SICNA

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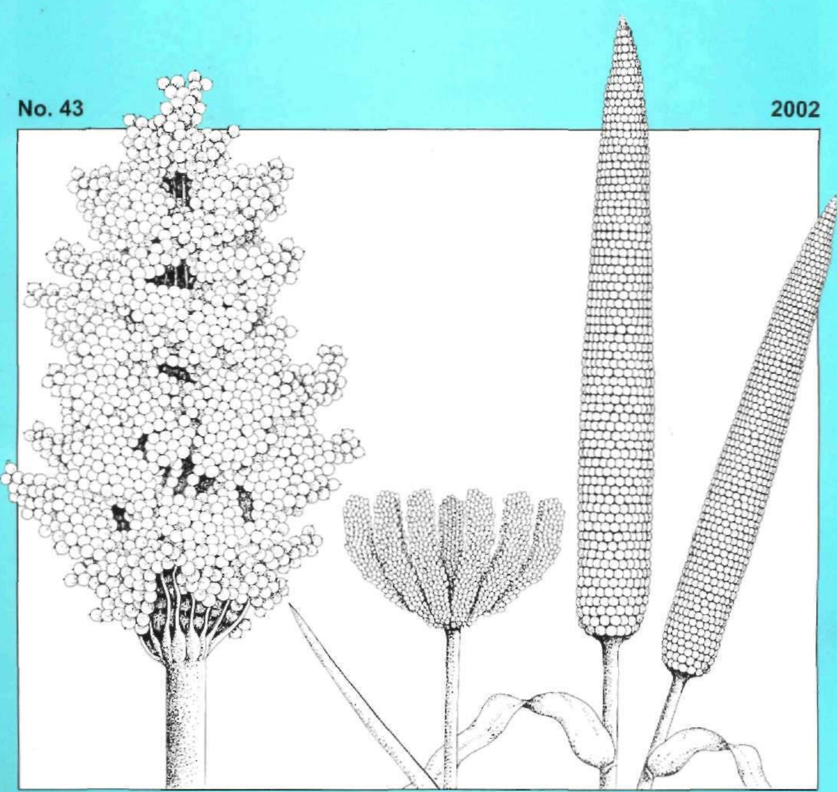

International Sorghum and Millets Newsletter

Co-publishers

SICNA
Sorghum Improvement Conference of North America

ICRISAT
International Crops Research Institute for the Semi-Arid Tropics

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 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 semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, chickpea, pigeonpea, and groundnut - five crops vital to life for the ever-increasing populations of the SAT. ICRISAT's mission is to conduct research that can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

ICRISAT was established in 1972. It is supported by the Consultative Group on International Agricultural Research (CGIAR), an informal association of approximately 50 public and private sector donors. It is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO). the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank. ICRISAT is one of 16 nonprofit CGIAR-supported Future Harvest Centers.

ISMN Scientific Editors 2002

J A Dahlberg R P Thakur

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Editorial

With this issue, the International Sorghum and Millets Newsletter (ISMN) publishes its 43rd volume, thus providing a valuable service to its authors and readers for over 40 years. The first issue of the Sorghum Newsletter was published in 1958 by the Sorghum Research Committee. WM Ross, who was located in Hays, Kansas, its first Scientific Editor. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) joined hands with the Sorghum Improvement Conference of North America (SIGNA) and the University of Georgia in 1994 to jointly sponsor the publication of what then became the International Sorghum and Millets Newsletter (ISMN) and volume 35 was co-edited by RR Duncan, University of Georgia, Griffin, USA, and CT Hash (ICRISAT). Since 1996, ISMN has been cosponsored by ICRISAT and SICNA.

The ISMN has come a long way since its inception and has grown to become an important avenue for the rapid communication of results from scientific research on sorghum, pearl millet and other small-grained millets. Today, the ISMN has a total circulation of over 1500. Its readership covers scientists, industrialists, educationists, farmers and others interested in these crops.

ISMN contains articles across the disciplines of agronomy, biotechnology, breeding, genetics, entomology, pathology, physiology, and news items and current literature. The contributors to ISMN belong to all continents where these crops are being researched and/or grown.

This issue contains 6 papers reprinted from SMINET News Volume 3, Number 2, December 2001; research highlights on pearl millet, and 40 research articles; 30 on sorghum and 10 on millets. These articles cover aspects of work on: germplasm (3), and genetics and breeding (11), agronomy (7), and pests and diseases (18). Of the 40 articles, 29 are about work on the crops in India, 6 on work in USA, 3 on work in Africa, and 1 each on work in Australia, China, and Russia.

We would like to thank the reviewers of these articles who made their positive contributions in a timely manner to support publication of this issue. They include AG Bhasker Raj, N Kameswara Rao, JVDK Kumar Rao, V Mahalakshmi, S Pande, V Panduranga Rao, KN Rai, BVS Reddy, OP Rupela, Piara Singh, HC Sharma, and VA Tonapi (ICRISAT, Patancheru); S Indira and TG Nageshwar Rao [National Research Centre for Sorghum (NRCS), Hyderabad]; RDVJ Prasada Rao [National Bureau of Plant Genetic Resources (NBPGR), Hyderabad], and R Kochenower, B Klein, S Bean, J Stack, B Rooney, B Pendleton, and AB Maunder (SICNA, USA).

We would also like to thank Sue Hainsworth, the technical editor, for her interest and commitment to high quality, accurate publication, TNG Sharma for his painstaking typesetting and preparation of manuscripts for printing, and to VS Reddy for carefully and efficiently handling the manuscripts and helping us to correspond with authors and reviewers.

We encourage our readers to provide us their comments and news items, in addition to research notes, for publication in the next issue (Vol. 44, 2003) of the ISMN. We look forward to your positive input to help us do a better job for you.

JA Dahlberg **RP Thakur**

SMINET News Vol. 3, No. 2 (Dec 2001)

Sorghum and Millet Improvement Program (SMIP) Midterm Review

G M Heinrich and M A Mgonja (International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), PO Box 776, Bulawayo, Zimbabwe)

The Southern African Development Community (SADC)/International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sorghum and Millet Improvement Program (SMIP) Phase IV represents several significant changes from previous phases. It focuses on Botswana, Mozambique, Tanzania, and Zimbabwe, and it is organized around a commercial focus on expanding market demand for target crops. Phase IV also emphasizes a much broader range of public and private sector partners than earlier phases.

The SMIP Midterm Review (MTR) was conducted from 18 June to 2 July 2001. The review team had meetings with ICRISAT staff, consulted project documents, and met a range of stakeholders in Zimbabwe. Members of the team also traveled to Botswana, Mozambique, and Tanzania to consult stakeholders.

The Project

SMIP is organized around four themes or Intermediate Results (IRs).

The majority of the review addresses the accomplishments and challenges of these four themes.

IR 1.1 Farmers have access to a wider range of improved varieties resulting in higher rates of adoption

SMIP builds on the release of over 40 varieties of sorghum and millet by national programs during earlier phases of the project. The current phase seeks to improve the adoption of these varieties by paying particular attention to the development of appropriate seed systems and stimulating commercial demand for the crops that should increase the demand for seed. Additional activities include improved conservation and dissemination of germ-plasm resources, development of varieties for industrial use, and technical support to breeder seed production.

The review team made several recommendations:

- Instead of attempting to develop commercial seed capacity with organizations such as churches and primary schools, contracts could be made for the production of seed packs that can be demonstrated and sold both through these organizations, and by commercial outlets.
- Learn from past success: for example, consider the successful schemes promoted by the project under which nongovernmental organizations (NGOs) organize farmers as contract growers for seed companies.
- Continue the project's efforts in seed policy reform and coordinate these efforts with those of other organizations (e.g., other CGIAR centers) that have similar goals.
- Ensure that the targets and justification for any varieties released are well specified.
- Pursue the goal of instituting a regional variety release and testing system in conjunction with other centers and the Southern African Centre for Cooperation in Agricultural Research (SACCAR).

IR 1.2 Farmers in targeted areas use a wider range of crop management options, leading to increased productivity

The project includes a significant component on crop management research. The goal is to test and demonstrate best-bet crop management options at selected locations in Tanzania and Zimbabwe through participatory methods and farmer field schools (FFS). The project believes that the adoption of improved crop management will be more likely if farmers have access to markets for their grain, and hence the project attempts to establish these linkages. The following recommendations were made:

- Document and analyse the performance of the new technologies so that results can be shared with other organizations working on crop management.
- Test the hypothesis that increased commercial demand encourages the use of the crop management technologies promoted by the project.
- Document and analyse the experiences with FFS as a method of technology diffusion.
- Explore more collaboration with other organizations that are testing and promoting crop management technology in the region.

IR 1.3 Broader public and private partnerships promoting regional technology development, exchange and application

Phase IV attempts to involve a much wider range of stakeholders, including public sector research and extension, farmers' organizations, policymakers, NGOs, and a wide range of private firms. The project is establishing a regional Sorghum and Millet Improvement Network (SMINET) to serve the needs of these stakeholders. It is also establishing other forms of information exchange, such as regional databases and research projects, and demonstrations for technology exchange. The review team recommended:

- Document specific linkages between organizations from different sectors that SMIP has helped to establish
- Recognize the importance of distinguishing between those activities that can benefit from a network and those that can be pursued on a pilot project basis.
- Give attention to the importance of beginning to identify the dimensions and limitations of a future network, as many of the activities envisioned may be more appropriately managed by more flexible, short-term modalities.
- Consider coalitions with other similar entities for developing consistency and critical mass in such areas as seed policy reform or crop management research.

IR 2.1 Market systems linking grain producers and industrial consumers

A major new thrust is the exploration of commercial markets for sorghum and pearl millet. This is based on the proposition that better markets for these crops will lead to increased adoption of technology. The project has pursued a number of activities to encourage wider use of these crops, particularly in the milling industry, and to improve grain-marketing procedures. A food technology pilot laboratory at Matopos was constructed during a previous project phase, and a decision must be taken on its disposition. The review team recommended:

- A set of specific short-term consultancies to explore a broader range of potential industrial uses for sorghum (e.g., for starch or glucose).
- A consultancy to examine the potential of regional and international markets for the target crops.
- Establishment of business innovation grants to encourage private-sector research and testing of sorghum-based products.
- A partnership with one or more NGOs to help establish better market access for sorghum.
- Divestiture of the pilot plant facility.

Project Management and Partnerships

The project is being competently managed and coordinated. It has the advantage of building on 15 years of previous work. There have been concerns about the current strategy of limiting activities to four countries, but additional activities have helped ensure some technology exchange with other countries in the region. Although SMIP is designed to be centrally initiated and managed, there should be additional opportunities to attract initiative and investment from potential partners. This is particularly important if the project is to encourage sustainable partnerships and active networking in the future. More thought should also be given to the best means of representing various sectors in project manage-ment. Finally, although individual project components attempt to address the commercialization focus, more effort is needed to use this as a unifying theme across the project.

Links to USAID Strategy

The development and evolution of the project has taken place at a time of significant change at both the United States Agency for International Development (USAID) and ICRISAT. USAID was considering the nature of support for sorghum and millet research, its interests in regionalization, and an increased emphasis on market-led agricultural development. At the same time ICRISAT was undergoing a number of administrative changes, and decisions were being made about the Institute's future role in southern Africa. The resulting project thus juxtaposes new and historical mandates. The commercialization strategy sits somewhat uneasily with crops that have traditionally been considered principal sources of food security. The final project document reflects some ambivalence about the shift in focus, and although the vision statement reflects the priority of market-led strategies, the majority of the principal indicators and benchmarks are not particularly commercially focused. This makes an MTR somewhat problematic as the project is being asked to respond to evolving donor priorities.

Conclusions

- The staff of SMIP has responded to the challenges and reorientation of the new project with great energy and imagination. The MTR confirms that the project is largely on course with respect to its target indicators and benchmarks. SMIP staff has established solid foundations to provide valuable experience and new partnerships that will help define the course of sorghum and millet research in the region. The MTR provided a number of recommendations that the SMIP team may wish to consider during the remainder of the project. The recommendations are basically divided into four areas:

- Exploration of further commercial opportunities in both grain and seed marketing
- Pursuit of selected policy objectives
- Synthesis of experience in plant breeding and agronomy so that this type of work can be done more efficiently in the future
- A careful analysis of various experiences in trying to form new partnerships.

It is the identification of the most efficient means of encouraging such partnerships that holds the key to determining future strategies for sorghum and millet research in the region.

Quality Analysis of Tanzanian Photoperiod-sensitive Sorghums and Potential for their Improvement through the Lead NARS Approach

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Rationale

Past breeding objectives, strategies, and achievements of the Sorghum and Millet Improvement Program (SMIP) correctly targeted the needs of farmers in drought-prone, less-endowed environments. More than 45 accessions of sorghum and pearl millet germplasm that are early maturing have been developed and released for small-scale farmers. An internal review during 2000 noted an obvious gap in technology for the wet semi-arid tropics (SAT) whose production system includes late-maturing photoperiod-sensitive sorghum. Such postharvest concerns such as storability, quality, processing, and utilization require-ments had not been adequately addressed. Based on these deficiencies and outputs from the October 2000 workshop for breeders, farmers, and industry, a need to develop and disseminate technology suitable for increas-ing productivity in these areas was identified. The purpose is to ensure that effective products are available to farmers in all SAT locations to enable them to steadily grow their way out of poverty and food insecurity. To use regional resources efficiently, a Lead national agricultural research systems (NARS) concept was adopted, whereby a breeder from Zambia would lead the photoperiod work and the developed materials would be tested in Tanzania and Mozambique.

The current traditional late-maturing photoperiod-sensitive varieties have provided farmers with sustainable production. These varieties are mainly white-seeded with a pearly white endosperm. The photoperiod-sensitive landraces are specifically adapted for yield, quality, and their defensive capacity against biotic and abiotic stresses. In particular, they have been shown to be less susceptible to damage by birds and storage pests than other cultivars. They are also unaffected by grain molds because they mature at the end of the rainy season. Their cooking quality is excellent, and in southern Tanzania and central and northern Mozambique, their food products are compa-rable and similar to those made from rice *(Oryza sativa* L). Because of these qualities, the photoperiod-sensitive mate-rials have roles in both food security and in the output market. Yet, their potential is not well documented and is therefore not well known because there has been minimal research work in crop improvement and management of this material.

Approach

In a variety adoption and seed survey conducted in Tanzania, 14 local sorghum landraces were collected and their food quality assessed for comparison with standard improved and released sorghum varieties. The local photoperiod-sensitive landraces were analyzed for: visual hardness score, kernel weight, floaters, size fractions (large, medium, and small), dehulling loss, milling yield, water absorption, agtron readings (colour of flour), and tannin contents. Dehulling loss, milling yield, and agtron readings have important bearing on suitability for milling and acceptability of the final product. Vitreous pearly white endosperm types, for example, have high commercial milling yields and are highly sought by industry. High agtron readings translate into whiter products and are preferred in the market.

Results

All 14 landraces had unique grain-quality traits. Their hardness indices (characterized by visual hardness score), floaters, and water absorption index, complemented by the quantitative dehulling loss, were compared to those of such released improved varieties as Macia and Pato. The landrace mean values particularly for visual hardness, floaters, water absorption, and dehulling loss were far better and more acceptable than those of released short-season sorghums. The agtron readings (dry) of landraces were also better than those of the released cultivars (Table 1).

Table 1. Grain quality evaluation of fourteen photoperiod-sensitive sorghum varieties from southern Tanzania in comparison to two improved varieties Maria and Pato

Cultivar	Visual hard-ness score	Kernel weight (g/100)	Floaters (%)	Dehull-ing loss (%)	Milling yield (%)	Water absorp-tion (%)	Size fraction[1]			Agtron reading-Dry	Agtron reading-Wet	Tannin content (%CE)
							Large	Medium	Small			
Wanahe(a)	4.9	1.88	0	13.75	85.04	6.7	0.50	98.88	0.51	79.6	60.5	0.00
Dimule	4.8	2.16	1	12.70	86.78	5.2	0.39	99.60	0.10	81.0	61.4	0.00
Wanahe(b)	4.8	2.49	2	12.53	86.75	5.9	32.95	66.65	0.42	77.1	56.2	0.00
Namcheta	4.8	2.36	0	12.11	87.72	4.3	32.95	66.65	0.42	79.6	60.5	0.00
Mwavuli	4.7	2.54	1	13.75	85.04	6.4	32.95	66.65	0.42	79.6	60.5	0.00
Mpunga	4.7	2.18	12	13.75	85.04	7.4	32.95	66.65	0.42	79.6	60.5	0.00
M Kimakua	4.6	2.00	0	14.13	85.48	6.9	32.95	66.65	0.42	82.0	65.6	0.00
Lionja 2	4.6	3.58	1	13.75	85.04	7.5	32.95	66.65	0.42	79.6	60.5	0.00
Kimakonde	4.6	1.93	2	13.17	84.70	6.2	0.02	98.40	1.58	78.2	57.0	0.00
Meele b	4.5	1.96	3	14.68	81.43	6.7	32.95	66.65	0.42	79.0	59.4	0.00
Lionja	4.3	3.23	2	14.63	84.78	5.4	85.61	14.37	0.05	80.7	62.5	0.00
Meele a	4.2	2.89	1	14.11	83.82	7.0	24.03	75.77	0.27	75.0	54.5	0.00
Chijenja	4.0	2.95	0	15.72	83.98	6.7	87.15	12.88	0.00	83.7	67.4	0.00
Mkia Kondoo	3.7	3.46	2	13.75	85.04	7.7	32.95	66.65	0.42	79.6	60.5	0.00
SE±	0.342	0.027	0.979	0.176	0.569	0.192	0.570	0.584	0.018	0.276	0.349	0.00
Mean	4.53	2.54	1.95	13.75	85.05	6.43	32.95	66.65	0.42	79.57	60.54	0.00
CV(%)	10.7	1.5	70.9	1.8	0.9	4.2	2.4	1.2	6.0	0.5	0.8	0.8
Macia	3.6	1.68	22	15.20	81.60	14.30	0.26	99.27	0.38	75.3	56.1	0.0
Pato	3.4	3.56	23	7.23	87.00	4.0	80.54	9.44	0.00	74.5	53.2	0.0

1. Large: % > 4.0 mm^2; Medium: % 4.0-2.6 mm^3; Small: % < 2.6 mm

Note: Commercial maize meal; Agtron Reading - Dry = 83.4, and Agtron Reading - Wet = 67.1

Grain hardness (visual score) for 9 out of 14 photoperiod-sensitive varieties was superior to that of Macia or Pato, scoring ≥ 4.6 on the visual hardness score scale compared to just 3.4 for Pato and 3.6 for Macia. All of them were also superior as determined by the floaters test; only 0-3% kernels floating compared to over 22 for Macia or Pato. The only exception was Mpunga with 12% floaters (Table 1). On ability to produce white flour, the best entry, Chijenja had agtron readings of 83.7 (dry) or 67.4 (wet) compared to 75 and 56 for Macia and 74 to 53 for Pato. Chijenja compared very well with commercial maize (*Zea mays* L.), that gave readings of 83 (dry) and 67 (wet). Other varieties with agtron readings similar to maize were Dimule, Meele, Kimakua, and Lionja (≥ 80). These results that show that these varieties have potential for commercial milling.

Conclusion

The late-maturing sorghum landraces grown in southern Tanzania have such unique quality traits as vitreous pearly endosperms and high commercial milling yields. Strategies for introgression of such quality traits into adapted sorghum varieties and improvement of the agronomic characteristics of photoperiod-sensitive sorghums are objectives of the current sorghum improvement strategy through the lead NARS spearheaded by the Zambia National Program.

Field Days in Tanzania Enhance Regional Spillover of Models and Technology Developed in SMIP Pilot Countries

M A Mgonja and E S Monyo (International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), PO Box 776, Bulawayo, Zimbabwe)

The primary aim of SMINET is to provide evidence that two or three countries are adopting processes and technology developed in pilot countries through previous investments and from SMIP IV to increase adoption of improved varieties or enhance crop management practices. Phase IV of the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP IV) is targeting 4 pilot countries. Field days were suggested as the best way to:

- Expose national agricultural research systems (NARS) scientists and other collaborators from non-pilot countries to activities in SMIP IV target countries.

- Identify technologies and processes implemented or tested in SMIP IV target countries for possible emulation in other Southern African Development Community (SADC) countries.

- Assist in implementation of activities to effect spillover to non-target countries.

The SMIP seed system has assisted NARS in three target countries (Mozambique, Tanzania, and Zimbabwe) to establish a revolving fund account for sustainable breeder seed production, and to test various models that may improve alternative seed delivery systems. Community seed production through primary schools and farmer groups are being tested in two districts (Dodoma and Singida) in Tanzania. Regional networking and seed systems field days were organized in May 2000 and May 2001 to:

- Popularize the concept of the dissemination of improved seed through farmer groups

- Introduce the rural schools seed production concept to three other SADC countries

- Facilitate regional spillover of the initiative.

Representatives from Botswana, Malawi, Mozambique, the Republic of South Africa (RSA), and Zambia were invited and supported through SMIP. After the field tours, participants outlined each country's seed system, challen-ges, interventions to date, and lessons learned from the field day. They discussed how they would continue to tackle the seed availability constraint; not single-handedly but in collaboration with partners.

Outcomes

- Malawi partners (World Vision International and the NARS breeder) indicated interest in emulating the primary school model. SMIP provided Malawi with nuclear seed (2 kg) of sorghum *[Sorghum bicolor* (L.) Moench] (varieties Pirira 1 and Pirira 2) and pearl millet [*Pennisetum glaucum* (L.) R. Br.] (varieties Nyankombo and Tupatupa). During the 2001 season Malawi produced 300 kg of Pirira 1 that was certified by the Malawi Seed Services Unit. Experiences from pilot countries suggest that while pursuing community-based seed production, collaborators should consider the sustainability of the schemes, seed marketing, and adherence to quality . A seed production training course for collaborators was held 20-22 November 2001.

- A different set of strategies was articulated for the Northern Province (NP) of RSA to reach small-scale/ emerging farmers with quality seed of improved sorghum and millet varieties.

- A stakeholders' workshop was held in August 2001 entitled *'Challenges and opportunities to increase smallholder benefits from sorghum and millet production systems in the semi-arid areas of the Northern Province of South Africa'.* 26 participants from various organizations in NP and elsewhere in in RSA with interests in community development work in NP. The major challenges lie in the areas of variety improvement, soil fertility, seed systems and regulatory aspects, marketing, and governance.

