghum *(Sorghum bicolor* (L) Moench). Journal of the Science of Food and Agriculture 84(12): 1521-1527.

Rebe M, van den Berg J and **Donaldson G. 2004.** Status of leaf feeding resistance and oviposition preference of *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) for sweet sorghum *(Sorghum bicolor)* landraces. International Journal of Pest Management 50(1):49-53.

Reinbott TM, Conley SP and **Blevins DG. 2004.** No-tillage corn and grain sorghum response to cover crop and nitrogen fertilization. Agronomy Journal 96(4): 1158-1163.

Rooney WL. 2004. Sorghum improvement - integrating traditional and new technology to produce improved genotypes. Advances in Agronomy 83:37-109.

Saini VK, Bhandari SC and **Tarafdar JC. 2004.** Comparison of crop yield, soil microbial C, N and P, N-fixation, nodulation and mycorrhizal infection in inoculated and non-inoculated sorghum and chickpea crops. Field Crops Research 89(l):39-47.

Sajjan AS, Pawar KN, Dhanaieppagol MS and **Biradar BD. 2004.** Influence of water stress treatments on seed quality of sorghum genotypes. Crop Research 27(1):46-49.

Salzman KZ, Salzman RA, Ahn JE and **Koiwa H. 2004.** Transcriptional regulation of sorghum defense determinants against a phloem-feeding aphid. Plant Physiology 134(1):420-431.

Sato S, Clemente T and **Dweikat I .2004.** Identification of an elite sorghum genotype with high in vitro performance capacity. In Vitro Cellular and Developmental Biology - Plant 40(1):57-60.

Seetharama N and **Rao BD. 2004.** Sustaining nutritional security. Hindu Survey of Indian Agriculture 2004, pp. 37-38.

Shanker AK, Djanaguiranian M, Sudhagar R, Jayaram K and **Pathmanabhan G. 2004.** Expression of metallothionein 3-like protein mRNA in sorghum cultivars under chromium (VI) stress. Current Science 86(7):901-902.

Sharma AD, Wajapeyee N, Yadav V and **Singh P. 2004.** Stress-induced changes in peptidyl-prolyl cis-trans isomerase activity of *Sorghum bicolor* seedlings. Biologia Plantarum 47(3):367-371.

Shelton JL, Matthews JO, Southern LL, Higbie AD, Bidner TD, Fernandez JM and **Pontif JE. 2004.** Effect of nonwaxy and waxy sorghum on growth, carcass traits, and glucose and insulin kinetics of growing-finishing barrows and gilts. Journal of Animal Science 82(6): 1699-1706.

Shin SI, Choi HJ, Chung KM, Hamaker BR, Park KH and **Moon TW. 2004.** Slowly digestible starch from debranched waxy sorghum starch: preparation and properties. Cereal Chemistry 81(3):404-408.

Shnontacchi M, Jasid S and **Puntarulo S. 2004.** Nitric oxide generation during early germination of sorghum seeds. Plant Science 167(4):839-817.

Singh BU, Padmaja PG and **Seetharama N. 2004.** Biology and management of the sugarcane aphid, *Melanaphis sacchari* (Zehntner) (Homoptera: Aphididae), in sorghum: a review. Crop Protection 23(9):739-755.

Singh BU, Padmaja PG and **Seetharama N. 2004.** Stability of biochemical constituents and their relationships with resistance to shoot fly, *Atherigona soccata* (Rondani) in seedling sorghum. Euphytica 136(3):279-289.

Sira P, Eduviges E and **Amaiz LM. 2004.** Laboratory scale method for isolation of starch from pigmented sorghum. Journal of Food Engineering 64(4):515-518.

Solymosi P. 2004. Allelopathy of *Sorghum bicolor* (L.) Moench. Novenyvedelem 40(5):237-244.

Stafa Z, Uher D, Macesic D, Pospisil A, Jantol Z, Gal S, Muzinic G and **Knezevic M. 2004.** Productivity and quality of fodder sorghum hybrids S. Sioux and Grazer N grown on family farms. Mljekarstvo 54(2):109-117.