- Delineation of zones using Geographical Information Systems (GIS) supported by stability analysis of a SADC regional Multi-Environment Trial revealed that such sorghum varieties as Macia, Sima, and Pirira 2; and pearl millets Okashana 1 and PMV 3 have high potential adaptability in NP.

- The Mother-Baby trials for sorghum and millet currently funded by the Commercial Farmers Union will be implemented to further confirm the suitability of these varieties prior to their recommendation for listing in NP.

- Small-scale farmers can access sorghum and millet seed through a recognized and legalized community-based seed supply system. The South Africa National Seed Organization (SANSOR) representative provided an overview of regulatory aspects, particularly the minimum requirements of seed testing and plant genetic auditing for producing and selling legal seed. This is a status through which seed of improved RSA-listed varieties can reach small-scale farmers.

- The Progress Mill (PM), milling company in NP has an in-house Community Development Program (CDP) to empower previously disenfranchised communities.

This program ensures small-scale farmers' access to extension support, input supplies, infrastructure development, training, agricultural information, and markets. Progress Mill is committed to buying sorghum from small-scale farmers and has the infrastructure to accommodate 7000 t. A follow-up meeting was held by PM on 23 August 2001 and a work plan has been developed that will model marketing as a stimulant to the use of improved technology. A number of organizations have indicated their interest in participating in this work

- ICRISAT-SMINET will assist in organizing an exposure trip for a selected group of collaborators [Tompe Seleka, PM, SANSOR, Northern Province Department of Agriculture and Evironment (NPDAE), South Africa] to Namibia to study smallholder seed production by the Northern Namibia Seed Growers Association in order to develop a seed system that will help the small-scale farmers of NP.
- ICRISAT-SMIP is leading the development of a concept note that will address *Challenges and opportunities to increase smallholder benefits from sorghum and millet production system in the semi-arid areas of the Northern Province of South Africa'.* This will be submitted through the USAID Regional Centre for Southern Africa (RCSA) support on good governance for RSA
- In three districts of NP field activities were initiated during the 2001/2 season to introduce improved technology for sorghum and millet and strengthen links with the output markets. The objective is to test the hypothesis that output markets will stimulate small-scale farmers to adopt and use improved technology. This work is implemented in collaboration with public and private partnerships within and outside NP.

Five SMIP non-pilot countries were exposed to the seed system models practiced in pilot countries. Follow-up meetings in RSA helped in developing work plans and strategies to link grain markets with the use of improved sorghum and millet technologies. The primary school seed production model is being emulated in Malawi.

Field days have proved effective in efficient regional technology exchange in that various models can be developed in a few pilot countries for adaptation across the region depending on similarity of constraints, and socioeconomic and policy systems.

Regional Collaboration for Research Impact: the Case for SADC Regional Development and Adaptability of Improved Sorghum and Pearl Millet Varieties

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Introduction

Public and private investments in technology development offer high payoffs if the resulting technologies are distributed and applied regionally across national borders. Economies of scale are commonly being sought in the private sector and in public-funded, international agricultural research systems. The international application of technology and associated scale economies are readily apparent in the experience of the ICRISAT/ Southern African Development Community (SADC)-Sorghum and Millet Improvement Program (SMIP), which has shown that regional collaboration in crop breeding makes good agricultural and economic sense. Recent analyses of the adaptation of sorghum and pearl millet varieties in southern Africa provide a scientific justification for strengthening regional collaboration in breeding. This evidence is reinforced by the fact that countries throughout southern Africa have clearly benefited from spillovers in crop varieties. The regionaiization of seed markets has provided a foundation for seed delivery to flood- and drought-relief programs. The implications of these findings merit further discussion.

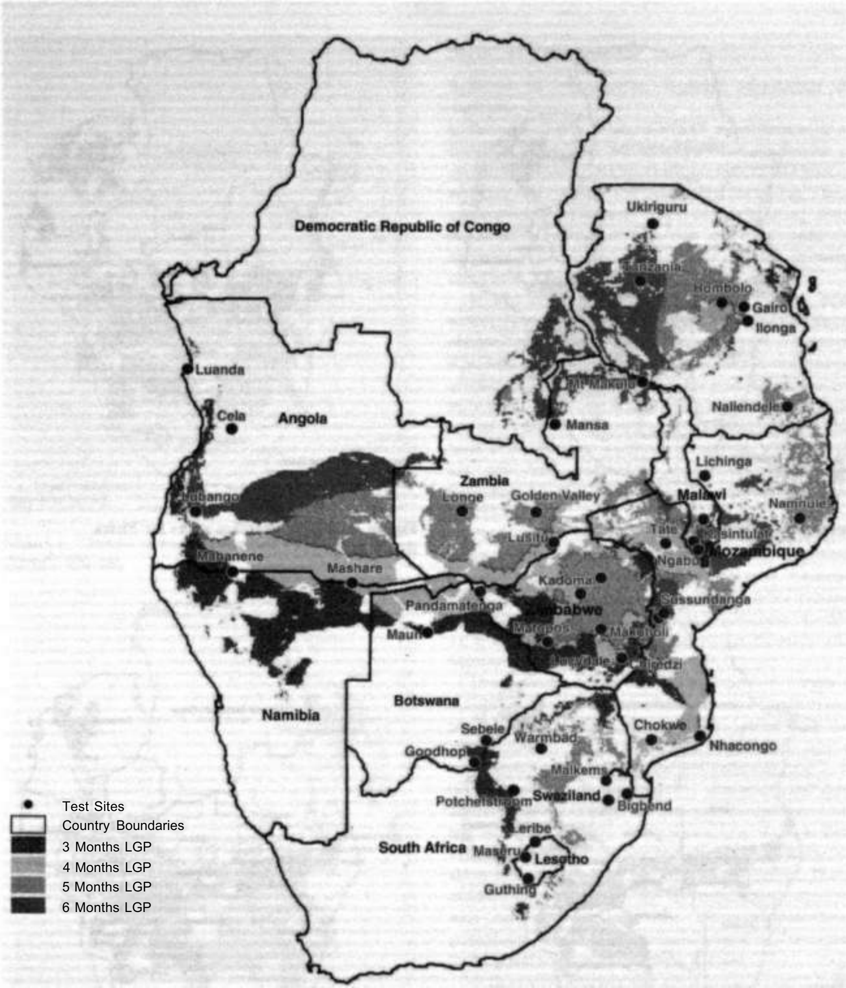

Figure 1. Geographical information systems (CIS) on lengths of growing period in southern African countries

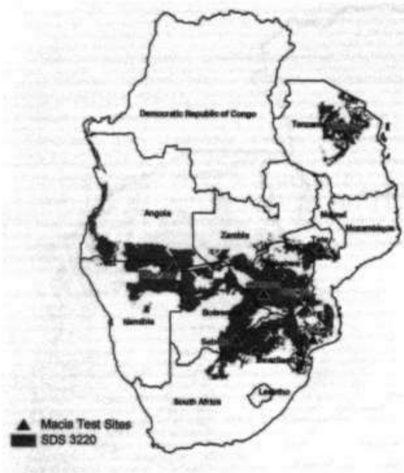

Figure 2. Regional adaptability of Macia

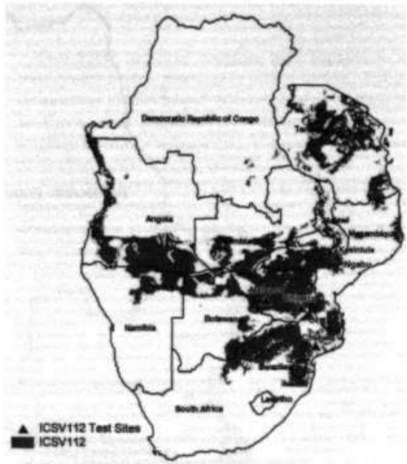

Figure 3. Climate adaption zones for Pirira (ICSV 112)

Figure 4. Climate adaption zones for SV 3

Figure 5. Climate adaption zones for SV 4

Figure 6. Climate adaption zones for PMV 3 (SDMV 920-40)

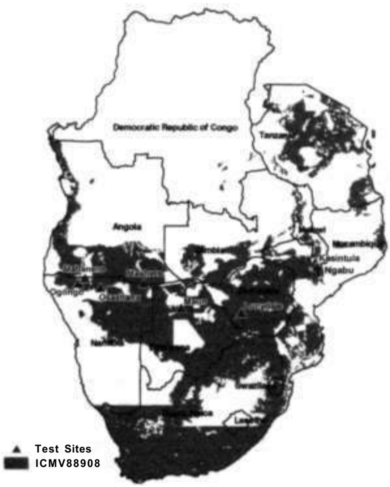

Figure 7. Climate adaption zones for Okashana 1 (ICMV 88908)

SADC/ICRISAT SMIP

Spillover of technologies: regional adaptability of varieties

In the early 1980s, when ICRISAT established a crop-breeding program at the Matopos Research Station in southern Zimbabwe, it imported more than 12,343 lines of sorghum and 7000 lines of pearl millet for testing. These encompassed germplasm collections originating from hundreds of sources. A portion of these materials appeared well-adapted to southern Africa's growing conditions.

In one famous case, the Okashana 1 variety, now widely grown in Namibia, originated from germplasm obtained in northern Togo. This was tested and selected in ICRISAT's program in central India, and distributed to southern Africa via SMIP, where it proved its productivity in trials in Zimbabwe before being sent to Namibia for testing. Namibian farmers then selected this variety on the basis of its favorable yield and plant traits. Okashana 1 has now been released in four SADC counties—Botswana, Malawi, Namibia, and Zimbabwe (as Nyan-khombo).

Similar patterns have emerged from ICRISAT's sorghum breeding program. The variety Macia has proved productive enough to be released in Botswana, Mozambique, Namibia, Tanzania, and Zimbabwe. ICSV 112 has been released under various names; in Zimbabwe (as SV 1), Swaziland (as MRS 12), Malawi (as Pirira 2), and Mozambique (as Chokwe).

These patterns of release led ICRISAT to initiate a statistical analysis of zones of adaptation of sorghum and pearl millet germplasm. This analysis started with the characterization of agroecological similarities across breeding test sites using the Spatial Characterization Tool (SCT) developed by Texas A&M. Geo-referenced data on rainfall, minimum temperature, maximum temperature, and the length of the growing season (Fig. 1) were first used to identify approximate boundaries of suitability for alternative populations of sorghum and pearl millet. These included early-, medium-, and late-maturing varieties, as well as areas suitable for photoperiod-sensitive germplasm. The SADC regional domains of adaptation for sorghum and pearl millet were defined.

A follow up analysis was done, using Geographical Information Systems (GIS) to delineate areas in the SADC region where popular multiple-released sorghum and pearl millet improved varieties might be adapted. The major test sites and areas of adaptation for each variety were characterized, values of the climatic variables were tabulated, and the ranges of the values determined. The

SADC GIS databases were queried using the SCT to search for all areas with characteristics falling within the specified ranges (Table 1). These areas were delineated as SADC regional domains for adaptation of a particular variety. Maps were developed that delineate regional adaptation of the multiple-released varieties of sorghum, e.g., Macia, ICSV 112, SV 3, and SV 4, and pearl millet varieties PMV 3 and Okashana 1 (Figs. 2-7).

Efficiency in regional crop improvement strategies

After proving potential application of spillover of improved technologies/varieties, the next step was to add a biological and statistical basis to justify pursuance of methodical and efficient regionalized crop improvement strategies. The number and location of testing sites are critical factors that affect the efficiency of, and potential gains from breeding. The selected test sites must be representative of the conditions of the target production areas for objective targeting of varieties.

The sequential retrospective pattern analysis, exploiting available long-term Multi-Environment Trial (MET) data from trials conducted in the SADC region over the past decade provided a unique opportunity and an objective basis for stratifying and grouping test sites. The stratification was based on similarity of sites' variety yield differentiation and has facilitated selection of a few representative test sites for future regional testing of varieties and hybrids (Mgonja et al. 2002). One inference is that breeding selections can be performed at a subset of sites picked from within each of the identified site groups that are also characteristic of broader agroecological domains.

The results were presented at various SADC regional fora such as the SADC Seed Security Network (SSSN), and also at national meetings. Based on the results of this work, there is justification for spillover of varieties across the region and this also supports the initiation of formalized regional seed marketing of small and coarse grains. These analyses have led sorghum and pearl millet breeders in southern Africa to endorse formal initiatives for regional variety development and release of new varieties. The implications of these agreements are substantial:

- One corollary is that every national agricultural research program need not maintain its own independent sorghum or pearl millet breeding program.
- National breeders can be confident about using trial results obtained from neighbors with similar breeding ecologies.
- By inference, countries with larger or more diverse areas of sorghum or pearl millet may be justified in maintaining larger investments in breeding programs for these crops. Countries with smaller crop areas that are similar to the ecologies of their neighbors may be justified in maintaining only small investments, aiming to simply confirm the testing results obtained from their neighbors.

Table 1. Ranges of climatic variables for delineating SADC regional adaptation of sorghum and pearl millet varieties

Variety	Annual rainfall (mm)	Minimum temperature (ºC)	Maximum temperature (ºC)
Sorghum			
Macia = Phofu = SDS 3220	396 - 775	10-23	20 - 40
Kuyutna = SDS 3136-2/WSV387	473 - 758	10-23	20 - 38
Pirira 1 =	602-961	10-22	20 - 38
ICSV 112 (Chokwe, MRS 12, SV 1, Pirira 2	435-951	10-23	20-38
ICSV 88060 = (SV 2)	435 - 709	10-18	20 - 36
SV 3	435 - 709	10-18	20 - 36
SV 4	435 - 709	10-18	20-36
Pearl millet			
ICMV 88908 (Okashana 1 and Nyankombo)	322 - 952	10-23	20-38
Okashana 2 = SDMV 93032	357 - 754	10-18	20-37
SDMV 92040 = Kangara, PMV 3	404-709	10-16	20-35
PMV 2 = SDMV 89004	435 - 754	10-18	20-36
SDMV 89005 (Kuphanjala 1 and Tupatupa)	602 961	10 23	20 - 38

- Ultimately, countries can concentrate their resources on crops and agroecologies for which they maintain higher or more unique needs.
- A second corollary of these findings is the justification for regional, as opposed to national, variety release. Regional releases allow the prospect of rapidly delivering new varieties to large numbers of farmers. Multiple rounds of variety testing across national borders can be replaced with a single round that covers a wider region.
- A third result is the potential opening of regional seed markets.
- Commercial incentives are limited for the multiplication of most open- and self-pollinated varieties.
- National markets are too small to justify any scale of investment. However, regional seed markets offer the prospects of larger, and perhaps steadier, investment returns. In fact, much of the multiplication of open- and self-pollinated varieties currently being pursued in southern Africa is aimed toward the regional market for flood and drought-relief seed.
- The regionalization of variety release would simply strengthen the justification for investments in these seed markets.
- The SADC Seed Committee has agreed to examine the case for the regionalization of releases for sorghum and pearl millet

Reference

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Potential Use of Sorghum in School Feeding Programs

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Each year, up to 10,000 t of maize *(Zea mays* L.) are being used in primary school feeding programs in the Dodoma and Singida Regions of central Tanzania under an initiative supported by the World Food Programme (WFP) of the United Nations. This encourages the consumption of maize in areas where sorghum *[Sorghum bicolor* (L.) Moench] is the main staple food. These programs also reinforce the perception that maize is a high-quality, modern food, whereas sorghum is a poor man's traditional food.

Tanzania's school feeding program also biases domestic grain markets. In most years the maize used in the program is derived from domestic grain stocks. Much of it is purchased in high rainfall regions of the country. But when rains are favorable, maize supplies are also obtained from small-scale farmers in such low rainfall areas as Dodoma and Singida. As a result, farmers are being encouraged to plant more maize, and traders are being encouraged to amass this product. In contrast, more drought-tolerant crops like sorghum are delegated to the status of subsistence crops.

ICRISAT and a local miller, Power Foods Ltd., approached the WFP to determine whether locally produced sorghum could replace a portion of the maize used in these school-feeding programs. We determined that the immediate constraint was skepticism about the acceptability of sorghum among school children. ICRISAT then asked the Tanzania Food and Nutrition Centre (TFNC) to implement an independent set of sensory taste trials to evaluate the acceptability of sorghum in breakfast porridge *(uji)* and stiff porridge *(ugali)* used for lunches. Power Foods agreed to provide the sorghum meal for these tests.

Three schools currently receiving maize for their feeding programs were nominated by Dodoma's regional authorities to participate in the taste trials. A sample of 106 students participated in the trials. Each student received soft sorghum porridge *(uji)* made from both dehulled and undehulled grain. On a different day, each received stiff sorghum porridge (*ugali)* made from dehulled and undehulled sorghum grain. These samples were served as regular meals.

Almost 98% of the students found the sorghum acceptable as a replacement to maize in breakfast and lunch meals. These students rated the overall acceptability of the *uji* made from dehulled sorghum meal approximately equal to the version made from undehulled grain. But if offered a choice, most would select the breakfast porridge made from dehulled grain, because of the whiter color of this product.

If the sorghum is to be made into *ugali,* as that is commonly eaten for lunch, the survey results suggest this grain be dehulled. There is a strong and statistically significant preference for the dehulled sorghum flour, that is said to be smoother and whiter than the product made from undehulled flour.

SMIP's recent market surveys indicate that in favorable rainfall years, sorghum can readily be purchased on the local market for such school-feeding programs. More importantly, the introduction of this product would significantly stimulate domestic sorghum production. And such a program would encourage farmers to invest in adopting better varieties and management technologies.

The development of the market for sorghum would reduce incentives to grow maize in drought-prone regions. If a consistent market for sorghum is created, this will also benefit industry. More competitive sorghum purchases will reduce grain assembly and transport costs. Sorghum will be more readily available to millers and the animal feeds industry at favorable prices.

If Tanzania experiences drought, it would be easy to replace the domestic grain supply with imports of sorghum grain. In 1992 the United States provided sorghum to Zimbabwe for use in food aid programs. This grain was marginally cheaper than maize and just as acceptable to consumers. African sorghum exporters include the Republic of South Africa and the Sudan. Alternatively, the school feeding program could readily shift back to 100% maize, at least until domestic sorghum supplies recover.

SMIP is now encouraging the WFP to substitute at least 10% of the maize currently destined for Tanzania's school-feeding program with sorghum. It is hoped this will increase to 50% substitution in the sorghum-growing regions of the country within the next few years.

Adoption of Improved Sorghum and Pearl Millet Varieties in Tanzania

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Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] and pearl millets [*Pennisetum glaucum* (L.) R. Br.] are important cereals for food security in the central high plateau comprising Singida and Dodoma regions of Tanzania, and come second to maize (*Zea mays* L.) in the Western (Tabora, Shinyanga, and Mwanza), and Southern (Mtwara, Lindi, and Ruvuma) Zones (Anonymous 1998). In Dodoma, Singida, Shinyanga, Mwanza, and Mara, sorghum and millets account for most of the national area under sorghum cultivation, while Dodoma, Singida, Shinyanga, and Tabora account for a large proportion of the national area under pearl millets. The area under millets includes both pearl millet and finger millet. The latter is grown mostly in Rukwa, Mara, and Kilimanjaro, and accounts for approximately one-third of the total millet hectarage.

The importance of sorghum and millets in the food basket of the Tanzanian population has led to considerable technological development, particularly of improved varieties that will provide a solid foundation for increasing farm-level productivity and incomes. A number of institutions such as the Food and Agriculture Organization of the United Nations (FAO), realizing the importance of quality seed of improved varieties, have from time to time provided farmers with seed through relief programs. Private seed companies have not fully engaged in the commercial aspects of developing seed of open-pollinated varieties or seed of small and coarse grains like sorghum and pearl millet. To ensure sustainable availability of quality seed of improved varieties of these crops, SMIP worked closely with both public and private institutions to develop alternative seed systems strategies in three SADC countries including Tanzania, and measured the impact of this intervention.

Improved varieties

Under the terms of the impact-monitoring plan for SMIP Phase IV, a baseline estimate must be established for adoption of improved varieties in each of four pilot countries. In Tanzania, the baseline established in the early 1990s suggested that the level of adoption of new sorghum and pearl millet varieties was as low as 5%. Since then, two new sorghums (Pato in 1995 and Macia in 1999) and two pearl millets (Okoa and Shibe in 1994) have been released. These new varieties supplement other sorghums released previously (Tegemeo in 1986, Serena, Seredo, and Lulu in the late 1960s and early 1970s) and pearl millet Serere 17 in the early 1970s. Recent efforts to multiplty and promote these improved varieties are known to have resulted in a significant increase in adoption, but the actual level of adoption has not been officially documented. Therefore, an adoption survey was deemed a necessary part of the impact-monitoring plan of the SMIP Phase IV program, that would indicate:

- Increased levels of adoption for improved sorghum and millet varieties from 7-20% in the three target countries Tanzania, Zimbabwe, and Mozambique from 1997/8 to 2002/3.
- Increase in area sown to new sorghum varieties from 64 thousand ha in 1997/8 to 260 thousand ha, and pearl millet from 37 thousand ha in 1997/8 to 118 thousand ha by 2002/3.

This would imply promotion of adoption of new sorghum varieties by 520 thousand fanners and of pearl millet varieties by 235 thousand farmers in the three target countries.

Survey methodology

A formal survey was conducted to assess the level of adoption and acceptance of the new improved sorghum and pearl millet varieties. The survey also evaluated household strategies for seed supply, and the degree to which farmers are replacing traditional varieties of sorghum and pearl millet. Information was derived from nine regions of Tanzania (Arusha, Dodoma, Lindi, Mara, Mtwara, Mwanza, Shinyanga, Singida, and Tabora). Distr-icts were selected according to the importance of the crops in terms of hectarage, production, and consumption. Two districts were selected from each region, except in Tabora and Arusha, where only one district from each was chosen. Villages and respondents were selected at random, and gender was taken into consideration. The 16 most important districts for the production of sorghum and pearl millet were covered. A minimum of 8 respondents was interviewed from two villages in each district, totaling 16 respondents per district. The exception was Kondoa District in Dodoma, where 24 farmers were interviewed because of the differential distribution of sorghum and pearl millet areas in the district, and Kwimba, Misungwi, and Bunda, where 17 farmers were interviewed in each district. The national survey therefore involved a total of 267 respondents. The varieties Tegemeo, Pato, Macia, Serena, and Seredo were targeted for sorghum adoption, and Serere 17, Okoa, and Shibe for pearl millet adoption.

Results

The survey revealed that the proportion of farmers who are aware of the new improved sorghum varieties ranges from about 16% in Lindi (Southern Tanzania) to as high as 80% in Dodoma (Central Tanzania). Those with experience in growing these varieties also ranged from as low as 6% (Lindi) to as high as 62% in Dodoma (Table 1).

Table 1. Proportion (%) of farmers aware of new sorghum varieties and experienced in growing them, Tanzania, 2001

	Farmers				
	Aware		Experienced		
Region	Improved	Local	Improved	Local	Number of respondents
Dodoma	79.5	20.5	61.5	38.5	40
Singida	60.0	40.0	38.1	61.9	32
Tabora	60.0	40.0	35.0	65.0	16
Shinyanga	63.1	36.9	45.0	55.0	32
Mwanza	50.5	49.5	42.0	58.0	50
Mara	45.6	54.5	47.1	53.0	17
Lindi	15.7	84.4	6.3	93.7	32
Mtwara	28.1	71.9	20.3	79.7	32
Arusha	36.0	64.0	29.2	70.8	16
Weighted mean[1]	56.8	43.2	42.3	57.7	267

1. Weighted against the proportion of sorghum area within the region

Table 2. Mean area sown to improved sorghum varieties, based on 2001 adoption survey study, Tanzania

Region/area ('000 ha)	Dodoma	Singida	Shinyanga	Mwanza	Other major	Other minor	Total	Improved (%)
Reference area	97	60	121	73	158	165	674	
Improved	46	18	50	37	53	40	244	36
Local	51	42	71	36	105	125	430	

The survey results were weighted against the national hectarage sown to sorghum, and revealed that improved sorghum varieties currently occupy approximately 36% of the area under sorghum (Table 2).

Similarly, the proportion of farmers who are aware of the existence of the new improved pearl millet varieties, ranges from a low of just 2% in the Lake Zone (Mwanza) to a high of 44% in the Central Zone (Dodoma). The proportion of farmers experienced in growing the varieties ranges from 0% (Mwanza) to 33% (Dodoma) (Table 3).

The survey results were weighted against the national hectarage, and showed that the improved pearl millet varieties now occupy approximately 27% of the total area sown to pearl millet. It has taken more than 6 years to reach these levels of adoption, from the time the last releases were made in 1994 for the pearl millet varieties Okoa and Shibe, and in 1995 for the sorghum variety Pato. As a result of the combined functioning seed systems in the Central Zone, and the national drought relief efforts, Macia, the most recent release, is rapidly becoming known to farmers. The survey further revealed that a majority of farmers in Tanzania have learned about the new improved varieties through the Extension Service (over 70% for the variety Pato), whereas about 22% learned of this variety from other farmers.

Contribution toward achieving SMIP impact indicators

The major SMIP impact indicator seeks a regional increase in adoption levels to 20%, from base values of 7%, set in 1998. The progress made in Tanzania so far guarantees that the project impact indicators will be met. These adop-tion levels (36% adoption for sorghum and 27% for pearl millet) will contribute significantly towards meeting the target impact indicators.

Table 3. Proportion (%) of farmers aware of new pearl millet varieties and experienced in growing them, Tanzania, 2001

	Farmers				
	Aware		Experienced		
Region	Improved	Local	Improved	Local	Number of respondents
Dodoma	43.8	56.3	32.5	67.5	40
Singida	42.2	57.8	26.6	73.5	32
Tabora	-	-	-	-	16
Shinyanga	18.8	81.2	14.1	86.0	32
Mwanza	2.0	98.0	-	-	50
Mara	-	-	-	-	16
Lindi	-	-	-	-	33
Mtwara	-	-	-	-	32
Arusha	-	-	-	-	16
Weighted mean	29.7	52.2	21.1	55.9	267

Sorghum Research Reports

Germplasm

Geographic Distribution of Basic and Intermediate Races in the World Collection of Sorghum Germplasm

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Sorghum [*Sorghum bicolor* (L.) Moench] is of tropical origin, but it has also been adapted through selection to temperate regions. It is the staple food of many people in Africa, Asia and is a major feed crop in Argentina, Australia, Mexico, South Africa and the USA. It was probably domesticated in northeastern Africa, in an area extending from the Ethiopian-Sudanense border to Chad (Doggett 1970; de Wet et al. 1976). From this area, it spread to India, China, the Middle East, and Europe.

Sorghum is an immensely variable genus and is subdivided into five sections *Chaetosorghum, Heterosorghum, Parasorghum, Stiposorghum and Sorghum* (de Wet 1978). The sorghum section includes cultivated grain sorghum, a complex of closely related annual taxa from Africa, and a complex of perennial taxa from southern Europe and Asia. The range of genetic variability available in cultivated races and their wild relatives is extensive, and the extreme types are so different as to appear to be separate species (Prasada Rao and Mengesha 1988). Although collection and conservation of genetic resources of sorghum attracted the attention of botanists and breeders about three decades ago, they have become increasingly important in recent years due to the replacement of many landraces with genetically uniform varieties and hybrids, and the large-scale destruction of natural habitats of wild and weedy relatives by urbanization and industrialization (Prasada Rao and Ramanatha Rao 1995).

The genebank at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) currently conserves 36,774 accessions assembled from 90 countries (Table 1). As and when received, new sorghum germplasm accessions characterized for 23 morphological and agronomic traits during postrainy seasons at ICRISAT, Patancheru, India between 1974 and 2002. Following Harlan and de Wet (1972), and based on the inflorescence and spikelet characters that are most stable and least influenced by the environment, the germplasm accessions maintained at ICRISAT are classified into five basic races; Bicolor, Guinea, Caudatum, Kafir, and Durra and ten intermediate races; Guinea-bicolor, Caudatum-bicolor, Kafir-bicolor, Durra-bicolor, Guinea-caudatum, Guinea-kafir, Guinea-durra, Kafir-caudatum, Durra-caudatum, and Kafir-durra. These races have the following characteristics:

Bicolor: grain elongate, sometimes slightly obovate, nearly symmetrical dorso-ventrally; glumes clasping the grain, which may be completely covered or exposed as much as ¼ of its length at the tip.

Guinea: grain flattened dorso-ventrally, sublenticular in outlilne, twisting at maturity nearly 90 degrees between gaping involute glumes that are from nearly as long to longer than the grain.

Caudatum: grain markedly asymmetrical, the side next to the lower glume flat or in extreme cases even somewhat cancave, the opposite side rounded and bulging: the persistent style often at the tip of a beak pointing toward the lower glume; glumes of the length of grain or less.

Kafir: grain approximately symmetrical, more or less spherical: glumes clasping and variable in length.

Durra: grain rounded obovate, wedge-shaped at the base and broadest slightly above the middle; glumes very wide, the tip of a different texture from the base and often with a transverse crease across the middle.

Table 1. Proportion of various races and intermediate races based on 35652 sorghum germplasm accessions in ICRISAT genebank

Races/Intermediate races	Number of accessions	%
Bicolor	1443	4.05
Caudatum	7448	20.89
Caudatum-bicolor	1416	3.97
Durra	7788	21.84
Durra-bicolor	2336	6.55
Durra-caudatum	4304	12.07
Guinea	4781	13.41
Guinea-bicolor	333	0.93
Guinea-caudatum	3388	9.50
Guinea-durra	219	0.61
Guinea-kafir	106	0.30
Kafir	1274	3.57
Kafir-bicolor	136	0.38
Kafir-caudatum	404	1.13
Kafir-durra	276	0.77
Total	35652	100.00

In general, race Bicolor includes primitive forage sorghums with sweet stems. Kafir sorghums provide important staple food across the eastern and southern savanna from Tanzania to South Africa. Most commercially important male-sterile lines are derived from Kafir landraces as they are insensitive to photoperiod, a relatively unusual trait. Guinea sorghums are the oldest specialized group, which are mostly photoperiod sensitive, resistant to grain mold, and grown primarily in West Africa. Caudatum sorghums are of most recent origin, and are used for brewing traditional opaque beers in East African countries. Durra and Caudatum sorghums are widely used in crop improvement programs in Asia and Kafir in Southern Africa. Most of the present-day cultivars under cultivation in tropical countries are derived from Caudatum landraces. In this paper, we summarized the composition of the germplasm maintained at ICRISAT, and the distribution of its component races and intermediate races across various countries in the world.

The collection assembled at ICRISAT is predominantly represented by the basic races; Durra (21.8%), Caudatum (20.9%,), and Guinea (13.4%). Among the intermediate races, Durra-caudatum (12.1%), Guinea-caudatum (9.5%), and Durra-bicolor (6.6%) are represented (Table 1). Although ICRISAT's sorghum germplasm collection originated from 90 countries, for the purpose of this analysis, only countries where the number of accessions were 100 or more were considered. The analysis revealed that three countries namely; India, Uganda, and Zimbabwe are represented by all the five basic and ten intermediate races. USA, Zambia, and India

Table 2. Countrywise distribution of sorghum races and intermediate races

Country	B[1]	C	CB	D	DB	DC	G	GB	GC	GD	GK	K	KB	KC	KD	Total
Benin	1		2	1		2	184	4	3							197
Burkina Faso	7	4	9	23	5	7	414	5	68	2						544
Burundi		107	3	4	1	3	3	2	12						1	136
Cameroon	11	1313	34	364	20	275	202	37	219	2						2477
China	21	231	152	9	16	85	1	5	41		1	7	31	17	6	623
Ethiopia	149	401	125	1870	1063	457	15	10	191	10		6	2	3	10	4312
India	344	142	113	3575	543	380	773	25	144	56	1	12	10	6	34	6158
Kenya	26	748	27	5	6	38	10	1	103	2		1		1		968
Lebanon	18	30	51	23	13	142	2	2	36	12		17		12	2	360
Lesotho	4	8	7	1	1	2	1		63		9	103	4	60	6	269
Malawi	5	19	13	5	1	8	258	19	59	13				1		401
Mali	13	26	11	70	35	42	473	8	14	1				1		694
Niger	14	32	51	63	43	100	34	6	62	3						408
Nigeria	34	231	60	63	52	265	657	97	186	17		4	3	5	1	1675
Rwanda	2	220	1	44	1	19			2	1						290
Senegal	3	2	6	10	2	5	190	2	19							239
Sierra Leone							107									107
Somalia		11		424	I	3			2							441
South Africa	25	189	63	14	3	24	22	2	23		2	455	9	49	22	902
Sudan	83	992	124	228	47	310	42	10	510	27		23	11	39	2	2448
Tanzania	12	106	16	50	5	17	373	9	96	7		2	2	4		699
Togo	3	9	4	11	1	1	244	4	17							294
Uganda	38	1269	34	15	14	42	34	3	227	2	2	20	3	6	11	1720
USA	321	317	156	139	49	267	69	21	177	12	64	235	42	110	70	2049
Yemen	11	121	32	330	221	1339	1	1	90	8		2		1	5	2162
Zambia	22	52	50	3	1	10	86	6	128	1				1	1	361
Zimbabwe	13	238	68	74	10	110	256	10	535	19	10	149	3	27	45	1567
Total	1180	6818	1212	7418	2154	3953	4451	289	3027	195	89	1036	120	343	216	32501

1. B=Bicolor; C=Caudatum; CB=Caudatum-bicolor; D=Durra; DB=Durra-bicolor; DC=Durra-caudatum; G=Guinea; GB=Guinea-bicolor; GC=Guinea-caudatum; GD= Guinea-durra; GK=Guinea-kafir; K=Kafir; KB= Kafir-bicolor; KC=Kafir-caudatum; KD=Kafir-durra

are dominated by race Bicolor; West African countries including Sierra-Leone, Benin, Togo, Senegal, Burkina Faso, Mali, Malawi, and Tanzania by Guinea; East African countries by Caudatum; the southern African countries South Africa, Lesotho, Zimbabwe by Kafir; and Somalia, India and Ethiopia by Durra. Among the intermediate races, the majority of the Caudatum-bicolor accessions are from China, Lebanon, Zambia, and Niger; Durra-bicolor form Ethiopia, Niger, Yemen, and India; Durra-caudatum from Yemen, Lebanon, Niger, Nigeria, China, USA, Sudan, Cameroon, Ethiopia, and Zimbabwe; Guinea-caudatum from Zambia, Zimbabwe, Lesotho, Sudan, Niger, Malawi, Tanzania, Uganda, Burkina Faso, and Nigeria, and Kafir-caudatum from Lesotho, and South Africa (Table 2).

Natural selection for adaptation to environment and farmer's preference for specific uses or specific cropping systems is known to have accounted for most of the morpho-agronomic diversity in crops. This analysis reveals that racial divergence in sorghum is related to geographic origin and this enables breeders to narrow down their search to meet breeding objectives and germplasm collectors to target specific geographic areas for specific **races.**

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Sorghum Germplasm Collection from Drought-Prone Areas of Southern Maharashtra

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Introduction

Sorghum (*Sorghum bicolor* (L.) Moench], the second largest grain crop in India until the Green Revolution, presently occupies the third place in terms of area sown and fifth place in production amongst the food grains. Postrainy-season (*rabi*) sorghum is unique to India in that it is grown on residual soil moisture. It is a major cereal of the drought-prone areas and is grown over 5.89 million hectares, primarily in the states of Maharashtra, Kamataka, and Andhra Pradesh. Postrainy-season sorghum is a major source of food and fodder and an important component of the dryland economy of these states, particularly in Maharashtra, where 75% of the total area cultivated in the postrainy season is under this crop. The major constraints restricting yield improvement are drought on medium-to-shallow soils, shoot fly *(Atheri-gona soccata* Rondani), charcoal rot (*Macrophomina phaseolina* (Tassi) G Goid) and cold. The present exploration was undertaken to collect germplasm in the drought-prone areas of Maharashtra, so that it could be used in breeding programs for resistance to both biotic and abiotic stresses.

Materials and methods

The National Research Centre for Sorghum (NRCS), being the National Active Germplasm Site (NAGS) for sorghum, has been identified to explore, collect, characterize and evaluate sorghum germplasm under the National Agricultural Technology Project (NATP) on Rainfed Nutri-tious Production System 10 **(RNPS-10).** The NRCS has previously undertaken explorations in the drought-prone areas of Maharashtra to collect diverse sorghum germ-plasm. This exploration was undertaken to supplement the previous collections of Gopal Reddy et al. (1993; 1996) and Elangovan and Prabhakar (2001). Previous collectors observed that there was considerable variability in post-rainy-season sorghum in Maharashtra where missions targeted the districts of Buldana, Jalgaon, **Dhule, Aurangabad, Jalna, Parbhani,** Beed, Satara **and**

Sangli. Solapur district, one of the major postrainy season sorghum growing areas was not covered by the earlier mission. The prime objective of the present mission was to collect drought-tolerant sorghum germplasm from Solapur and Sangli districts.

The team comprised of two members from NRCS, Hyderabad and one from the Centre on *Rabi* Sorghum (CRS), Solapur.

The CRS and Mahatma Phule Krishi Vidyapeeth (MPKV) were contacted for relevant information on sorghum-growing areas for collection. Farmers, informants, and shepherds were interviewed to collect information on history, cultivation practices, and other details.

Panicle samples were collected by selective sampling method either from the standing crop, or from heaps in

Table 1. Passport data of local landraces in drought-prone areas of southern Maharashtra, India, postrainy season 2000/1

				Plant characteristics				
collector's number	Cultivar	Village	District	Height	Seed color	Seed size	Panicle shape	Pigmentation
PU-1	Pandharpur Local	Pandharpur	Solapur	Medium	Pearly white	Bold	Semi-compact	Purple
PU-2	Bikkulinge Local	Bikkulinge	Solapur	Medium	Pearly white	Bold	Semi-compact	Purple
PU-3	Tandulwadi Local	Tandulwadi	Solapur	Dwarf		Bold	Semi-compact	Purple
PU-4	Kusmod Local	Kusmod	Solapur	Medium	White	Bold		Purple
PU-5	Sherwadi Local	Sherwadi	Solapur	Medium	Pearly white	Medium		Purple
PU-6	Umbergaon Local	Umbergaon	Sangli	Medium	Pearly white	Bold	Semi-compact	Purple
PU-7	Gomewadi Local	Gomewadi	Sangli	Medium	Pearly white	Bold	Semi-compact	Purple
PU-8	Limb Local 1	Limb	Sangli	Medium	Pearly white	Bold	Semi-compact	Purple
PU-9	Limb Local 2	Limb	Sangli	Medium	White	Medium	Compact	Purple
PU-10	Eknud Local 1	Eknud	Sangli	Medium	Pearly white	Bold	Semi-compact	Purple
PU-11	Eknud Local 2	Eknud	Sangli	Medium	White	Bold	Semi-compact	Purple
PU-12	Shalu Jowar	Kalmbi	Sangli	Medium	Pearly white	Bold	Semi-compact	Purple
PU-13	Kerewadi Local 1	Kerewadi	Sangli	Medium	Pearly white	Medium	Compact	Purple
PU-14	Kerewadi Local 2	Kerewadi	Sangli	Medium	Pearly white	Bold	Semi-compact	Purple
PU-15	Junoni Local 1	Junoni	Solapur	Medium	Pearly white	Medium	Semi-compact	Purple
PU-16	Junoni Local 2	Junoni	Solapur	Medium	White	Medium	Semi-compact	Purple
PU-17	Junoni Local 3	Junoni	Solapur	Medium	Pearly white	Very bold	Semi-compact	Purple
PU-18	Udunwadi Local	Udanwadi	Solapur	Tall	Pearly white	Very bold	Semi-compact	Purple
PU-19	Kachrewadi Local	Kachrewadi	Solapur	Medium	White	Bold	Compact	Purple
PU-20	Mangud Local	Mangud	Solapur	Medium	Creamy	Bold	Semi-compact	Purple
PU-21	Kaulee Local 1	Marwade	Solapur	Medium	White	Medium	Loose	Purple
PU-22	Kaulee Local 2	Marwade	Solapur	Tall	White	Medium	Loose	Purple
PU-23	Mangalweda Maldandi 1	Marwade	Solapur	Medium	Pearly white	Bold	Semi-compact	Purple
PU-24	Mangalweda Maldandi 2	Mangalweda	Solapur	Medium	Pearly white	Bold	Semi-compact	Purple
PU-25	Mangalweda Maldandi 3	Brahmapuri	Solapur	Medium	Pearly white	Bold	Semi-compact	Purple
PU-26	Tandulwadi Local (Dagdi)	Tandulwadi	Solapur	Medium	Reddish Brown	Medium	Compact	Purple
PU-27	Bhamla Tanda Maldandi	Bhamla Tanda	Solapur	Medium	Pearly white	Medium	Semi-compact	Purple
PU-28	Chugi Maldandi 1	Chugi	Solapur	Medium	Creamy	Bold	Compact	Purple
PU-29	Tandulwadi Maldandi 1	Tandulwadi	Solapur	Medium	Pearly white	Bold	Semi-compact	Purple
PU-30	Tandulwadi Maldandi 2	Tandulwadi	Solapur	Medium	Pearly white	Bold	Semi-compact	Purple
PU-31	Tandulwadi Maldandi 3	Tandulwadi	Solapur	Medium	Pearly white	Bold	Semi-compact	Purple
PU-32	Sultan Puri Local	Sultanpur	Solapur	Medium	Creamy white	Medium	Semi-compact	Purple
PU-33	Chungi Maldandi 2	Chungi	Solapur	Medium	Pearly white	Bold	Semi-compact	Purple
PU-34	Darganhalli Maldandi	Darganahalli	Solapur	Medium	Creamy white	Medium	Semi-compact	Purple

fields after harvest. The mission adapted the following parameters to identify drought-tolerant plant types: medium tall, stay-green trait, medium stem thickness and postrainy adaptation. Emphasis was given to the stay-green character that is associated with drought tolerance and fodder quality.

Results and discussion

The explored area is a rainfed zone. The Planning Commission of India (1989) classified the Indian agro-climatic zones in 15 regions based on their crop diversity and micro-climates. Southern Maharashtra is classified as a Western Plateau and Hills region. The Solapur district recorded an annual rainfall of 753 mm and Sangli district 1200 mm for 2000/1. Temperatures ranged from 11-41 °C in Solapur and 15-36 °C in Sangli, and the topography of the soil was of medium depth in Sangli while it ranged from shallow-to-medium depth in Solapur.

Pearl millet [*Pennisetum americanum* (L.) Leeke], black gram [*Vigna mungo* (L.) Hepper], green gram [*Vigna radiata* (L.) Wilczek], cowpea [*Vigna unguiculata* (L.) Walp.], *rabi* sorghum, safflower (*Carthamus tinctorius* L.), pomegranate (*Punica granatum* L.), grapes (*Vuis vinifera* L.), sugarcane (*Saccharum officinurum* L.), red gram [*Cajanus cajan* (L.) Millsp.] and sunflower *{Helianthus annus* L.) were the main crops in Solapur and sugarcane, cotton (*Gossypium herbaceum* L.), postrainy sorghum, safflower, and sun-flower in Sangli. In most of the areas, sorghum is cultivated as a sole crop but is sometimes grown mixed with safflower.

A total of 34 samples were collected and the complete passport data of the collection is given in Table 1.

Farmers prefer fodder from postrainy season sorghum because of its high quality. Most of the samples collected were of the Maldandi type, i.e., medium-tall to tall in height, with stay-green trait, semi-compact panicles, and pearly-white lustrous seed. A few samples resembled *dagdi* types with hard, compact panicles and *lakdi* types with small, compact panicles and small seed.

The majority of the samples were from medium-tall to tall plants, although a few dwarf types were also collected. The diversity in panicle shapes collected is shown in Figure 1. The panicles were semi-compact to compact, and the seed color varied from white to pearly white, creamy white, and reddish brown. The seed size ranged from medium bold to very bold. The local landraces, *dagadi* and popcorn were also collected. PU-21 and PU-22 with loose panicles, PU-17 and PU-18 with pearly white lustred panicles and very bold seed, and PU-21 with deep purple long grains were some of the special types collected.