Sudha KN, Prasanna BM, Rathore RS and **Setty TAS. 2004.** Genetic variability in the Indian maize germplasm for resistance to sorghum downy mildew *{Peronosclerospora sorghi)* and Rajasthan downy mildew *(Peronosclerospora heteropogoni).* Maydica 49(l):57-64.

Sweeney DW and **Moyer JL. 2004.** In-season nitrogen uptake by grain sorghum following legume green manures in conservation tillage systems. Agronomy Journal 96(2):510-515.

Tamado T and **Milberg P. 2004.** Control of parthenium *(Parthenium hysterophorus)* in grain sorghum *(Sorghum bicolor)* in the smallholder farming system in Eastern Ethiopia. Weed Technology 18(1):100-105.

Tefera T. 2004. Fanners' perceptions of sorghum stem-borer and farm management practices in eastern Ethiopia. International Journal of Pest Management 50(l):35-40.

Tellez-Luis SJ, Gonzalez-Cabriales JJ, Ramirez JA and **Vazquez M. 2004.** Production of transglutaminase by *Streptoverticillium ladakanum* NRRL-3191 grown on media made from hydrolysates of sorghum straw. Food Technology and Biotechnology 42(1): 1-4.

Tellez-Luis SJ, Ramirez JA and **Vazquez M. 2004.** Application in restructured fish products of transglutaminase obtained by *Streptoverticillum ladakanaum* in media made from hydrolysates of sorghum straw. Journal of Food Science 69(1):FMS1-FMS5.

Teaso T, Claflin LE and **Tuinstra MR. 2004.** Estimation of combining ability for resistance to fusarium stalk rot in grain sorghum. Crop Science 44(4): 1195-1199.

Triggs JM, Kimball BA, Pinter Jr PJ, Wall GW, Conley MM, Brooks TJ, LaMorte RL, Adam NR, Ottman MJ, Matthias AD, Leavitt SW and **Cerveny RS. 2004.** Free-air CO_2 enrichment effects on the energy balance and evapotranspiration of sorghum. Agricultural and Forest Meteorology 124(1/2):63-79.

Tudu PC, Bhattacharya S, Nanda MK and **Mukherjee AK. 2004.** Herbage yield and nutritional qualities of sorghum varieties under different levels of nitrogen. Environment and Ecology 22(1):129-131.

Verdoucq L, Morinlere J, Bevan DR, Escn A, Vasella A and **Henrissat B. 2004.** Structural determinants of substrate specificity in family 1 beta-glucosidases. Novel insights from the crystal structure of sorghum dhurrinase-1, a plant beta-glucosidase with strict specificity, in complex with its natural substrate. Journal of Biological Chemistry 279(30):31796-31803.

Whitbread AM. 2004. Grain sorghum production and soil nitrogen dynamics following ley pastures on a vertosol in Queensland, Australia. ACIAR Proceedings 115:115-125.

White CE, Lopez FD and **McDowell LR. 2004.** Effects of virginiamycin and fat on utilization of grain sorghum diets by swine. Journal of Animal and Veterinary Advances 3(2):74-80.

Yadav R, Grewal RPS and **Pahuja SK. 2004.** Multivariate analyses in forage sorghum *(Sorghum bicolor* (L.) Moench). Indian Journal of Genetics and Plant Breeding 64(l):39-45.

Yang X and **Scheffler BE. 2004.** SOR1, a gene associated with bioherbicide production in sorghum root hairs. Journal of Experimental Botany 55(406):2251-2259.

Yang XH, Owens TG, Scheffler BE and **Weston LA. 2004.** Manipulation of root hair development and sorgoleone production in sorghum seedlings. Journal of Chemical Ecology 30(1):199-213.

Yetneberk S, de Kock HL, Rooney LW and **Taylor JRN. 2004.** Effects of sorghum cultivar on injera quality. Cereal Chemistry 81(3):314-321.

Yonli D, Traoré H, Hess DE, Abbasher AA and **Boussim IJ. 2004.** Effect of growth medium and method of application of *Fusarium oxysporum* on infestation of sorghum by *Striga hermonthica* in Burkina Faso. Biocontrol Science and Technology 14(4):417-421.