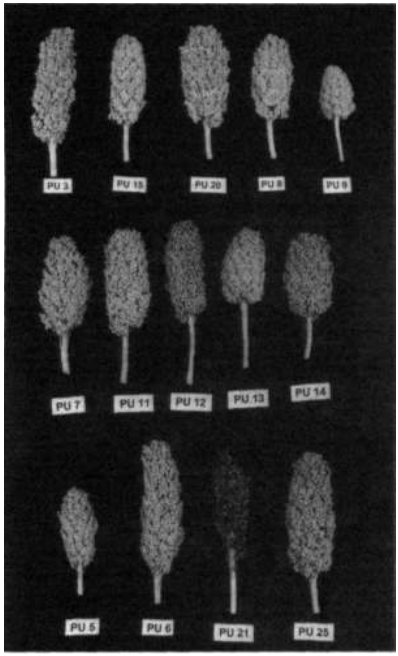

Figure 1. Diversity of sorghum germplasm collected from southern Maharashtra

The collected germplasm could prove to be drought tolerant since drought was prevalent in the targeted areas. The samples will be evaluated under both natural and stress conditions for drought tolerance to determine their potential use in breeding programs. Although the Solapur and Sangli districts were adequately covered during this mission, the neighboring rainfed areas also need to be explored for valuable sorghum landraces.

Acknowledgments

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Vacuum Storage and Seed Survival in Pearl Millet and Sorghum

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Introduction

Seed longevity is controlled by three major factors-moisture content, temperature and oxygen concentration in the storage environment (Roberts 1972). The effects of moisture content and temperature on seed longevity have been extensively studied. Ellis and Roberts (1981) quantified the relationships and developed equations to estimate seed viability after storage in any environment. Many researchers have also investigated the effect of air (oxygen), vacuum and other inert gases on seed survival, however, the reported results were variable and sometimes contradictory. Tao (1989) reviewed the literature and concluded that the benefit from vacuum storage is limited and variable, hence it should not be used for conservation by multi-crop genebanks. Nevertheless, much of the confusion on the effect of various gases and vacuum in previous reports appears to have resulted from lack of appreciation of the role of seed moisture content (MC). Ibrahim and Roberts (1983), investigating seed viability in lettuce, found evidence for an interaction between MC and the partial pressure of oxygen—at MCs below a critical value (15%), oxygen was found to be deleterious to seed survival, but above this MC the response changed and oxygen increased longevity. Ibrahim and Roberts (1983) also found that the lower the MC below 15%, the greater the relative beneficial effect of excluding oxygen. Eliminating oxygen from storage, therefore, is expected to improve the longevity of seeds, especially at the low MCs (5 ± 2%) used for long-term conservation. We studied the effect of vacuum on the longevity of pearl millet [*Pennisetum glaucum* (L.) R.Br.] and sorghum [*Sorghum bicolor* (L.) Moench] seeds by storing them under a range of conditions that accelerated their deterioration and the results are presented here.

Materials and methods

Sorghum (cv. Maldandi) seeds with 8.4% initial MC and 98% germination and pearl millet (cv. Sadore local) seeds with 9.2% initial MC and 94% germination were used for the study. The effect of vacuum on seed longevity was studied at three MCs: 6%, 10% and 14%. The MCs were adjusted by holding the seeds on saturated salt solutions of LiCl (13% RH), $MgCl_2$ (33% RH), and NaCl (75% RH) for about a week at 25°C. Each seed lot was then subdivided into aliquots of 5 g and hermitieally sealed in small aluminum foil envelopes in air or with vacuum using an Audionvac VM101H® vacuum-sealer programmed to a pressure of -0.95 bar. Seeds were held at 50°C to accelerate ageing and sampled at regular intervals to study seed deterioration. The sampling intervals ranged from once every day (50°C and 14% mc) to once in 8 weeks (50°C and 6% mc), depending on the storage treatment. In addition to 50°C, pearl millet seeds were also stored to 35°C. The initial viability of seeds was estimated at the beginning of storage and subsequently at each sampling time by conducting germination tests using four replicates each of 50 seeds. Germination was expressed as the percentage of normal seedlings produced after 7 days of incubation at 20°C.

Results and discussion

There was gradual loss in germinability of the seeds under all storage conditions. Seeds stored at the high temperature (50°C) and/or high MC (14%) deteriorated faster compared with other treatments. Under similar conditions of storage, pearl millet seeds survived longer than those of sorghum. Within each crop, differences were observed in rate of seed deterioration between vacuum and air-storage treatments, especially at the low MC. Since there was gradual loss in viability in all seed lots, the data on seed survival were subjected to probit analysis and seed longevity was expressed as half-viability period (P_{50}), i.e., time taken for viability to decrease to 50%. Analysis of variance of the estimates of P_{50} showed significant effects of MC, vacuum and their interaction on seed survival at 50°C ($P < 0.001$). Decreasing seed MC from 14% to 6% increased longevity in both air and vacuum (Table 1). However, the increase in seed longevity with the decrease in seed MC was more in seeds stored under vacuum than those stored in air. Thus, in pearl millet seeds stored at 50°C, decreasing seed MC from 14% to 6% increased seed longevity by a factor of 189 under vacuum storage, but a similar reduction in seed MC increased longevity by a factor of 145 in air storage. In sorghum, decreasing seed MC from 14% to 6% increased seed longevity by a factor of 80 under vacuum, compared with the 52-fold increase when sealed in air.

Table 1. Longevity (estimated as half-viability period, P_{50}) of pearl millet and sorghum seeds stored under different conditions

	Storage condition		P_{50} (days)	
Crop	Temperature (°C)	Moisture content (%)	Vacuum	Air
Pearl millet	50	14	3.7	3.7
		10	44.8	42
		6	697.8	538.8
Pearl millet	35	14	30.5	33.9
		10	422.4	392.1
		6	3060.7	2931.7
Sorghum	50	14	2.7	2.5
		10	25.6	24.7
		6	218.2	130.2

A comparison of the effect of vacuum within each MC at 50°C showed that in both pearl millet and sorghum, while survival of seeds in vacuum and air was similar at 14% MC, and marginally higher in vacuum at 10% MC, longevity was substantially higher under vacuum at 6% MC (Figure 1). At 35°C in pearl millet, seeds stored in air with 14% mc survived longer than those in vacuum, and those stored with 10% and 6% MCs survived better in vacuum than in air, although the differences were statistically insignificant. At the low MC (6%), germination remained very high in both air (89%) and vacuum (85%) at the end of this study after 216 weeks,

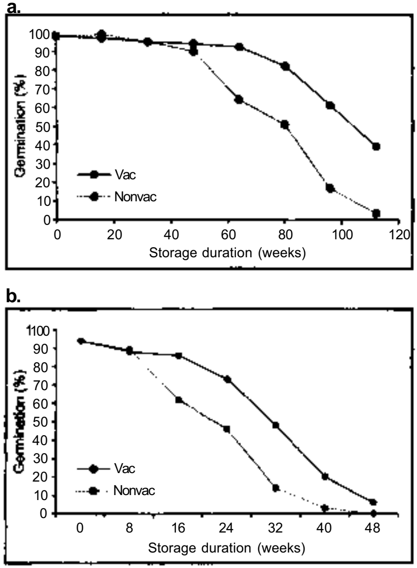

Figure 1. Survival of a. pearl millet and b. sorghum seeds hermetically stored with 6% moisture content at 50°C

hence the values of P_{50} derived through extrapolation could have underestimated the potential differences and therefore the benefit of the vacuum. The results presented here also demonstrate the potential benefit of storing seeds with very low MCs, irrespective of vacuum. Thus, pearl millet seeds stored with 6% MC at temperatures as high as 50°C retained good germination (>85%) even after one year.

Conclusions

- Seeds dried to 6% MC retain viability for considerably long periods, and replacing air with vacuum further enhanced seed longevity
- Vacuum packing had no significant effect on longevity of sorghum and pearl millet seeds stored at 14% and 10% MCs
- Pearl millet seeds survived longer than sorghum under similar conditions of storage.

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Genetics and Breeding

Cross-Linked Sorghum-Rice Physical Maps: Update on Research

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Substantial new genomic resources for sorghum research have been produced under a National Science Foundation (NSF) project entitled 'Cross-Linked Sorghum-Rice Physi-cal Maps', led by A Paterson and including 8 co-Principal Investigators located at the University of Georgia (USA; Bhandarkar, M-M Cordonnier-Pratt; A Gingle; J Kececio-glu, L Pratt); Clemson University (R Dean, R Wing), and Cornell University (S Kresovich). This project greatly advanced the quantity and characterization of genomic resources for sorghum and its relatives. A partial summary of selected results was published (Draye et al. 2001). A few examples of research tools generated include an approximately 2,600 locus molecular map of sorghum (Bowers et al. 2002) including 1048 (40.3%) heterologous loci as links to most public maps for maize (*Zea mays* L.), rice [*Oryza saliva* L.), sugarcane [*Saccorum officinalis* L.), Buffelgrass (*Cenchrus ciliaris* L.), Bermudagrass [Cynodon dactylon (L.) Pers.]; and the small grains; two BAC libraries, a 17x coverage BAC library of *Sorghum bicolor* (L.) Moench (available from R Wing; www.genome. clemson.edu) and 13x (73,728 clones of average 132 kb inserts) of *Sorghum propinquum* (Kunth) Hitchc. (available from A Paterson; www.plantgenome.uga.edu); finger-prints for 10x coverage of the *S. bicolor* (SB) and *S. propinquum* (SP) BAC libraries (on line at http://www.genome. clemson.edu/projects/sorghum/fpc); RFLP-to-BAC hybridization data for most of the mapped probes; 10 cDNA libraries, 184,320 arrayed clones, and 50,000 cDNA clones sequenced from each end (see Genbank for sequences, and request clones from L Pratt); 5,000 from each library; sequencing of all sorghum RFLP probes on the high-density map and their exploration for SSRs and homologues (see Schloss et al. 2002); study of the allelic richness of coding sequences and genomic DNA sequences in 57 diverse sorghum accessions (in progress; see www.igd.cornell.edu); and a Web-accessible database (cggc.agtec.uga.edu/cggc). Many additional publications are in progress. The grant was recently renewed for September 20001-September 2005.

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Use of Male Sterility for Isolating Apomictic Sorghum Lines

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Isolation and investigation of lines with elements of apomixes is an area within modern plant genetics closely related to both fundamental problems of sexual reproduc-tion and applied tasks of plant breeding. Sorghum [*Sorghum bicolor* (L.) Moench] is a useful species for investigating apomixis in that: 1. there is a great variety of different types of male-sterility systems that suppress the formation of functional pollen and self-fertilization in either sorghum genotype, which would produce plants with seed set in the absence of the sexual process; 2. it possesses a large inflorescence with many ovules each located in its own ovary, and fertilization can be visualized by observing the stigma condition; 3. the existence of dominant marker genes *Rs* determining antho-cyanin pigmentation of the coleoptile and first leaves of seedlings allows application of a progeny test for verifica-tion of the cyto-embryological data.

Previously, we have reported on the sorghum line AS-1 with elements of apomixis (Elkonin et al. 1995; Enaleeva et al. 1996). This line was obtained as a result of selection in progeny of regenerants from tissue culture of a plant with cytoplasmic male sterility that set seeds in bagged panicles with a very low level of pollen fertility. Cyto-embryological analyses revealed the presence of aposporous embryo-sacs (ESs), enlarged additional cells with one or several nuclei- and apomictic proembryos, which developed in both the aposporous and meiotic ESs. The frequency of ovules with aposporous structures (APS) (ESs and additional cells) varied considerably (0-50%) in different plants. As a result of subsequent selection the AS-Ih subline was obtained, in which the average APS frequency increased up to 77% (up to 90% in individual plants). However, formation of an apomictic proembryo was never observed in this subline. Another subline, AS-Ia, which was characterized by a medium APS frequency (26.3%), maintained its ability for autonomous embryo formation (average 1.8-2.7%) in different seasons; in some plants up to 8%). This frequency was stable in three different seasons. These data indicate different genetic controls of APS formation and initiation of autonomous embryo development. The APS frequency varied in different panicles on the same plant and can be modified by phytohormone injections. To verify the presence of apomixis the emasculated plants of AS-Ia subline were crossed with the marker line Volzhskoe-4w (V-4w) homo-zygous for dominant genes *Rs* conditioning purple pigmentation of seedlings. Green maternal plants appeared in three out of five individual crosses, with a frequency from 2.7% to 23.9%. Therefore, the progeny test confirmed that cytologically observed apomictic proembryos indeed develop into apomictic plants.

Another line, Atc-114, was obtained as a result of crossing a male-sterile plant of the line Atc-SK-723 bearing dominant gene Ms_{tc} with the line KVV-114. In the BC1 (Atc-SK-723/KW-'II4//KW-114), there were plants with complete male sterility, which set seeds; stigmas on the ovaries, in which seed development occurred, remained 'fresh' for a long time. Similar male-sterile plants with seed setting were observed in the AN_2 after further backcrossing male-sterile plants from BC1 with the line KVV-114. Cyto-embryological analysis of male-sterile plants from BC2 showed that in four out of five plants, 5 days after flowering, aposporous ESs in 2.5-23.7% of the ovules were observed alongside large uni- and multinuclear cells (12.5-51.4%). After 8 days of flowering in one of these plants, apomictic embryos developing autonomously without pollen tube penetration were observed in aposporous ESs. Analysis of the progeny obtained by pollination of these plants with pollen of the marker line V-4w showed that 5.5-17.8% of the seedlings in different crosses had a green color resembling the maternal line. Thus, the progeny test confirmed the results of cyto-embryological investi-gation, and the frequency of maternal seedlings correlated with the frequency of aposporous ESs.

These data indicate the ability of the line Atc-114 for facultative apomictic reproduction through apospory. Further experiments are planned for increasing the frequency of this trait and the understanding its inheritance pattern. Careful analysis of bagged panicles of male-sterile plants during and after flowering allows isolation of genotypes with genes for apomixes.

Acknowledgment

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Release of Four A/B Sorghum Parental Lines ATx642 through ATx645

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Four sorghum [*Sorghum bicolor* (L). Moench] female parental lines have been evaluated in hybrid combinations over several environments for agronomic and yield traits. These lines were selected for release based on their agronomic desirability and unique combinations of disease resistance and grain quality traits that are of importance to sorghum breeders, and their performance in hybrids. The characteristics and traits found in these lines should be of value to the sorghum breeding industry. Some of these lines may be directly useful as parents, while others may be more useful as breeding stock. All four lines are in the A_1 cytoplasmic male-sterility system. Maintainer lines of all four females lines will also be released.

Proposed names and seed handling

These lines were selected, increased and developed in the sorghum breeding program based at Lubbock, Texas, USA, but with selection and evaluation done statewide. The lines and their hybrids were evaluated in replicated yield and agronomic experimental trials at various locations in Texas and in regional yield trials located in various states. We propose that these lines be released as parental lines. Using the numbering system of the Texas Agricultural Experiment Station Sorghum Improvement Program, these parental lines should be designated as A/BTx642 through A/BTx645. Upon release, the lines will be registered in *Crop Science* and seed of these lines will be deposited at the National Seed Storage Laboratory in Fort Collins, Colorado. Seed will be maintained and distributed by the Texas Agricultural Experiment Station at the Texas A & M University Agricultural Research and Extension Center at Lubbock, Route 3, Box 219, Lubbock, Texas 79403-9757, USA.

Breeding history and methodology

All of these lines were developed from intentional crosses using the pedigree method of plant breeding. The pedigrees for the four parental lines are listed in Table 1. Most of the parents in the pedigrees of these germplasms have been publicly released. Male-sterile (A-line) versions of these B-lines were created via backcrossing with ATx623 as the source of A_1 cytoplasm. Each A-line has 15 or more backcrosses and is identical to its B-line counterpart in all phenotypic traits. The A-lines are 100% male-sterile except that ATx642 will sometimes set scattered seed under hot, drought stressed conditions. All four parental lines are three dwarf lines ($dw_1Dw_2dw_3dw_4$) and have no testa ($b_1b_1B_2B_2$) (Schertz and Stephens 1966). From 1991 to 2000, these lines and their hybrids were included in numerous replicated tests within the state of Texas with some hybrids also included in various national yield trials to determine the merits and weaknesses of each line for as many agronomic traits as possible. Following is a more complete description of each line:

A/BTx642 tested as B35, was originally selected from a BC_1F_2 population from the cooperative Texas A & M University(TAMU), Texas Agricultural Experiment Station (TAES)/United States Department of Agriculture (USDA), Agricultural Research Service (ARS) Sorghum Conver-sion Program at Chillicothe, Texas (Table 1). IS 12555 (SC35) is a photoperiod-sensitive Durra from Ethiopia and is a restorer line in the A_1 cytoplasmic male-sterility system. Selection and evaluation in the F_3 to the F_{10} generation that led to the development of this line were made in one or more of the following locations: Lubbock Texas and Mayaguez (Puerto Rico). In the final generation of selection, 20 individual panicles of the line were self-pollinated and bulked to create the experimental line. Since that time, this line has been maintained by self-pollination. From 1991 to 2000, it has been included in numerous replicated tests as an inbred line and in hybrid combination to determine the merits and weaknesses of the line for as many agronomic traits as possible.

A/BTx643 tested as A/BI (this code does not designate sterility system), was originally selected from a F_2 population at Halfway, Texas (Table 1). Selection and evaluation in the F_3 to the F_{10} generation that led to the development of the line were made in one or more of the following locations; Lubbock (L), Halfway (H), Beeville

Table 1. Designation, evaluation codes, grain and plant descriptor, and pedigrees of the sorghum breeding lines proposed for release

Designation	Evaluation code	Pericarp color[1]	Plant color	Pedigree
A/BTx642	A/B35	LY	P	[(BTx406[2] IS125S5(SC35)$_{F3}$) x IS12555]-6
A/BTx643	A/B1	W	PR	(BTX625[3] B35)-HL19-HL9-B4-Bbk-P3-L3-P3-L2
A/BTx644	A/B803	R	P	(BTx3042[4] (BTx625 x B35))-L3-B3-OG2-OGbk-P2-L3-PI-LI-PI
A/BTx645	A/B807	R	PR	(BTx623 x (BTx625 x B35))-37B-Bbk-BHbk-P3-LI-P2-LI-PI

1. LY = Lemon Yellow; W = White; R = Red; P = Purple; PR = Purplish-red
2. BTx406 is a 4-dwarf Martin derivative
3. BTx625, (BTx3197 x SC170-6), is a later, shorter sister selection *of* BTx623; SC170-6 is a BC_1 selection from the conversion of IS12661, a Zerazera from Ethiopia.
4. BTx3042 is an early Redbine

(B), Corpus Christi (CC) Texas, and Mayaguez and Isabella (P) Puerto Rico. In the final generation of selection, 20 individual panicles were self-pollinated and bulked to create the experimental line. Since that time, this line has been maintained by self-pollination. From 1991 to 1999, it has been included in numerous replicated tests as an inbred line and in hybrid combination to determine the merits and weaknesses of the line for as many agronomic traits as possible.

A/BTx644 tested as A/B803, was originally selected from a F_2 population at Halfway, Texas (Table 1). Selection and evaluation in the F_3 to the F_{10} generation that led to the development of this line were made in one or more of the following locations; Lubbock (L), Beeville (B), Orange Grove (OG), Corpus Christi (CC), College Station (C) and Chillicothe (CV), Texas, and Mayaguez and Isabella (P) Puerto Rico. In the final generation of selection, 20 individual panicles were self-pollinated and bulked to create the experimental line. Since that time, this line has been maintained by self-pollination. From 1992 to 1997, it has been included in numerous replicated tests as an inbred line and in hybrid combination to determine the merits and weaknesses of the line for as many agronomic traits as possible.

A/BTx645 tested as A/B807, was originally selected from a F_2 population at Lubbock, Texas (Table 1). Selection and evaluation in the F_3 to the F_{10} generation that led to the development of this line were made in one or more of the following locations; Lubbock (L), Beeville (B), Berclair (BH), Corpus Christi (CC), Orange Grove (OG) Texas, and Mayaguez and Isabella (P) Puerto Rico. In the final generation of selection, 20 individual panicles were self-pollinated and bulked to create the experimental line. Since that time, this line has been maintained by self-pollination. From 1993 to 2000, it has been included in numerous replicated tests as an inbred line and in hybrid combination to determine the merits and weaknesses of the line for as many agronomic traits as possible.

Line description and performance (in hybrid combinations)

Any gene symbols used in the description of these lines are those recommended by Schertz and Stephens (1966). All of these parental lines are in the A, cytoplasmic genetic male-sterility system (Stephens and Holland, 1954). The A-lines are 100% male-sterile. All four parental lines are three dwarf lines ($dw_1Dw_2dw_3dw_4$) and have no testa ($b_1B_2B_2$). The lines are purple or purple-red plant color, with various pericarp color (Table 1). These lines were developed in the drought resistance breeding program of the Texas Agricultural Experiment Station and posses various combinations of pre and post-flowering drought resistance. These lines should prove useful in the development of drought- and lodging-resistant hybrids for commercial release. None of these lines have a pigmented testa. A brief description explaining why each line is proposed for release follows: A/BTx642, tested as A/B35, is a lemon-yellow pericarp, purple colored plant. The panicle is semi-compact, erect, elliptic, 6-8" in length with a Durra head type. Rachis branches are short, stiff. The grain is nearly round, only slightly pointed and partially covered with hairy glumes. It is slightly later and shorter in height than BTx378 and BTx623. It possesses excellent post-flowering drought tolerance (known as stay-green), charcoal rot [*Macrophomina phaseolina* (Tassi) G Goid.J resistance, and lodging resistance, and produces hybrids with excellent stay-green, charcoal rot resistance, and lodging resistance. In all hybrid combinations tested, the stay-green reaction expresses itself well in the F_1. The line, B35, is the best source of resistance to post-flowering drought (stay-green) and has been used extensively in drought breeding programs around the world, and in molecular genetics research to identify stay-green quantitative trait loci (QTLs). The line and its hybrids possess excellent resistance to several different types of lodging: charcoal rot or drought stress type lodging, weak neck peduncle breakage, and after-freeze stalk breakage. The line is susceptible to pre-flowering drought stress, and is sometimes delayed in flowering under hot, drought stressed conditions. However, many of its hybrids possess a good combination of pre- and post-flowering drought tolerance. in most hybrid combinations with common white- or red-seeded males, it will produce a light red pericarp grain on the hybrid. It is resistant to head smut [*Sporisorium relianun* (Kuhn) Langdon & Fullerton] and head blight [*Fusarium moniliforme* Sheld.], but susceptible to downy mildew [*Peronospora sorghi* (Weston & Uppal) C.G Shaw], anthracnose [*Colletotrichum graminicola* (Ces.) G.W. Wilson], most leaf diseases, and is tolerant to maize dwarf mosaic virus (MDMV). The line expresses a physiological leaf spot reaction near maturity, but does not appear to affect performance. The line combines well with certain pollinators, such as RTx430, but does not perform well with certain other R-lines. Hybrids of ATx642 have produced above-average yields, especially under limited irrigation or dryland, or under late-season drought conditions, but has somewhat reduced yield potential under high yield or fully irrigated conditions (Tables 2-5 and 6).

A/BTx643, tested as A/BI (this code does not designate sterility system), has white, translucent pericarps, and purple-red colored plants. The panicle is semi-loose, long, and rectangular in shape. Rachis branches are moderately long and erect. The grain is slightly oval and slightly turtle-shaped with glabrous glumes. It is slightly later than BTx378 in South Texas, but earlier in West Texas and similar in height to BTx378. It is similar in maturity but shorter than BTx623. Its hybrids tend to be later in relative maturity in South Texas and become earlier in northern areas. It possesses good post-flowering drought tolerance, charcoal rot resistance, and lodging resistance. It also possesses moderate tolerance to pre-flowering drought stress. The stay-green in A1, however, is not as dominant as in ATx642 (A35) and in some combinations is completely recessive. Hybrids will vary in their expression of stay-green from very good, to intermediate, to poor depending on the male parent. It is very susceptible to head smut and leaf blight [*Exserohilum turcicum* (Pass.) Leonard Suggs], and susceptible to anthracnose. It should be used in hybrids only with males with good head smut resistance in areas of high head smut incidence. It is moderately resistant to downy mildew, tolerant to MDMV, and highly resistant to fusarium head blight. The line has excellent sterility (similar to ATx623) and has excellent general combining ability. It has moderate resistance to grain mold/ weathering. The line and its hybrids tend to mature later in South Texas and get progressively earlier in more northern latitudes. Hybrids of AI are shorter, more open-headed and more attractive in appearance than ATx623 hybrids. Depending upon the male parent, hybrids have produced above-average yields, especially under dryland, limited moisture conditions, but also have good yield potential under high yield or fully irrigated conditions (Tables 2-5 and 7).

A/BTx644, tested as A/B803, has a light red (slightly orange tint) somewhat translucent pericarp, and a purple colored plant. The panicle is rectangular to slightly oval and long (20-30 cm), moderately open and somewhat drooping at maturity. The rachis branches are moderately long, not stiff. The grain is nearly round but slightly pointed with glabrous glumes. It is slightly earlier and shorter in height than BTx378 and BTx623. The line and its hybrids tend to be later in South Texas and get progressively earlier in more northern latitudes. It

Table 2. Descriptive plant and grain characteristics of the sorghum breeding lines proposed for release

Line designation	Phenotypic pericarp color	Genetic pericarp color	Mesocarp thickness	Plant color	Glume color	Awns	Midrib	Glume coverage (%)
BTx642	Lemon-yellow, chalky	rrYY	Thick	Purple	Lite-reddish purple	Present	Dry	40
BTx643	White, pearly	RRyy	Thin	Red	Red	Absent	Juicy	30
BTx644	Red, rather pearly	RRYY	Moderately thin	Purple	Purple	Absent	Juicy	35
BTx645	Dark red, pearly	RRYY	Thin	Red	Purple-red	Absent	Juicy	35

Table 3. Agronomic characteristics of BTx642-BTx645[1] sorghum parental lines in various sites throughout Texas

Location/ Destination	Parental line	Days to anthesis	Plant height (cm)	Panicle exertion (cm)	Agronomic desirability rating[2]	LPD rating[3]	Stalk lodging (%)	1000-grain mass (g)
Lubbock	BTx642	71	96.5	12.7	2.2	1.4	0	28.4
	BTx643	65	91.4	2.54	2.0	1.7	5	30.1
	BTx644	58	88.9	10.3	2.5	1.5	7	23.8
	BTx645	62	101.6	7.6	2.2	2.2	13	30.4
	BTx378	70	94.0	7.6	2.8	2.7	20	31.4
	BTx623	64	101.6	5.1	2.6	2.8	50	30.6
Corpus	BTx642	80	96.5	15.2	2.9	2.6	0	-
Christi	BTx643	78	96.5	5.1	1.9	2.6	0	-
	BTx644	78	91.4	12.7	1.9	2.7	2	-
	BTx645	77	96.5	10.3	2.1	3.3	10	-
	BTx378	75	99.1	12.7	2.4	3.2	15	-
	BTx623	78	106.7	7.6	2.1	3.5	20	-

1. BTx642 = B35; BTx643 = B1; BTx644 = B803; BTx645 = B807
2. 1-5 Very good to very poor
3. LPD = Leaf and plant death rating: 1 = all green, 3 = 50% of leaf area dead, 5 - entire plant dead

Table 4. Disease and other ratings[1] of BTx642-645 sorghum parental lines in various sites throughout Texas[2]

Designation	Head smut (%)	Downy mildew (%)	Anthrac-nose rating	Fusarium head blight rating	Chemical/ insecticide burn rating	Pre-flowering drought rating[3]	Post-flowering drought rating
BTx642	0	10	4.8	1.0	3.5	4.0	2.6
BTx643	30	0	4.0	1.0	1.0	2.5	2.6
BTx644	5	0	3.0	2.5	1.0	3.1	2.7
BTx645	10	0	4.0	3.0	1.0	2.1	3.3
BTx378	3	2	1.0	3.5	3.0	2.7	3.4
BTx623	30	0	5.0	2.5	1.0	3.3	3.5

1. Disease and burn ratings 1 = resistant through 5 = death
2. All ratings were taken at Corpus Christi except anthracnose (College Station) and fusarium head blight (Lubbock)
3. Drought rating 1 = very good through 5 = very poor

possesses excellent pre-flowering drought tolerance and a slight degree of stay-green with some lodging resistance. In most hybrid combinations, it will produce a light red pericarp grain. It is moderately resistant to head smut, and downy mildew, and most leaf diseases, and is tolerant to MDMV. The grain is rounder in shape and slightly smaller than grain of BTx643 and BTx645. The line combines well with many pollinators. Hybrids of ATx645 have produced above-average yields under dryland conditions, but generally yield slightly less than ATx643 and ATx645 hybrids under higher yield potential conditions (Tables 2-5 and 8).

A/BTx645, tested as A/B807, has a dark red, translucent pericarp, and a purple-red colored plant. The panicle is rectangular to slightly oval and long (25-33 cm) and semi-loose. The rachis branches are moderately long, erect, and not stiff. Glumes are slightly pointed and slightly hairy. The grain is moderately large, somewhat oval and pointed, and threshes easily and cleanly from the glumes. It is slightly earlier and shorter in height than A/BTx378 and BTx623. The line and its hybrids tend to be later in South Texas and get progressively earlier in more northern latitudes. The dark red grain has a moderately high level of grain mold/weathering resistances that transfers well into the F_1 hybrids, resulting in attractive appearance and high test-weight grain. The panicle is moderately loose as are its hybrids. The line and its hybrids possess excellent pre-flowering drought

Table 5. Agronomic performance of various hybrids of ATx642 (A35), ATx643(AI), ATx644 (A803), and ATx645 (A807) hybrids from Lubbock and Halfway

Hybrid/Pedigree	LPD[1] rating (1993)	LPD[1] rating (1994)	Lodging[2] (%) (1994)
A35 x Tx430	2.6	2.7	2
AI xTx430	3.8	3.9	31
A35 x Tx436	*2.6*	2.7	1
AI xTx436	3.5	4.1	7
A35 x BE2668	2.6	2.7	4
A! x BE2668	3.3	4.0	22
A803 x BE2668	-	3.1	6
A807 x BE2668	-	4.1	26
A35 x 86EON36	2.9	2.9	3
AI x 86EON361	4.0	4.5	68
A35 x P37-3	3.2	2.5	3
AI X P37-3	4.3	4.7	62
A35 x 89CC443	-	-	-
ATx399 x Tx430 (check)	-	4.2	41
ATx2752 x Tx430 (check)	-	4.0	27
ATx378 x Tx430 (check)	-	4.3	55
DK 46 (check)	-	3.2	8

1. Leaf and plant death rating: 1 = all green; 3 = 50% of leaf area dead; 5 = entire plant dead. Ratings are mean of Lubbock and Halfway
2. Primarily drought stress type lodging, Lubbock

Table 6. Performance (% of checks) of hybrids using A35 (ATx642) as the female relative to the performance of 3 common checks[-1] and the overall test mean where the experimental hybrids and the checks were evaluated in the same environment

		Yield (%) of ATx642 hybrids relative to			
Location	Year	ATx399 x RTx430	ATx378 x RTx430	ATx2752 x RTx430	Test mean
Gregory	1994	88.9	79.8	79.4	90.0
Thrall	1993	102.8	108.0	108.6	110.0
Granger	1997	99.7	81.0	89.5	101.0
	1998	86.4	77.2	92.3	97.1
	1999	105.9	86.6	101.2	106.0
	2000	106.8	94.1	97.1	103.9
Prosper	1998	79.1	87.6	118.6	100.7
	2000	102.2	101.0	106.1	108.9
Lubbock	1993	111.7	100.4	92.7	112.7
	1994	118.3	108.7	118.5	123.7
	1997	112.8	122.0	109.0	97.0
	1998	105.0	95.5	91.1	113.1
	1999	78.9	63.8	72.2	66.4
Halfway Dryland	1994	152.7			
Halfway	1997	152.3	166.6	159.5	136.9
	1998	114.5	106.7	101.0	112.2
	1999	101.1	109.2	109.7	128.4
	2000	95.4	89.9	90.3	99.2
Dumas	2000	155.4	156.4	142.4	135.2
Mean		108.9	101.9	1044	107.9

1. Common checks ATx399 x RTx430, ATx378 X RTx430, ATx2752 x RTx430

Table 7. Performance (% of checks) of hybrids using A1 (ATx643) as the female relative to the performance of 3 common checks[1] and the overall test mean where the experimental hybrids and the checks were evaluated in the same environment

		Yield (%) of ATx643 hybrids relative to			
Location	Year	ATx399 x RTx430	ATx378 x RTx430	ATx2752 x RTx430	Test mean
Weslaco	1993	103.0	108.3	102.8	104.2
	1994	102.2	90.0	99.7	99.3
	1997	109.7	88.6	98.3	101.3
Gregory	1993	113.3	94.6	96.7	104.5
	1997	114.7	85.2	94.4	99.8
Thrall	1993	103.0	108.2	108.8	109.8
Castroville	1994	111.4	99.2	102.7	106.9
	1997	103.3	85.7	95.3	93.7
College	1994	123.7	102.8	104.7	122.0
Station	1998	108.8	103.8	96.9	106.6
	1999	113.4	99.9	98.2	99.1
McKinney	1993	126.2	129.2	113.0	104.1
	1994	90.8	92.4	109.5	98.9
Granger	1997	106.1	86.1	95.3	107.0
Prosper	1997	66.5	58.6	59.2	74.9
Lubbock	1993	81.2	73.0	67.4	81.9
	1994	75.1	69.0	75.3	78.5
	1997	101.1	109.3	97.6	86.9
	1999	95.6	77.3	87.6	80.4
Halfway	1994	97.6		85.0	92.2
	1997	122.7	134.2	128.5	110.3
	1998	107.0	99.7	94.4	104.8
	1999	68.0	73.4	73.7	86.3
Dumas	1993	87.9	80.7	79.4	85.6
Mean		101.3	93.4	94.4	97.5

1. Common checks ATx399 X RTx430, ATx378 X RTx430, ATx2752 X RTx430

Table 8. Performance (% of checks) of hybrids using A803 (ATx644) as the female relative to the performance of 3 common checks[1] and the overall test mean where the experimental hybrids and the checks were evaluated in the same environment

		Yield (%) of ATx644 hybrids relative to			
Location	Year	ATx399 x RTx430	ATx378 x RTx430	ATx2752 x RTx430	Test mean
Gregory	1993	90.0	75.2	76.0	83.1
	1997	117.1	87.0	96.4	101.9
Danenang	1993	94.9	88.7	86.2	88.4
McKinney	1993	137.2	140.6	122.9	113.3
	1994	84.6	86.1	102.0	92.1
College Station	1994	96.0	79.8	82.3	94.7
Lubbock	1997	111.2	120.2	107.4	95.6
Mean		104.4	96.8	96.2	95.6

1. Common checks ATx399 X RTx430, ATx378 X RTx430, ATx2752 X RTx430

Table 9 Performance (% of checks) of hybrids using A807 (ATx645) as the female relative to the performance of 3 common checks' and the overall test mean where the experimental hybrids and the checks were evaluated in the same environment

		Yield (%) of ATx645 hybnds relative to			
Location	Year	ATX399 x RTx430	ATx378 x RTx430	ATx2752 x RTx430	Test mean
Weslaco	1993	100 1	106 2	100 7	102 1
	1997	1182	95 5	105 9	109 1
	1998	108 1	85 0	95 4	98 0
	1999	103 2	103 3	103 4	104 8
Gregory	1995	1142	95 4	96 5	105 4
	1997	121 2	90 0	99 8	105 5
	1999	107 0	98 4	95 6	105 2
	2000	111 2	100 2	103 9	99 7
Thrall	1993	97 2	102 1	102 6	103 6
Granger	1997	1106	89 8	99 3	111 5
	1998	91 8	90 8	98 0	103 1
	1999	109 6	90 5	104 8	109 5
McKmney	1993	129 3	132 5	1158	106 7
Prosper	1997	68 9	60 7	61 4	77 6
	1998	79 0	87 5	1184	100 5
	1999	103 3	90 5	97 5	109 0
Lubbock	1993	70 3	63 2	58 4	70 9
	1997	916	99 0	88 5	78 8
	1998	95 2	86 6	82 6	102 6
Halfway	1993	105 5		95 1	105 3
	1997	1197	131 0	125 4	107 6
	1998	107 3	100 0	94 7	105 1
	1999	87 1	94 1	94 5	1106
Dumas	1997	108 9	94 2	99 3	102 4
	1998	98 8	92 5	868	101 7
	1999	97 6	88 8	91 3	102 6
Mean		102 1	94 7	96 6	101 5

1 Common checks AIx399 X RTx4W ATx378 X RTx430 ATx2752 X RTx430

tolerance, but with no stay-green, but does possess moderate lodging resistance. It is very susceptible to head smut, moderately resistant to downy mildew, tolerant to MDMV, and moderately resistant to leaf diseases. The line has excellent general combining ability. Hybrids of ATx645 have produced above average yields under a wide range of conditions (Tables 2-5 and 9).

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Genetic Diversity Studies in Sorghum

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Introduction

In any crop improvement program, genetic diversity is an essential prerequisite for hybridization. Diverse parents are expected to yield hybrids that exhibit more heterotic expression in addition to generating a broad spectrum of variability in segregating generations. The D^2 statistic is a useful multivariate statistical tool for effective discrimination among various genotypes on the basis of genetic diversity (Murthy and Arunachalam 1966; Sonawane and Patil 1991). An attempt has been made in the present study to assess the nature and magnitude of genetic divergence for yield and its components in available exotic sorghum *[Sorghum bicolor* (L.) Moench.] germplasm and derivatives at the National Research Centre for Sorghum (NRCS), Rajendranagar.

Materials and methods

Eighteen exotic collections and 30 established genotypes from the Indian National Programme that have different geographical origins (Table 1) and represent a spectrum of variation were grown at NRCS during the rainy season 2001 in a randomized-block design with three replications. Each entry had two rows each 4-m long with 45 cm row-to-row spacing and 15 cm plant-to-plant spacing. Five randomly selected plants from each genotype were used to record observations on time to 50% flowering (d), plant height, panicle length, number of primaries panicle^{-1}, seeds branch^{-1}, and grain yield. The data was subjected to statistical analysis. Wilk's criterion was used to test the significance of pooled differences in mean values for all the six characters. Genetic diversity was studied using Mahalanobis D^2 and clustering of genotypes was done according to Tocher's method as per Rao (1952).

Results and discussion

The analysis of variance showed highly significant differences among genotypes for all the characters studied indicating the existence of considerable amount of variability in the experimental material. Plant height contributed enormously (60%) to the total variation followed by panicle length (12%) and time to 50% flowering (11%). Multivariate analysis based on Mahalanobis D^2 statistics grouped the genotypes into five clusters (Table 1).

Cluster I was the largest and consisted of 30 genotypes followed by clusters II (10 genotypes), III (4 genotypes), and IV (3 genotypes). Cluster V had only 1 genotype. The intra- and inter-cluster D^2 values among 48 genotypes (Table 2) revealed that cluster III recorded the minimum intra-cluster value (3.42) indicating that the cultivars within this cluster were similar. On the other hand, cluster I showed a maximum intra-cluster value (5.47) followed by cluster 1 (5.05) indicating the existence of diverse cultivars in these clusters.

Inter-cluster differences were maximum between cluster III and cluster V (26.25), followed by clusters 1 and V (21.10), and clusters III and IV (18.33), indicating that the genotypes included in different clusters could give high heterotic responses and better segregants after hybridiza-tion. It was gratifying to note that cluster III included temperate germplasm from USA while cluster IV included tropical germplasm from Sudan. Cluster V included only one genotype, an Indian local. Apart from clusters III, IV, and V, clusters I and II did not necessarily follow geographic distribution.

The cluster means estimated over the genotypes for the 6 characters presented in Table 3 reveal considerable inter-cluster variation. Cluster II showed maximum grain yield plant^{-1} and included most of the promising varieties from the Indian National Programme. Cluster III recorded least plant height and also exhibited the maximum number of primaries panicle^{-1} and number of seeds branch^{-1}. Clusters IV and V showed high means for plant height and low means for primaries panicle ', and seeds branch^{-1}. The genotypes included in these two clusters appear to be photoperiod-sensitive.

The clustering pattern observed in the present study reveals that genetic diversity was not necessarily parallel to geographic diversity. Genotypes evolved in the same area were grouped into different clusters. Similar results were reported by Narkhede et al. (2000), Gurpreet Singh et al. (2001), and Kadam et al. (2001). Maximum heterosis is expected from crosses with parents belonging to the most divergent clusters. In the present study, the maximum distance was found between clusters—III and V; I and V; 111 and IV -and hence the crosses involving parents from these clusters are expected to exhibit high heterosis and maximum transgressive segregants.

Table 1. Distribution of 48 sorghum genotypes in five clusters based on multivariate analysis

Cluster	Number of genotypes included	Genotype	Pedigree	Origin (source)
I	30	CSH 17	(AKMS 14A x RS 673)	NRCS (AICSIP)[1]
		SPH 1183	(AKMS 14A x R 301-2)	Akola (AICSIP)
		SPV 1526	(SPV 233 x SPV 1072)	Udaipur (AICSIP)
		RS 673	[(CS 3541 x CO 18) x (CO 27 x 1022)] x K 24-1	NRCS (AICSIP)
		RS 29	SC 108 x Tall mutant of CS 3541 (SPV 126)	NRCS (AICSIP)
		CSH 14	(AKMS 14A x R 150)	Akola (AICSIP)
		CSH 9	(296A x CS 3541)	NRCS (AICSIP)
		CSV 13	(IS 12622 x 555) x IS 3612 x 2219B x M35-1-5-2	1CRISAT
		1-12	(SSV53 x SPV 475)-7-1-1-1	Indore (AICSIP)
		CSH 16	(27 A x C 43)	NRCS (AICSIP)
		IMS 9B	(MA 9B x Vidisha 60-1)-11-4-2-5-5	Indore (AICSIP)
		CSV 15	(SPV 475 x SPV 462)	NRCS (AICSIP)
		SPH 1249	(NSH 2123)	Nuziveedu seeds, India
		AKMS 14B	(MR 760 x BT 623) x AKMS 2B	Akola (AICSIP)
		SPV 96	(148 x 512)	Udaipur (AICSIP)
		CS 3541	IS 3675 x IS 3541	NRCS (AICSIP)
		SPV 1489	(SPV 946 x SPV 772)	Udaipur (AICSIP)
		AKR 150	(CS 3541 x 900)	Akola (AICSIP)
		C-43	(CS 3541 x IS 23549)	NRCS (AICSIP)
		27 B	(83 B x 199 B)	NRCS (AICSIP)
		IS 14388	-	Swaziland (ICRISAT)
		EC 452937	-	USA
		EC 452918	-	USA
		EC 453011	-	USA
		EC 453037	-	USA
		EC 451043	-	USA
		EC 452936	-	USA
		EC452398	-	USA
		EC 451086	-	USA
		296 B	(IS 3922 x Karad local)	NRCS (AICSIP)
II	10	SPV 1474	(Sel. from PVK 801 x SPV 881)	Parbhani (AICSIP)
		SPV 1517	(SPV 462 x SPV 526)	NRCS (AICSIP)
		SPV 1532	(SPGM 14059 x SR 424)	Surat (AICSIP)
		SPV 1513	(Sel. from CSV 15 x GD 10833)	Palem (AICSIP)
		SPV 1514	(Sel. from SPV 462 x IS 7369)	Palem (AICSIP)
		SPV 1518	(Sel. from CSV 15 x IS 22149)	Palem (AICSIP)
		CSH 13	(296 A x RS 29)	NRCS (AICSIP)
		CSH 18	(IMS 9A x Indore 12)	Indore (AICSIP)
		IS 3160	-	South Africa (ICRISAT)
		IS 4694	_	India (ICRISAT)
III	4	EC 450991	-	USA
		EC 451045	-	USA
		EC 450995	-	USA
		EC 451039	-	USA
IV	3	IS 25010	-	Sudan (ICRISAT)
		IS 24982	-	Sudan (ICRISAT)
		IS 3512		Sudan (ICRISAT)
V	1	Y-75	Indian *kharif local*	Andhra Pradesh, India

1. AICSIP = All India Coordinated Sorghum Improvement Project

Table 2. Average intra- (along diagonal) and inter-cluster D^2 estimates in sorghum

Cluster	I	II	III	IV	V
I	5.05	7.50	7.27	13.49	21.10
II		4.50	11.87	8.58	15.56
III			3.42	18.33	26.25
IV				5.47	8.96
V					0.00

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Table 3. Cluster means for different characters in sorghum

Cluster	Time to 50% flowering (d)	Plant height (cm)	Panicle length (cm)	Primaries panicle^{-1}	Seeds branch^{-1}	Seed yield plant^{-1} (g)
I	70.0	138.8	28.0	50.7	50.8	28.9
II	75.2	195.0	26.5	56.1	53.5	34.0
III	71.8	81.0	24.1	61.0	55.0	28.9
IV	72.1	254.2	20.0	49.5	25.7	21.0
V	77.0	326.0	20.0	41.0	14.0	31.3

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Combining Ability Studies for Grain Yield and its Components in Postrainy-season Sorghum Grown in Medium-deep and Shallow Soils

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Introduction

Postrainy-season (*rabi*) sorghums [*Sorghum bicolor* (L.) Moench] are unique to India, where they are grown under residual and receding soil moisture situations primarily in the states of Maharashtra, Karnataka, and Andhra Pradesh. Since there is no remunerative cereal alternative to sorghum, such crops are crucial for food and fodder security in drought-prone areas of these states that receive only 8% of the annual rainfall during the postrainy season. Because the crop is grown over large areas in medium (45-90 cm) and shallow (45 cm) soils where drought occurs much faster than in deep soils (> 90 cm), sorghum productivity is very low (611 kg ha^{-1}). Efforts made at various sorghum-breeding centers to develop hybrids adapted to the postrainy season, have not been very fruitful. So, much of the sorghum area is still under traditional local sorghum cultivars. To elevate the productivity levels of postrainy-season sorghum, there is an urgent need to develop hybrids adapted to the shallow and medium soils that cover 70% of the total sorghum area cultivated in this season (Bapat and Gujar 1990). The present study was planned to identify parents (both CMS lines and restorers) and their hybrids that are suitable for cultivation in the postrainy season.