Yu J, Tuinstra MR, Claassen MM, Gordon WB and **Witt MD. 2004.** Analysis of cold tolerance in sorghum under controlled environment conditions. Field Crops Research 85(l):21-30.

Zhan QW and **Qian ZQ. 2004.** Heterosis utilization of hybrid between sorghum *[Sorghum bicolor* (L.) Moench] and sudangrass *[Sorghum sudanense* (Piper) Stapf]. Acta Agronomics Sinica 30(0:73-77.

Zhan QW and **Wang BF. 2004.** Numerical analysis of biological characteristics of *Sorghum bicolor* and *Sorghum sudanense.* Acta Prataculturae Sinica 13(2):61-66.

Zhu-Salzman K, Salzman RA, Ahn JE and **Koiwa H. 2004.** Transcriptional regulation of sorghum defense determinants against a phloem-feeding aphid. Plant Physiology 134(1):420-431.

Millets-2004

Ahanchede A and **Poirier-Hamon S. 2004.** Why no tetraploid cultivar of foxtail millet? Genetic Resources and Crop Evolution 51(3):227-230.

Ahn C and **Sparks RE. 2004.** Dynamic model to predict responses of millets *(Echinochloa* sp.) to different hydrologic conditions for the Illinois floodplain-river. River Research and Applications 20(5):485-498.

Ashraf M and **Hafeez M. 2004.** Thermotolerance of pearl millet and maize at early growth stages: growth and nutrient relations. Biologia Plantarum 48(1):81-86.

Ayo JA. 2004. Effect of *acha (Digitaria exilis* Staph) and millet *(Pennisetum typhodium)* grain on *kunun zaki.* British Food Journal 106(7):512-519.

Babitha MP, Prakash HS and **Shetty HS. 2004.** Purification and properties of lipoxygenase induced in downy mildew resistant pearl millet seedlings due to infection with *Sclerospora graminicola.* Plant Science 166(1):31-39.

Baltensperger DD, Frickel GE, Neison LA, Krall JM, Vigil M, Hain J, Johnson J, Stymiest C and **Rickertsen JR. 2004.** Registration of 'Horizon' proso millet. Crop Science 44(2): 688-689.

Bélair G, Dauphinais N, Fournier Y and **Dangi OP. 2004.** Pearl millet for the management of *Pratylenchus penetrans* in flue-cured tobacco in Quebec. Plant Disease 88(9):989-992.

Belton PS and **Taylor JRN. 2004.** Sorghum and millets: protein sources for Africa. Trends in Food Science and Technology 15(2):94-98.

Chaluvaraju G, Basavaraju P, Shetty NP, Deepak SA, Amruthesh KN and **Shetty HS. 2004.** Effect of some phosphorous-based compounds on control of pearl millet downy mildew disease. Crop Protection 23(7):595-600.

Dadhich LK. 2004. Plant morphology, yield, nutrient content and uptake of fodder pearl millet as influenced by S, Zn supply and its intercropping with cowpea. Annals of Agri Bio Research 9(2): 183-188.

de Rouw A. 2004. Improving yields and reducing risks in pearl millet farming in the African Sahel. Agricultural Systems 81(l):73-93.

Deepak SA, Oros G, Raj SN, Shetty NP and **Shetty HS. 2004.** Iprovalicarb has potential for the control of downy mildew of pearl millet. Acta Phytopathologica et Entomologica Hungarica 39(1/3):55-70.

Diouf O, Broo YC, Diouf M, Sarr B, Eyletters M, Roy MH and **Delhaye JP. 2004.** Response of pearl millet to nitrogen as affected by water deficit. Agronomie 24(2):77-84.

Dous AN, Devos KM, Gadberry MD, Gale MD and **Kellogg EA. 2004.** Genetic control of branching in foxtail millet. Proceedings of the National Academy of Sciences of the United States of America 101(24):9045-9050.

Gaffa T, Yoshimoto Y, Hanashiro I, Honda O and **Kawasaki S. 2004.** Physicochemical properties and molecular structures of starches from millet *(Pennisetum typhoides)* and sorghum *(Sorghum bicolor* L. Moench) cultivars in Nigeria. Cereal Chemistry 81(2):255-260.