Materials and methods

Three CMS lines; 53A, 104A, and 116A were crossed with 12 restorers SPV 504, SPV 783, SPV 839, SPV 913,

Table 1. Analysis of variance (for combining ability) for grain yield and component characters in postrainy-season sorghum grown in medium-deep (M) and shallow (S) soils, MPKV, Rahuri, India, postrainy season 1995

Source	d.f.	Soil	Time to 50% flowering (days)	Time to maturity (days)	Plant height (cm)	Leaves plant^{-1}	Leaf area plant^{-1} (cm^2)	Panicle length (cm)	Panicle breadth (cm)	Panicle mass (g)	Seeds plant^{-1}	1000-grain mass (g)	Grain yield plant^{-1}
Replication	2	M	0.84	0.63	0.75	0.08	90.00	0.62	0.04	1.41	3696.00	0.31	0.36
	2	S	0.83	0.25	1.25	0.05	200.00	1.35	0.09	1.03	240.00	0.23	0.46
Female	2	M	24.28**[2]	29.31**	1019.25**	2.26*[1]	54560.00*	7.05*	2.40**	495.95*	1286584.00**	164.3**	459.67*
	2	S	18.78**	20.06**	1072.25**	1.49*	32632.00*	4.95*	4.25**	124.68**	286792.00**	50.60*	101.35*
Male	11	M	148.78**	210.38**	1128.64**	2.08**	134350.60**	10.07**	0.87**	273.06**	239111.30**	55.34**	252.61**
	11	S	109.84**	162.99**	1275.68**	1.44**	60496.00**	8.64**	0.64**	104.04**	167216.00**	38.34**	91.24**
Female ×	22	M	8.2**	1.98**	151.77**	0.68**	12151.27**	1.96**	0.17**	102.16**	99942.55**	21.05**	96.93**
Male	22	S	0.99**	1.35**	239.25**	0.45**	5551.27**	1.35**	0.12**	19.01**	36069.82**	11.37**	18.24**
Error	70	M	0.41	0.74	4.56	0.06	47.54	0.57	0.04	0.88	128.00	0.07	0.46
	70	S	0.52	0.59	5.97	0.05	238.97	0.46	0.02	0.37	60.11	0.24	0.80
σ^2 gca		M	3.81	5.24	40.98	0.07	3657.96	0.29	0.06	12.55	29462.45	3.25	11.52
		S	2.81	4.01	41.54	0.04	1822.79	0.24	0.10	4.24	8485.96	1.47	3.47
s^2 sca		M	0.14	0.41	49.07	0.21	4034.58	0.46	0.35	33.76	33271.53	6.99	32.16
		S	0.16	0.25	77.76	0.13	1770.76	0.29	0.03	6.21	1203.25	3.71	5.81
σ^2 gca/s^2 sca		M	27.21	12.78	0.83	0.33	0.91	0.63	0.17	0.37	0.88	0.56	0.35
		S	17.56	16.04	0.53	0.31	1.02	0.82	3.33	0.68	7.05	0.39	0.59
H^2(ns)		M	93.30	90.08	60.45	33.08	64.18	36.21	24.80	42.01	63.82	52.77	41.40
		S	89.26	90.47	49.80	33.63	64.46	39.01	79.46	56.27	58.45	42.68	51.97
$2\sigma^2$ gca /		M	0.98	0.96	0.62	0.40	0.64	0.41	0.25	0.42	0.64	0.53	0.18
$2\sigma^2$ gca + σ^2 sca		S	0.97	0.97	0.52	0.38	0.67	0.62	0.87	0.57	0.93	0.44	0.54

1. * = significant at 5%
2. ** = significant at 1%

Table 2. Estimates of general combining ability (gca) effects of male and female parents for grain yield and its component characters in postrainy-season sorghum grown in medium-deep (M) and shallow (S) soils, MPKV, Rahuri, India, postrainy season 1995

Source	Soil	Time to 50% flowering (days)	Time to maturity (days)	Plant height (cm)	Leaves plant^{-1} (cm^2)	Leaf area plant^{-1} (cm)	Panicle length (cm)	Panicle breadth (g)	Panicle mass (g)	Seeds panicle^{-1}	1000–seed mass (g)	Seed yield plant^{-1}
53A	M	–0.85**[2]	–0.88**	–6.09**	–0.26**	6.70**	–0.41**	0.03	–0.64**	–63.54**	1.13**	–0.41**
	S	–0.44**	–0.86**	–6.12**	0.18**	–29.83**	–0.31**	0.02	–0.25*	–20.42**	–0.16	–0.65**
104A	M	0.06	–0.05	2.32**	0.02	41.84**	0.48**	–0.27**	–3.35**	–149.09**	1.33**	–3.35**
	S	–0.39**	0.39**	1.76**	–0.02	–0.53	0.40**	–0.35**	1.72**	–77.28**	1.25**	–1.26**
116A	M	0.79**	0.93**	3.77**	0.24**	35.13**	–0.08	0.24**	3.99**	212.63**	2.46**	3.76**
	S	0.83**	0.47**	4.36**	0.20**	30.36**	–0.09*	0.33**	1.97**	97.69**	–1.09*	1.91**
SE±	M	0.11	0.14	0.35	0.04	1.15	0.12	0.03	0.16	1.18	0.04	0.11
	S	0.12	0.13	0.41	0.04	2.57	0.11	0.02	0.10	1.29	0.08	0.15
SPV 504	M	1.54**	3.37**	–13.41**	–0.16*	80.41**	–0.52	0.28**	2.88**	32.76**	1.08*	0.71**
	S	1.75**	3.56**	–6.71**	–0.48**	50.84**	0.04	0.08	–3.12**	–120.36**	2.26**	–1.51**
SPV 783	M	2.54**	2.26**	–17.19**	0.15	–41.46**	0.03**	–0.42**	–10.25**	279.09**	1.33**	–9.56**
	S	2.19**	1.22**	–13.45**	–0.65**	–3.68	–0.04	0.24**	–6.16**	–155.14**	–0.65**	–5.68**
SPV 839	M	–0.46*[1]	0.48	11.35**	–0.25**	–73.37**	0.78**	0.06	–3.89**	173.69**	–3.99**	0.02
	S	0.19	1.22**	14.77**	0.63**	–151.39**	0.28	0.29**	–2.14**	–15.25**	–0.90**	1.36**
SPV 913	M	–8.68**	–10.19**	–3.60	–0.72**	162.41**	–1.50**	–0.08	1.66**	–32.54**	1.82**	1.80**
	S	–7.47**	9.66**	–2.31	–0.10	11.23*	1.67**	0.12*	–3.14**	–136.03**	1.14**	3.08**
SPV 932	M	1.20**	–0.63*	–2.43**	0.30**	–16.68**	0.74**	0.51**	10.26**	286.02**	–0.33**	9.82**
	S	0.97**	0.55*	4.02**	0.06	–72.86**	1.57**	0.37**	3.61**	167.19**	–1.63**	3.48**
SPV 1090	M	2.54**	2.93**	6.99**	0.97**	82.39**	–0.10	0.25**	7.06**	132.69**	0.92**	5.38**
	S	2.08**	2.78**	9.04**	0.30**	43.54**	0.20	–0.04	3.70**	83.42**	1.08**	4.82**
SPV 1102	M	1.65**	1.59**	–0.10	–0.05	–278.67**	0.19	–0.19**	–1.14**	141.35**	–1.24**	3.56**
	S	1.64**	1.56**	–2.30**	0.12	–129.82**	–0.33	–0.30**	–0.92**	47.69**	0.16	–1.40**
SPV 1155	M	3.43**	4.82**	–1.59*	0.24**	109.82**	–0.38	–0.16*	1.75**	–154.54**	3.60**	–0.76**
	S	2.42**	3.77**	–6.54**	–0.10	29.92**	0.39	0.24**	1.10**	–155.47**	3.41**	–1.42**
SPV 1159	M	1.43**	3.15**	9.90**	0.57**	–52.17**	–2.09**	0.47**	–0.59	–3.87	0.91**	–1.47**
	S	1.41**	3.11**	15.26**	0.19	105.33**	–1.84**	0.47**	1.56**	–13.81	1.16**	–1.62**
SPV 1172	M	1.09**	0.93**	–17.39**	–0.43**	–110.79**	0.73**	–0.18**	–5.65**	–54.87**	–4.87**	–8.16**
	S	0.97**	0.53*	–18.95**	–0.32**	100.68**	–0.40	–0.13*	5.50**	258.75**	3.28**	3.82**
SPV 1173	M	1.98**	0.82**	14.57**	–0.05	30.75**	–0.49	–0.18**	1.04**	1.24	0.29*	0.99**
	S	1.08**	0.11	–9.55**	–0.26	39.52**	–0.53*	–0.31**	–1.29**	136.30**	–2.61**	1.27**
Sel 3	M	–8.24**	–9.52**	9.59**	–0.56**	107.38**	–1.48**	–0.35**	–3.11**	–159.32**	2.31**	–2.33**
	S	–7.25**	7.44**	16.73**	0.61**	23.30**	–1.04**	0.01	1.30**	–1.92**	2.19**	2.69**
SE ±	M	0.21	0.28	0.71	0.08	2.30	0.25	0.06	0.31	3.77	0.08	0.23
	S	0.24	0.25	0.81	0.08	5.15	0.22	0.05	0.20	2.58	0.16	0.30

1. Significant at 5%
2. Significant at 1%

SPV 932, SPV 1090, SPV 1102, SPV 1155, SPV 1159, SPV 1172, SPV 1173 and Sel 3 in a line x tester mating design to produce 36 F_1 hybrids. All the 36 F_1s, and their parents were sown in two soils; medium (45-90 cm) deep and shallow (< 45 cm) deep at the Postgraduate Farm, Department of Botany, Mahatma Phule Krishi Vidyapeeeth (MPKV), Rahuri, with three replications during the postrainy season 1995. The entries were sown in 4-row 11.01m^2 plots replication^{-1} at 45 x 15 cm spacing. Observations were recorded on 10 random plants for; time to 50% flowering (days), time to maturity (days), plant height (cm), leaves plant^{-1}, leaf area (cm^2), panicle length (cm), panicle breadth (cm), panicle mass (g), seeds panicle^{-1}, 1000-grain mass (g), and grain yield plant^{-1} (g). Data was subjected to statistical analysis (Kempthorne 1957; Arunachalam 1974).

Results and discussion

The analysis of variance for combining ability (Table 1) revealed significant differences among females, males, and females x males for all traits. The magnitude of expression was higher in medium-deep soils than in shallow soils. Time to 50% flowering and maturity were governed by additive gene action (Senthil and Palanisamy 1994) in both medium-deep and shallow soils. Non-additive gene action was observed for grain yield, 1000-grain mass, leaves plant^{-1} (Yang 1991), plant height, panicle length, and panicle mass (Patil and Thombre 1986) in plants grown at both soil depths. Leaf area, panicle breadth, and grain yield plant^{-1} showed non-additive gene action in medium-deep soil, and additive gene action in shallow soil (Dabolkar and Baghel 1980).

The general combining ability (gca) effects of female parents (Table 2) were consistent for most of characters in medium-deep and shallow soils. The male-sterile line 116A had the best gca, not only for grain yield in both soils, but also for such component traits as panicle breadth, panicle mass, and seeds panicle^{-1}. However, 116A does not produce progeny with desirable grain size. CMS 53A and 104A had negatively significant gca effects, in both soils. Among males, SPV932, SPV 1090, and SPV 1173 were the best gca for seed yield and most yield-contributing characters in both soils.

CMS 53A and restorer SPV 913 and Sel 3 had good gca in both soils for times to 50% flowering and maturity, but poor gca for seed yield. SPV 932 had good gca for panicle length, breadth, mass, number of seeds, and grain yield in both soils. SPV 1090 was one of the best gca for grain yield, and apart from yield, it exhibited significant desirable gca effects for six characters: plant height, leaves plant^{-1}, leaf area plant^{-1}, panicle mass, seeds panicle^{-1}, and 1000-grain mass in both soils. The parent SPV 1155 was a good combiner for panicle mass and 1000-grain mass, but, was a poor combiner for yield in both soils. Sel 3 was a good general combiner in shallow soil, but poor combiner in medium-deep soil for grain yield, but for 1000-grain mass it is a good combiner on both soils. In shallow soil, SPV 1172 showed gca for five traits (leaf area, panicle mass, seeds panicle^{-1}, 1000-grain mass, and grain yield). This suggests that parents with desirable gca for grain yield also had desirable gca for a number of yield-component traits. Such parents may therefore be useful in hybridization programs.

Specific combining ability (sea) effects indicated heterotic effects of crosses in two soils. The cross combinations; 116A x SPV 1090, 104A x SPV 932, 104A x SPV 1172, and 53A x Sel 3 recorded high and significant sea effects for grain yield in medium-deep soils. On the contrary, cross combinations; 104A x SPV 1173, 53A x SPV 1090, 53A x SPV 1102, and 104A x Sel 3 had high and significant sea effects for grain yield in shallow soils.

Cross combinations 104A x SPV 932, 53A x SPV 1090, 104A x SPV 1173, and 116A x SPV 839 had desirable and significant sea effects for grain yield in both soils. These cross combinations involved high, average, and poor general combiners.

Measurement of sca revealed a non-additive gene action for the inheritance of yield-contributing characters (panicle breadth, panicle mass, and grain yield in medium-deep soil, and 1000-grain mass in shallow soil) indicating that hybrids with high manifestation of vigor could be produced. Further, identified parents with gca could be gainfully used in breeding programs to improve grain yield in postrainy-season sorghum grown in both medium-deep and shallow soils.

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Genetic Architecture of Yield and its Contributing Characters in Postrainy-Season Sorghum

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Introduction

Knowledge of the genetic behavior of various characters is important in the selection of superior parents for hybridization is a successful breeding program. The present study was undertaken to assess the combining ability of different genotypes for seed yield and its components in postrainy-season sorghum [*Sorghum bicolor* (L.) Moench] using line x tester analysis with the objectives of studying gene action governing yield and its contributing characters, and of identifying good parents from a set of established varieties, local germplasm, and derived lines.

Materials and methods

The experimental material consisted of 32 hybrids of postrainy-season sorghum that resulted from crossing between eight lines: RSLG 227, RSLG 241, RSLG 262, RSLG 383, RSP 1, RSP 3, (IS23399XNR1349)-2-2-4-I and E36-1, and four testers: CSV 8R, CSV 14R, CSV 216R and SPV 1155. All the 44 entries (32 F_1s and 12 parents) were grown in a randomized-block design with two replications during the postrainy season of 2001/2. Each plot consisted of two 4-m long rows with 60 cm interrow and 15 cm intrarow spacing. Observations for 8 characters were recorded on five randomly selected plants of each genotype in each replication. Combining ability was analyzed according to Kempthorne (1957). Based on general combining ability (gca) effects, the parents were categorized into high (positive and significant), average (positive and non-significant), and poor (negative) combiners.

Results and discussion

Analysis of variance for combining ability (Table 1) revealed that mean squares due to testers were significant for plant height and panicle length, while the mean squares due to line x tester interaction were significant for all the characters studied, except days to 50% flowering, indicating that the variation in hybrids in terms of the characters studied is likely to be largely influenced by the interaction. In general, the mean squares due to testers were larger for most of the important yield attributes than those for lines, indicating greater diversity amongst the testers than among the lines.

The estimates of variances indicated the specific combining ability (sca) variances to be higher than the gca variances for all the characters studied. This shows the predominance of non-additive gene action in the inheritance of these characters. Similar to the present findings, the importance of non-additive gene effects for grain yield and other attributes in sorghum have also been observed by Hovny et al. (2000), and Badhe and Patil (1997). Kadam et al. (2000) reported sca variance to be higher than gca variance for plant height which is in

Table 1. Analysis of variance for combining ability in postrainy-season sorghum

Source	d.f.	Time to 50% flowering	Plant height (cm)	Panicle mass (g)	Panicle length (cm)	Primaries panicle^{-1}	Seeds branch^{-1}	100-grain mass (g)	Seed yield (g)
Lines	7	15.88	1243.24	610.34	4.16	223.60	156.92	0.54	711.09
Testers	3	5.89	4212.27*[1]	623.52	19.35*	137.62	348.79	0.56	782.52
Lines x testers	21	16.57	1340.5**	787.4**	5.69*	167.02**	389.7**	0.27*	532.6**
Error	31	10.86	231.36	267.93	2.63	61.90	68.53	0.15	151.50
σ^2 gca		-0.03	7.63	-1.66	0.03	0.30	-1.68	0.002	1.92
σ^2 sca		2.85	554.55	259.72	1.53	52.56	160.61	0.06	190.54
σ^2 gca/σ^2 sca	-0.01	0.013	-0.006	0.019	0.005	-0.01	0.042	0.01	

1. * = significant at 5%, ** = significant at 1% levels of probability

accordance with the present study. Similarly, Pillai et al. (1995) reported non-additive gene action to be governing various panicle characters, while Subba Rao and Aruna (1997) observed the predominance of dominant gene effects for panicle mass and seed mass. Additive gene action was found important by Hugar et al. (1986) for days to 50% flowering, number of primary branches panicle^{-1}, and 100-grain mass.

Among the lines, RSLG241 was the best general combiner for grain yield and 100-grain mass, while (IS23399XNR1349)-2-2-4-l was the good general combiner for number of primaries panicle^{-1}, followed by RSP 1 (Table 2). RSP 3 was a good combiner for number of seeds branch^{-1} while RSLG 262 was the best combiner for panicle mass. In terms of panicle length, E36-1 was a good general combiner.

Among the testers, CSV 8R was found to have a high and desirable gca for grain yield, number of seeds branch^{-1}, and panicle length. Another male, CSV 216R was the best general combiner for plant height and number of primaries panicle'. SPV 1155 was found to be a good combiner for panicle length and 100-grain mass. However, with the exception of CSV 8R these testers had undesirable gca effects for grain yield and hence may not be useful in heterosis breeding. Of the parents tested RSLG 241 and CSV 8R exhibited favourable gca effects for grain yield while RSP 3, (IS23399XNR1349)-2-2-4-1, RSLG 262 and CSV 216R exhibited favourable gca effects for other important yield-attributing characters. These parents could be extensively used to achieve high yields through optimum combinations of these yield components.

Table 3 presents promising hybrids in terms of six important characters including grain yield. In the present study, the hybrid E36-1 x CSV 14R recorded the highest positive significant sca effect coupled with high mean yield. This cross involved parents with poor x poor gca effects, indicating the presence of non-allelic interactions and also manifested more heterosis than other hybrids. The same cross also registered significant sca effects along with a high mean for panicle mass, number of seeds branch^{-1}, and panicle length where the parents were average x poor general combiners for the first two characters, and high x poor general combiners for the third. RSLG 227 x CSV 8R was another hybrid with high mean and significant sca effects for grain yield, number of seeds branch^{-1}, and panicle length. The parents were poor/ average x high general combiners for the said traits. RSLG 241 x SPV 1155 gave high positive and significant sca values for grain yield and panicle mass along with high means for these characters. The same cross recorded low sca effects for 100-grain mass, while both the parents showed high gca effects. This cross probably had small non-additive gene effects resulting in few sca effects.