Garcia-Liamas C, Ramirez MC and **Ballesteros J. 2004.** Effect of pollinator on haploid production in durum wheat crossed with maize and pearl millet. Plant Breeding 123(2): 201-203.

Gunaga R and **Vasudeva R. 2004.** Effects of *Khaya senegalensis* leaf litter on the germination and seedling growth of finger millet. Allelopathy Journal 13(l):83-88.

Hall A, Blummel M, Thorpe W, Bidinger FR and **Hash CT. 2004.** Sorghum and pearl millet as food-feed-crops in India. Animal Nutrition and Feed Technology 4(1): 1-15.

Kamble MS, Dhonukshe BL, Kashid NV and **Gavhane VN. 2004.** Variability studies for weight of callus in finger millet [*Eleusine coracana* (L.) Gaertn.]. Research on Crops 5(1):66-72.

Karad SR and **Harer PN. 2004.** Heterosis in pearl millet *(Pennisetum glaucum* L.). Mysore Journal of Agricultural Sciences 38(1): 19-24.

Kaur P and **Kothari SL. 2004.** In vitro culture of kodo millet: influence of 2,4-D and picloram in combination with kinetin on callus initiation and regeneration. Plant Cell Tissue and Organ Culture 77(l):73-79.

Khurana MPS, Nayyar VK and **Singh D. 2004.** Direct and residual effect of applied zinc in pearl millet-pea-wheat cropping system in typic ustochrepts. Indian Journal of Ecology 31(1):11-13.

Kumar P, Joshi NL, Singh DV and **Saxena A. 2004.** Evaluation of pearl millet production systems for high yield and net carbon accumulation in soil and crop. Journal of the Indian Society of Soil Science 52(l):95-99.

Kwak CS, Lira SJ, Kim SA and **Park SC. 2004.** Antioxidative and antimutagenic effects of Korean buckwheat, sorghum, millet and job's tears. Journal - Korean Society of Food Science and Nutrition 33(6):921-929.

Lei V and **Jakobsen M. 2004.** Microbiological characterization and probiotic potential of koko and koko sour water, African spontaneously fermented millet porridge and drink. Journal of Applied Microbiology 96(2):384-397.

Li S. 2004. Case of drug dependence with millet tuberculosis. Chinese Journal of Drug Dependence 13(1): 17-24.

Urn S, Jwa MK, Mok C and **Park YS. 2004.** Changes in microbial counts, enzyme activity **and** quality of foxtail millet yakju treated with high hydrostatic pressure during storage. Journal - Korean Society of Food Science and Nutrition 33(3):576-581.

Lim S, Jwa MK, Mok C and **Park YS. 2004.** Changes in microbial counts, enzyme activity and quality of foxtail millet takju treated with high hydrostatic pressure during storage. Korean Journal of Food Science and Technology 36(2):233-338.

Mahawar RK, Sharma KC and **Sastry EVD. 2004.** Genetic divergence in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Annals of Agri Bio Research 9(2): 127-130.

Maiti RK and Singh VP. 2004. Biotic factors affecting pearl millet *(Pennisetum glaucum* (L.) R. Br.) growth and productivity - a review. Crop Research 27(l):30-39.

Manga VK and **Dubey LK. 2004.** Identificatin of suitable inbreds based on combining ability in pearl millet *(Pennisetum glaucum).* Indian Journal of Agricultural Sciences 74(2):98-101.

Marcellino LH, Neshich G, Neto AF and **Gander ES. 2004.** Opaque-2-like transcription factor from pearl millet. Protein and Peptide Letters 11(4):345-352.

Msuya DG. 2004. Submersion and soaking methods of processing finger millet seed in southern Tanzania. Seed Science and Technology 32(1): 177-186.

Mundra MC, Singh BP, Gupta SC and **Rinwa RS. 2004.** Interactive effect of biodynamic agriculture in yield maximization of pearl millet-wheat cropping system. Annals of Agri Bio Research 9(2): 197-201.

Ojijo NKO and **Shimoni E. 2004.** Rheological properties of fermented finger millet *(Eleucine coracana)* thin porridge. Carbohydrate Polymers 57(2): 135-143.

O'Kennedy MM, Burger JT and **Botha FC. 2004.** Pearl millet transformation system using the positive selectable marker gene phosphomannose isomerase. Plant Cell Reports 22(9):684-690.

Onyango C, Henie T, Ziems A, Hofmann T and **Bley T. 2004.** Effect of extrusion variables on fermented maize-finger millet blend in the production of uji. Lebensmittel Wissenschaft und Technologie 37(4):409-415.

Onyango C, Noetzold H, Bley T and **Henle T. 2004.** Proximate composition and digestibility of fermented and extruded uji from maize-finger millet blend. Lebensmittel Wissenschaft und Technologie/Food Science and Technology 37(8):827-832.

Paliares IN, Ferrari L and **Postulka EB. 2004.** Identification of cultivars of foxtail millet *(Setaria italica* (L.) Beauv.) from morphological and biochemical traits of their seed. Seed Science and Technology 32(1): 187-196.

Pawar KN, Lakshmana D, Jahagirdar S and **Guggari AK. 2004.** Physiological basis of growth and yield variation in pearl millet under rainfed situations. Karnataka Journal of Agricultural Sciences 17(1): 38-40.

Qian Z, Fan L, Jingjuan Y, Dengyun Z and **Guangming** A. **2004.** Cloning of lycopene beta-cyclase gene related to carotenoid biosynthetic pathway of millet *(Setaria italica).* Journal - China Agricultural University 9(1): 1-6.

Qiao W. 2004. Study on the process for preparing oxalic acid from broom corn millet shell by hydrolysis-oxidation-hydrolysis. Dyestuffs and Coloration 41(4):222-223.

Radjacommare R, Ramanathan A, Kandan A, Sible GV, Harish S and **Samiyappan R. 2004.** Purification and anti-fungal activity of chitinase against *Pyricularia grisea* in finger millet. World Journal of Microbiology and Biotechnology 20(3):251-256.

Raj SN, Shetty NP and **Shetty HS. 2004.** Seed bio-priming with *Pseudomonas fluorescens* isolates enhances growth of pearl millet plants and induces resistance against downy mildew. International Journal of Pest Management 50(1):41-48.

Rajasekaran NS, Nithya M, Rose C and **Chandra TS. 2004.** Effect of finger millet feeding on the early responses during the process of wound healing in diabetic rats. BBA - Molecular Basis of Disease 1689(3): 190-201.

Ram M, Balai CM, Kumawat BL and **Majumdar SP. 2004.** Response of pearl millet *(Pennisetum glaucum)* to flyash clay and nitrogen levels in loamy sand soil. Indian Journal of Agricultural Science 74(2):95-97.

Raman R and **Krishnaprabu S. 2004.** Effect of integrated nutrient management on nutrient uptake and yield of finger millet. Journal of Ecobiology 16(3): 197-200.

Rao MVSSTS, Manohar RS and **Muralikrishna G. 2004.** Functional characteristics of non-starch polysaccharides (NSP) obtained from native (n) and malted (m) finger millet *(ragi, Eleusine coracana,* Indaf-15). Food Chemistry 8(3):453-460.

Rao RSP and **Muralikrishna G. 2004.** Non-starch polysaccharide-phenolic acid complexes from native and germinated cereals and millet. Food Chemistry 84(4):527-531.

Rao SVR, Raju MVLN, Panda AK and **Sharma RP. 2004.** Replacement of maize with pearl millet *(Pennisetum typhoides)* on weight and nutrient basis in broiler chicken diet. Indian Journal of Poultry Science 39(1): 15-24.

Rao SVR, Raju MVLN, Reddy MR and **Panda AK. 2004.** Replacement of yellow maize with pearl millet *(Pennisetum typhoides),* foxtail millet *(Setaria italica)* or finger millet *(Eleusine coracana)* in broiler chicken diets containing supplemental enzymes. Asian Australasian Journal of Animal Sciences 17(6):836-842.