From the present study, it can be suggested that the crosses with the most sca effects for yield and yield-

Table 2. Estimation of general combining ability effects for different characters in postrainy-season sorghum

Source	Time to 50% flowering	Plant height (cm)	Panicle mass (g)	Panicle length (cm)	Primaries panicle^{-1}	Seeds branch^{-1}	100-grain mass (g)	Seed yield (g)
Lines								
RSLG 227	-0.22	12.28*	-6.59	0.65	-4.18	-1.18	-0.15	2.21
RSLG 241	-1.84	6.15	-4.21	-0.34	-3.43	0.56	0.36**	14.72**
RSLG 262	2.65*[1]	6.90	14.65*	-0.22	-4.06	-2.43	0.27	5.34
RSLG 383	0.03	-15.3*	-13.2*	-0.34	-4.31	-6.93*	-0.25	-14.0**
RSP 1	0.91	5.91	-2.84	-0.09	4.81*	-0.56	-0.01	-11.0**
RSP 3	0.15	1.65	0.53	-0.09	2.68	8.93**	0.19	-3.4
(IS23399 x NR1349)-2-2-4-1	-0.09	5.78	7.65	-0.97	9.93**	0.813	-0.05	6.46
E 36-1	-1.59	-23.3*	4.03	1.41*	-1.43	0.813	-0.37	-0.28
SE(gi)	1.16	5.37	5.78	0.57	2.30	2.92	0.13	4.35
Testers								
CSV 8 R	0.34	-18.9*	5.78	1.03*	0.87	5.25*	0.008	10.1**
CSV 14 R	0.15	-4.72	-7.46	-1.2**	-1.93	-0.93	-0.002	-2.65
CSV 216 R	0.59	19.91*	4.46	-0.72	3.75*	1.56	0.23*	1.46
SPV 1155	-0.78	3.72	-2.78	0.84*	2.68	-5.8**	0.23*	-5.96
SE(gj)	0.82	3.80	4.09	0.40	1.71	2.06	0.09	3.07

1. * = significant at 5%, ** = significant at 1% levels of probability

Table 3. Specific combining ability effects in selected crosses of postrainy season sorghum for six important characters

Characters/crosses	Mean of hybrid	gca effects of parents⁻¹ P1	P2	sca effects²
Panicle mass (g)				
E36-1 x CSV14R	126	A	P	38.71**
RSP 3 x CSV 8R	114	A	A	16.97
RSLG 241x SPV1155	108	P	P	23.78
SE (difference)	15			11.57
Panicle length (cm)				
RSLG 227 x CSV 8R	25	A	H	3.09*
E36-1 x SPV 1155	25	H	H	2.S3*
E36-1 x CSV 14R	23	H	P	2.33*
SE (difference)	1.5			1.14
Primaries panicle^{-1}				
RSP 1 x CSV 216R	98	H	H	19.37**
(IS23399XNR1349)-2-2-4-I x SPV 1155	88	H	P	10.68*
(IS23399XNR1349)-2-2-4-I x CSV 14R	81	H	P	2.93
SE (difference)	7.5			5.2
Seeds branch^{-1}				
E36-1 x CSV 14R	100	A	P	30.68**
RSLG 241 xCSV 14R	92	A	P	17.25**
RSLG 227 x CSV 8R	91	P	H	17.5**
SE (difference)	8.9			5.8
100-grain mass (g)				
RSLG 241 x CSV 8R	5.0	H	A	0.65*
RSP 3 x CSV 8R	4.7	A	A	0.54*
RSLG 241 x SPV 1155	4.6	H	H	0.02
SE (difference)	0.4			0.27
Seed yield (g)				
RSLG 227 x CSV 8R	108	A	H	18.91*
RSLG 241 x SPV 1155	107	H	P	21.97*
E36-1 x CSV 14R	106	P	P	30.15*
SE (difference)	11.3			8.7

1. H = high; A = average; P = poor
2. * = significant at 5%, ** = significant at 1% levels of probability

contributing characters involving good general combiners should be utilized to exploit hybrid vigor through heterosis breeding in postrainy-season sorghum. Crosses with high sca effects involving poor/average x high gca for the above characters could also be exploited. These crosses could also be utilized for further selection by intermating superior selections from all possible combinations followed by pedigree breeding to obtain high-yielding segregants. A combination of two poor general combiners might record the highly significant sca effects coupled with high per se performance, this might be due to the selective nicking ability of the parents. The exploitation of such characters could be possible if biparental matings are used in crosses.

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Simultaneous Selection for High-yielding and Stable Rainy-season Sorghum Hybrids

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Introduction

Because yield trials are conducted in diverse environments large and significant genotype x environment (G x E) interaction effects often hinder plant breeders' ability to select high-yielding genotypes suitable for commercial utilization by farmers. Stable performance is therefore considered an important aspect of yield trials as G x E interaction reduces progress from selection (Comstock and Moll, 1963). Researchers usually ignore G x E interaction, and base their genotypic selec-tion solely on mean performance across environments. Only recently has attention been focused on the usefulness of incorporating G x E interaction into geno-type selection (Kang and Pham, 1991). Even though many workers have advocated and proposed stability methods that combine yield and stability as a single criterion (Huhn, 1979; Eskridge, 1988; Kang, 1988; Kang and Pham, 1991; Bachireddy et al. 1992; Kang, 1993) such methods have not been used in practice. Yield-stability statistics (YS_i) proposed by Kang (1993) helps to identify high-yielding genotypes and also makes it less likely to commit Type II errors (chossing a genotype for cultivation when it is unstable in its performance). The present study applies this yield-stability analysis to identify sorghum [*Sorghum bicolor* (L.) Moench] hybrids that have high-yielding traits coupled general stability in the Initial Sorghum Hybrid Trials in the All India Coordinated Sorghum Improvement Project (AICSIP) for further evaluation in Advanced Trials. The application of this criterion helps to eliminate genotypes that are superior only in yield and not in their general adaptability to sorghum-growing environments. This obviously reduces the number of entries to be tested in advanced trials that are conducted at a large number of locations (35-50 per season), thus saving precious resources.

Material and methods

Twenty-five rainy-season (*kharif*) sorghum hybrids, two standard controls, CSH 13 and CSH 18, and a variety, CSV 15 were evaluated in a randomized complete-block design with three replications at 6 locations spread across rainy-season sorghum-growing regions in the Indian States of Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Uttar Pradesh, and Gujarat in 2000 under the All India Coordinated Sorghum Improvement Project. The grain yield (kg ha^{-1}) recorded at maturity was used to statistically analyze stability variance using the method of Shukla (1972). YS. were calculated following the method proposed by Kang (1993).

Kang's procedure: Kang's method consists of first grading each of the genotypes according to their performance and significance level of (d^2_i and then consider-ing the sum of the scores in the two grading, as a measure of genotypic superiority. The essential steps involved are the following. For each genotype (i) calculate d^2_i; (ii) assign ranks to genotypes from the highest to the lowest yield, with the lowest yield receiving rank 1; (iii) calculate the protected LSD for mean yield comparisons; (iv) adjust yield rank Y according to LSD [adjustment of +1 (on yield rank) for genotypic mean yield (GMY) > overall mean yield (OMY), + 2 for GMY ≥ 1 LSD above OMY, + 3 for GMY ≥ 2 LSD above OMY, -1 for GMY < OMY, -2 for GMY ≤ 1 LSD below OMY and -3 for GMY ≤ 2 LSD below OMY]; (v) determine signficance of d^2_i, using appropriate F test; (vi) assign the stability ratings, -8, -4 and -2 for d^2_i significant at 0.01,0.05 and 0.10 probability levels, and 0 for non-significant d^2_i (the higher the d^2_i, the less stable the genotype); (vii) sum adjusted yield rank, Y and stability rating, S for each genotype to determine YS_i statistic and finally alculate mean YS_i and identify genotypes (selection) with YS_i > mean YS_i.

Results and discussion

According to Kang's analysis, a genotype with YS_i statistics more than mean YS_i and non-significant stability variance (Shukla, 1972) is ideal for both high yield and stability. The mean YS_i value was 12.32 and 13 hybrids with YS_i >12.32 had potential for further testing. The mean grain yield of these hybrids was 5971 kg ha^{-1}, statistically equal to the mean yield (6063 kg ha^{-1}) of the 11 hybrids that could be selected on the basis of their grain yields alone (grain yield of hybrid > mean trial yield).

Of the 28 hybrids tested, 7 hybrids: CSH 13, RS 179A2 x RSCN 2105, PMS 37A x KR 199, PMS 37A x

Table 1. Yield stability statistics (YS_i) for simultaneous selection for mean grain yield (kg ha^{-1}) and stability in rainy- season hybrids across 6 Indian locations, rainy season 2000

Pedigree	Mean grain yield (kg ha^{-1})	Yield rank (Y#)	Adjust-ment to Y#[1]	Adjusted Y(Y)	Stability variance (σ^2_i)	Stability rating (S)	YS_i = (Y + S)
CSH 13	7225	28	3	31	304021	0	31[3]
RS 179A2 x RSCN 2105	6555	27	2	29	170384	0	29[1]
RS 97A2 x RSCN 2107	6553	26	2	28	8202314***	8	20[3]
PMS2A x KR 196	6399	25	2	27	2888710***	-8	19[3]
PMS 37A x KR199	5989	24	1	25	316056	0	25[3]
RS 179A2 x RSCN 2103	5725	23	1	24	1063507**	-4	20[3]
RS 179A2 x RSCN 2115	5693	22	1	23	2966990***	-8	15[3]
PMS 7A x IB 12	5688	21	1	22	841914*	-2	20[3]
PMS 37A x MR39	5682	20	1	21	762703	0	21[3]
RS 179A2 x RSCN 2107	5606	19	1	20	918693*	-2	18[3]
1115A2 x RSCN 2105	5579	18	1	19	504128	0	19[3]
RS 179A2 x RSCN 2117	5556	17	-1	16	1135188**	4	12
115A2 x RS 754	5495	16	-1	15	386366	0	15[3]
115A2 x RS 627	5455	15	-1	14	822105*	-2	12
RS 97A2 x RSCN 2103	5446	14	-1	13	350331	0	13[3]
RS 179A2 x RSCN 2106	5392	13	-1	12	208401	0	12
RS 179A2 x RS 628	5361	12	-1	11	529277	0	11
RS 179A2 x RSCN 2118	5326	11	-1	10	1031604**	-4	6
RS 179A2 x RS 624	5321	10	-1	9	197926	0	9
CSV 15	5308	9	-1	8	328668	0	8
PMS 7A x RS29	5300	8	-1	7	1427838***	-8	-1
RS 179A2 x RS 627	5279	7	-1	6	568172	0	6
RS 179A2 x RSCN 2100	5263	6	-1	5	410476	0	5
PMS 37A x C 43	5109	5	-1	4	218235	0	4
RS 179A2 x RSCN 2112	5051	4	-1	3	165573	0	3
RS 179A2 x RS 673	4911	3	-1	2	352615	0	2
RS 179A2 x RSCN 2110	4860	2	-2	0	2442440***	-8	-8
CSH 18	4810	1	-2	-1	385410	0	-1
Mean	5569						12.32
CD at 5%	914						

1. Adjustment to Y# - +1 for mean yield > overall mean yield (OMY), +2 for mean yield >1 LSD above +3 for mean yield >2 LSD above OMY; -1 for mean yield < OMY, -2 for mean yield <1 LSD below OMY, -3 for mean yield <2 LSD below OMY
2. *, **, *** Significant at 10%, 5%, and 1% levels of significance. It also indicates that genotype is unstable according to Shukla's model (1972)
3. Genotype selected on the basis of YS_1

MR 39, 115A2 x RSCN 2105, 115A2 x RS 754, and RS 97A2 x RSCN 2103 showed non-significant stability variance and YS_i values higher than the mean YS_i (Table 1). The mean grain yield of these 7 hybrids was 5995 kg ha^{-1}. On this basis, six new genotypes with good stability and high grain yields can be recommended for further testing in advanced trials. If the decisions were based only on mean hybrids performance, then the first 11 hybrids (grain yield of hybrid > mean trial yield) would have been recommended, leading to a Type II error. A consequence of committing a Type 1 error would be that growers could miss using a stable genotype, but the consequence of committing a Type II error could be disastrous for growers as they might grow an unstable genotype and suffer economically (Kang, 1993). Selection based on mean grain yield alone could clearly have increased the number of genotypes selected for advanced testing, and thereby enhanced the total cost of evaluation.

The use of G x E interaction encountered in crop performance trials is an important issue among plant breeders and agronomists. The integration of yield and stability using YS_i statistics helps to identify genotypes that perform well for both grain yield and adaptability, and also reduces the probability of committing Type II errors. It also helps to reduce the number of entries recommended for Advanced Trials, thus saving the total testing costs of multilocational trials.

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Agronomy

Evaluation of Forage Sorghum Hybrids for Yield and Morphological Traits

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Introduction

The increase in the livestock population has widened the gap between demand for, and supply of fodder in India. This gap can be narrowed by increasing productivity through breeding superior hybrids and varieties of forage crops. Among the forage crops, sorghum offers great potential to supplement fodder resources because of its wide adaptation, rapid growth, high green and dry fodder yields, and good quality. Single-cut varieties are generally dual-purpose types that combine seed and green fodder yield, whereas multicut varieties, are usually poor seed yielders (Lodhi et al. 1994). Multicut varieties generally provide 25 30% more dry matter than single-cut varieties under the same management system (Paroda and Lodhi 1980). Multicut forage sorghum hybrids should be developed to meet the present-day demand for fodder.

Hybrids were developed using multicut-type good quality pollinators, resistant to diseases and insect pests, on different grain sorghum male-sterile lines. Their performance was tested for yield and morphological traits to identify superior hybrids with potential commercial value.

Materials and methods

Eighteen hybrids and two standard controls (PCH 106 and FSH 92079) were grown in a randomized block design during the rainy season (*kharif*) 2000. The net plot size was 3 x 3.3 m^2. The spacing was 45 cm between rows, and 10 cm within rows. Data were recorded for green and dry fodder yields on a whole plot basis, subsequently converted into t ha^{-1}; leaf length and breadth, stem girth, percentage total soluble sugars (TSS), early vigor, plant height, number of leaves $plant^{-1}$, and number of tillers $plant^{-1}$ were used as selection criteria. The data were recorded on five randomly selected plants. The analysis of variance was calculated according to Panse and Sukhatme (1967).

Results and discussion

The prime objective of any forage breeding program is to develop hybrids or varieties with high fodder yields, good plant height, leafiness, high tillering, high rate of growth, early vigor, high TSS, regenerative ability, thin stems, and sweetness. Similar studies using the same criteria for yield and quality traits were conducted by Desale et al. (1993) and Sunku et al. (1998).

Hybrids HH 2 (69.00, 18.63), HH 88 (70.33, 18.29), and HH 85 (67.67, 18.27) had superior green (GFY) and dry (DFY) fodder yields to the best control entry, PCH 106 (67.33, 18.18) (Table 1). However, HH 82 (18.48) was obser-ved to be better than both controls on the basis of DFY. For GFY, HH 82 (66.00) was better than FSH

Table 1. Performance of forage sorghum hybrids based on fodder yields and rate of growth, Hisar, Haryana, India, rainy season, 2000

	Green fodder yield (t ha^{-1})						Dry fodder yield (t ha^{-1})					Rate of growth (cm day^{-1})	
Entry	1st cut	2nd cut	Total	Rank	Increase over better control (%)	Sweet (S)/ non-sweet (NS)	1st cut	2nd cut	Total	Rank	Increase over better control (%)	1st cut	2nd cut
HH 85	43.00	24.67	67.67	3	0.50	S	11.61	6.66	18.27	4	0.50	2.78	2.98
HH 86	32.67	26.00	58.67	9	-	s	8.49	6.76	15.25	9	-	2.43	2.5
HH 63	31.00	29.67	60.67	8	-	s	8.06	7.71	15.77	8	-	2.63	2.67
HH 87	33.00	25.00	58.00	10	-	s	8.58	6.50	15.08	10		2.73	2.96
HH 43	26.67	26.67	53.33	13	-	NS	6.67	6.67	13.33	13	-	2.49	3.16
HH 88	40.67	29.67	70.33	1	4.46	s	10.57	7.71	18.29	3	0.58	2.69	2.42
HH4	21.00	23.33	44.33	16	-	NS	5.04	5.60	10.64	17	-	2.41	3.15
HH 89	23.00	20.00	43.00	17	-	s	5.52	4.80	10.32	18	-	2.27	3.09
HH 90	22.00	17.67	39.67	19	-	NS	5.06	4.06	9.12	20	-	2.26	2.48
HH 91	28.00	26.33	54.33	11	-	S	7.00	6.58	13.58	11	-	2.39	2.23
HH 92	21.67	20.33	42.00	18	-	s	4.77	4.47	9.24	19	-	1.93	1.96
HH 93	26.00	20.00	46.00	15	-	s	6.24	4.80	11.04	15	-	2.05	2.23
HH 94	21.00	25.33	46.33	14	-	s	4.83	5.83	10.66	16	-	1.95	2.26
HH 32	31.33	32.67	64.00	6	-	s	8.46	8.82	17.28	6	-	2.72	3.38
HH 82	32.00	34.00	66.00	5	-	s	8.96	9.52	18.48	2	1.65	2.86	3.53
HH 2	40.00	29.00	69.00	2	-	s	10.80	7.83	18.63	1	2.48	2.63	2.98
HH 81	29.00	24.67	53.67	12	2.48	s	7.25	6.17	13.42	12		2.47	2.57
HH 5	28.00	25.33	53.33	13	-	s	6.72	6.08	12.80	14	-	2.59	2.98
Controls													
FSH 92079	32.00	30.00	62.00	7	-	s	8.32	7.80	16.12	7	-	2.62	2.62
PCH 106	39.33	28.00	67.33	4	-	NS	10.62	7.56	18.18	5	-	2.99	2.41
CD at 5%		79.36	39.64					20.21	10.33				
CV (%)		16.49	9.56					16.44	9.78				

Table 2. Performance of forage sorghum hybrids based on morphological traits and total soluble sugars (TSS), Hisar, Haryana, India, rainy season, 2000

Entry	Early vigour	Plant height (cm)	Leaves $plant^{-1}$ (number)	Tillers $plant^{-1}$ (number)	Leaf length (cm)	Leaf breadth (cm)	Stem girth (cm)	TSS (%)
HH 85	3.67	185.95	21.00	2.33	75.56	7.11	4.68	11.50
HH 86	3.33	162.11	20.89	2.78	75.22	7.23	4.92	11.67
HH 63	3.00	182.89	16.45	1.78	74.22	7.49	4.77	13.17
HH 87	3.67	183.11	16.67	1.44	71.89	7.53	4.32	11.83
HH 43	3.33	163.18	18.33	2.22	75.67	5.23	4.17	10.50
HH 88	3.33	177.72	16.67	1.89	71.55	6.58	4.66	11.67
HH 4	2.67	162.55	18.11	2.76	71.18	5.10	4.36	10.00
HH 89	3.33	152.44	17.22	1.93	67.89	6.67	4.49	13.00
HH 90	2.67	152.67	17.67	2.11	69.89	5.95	4.40	11.17
HH 91	3.00	160.00	17.00	1.89	67.34	6.51	4.80	13.50
HH 92	2.67	168.33	15.22	1.84	68.50	7.54	5.40	13.50
HH 93	3.00	139.33	18.67	2.42	64.22	6.69	3.95	11.00
HH 94	2.33	131.67	14.44	1.78	63.89	5.94	4.65	9.17
HH 32	3.33	182.11	20.67	2.67	74.89	4.82	3.92	10.50
HH 82	3.00	191.22	16.22	1.67	72.55	5.52	4.24	11.17
HH2	3.33	175.00	15.89	1.89	58.11	7.17	4.10	13.17
HH 81	2.67	165.89	17.89	2.11	65.67	8.03	5.17	11.17
HH5	2.67	172.11	14.89	1.78	71.67	6.17	4.88	11.00
Controls								
FSH 92079	3.00	175.22	16.44	2.33	70.33	4.60	3.77	10.00
PCH 106	3.67	199.89	18.00	1.78	83.22	5.54	4.41	11.17

92079 (62.00), the national control entry. All the four hybrids, i.e., HH 2, HH 88, HH 85, and HH 82, were juicy, had high TSS and relatively high growth rates (calculated by dividing plant height by number of days of growth) observed in both cuts (Table 2). The rate of growth in the 2nd cut was generally better than that of the 1 st cut, showing that most of the hybrids had good regenerative ability (Tables 1 and 2). This maybe because in most of these hybrids, one of the parents used in the crossing program was a multicut type with high regenerative ability. However, yields in the 1st cut were better than those in the 2nd cut because after cutting the crop was shorter, had fewer leaves, that were shorter and narrower than those from the 1st cut in spite of having good regenerative abilities. For such morphological traits as early vigor, plant height, leaves $plant^{-1}$, tillers $plant^{-1}$, leaf length, leaf breadth, and stem girth, these four hybrids, HH 2, HH 88, HH 85, and HH 82 were similar to the controls (Table 2).

According to yield, quality, and morphological traits, HH 2 and HH 82 were better than the controls and could be released for commercial cultivation after proper testing. The male-sterile lines and pollinators used in this trial could be further utilized to develop forage sorghum hybrids.

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Winter Season Adaptation Features in Sorghum

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The area under winter sorghum [*Sorghum bicolor* (L.) Moench] in Maharashtra has been stable for the last three decades, as the crop is equally valued for its fodder and grain. The last six quinquenneum witnessed a 30% rise in winter-season productivity (Nerkar 1998) from 0.48 t ha^{-1} to 0.62 t ha^{-1} at national level.

Winter sorghum hybrids will have a tangible impact only when both the male-sterile (A) and restorer (R) lines have seasonal adaptability. A close look of parental lines shows that they mostly include rainy-season lines with very few winter-adapted ones. CSH 13R has significant yield superiority over M 35-1 but is highly vulnerable to shoot fly (*Atherigona soccata* Rondani), and low temperatures and has inferior grain quality. CSH 15R is more adaptable than CSH 13R, through not equal to M 35-1. Hence, the present study of new male-sterile lines and restorers was inaugurated.

The experimental material consisting of 11 male steriles (9 rainy-season; PMS 1 A, PMS 2A, PMS 3A, PMS 4A, PMS 5A, PMS 6A, PMS 7A, PMS 8A, and PMS 19A, and 2 winter-season; 104A and 116A), 11 testers (6 rainy- season; KR 112, KR 189, KR 190, KR 191, KR 192 and PVK 801, and 5 winter-season; RS 585, RS 615, RS 29, SPV 492, and SPV 727) and their 121 F_1 hybrids together with CSH 13R, and CSH 15R. The material was evaluted in a randomized-block design trial with two replications in winter 1998/9. Each genotype was represented by a single (5-m) row plot with 45-cm inter- and 15-cm intra-row spacing. Seed setting (%) in selfed panicles was recorded on five randomly selected plants to judge fertility restoration in cold temperatures. Other observations included grain yield $plant^{-1}$, grain size, shape, color and luster, and agronomic acceptability.

An additional set of 121 F_1 and parents was also sown in two replications during early winter with susceptible and resistant checks to screen for shoot-fly tolerance.

In the present study, out of 121 hybrids, ten hybrids were promising for grain yield (Table 1). Hybrids based on new rainy-season male-sterile line PMS 19A with shoot-fly resistance with winter-adapted male parents; SPV 727, SPV 492 and RS 29 were promising for grain yield and had low percentages of shoot-fly deadhearts.