Rathi A, Kawatra A and **Sehgal S. 2004.** Influence of depigmentation of pearl millet *(Pennisetum glaucum* L.) on sensory attributes, nutrient composition, in vitro protein and starch digestibility of pasta. Food Chemistry 85(2):275-280.

Rathi A, **Kawatra A, Sehgal S** and **Housewright B. 2004**. Influence of depigmentation of pearl millet *(Pennisetum gluacum* L.) on sensory attributes, nutrient composition and in vitro digestibility of biscuits. Lebensmittel Wissenschaft und Technologie 37(2): 187-192.

Reddy N, **Rao K** and **Ahmed I. 2004.** Geographical patterns of diversity in pearl millet germplasm from Yemen. Genetic Resources and Crop Evolution 51(5):513-517.

Sankhala A, Chopra S and **Sankhala AK. 2004.** Effect of processing on tannin, phytate and in vitro iron in underutilized millets - *bajra (Pennisetum typhoideum)* and *kangi (Setaria italica).* Indian Journal of Nutrition and Dietetics 41 (2):55-62.

Schlecht E and **Buerkert A. 2004.** Organic inputs and farmers' management strategies in millet fields of western Niger. Geoderma 121(3/4):271-289.

Seetharama N and **Rao BD. 2004.** Sustaining nutritional security. Hindu Survey of Indian Agriculture 2004, pp. 37-38.

Sekulic DP, Gao F, Zhao H, Zelimer B and **Qian YY. 2004.** Prediction of the millet mass and topology of aluminum brazed joints. Welding Journal 83(3): 102-110-S.

Shailasree S, Kini KR, Deepak S, Kumudini BS and **Shetty HS. 2004.** Accumulation of hydroxyproline-rich glycoproteins in pearl millet seedlings in response to *Sclerospora graminicola* infection. Plant Science 167(6): 1227-1234.

Sharathchandra RG, Raj SN, Shetty NP, Amruthesh KN and **Shetty HS. 2004.** Chitosan formulation Elexa induces downy mildew disease resistance and growth promotion in pearl millet. Crop Protection 23(10):881-888.

Singh A and **Singh P. 2004.** Productivity of pearl millet and arum as intercrops under popular plantation. Indian Journal of Ecology 31(1):21-23.

Sivashanmugam P. 2004. Studies on hydrodynamics of annular circulating fluidised bed drier with millet ragi particles mixture. Journal - Indian Chemical Society 81(1):54—56.

Sreenivasulu N, Miranda M, Prakash HS, Wobus U and **Weschke W. 2004.** Transcriptome changes in foxtail millet genotypes at high salinity: identification and characterization of a PHGPX gene specifically up-regulated by NaCl in a salt-tolerant line. Journal of Plant Physiology 161(4):467-477.

Sterk G, Stein A and **Stroosnijder L. 2004.** Wind effects on spatial variability in pearl millet yields in the Sahel. Soil and Tillage Research 76(l):25-37.

Sundra KMS, Siddanunappa R, Girish MA and **Ravi MV. 2004.** Response of finger millet to levels of N and K in Vijayapura soil series of Karnataka. Mysore Journal of Agricultural Sciences 38(2): 145-148.

Tanzubil PB, Zakariah M and **Alem A. 2004.** Effect of nitrogen and farmyard manure on insect pests of pearl millet in northern Ghana. Tropical Science 44(l):35-39.

Thakur RP, Rao VP, Wu BM, Subbarao KV, Shetty HS, Singh G, Lukose C, Panwar MS, Sereme P, Hess DE, Gupta SC, Dattar W, Panicker S, Pawar NB, Bhangale GT and **Panchbhai SD. 2004.** Host resistance stability to downy mildew in pearl millet and pathogenic variability in *Sclerospora graminicola.* Crop Protection 23(10):901-908.

Thapa S and **Tamang JP. 2004.** Product characterization of kodo ko jaanr: fermented finger millet beverage of the Himalayas. Food Microbiology 21(5):617-622.

Trezzi MM and **Vidal RA. 2004.** Potential of sorghum and pearl millet cover crops in weed supression in the field: II • mulching effect. (In Pt.) Planta Daninha 22(1): 1-10.

Voortman RL, Brouwer J, Albersen and **Peter J. 2004.** Characterization of spatial soil variability and its effect on millet yield on Sudano-Sahelian coversands in SW Niger. Geoderma 121(1/2):65-82.

Wilson JP, Hess DE, Hanna WW, Kumar KA and **Gupta SC. 2004.** *Pennisetum glaucum* subsp. *monodii* accessions with *Striga* resistance in West Africa. Crop Protection 23(9):865-870.

Yadav OP. 2004. CZP 9802 - a new drought-tolerant cultivar of pearl millet. Indian Farming 54(3): 15-17.

Yadav RS, Hash CT, Bidinger FR, Devos KM and **Howarth CJ. 2004.** Genomic regions associated with grain yield and aspects of post-flowering drought tolerance in pearl millet across stress environments and tester background. Euphytica 136(3):265-277.

Yang JD, Zhao HL and **Zhang TH. 2004.** Different capacities of adaptation to high irradiance of horqin sandy land in mung bean and millet based on their leaf photosynthesis. Acta Agronomica Sinica 30(3):232-235.

Zaman Q and **Malik NH. 2004.** Performance of millet varieties for green fodder production under D.I. Khan conditions. Sarhad Journal of Agriculture 20(l):47-50.

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Information for ISMN Contributors

Publishing objectives

The International Sorghum and Millets Newsletter (ISMN) is published annually by the Sorghum Improvement Conference of North America (SICNA) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). It is intended as a worldwide communication link for all those interested in the research and development of sorghum *[Sorghum bicolor* (L.) Moench], pearl millet [*Pennisetum glaucum* (L.) R. Br.J, and minor millets, and their wild relatives. Though the contributions that appear in ISMN are reviewed and edited, it is expected that the work reported will be developed further and formally published in refereed journals.

What to contribute?

- Contributions should be current, scholarly and well justified on the grounds of new information.
- Results of recently concluded experiments, newly released varieties, recent additions to germplasm collections, registration notes for newly developed trait-specific breeding lines/germplasm, etc.
- Genome maps and information on probe-availability and sequences, and populations synthesized for specific traits being mapped.
- Short reports of workshops, conferences, symposia, field days, meetings, tours, surveys, network activities and recently launched or concluded projects.
- Details of recent publications, with full bibliographic information and 'mini reviews' whenever possible.
- Personal news (new appointments, awards, promotions, change of address, etc.).

Deadline for submission: 15 August 2005

How to format contributions

- Keep the items brief up to **6 pages (double-spaced) including data tables and figures.**
- Table should be separated from the text and placed upright (not landscape). Supply only the essential information; round off the data-values to just one place of decimal; use suitable units to keep the values small (eg, tons instead of kg).
- Keep the list of references short - not more than five references, all of which should have been seen in the original by the author. Provide all the details including author/s, year, title of the article, full title of the journal, volume, issue and page numbers (for journal articles), and place of publication and publishers (for books and conference proceedings) for every reference. **Cite references as in this issue.**
- Black-and-white photographs are welcome. Send disk-files whenever you submit line figures and maps.
- Express all quantities only in SI units. Spell out in full every acronym you use.
- Give Latin name of every crop, pest, or pathogen at the first mention.
- Submit one hard copy of the manuscript in the correct format to the Scientific Editor of the respective region at the address given below. Also send the manuscript MS Word file as email attachment.
- Include full address of all authors, and provide telephone, fax and e-mail of the **corresponding** author.

ISMN will carefully consider all submissions and will accept only those that conform to its scientific standard and requirements. The language of the Newsletter is English, but we will do our best to translate articles submitted in other languages. **Authors should closely follow the format and style of the articles in this issue to prepare the manuscripts.**

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About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political, international organization for science-based agricultural development. ICRISAT conducts research on sorghum, pearl millet, chickpea, pigeonpea and groundnut - crops that support the livelihoods of the poorest of the poor in the semi-arid tropics encompassing 48 countries. ICRISAT also shares information and knowledge through capacity building, publications and ICTs. Established in 1972, it is one of 15 Centers supported by the Consultative Group on International Agricultural Research (CGIAR).

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