Table 1. Main features of promising heterotic sorghum hybrids for winter-season cultivation

Hybrids	Grain yield $plant^{-1}$ (g)	Grain size	Grain shape	Grain color	Grain luster	Agronomic accepta-bility	Shoot-fly dead-hearts (%)	Seed setting (%)
PMS 8A x RS 29	82.95	Medium	Sublenticular	White-chalky	Non-lustrous	Low[1]	39.14	79.16
116A x RS 585	66.70	Medium bold	Spherical	Creamy	Lustrous	High[1]	38.88	7.91
PMS 7A x SPV 727	63.00	Medium bold	Spherical	Creamy	Lustrous	High[2]	30.33	2.98
PMS 19A x SPV 727	62.65	Medium bold	Spherical	White-pearly	Lustrous	High[2]	22.55	71.66
PMS 19A x SPV 492	61.90	Medium bold	Spherical	Creamy	Lustrous	High[2]	21.50	70.59
PMS 19A x RS 29	61.45	Medium bold	Sublenticular	White-chalky	Non-lustrous	Moderate[2]	14.02	59.80
116A x SPV 727	60.95	Medium bold	Spherical	White-pearly	Lustrous	Moderate[2]	33.56	0.00
104A x SPV 492	60.05	Bold	Spherical	White-pearly	Lustrous	High[2]	26.66	22.72
116A x KR 191	58.45	Medium bold	Spherical	Creamy	Lustrous	Moderate[2]	27.76	3.76
PMS 8A x SPV 492	58.15	Medium	Sublenticular	White-pearly	Lustrous	Moderate[1]	39.81	30.66
CSH 15 (Control)	42.50	Medium	Spherical	White-pearly	Lustrous	High	38.88	52.09

1. Compared to CSH 15
2. Compared to CSH 15 and M 35-1

The study indicated that hybrids based on shoot-fly resistant male-steriles (104A, 116A and PMS 19A) and restorers (RS 585, RS 615, SPV 492 and SPV 727) could be used in the winter season. These findings are in agreement with Kaul and Rana (1996). Biradar and Borikar (1985) also reported few shoot-fly deadhearts in resistant parents and progenies involving both resistant parents.

Hybrids PMS 8A x RS 29 though top ranking for grain yield, had low agronomic acceptability due to its non-lustrous and white, chalky grains . Hybrids PMS 19A x SPV 727, 116A x SPV 727, 104A x SPV 492, and PMS 8A x SPV 492 had medium-bold , lustrous, white pearly grains with high agronomic acceptability and good threshability. Chavan and Nerkar (1978) also reported that rainy x winter season hybrids may produce combinations of economic value that could be stable over both seasons. Kaul and Rana (1996) reported that total biomass productivity, and bold and lustrous grains are traits favoured by farmers to meet their household and market needs.

Low temperature is the second most important abiotic stress after drought for winter sorghum adaptation. When a crop is subjected to low temperatures below 10 - 15°C, common symptoms of chilling injury occur including; poor establishment, chlorosis of young seedlings, restricted growth and development, and in the case of certain cereals, spikelet sterility and reduced grain yield (Peacock 1982). Fertility restoration is major limitation to the manifestation of heterosis in winter sorghum (Kaul and Rana 1996).

During the present study, the minimum temperature fell below 10°C during meteorological weeks numbers 49 to 3 (3 Dec 1997 to 21 Jan 1998). Out of ten good-yielding hybrids, satisfactory seed setting under bagged conditions was noticed only in three; PMS 8A x RS 29, PMS 19A x SPV 727 and PMS 19A x SPV 492. Seed setting in the check hybrid, CSH 15 was poor (52.09%). The present study indicated that the lowest seed setting (%) was noticed in hybrids involving both winter based parents. This situation indicated the need to increase genetic diversity in parents and identify heterotic (rainy x winter) crosses suitable for winter seasons when cold waves generally coincide with reproductive phase of crop growth.

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Sorghum Hybrids and Varieties Suitable for Postrainy-season Cultivation in Northern Karnataka, India

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Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is an important staple food and fodder crop of northern Karnataka. Among the cereals, it ranks fifth in the world and third in India after wheat and rice. In India, it is grown on 10.5 million hectares where it produces 9.5 million tonnes because productivity is low, at 905 kg ha^{-1} (FAO 2000). The low productivity of sorghum in the medium-to-deep black soils in northern Karnataka, southern Maharashtra, and Andhra Pradesh is due to the poor adoption of improved cultivars in these drought-prone areas. Field experiments were conducted to evaluate and identify improved sorghum hybrids/varieties suitable for the postrainy season on the Vertisols of the Deccan Plateau in the Bellary region of northern Karnataka.

Materials and methods

Two field experiments were conducted in a randomized-block design with three replications on Vertisols during the postrainy season, 1998/99. In the first experiment, 13 sorghum hybrids with one variety (M35-1) as control and in the second 8 sorghum varieties were evaluated. All the usual agronomic practices and plant protection measures were followed. The sorghum crop was sown in an area 2.7 x 6.75 m^2 (18.225 m^2) in plots 1.8 x 6.15 m^2 (11.07 m^2) in both hybrid and varietal trials. Grain and fodder yields were recorded from each plot and converted into yields in t ha^{-1}.

Results and discussion

Total rainfall received during the cropping season was 283.3 mm over 16 rainy days (hybrid trial) and 275.4 mm over 15 rainy days (varietal trial). This favorable rainfall resulted in good crop growth with high dry-matter translocation to grains in almost all the hybrids and varieties, except in those susceptible to disease and pests.

Among the hybrids CSH 13R recorded a significantly high grain yield (3.86 t ha^{-1}) followed by SPH 1010 (3.40 t ha^{-1}), SPH 1079 (3.24 t ha^{-1}), and M35-1 (3.03 t ha^{-1}) (Table 1). During 1996/97, under Bellary conditions, CSH 13R performed better, or comparably to the top hybrids, i.e., SPH 634 and SPH 922 (Patil et al. 1999). There was little variation in straw yields among the hybrids. However, a high straw yield of 5.99 t ha'[1] was observed in SPH 1010. During the postrainy season SPH 733 and SPH 634 performed better than the rest of the hybrids at Rahuri, Mahol, and Solapur (Narkhede et al. 1997). The local variety (M35-1) produced high grain and straw yields that were comparable to those of the best hybrids, CSH 13R, SPH 1010, and SPH 1079 evaluated during that season.

Among the varieties evaluated during the postrainy season, the local control variety M35-1 outyielded (3.03 t ha^{-1}) the rest of the cultivars (Table 2). SPV 1413 (2.98 t ha^{-1} $^{-1}$) and SPV 1359 (2.92 t ha^{-1}) performed better than the rest of the varieties. In Maharashtra, the average performance of cultivars in 110 adaptive trials in cultivators' fields indicated that SPV 1359 (Phule Yashoda) produced higher grain and fodder yields than Swati and CSV 14R (Narkhede et al.1999). Similarly, in the rainy season of 1995, SPV 1134, SPV 1247, and CSV 14R performed better than the rest of the varieties evaluated at Dhule, Jalagaon, Karad, and Gadhinglaj in Maharashtra (Narkhede et al. 1997). These varieties produced more straw than others in the trial.

The high grain yields of both hybrids and varieties were mainly due to high dry-matter translocation and accumulation in their panicles. These trials show that the hybrids CSH 13R, SPH 1010, and SPH 1079 and varieties SPV 1413, SPV 1359, and M35-1 are well-suited to profitable cultivation in northern Karnataka during the postrainy season.

Table 1. Crop growth, yield and yield components of sorghum hybrids cultivated on Vertisols, postrainy season 1998/9, Bellary, Karnataka, India

	Yield (t ha^{-1})			Mass (g $plant^{-1}$)				
Hybrids	Grain	Straw	Plant height at harvest (cm)	Panicle	Grain	1000-grain mass (g)	Panicle length (cm)	Panicle diameter (cm)
M35-1	3.03	5.58	238.0	45.793	36.403	26.833	22.3	12.6
SPH 733	1.43	5.49	238.3	35.563	21.653	18.867	20.3	10.7
SPH 1010	3.40	5.99	242.3	52.043	37.870	26.967	24.1	12.8
SPH 1015	0.99	4.24	182.5	32.020	16.950	15.933	19.3	10.7
SPH 1020	2.41	4.86	228.3	38.787	25.670	22.333	20.3	11.7
CSH 15R	2.41	5.79	232.7	39.210	22.143	24.100	21.9	12.1
SPH 1034	2.11	4.88	242.7	34.530	21.877	20.733	20.7	12.7
SPH 1075	2.62	5.50	216.7	41.523	25.760	22.567	21.4	11.6
SPH 1026	3.23	5.67	254.3	48.077	32.123	26.467	24.1	12.4
SPH 1077	2.56	5.11	221.0	37.663	26.027	25.233	19.5	11.2
CSH 13R	3.86	5.76	240.3	52.380	38.343	28.033	24.8	13.1
SPH 1078	2.20	5.17	217.7	33.083	22.650	21.900	18.9	10.1
SPH 1079	3.24	5.23	233.3	50.923	37.677	27.567	24.5	12.4
SPH 1089	2.93	5.33	245.7	48.043	36.240	25.967	22.9	11.5
SE (mean)	±0.31	±0.45	±10.8	±4.907	±4.346	± 0.986	±1.04	±0.93
CD(0.05)	0.91	NS[1]	31.3	14.254	12.626	2.863	2.92	NS

1. NS = Not significant

Table 2. Crop growth, yield and yield components of sorghum varieties cultivated on Vertisols, postrainy season 1998/9, Bellary, Karnataka, India

Varieties	Yield ($t ha^{-1}$)		Plant height at harvest (cm)	Mass ($g plant^{-1}$)		1000-grain mass (g)	Panicle length (cm)	Panicle diameter (cm)
	Grain	Straw		Panicle	Grain			
SPH 1089	2.93	5.33	245.7	48.043	36.240	25.967	22.9	11.5
SPV 1155	1.63	2.75	212.3	32.321	21.763	22.567	16.8	10.3
SPV 1411	2.12	3.98	237.8	40.357	26.721	28.733	18.7	12.1
Swati	1.86	3.11	206.5	39.730	26.639	24.133	22.0	11.1
SPV 1413	2.98	4.41	247.3	48.511	35.675	28.400	18.4	12.3
CSV 14R	2.90	3.91	226.0	42.943	30.303	27.767	18.2	12.5
SPV 1380	2.51	4.41	235.8	39.753	28.328	27.000	19.6	11.1
SPV 1359	2.92	4.68	230.0	45.884	33.405	30.467	19.4	12.8
M35-1	3.03	4.92	228.7	51.183	35.719	30.600	19.4	13.6
SE (mean)	±0.30	±0.44	±10.8	±3.187	±2.87	±1.494	±1.03	±0.76
CD (0.05)	0.61	1.33	NS[1]	9.667	8.71	4.533	NS	NS

1. NS = Not significant

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Response of Sorghum to in situ Water Conservation Practices

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Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is an important cereal crop in the semi-arid tropics. In India more than 70% of the total cultivable area is rainfed and produces about 48% of food grains. Uncertain and erratic rainfall often causes severe drought stress during the crop growth period thus leading to frequent crop failure. Rainfed crops can be successfully grown by proper in situ conservation of rainwater (Gupta and Bhan 1993). The broadbed-and-furrow (BBF) system of sowing, compartmental bunding and random-tied ridging can provide good opportunities for the crop plant to store and extract moisture from soil. An on-farm experiment was carried out to study the response of sorghum to different soil and water conservation techniques in the Veppur watershed area of Tamil Nadu, India, during the rainy seasons of 1999 and 2000.

Materials and methods

Sorghum cv CO 26 was sown at a spacing of 45 x 15 cm on 22 July 1999 and 4 August 2000. The water conservation treatments consisted of BBF system,

Table 1. Effect of water conservation methods on growth, yield, soil moisture content and cost/benefit ratio of rainfed sorghum (Pooled data of 1999 and 2000)

Treatments	Germination (%)	Plant height (cm)	Leaf area index	Panicle length (cm)	Grains panicle^{-1}	Yield (t ha^{-1})		*Soil moisture content* (*w/w*) (%) Soil depth (cm) 50 DAS			75 DAS			Cost/ benefit ratio
						Grain	Stover	0-15	15-30	30-5	0-15	15-30	30-5	
Broadbed-and-furrow	83.5	139.3	4.97	19.8	1075	2.1	8.0	64.13	63.72	63.27	68.01	67.63	67.20	1.83
Compartmental bunding	81.3	131.9	4.72	18.3	1044	2.0	8.3	61.99	61.62	61.18	66.30	65.90	65.59	1.75
Random-tied ridging	79.1	120.6	4.45	17.3	995	1.9	6.8	59.14	58.68	58.29	63.65	63.29	62.77	1.69
Control	75.3	113.4	4.14	14.8	958	1.7	6.5	57.13	56.79	56.17	61.82	61.34	60.91	1.51
S.Ed	0.51	2.52	0.22	033	23.2	26.1	56.8	0.41	0.40	0.39	0.39	0.38	0.36	-
CD (P=0.05)	1.04	5.07	0.46	0.68	46.3	53.8	114.2	0.84	0.82	0.79	0.78	0.76	0.74	

compartmental bunding, random-tied ridges and a farmers' practices control. The treatments were laid out in a *randomizcd-block design with five replications. The* soil was a clay loam Vertisol with pH 8.1, low in available N (132 kg ha^{-1}), low in available P_2O_5 (16 kg ha^{-1}) and high in available K_2O (414 kg ha'^{1}). The recommended dose of fertilizers (45:22.5:22.5 kg N-P-K ha^{-1}) were applied uniformly to all the plots. Rainfall, 483 mm in 1999, and 511 mm in 2000 (mean 497 mm) was received during the cropping periods.

Results and discussion

All the water conservation techniques significantly improved the growth, yield attributes and yield of rainfed sorghum (Table 1). Among these techniques, the sorghum crops grown in the BBF system recorded higher germination (83.5%), plant height (139.3 cm), leaf area index (4.97), panicle length (19.8 cm), grains panicle^{-1} (1075), grain (2.1 t ha^{-1}), and stover (8.0 t ha^{-1}) yields with a cost/benefit ratio of 1.83. The sorghum grain yield in the BBF system increased by 22.92% over the farmer's practice control. BBF was followed by compartmental bunding *and random-tied ridging. The increased yield of rainfed* sorghum was attributed to the fact that more rainwater is harvested and stored in the BBF system. These results are similar to those reported by Sounda et al. (1989). Higher soil moisture contents at various soil depths at two crop growth stages were recorded in the BBF system than those in the control. Soil moisture contents were highest in the BBF system and decreased in the following order compartmental bunding > random-tied ridging > control. Irrespective of water-conservation method, the 0-15 cm soil layer had *more moisture than the deeper soil*

Conclusion

The BBF system conserved more rainfall in the soil profile resulting in higher productivity of rainfed sorghum in the Veppur watershed area of Tamil Nadu, India.

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Response of Grain Sorghum to Irrigation Methods, Coconut Coir Waste Levels and Hydrophilic Weirs in Northwestern Tamil Nadu, India

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Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is a major food crop in the semi-arid tropics where it is mostly grown as a rainfed, and occasionally an irrigated crop. In India, sorghum is cultivated on 11.57 million hectares with a production of 11.09 million t and productivity of 958 kg ha^{-1}. Sorghum occupies 6.7% to the total irrigated area (Anonymous 1998). The availability of irrigation water limits the possible increase in area and productivity of sorghum. In several parts of India, the water table has receded considerably, and under such situations the importance of water saving by efficient irrigation to avoid yield reduction is necessary. Every year 6.6 million t of coir (coconut fiber) waste, a by-product from coir industries are available in India (Kamaraj 1994). Coir waste has a high water-holding capacity and can be used as an amendment to improve the physico-chemical properties of soil. In the present study, the influence of irrigation methods, coir waste levels, and hydrophilic weirs on sorghum production were studied at Tamil Nadu Agricultural University (TNAU), Coimbatore, during 1999/2000.

Materials and methods

The experimental soil was a sandy clay loam with a pH of 8.2, 186 kg available nitrogen (N) ha^{-1}, 11 kg available phosphorus (P) ha^{-1}, and 413 kg available potassium (K) ha^{-1}. The 9 treatments were as shown in Table 1. The experiment was laid out in randomized-block design wifh

Table 1. Effect of irrigation methods, coir pith levels, and hydrophilic weirs on grain sorghum (pooled data from summer and rainy-season crops)

Treatment	Growth parameters		Yield parameters			Yield (t ha^{-1})		Water requirement (mm)	Water-use efficiency (kg ha^{-1} mm)	Labor required for irrigation (man-hours ha^{-1})
	Plant height (cm)	Leaf area index	Panicle length (cm)	Grains panicle^{-1}	Panicle mass (g)	Grain	Stover			
1 Continuous irrigation + 10 t ha^{-1} coir pith	146.4	4.219	22.97	1269	43.37	4.9	10.9	415	11.83	103.4
2 Continuous irrigation + 10 t ha^{-1} coir pith + hydrophilic weir	157.1	4.526	24.52	1326	46.86	5.3	11.7	443	11.91	116.2
3 Continuous irrigation + 20 t ha^{-1} coir pith	160.6	4.722	25.71	1393	48.87	5.3	12.3	468	11.84	109.3
4 Continuous irrigation + 20 t ha^{-1} coir pith + hydrophilic weir	171.9	5.089	27.56	1466	52.68	6.0	13.2	492	12.11	130.4
5 Surge irrigation + 10 t ha^{-1} coir pith	145.2	4.215	22.91	1256	43.25	4.9	10.9	344	14.25	73.6
6 Surge irrigation + 10 t ha^{-1} coir pith + hydrophilic weir	155.8	4.518	24.43	1312	46.78	5.3	11.7	361	14.58	88.7
7 Surge irrigation + 20 t ha^{-1} coir pith	159.7	4.713	25.64	1380	48.75	5.5	12.3	384	14.39	80.2
8 Surge irrigation + 20 t ha^{-1} coir pith + hydrophilic weir	170.9	5.076	27.47	1454	52.52	5.9	13.2	404	14.72	96.9
9 Basin furrow irrigation	159.2	4.644	25.36	1374	47.99	5.4	12.0	608	8.93	165.2
CD ($P < 0.05$)	2.2	0.044	0.41	23	0.57	83	125	-	-	-

three replications. For surge and continuous irrigations, ridges and furrows were formed at 90-cm spacing up to 100 m distance with a 0.5% slope in one direction. Coconut fiber (coir) waste was incorporated into the soil using a ridge plow. Inlet pipes (6-cm diameter, 50-cm long) were made by rolling waste aluminium sheet obtained from an off-set press into pipes that were tied with polythene twine at both the ends to avoid unrolling. One end of the inlet pipe was covered with a polythene bag and placed at the head of the each furrow so irrigation water could be easily diverted into the furrow. Irrigation was scheduled at 0.6 irrigated water/cumulative pan evaporation (IW/CPE) ratio. For surge irrigation, water was applied at 10 minutes 'on' and 'off intervals. Irrigation water was poured @ 1 L sec^{-1} to each furrow and 4-6 furrows were irrigated at a time based on the discharge rate of the pump. Sorghum variety CO 26 was sown at a spacing of 90/2 x 5 cm = 45 x 15 cm (double-row geometry). Hydrophilic weirs were fabricated using coconut epicarp 5.0 cm high nailed to the middle of a 15-cm long bamboo peg (with one end sharp). Other weirs 7.5-cm tall were also made. The weirs were placed across the furrows at 50- and 75-m distances, 30 days after sowing (DAS) in continuous and surge irrigation treatments to overcome the penultimate depression of the crop (50-75 m along the furrow) (Rajagopal and Dhanapal 1994).

Results and discussion

The results revealed that irrigation methods, levels of coir pith, and hydrophilic weirs significantly improved growth and yield of grain sorghum (Table 1). Treatment 8 resulted in maximum plant height (171.9 cm), leaf area index (5.089), number of seeds $panicle^{-1}$ (1466), panicle length (27.56 cm), panicle mass (52.68 g), grain (5.6 t ha^{-1}), and stover (13.2 t ha^{-1}) yields (Table 1). A yield increase of 9.72 % was obtained by Treatment 8 over Treatment 9. This yield increase in Treatment 8 is probably due to the adequate soil moisture provided by continuous irrigation, the steady supply of nutrients and water by the coir pith, and hydrophilic weir placement that resulted in the ponding of water 50-75 m along the furrow which further increased the soil moisture content. Treatment 5 recorded lower growth, yield and yield parameters. Treatment 3 increased grain yield signifi-cantly more than the 10 t ha^{-1} coir waste application (Treatment 1). Treatments without weirs registered lower growth and yields of sorghum which might be due to the lower soil moisture contents 50-75 m along the furrows in both continuous and surge irrigation because the water flowed through faster than in furrows with weirs.

Treatment 5 consumed less irrigation water (344 mm) and man hours for irrigation (73.6). This might be due to the more rapid water front advance in surge irrigation (Bishop et al. 1981). Treatment 7 gave higher water-use efficiency (14.72 kg of sorghum grain ha^{-1} mm of irrigation water used) than Treatment 4. Treatment 9 consumed the most irrigation water (608 mm) and labor for irrigation (165.2 man hours ha^{-1}) with the lowest water-use efficiency (8.93 kg grain ha^{-1} mm of water) which might due to the deep percolation of its irrigation water. Treatment 8 produced sorghum yields comparable to those of Treat-ment 4 with considerable water saving (17.88%).

It can be concluded that Treatment 8, i.e., surge irrigation + 20 t coir pith ha^{-1} + hydrophilic weirs placed at 50 and 75 m levels across the furrow can be recommended as a way to increase productivity with considerable irrigation water saving in the cultivation of grain sorghum.

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Effect of Lime-induced Iron Stress on Plant Growth, Seed Yield, and Quality in Sorghum

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Introduction

Iron (Fe) is a micro-nutrient that is usually present in all soils in sufficient quantities for crop growth. Iron availability mostly depends on its interaction with soil type, crop plant, and translocation through the shoot to young leaves in advanced growth stages. In soils of Fe-deficient regions, iron availability is reduced by high pH and calcium carbonate ($CaCO_3$) (Naik and Joshi 1981). In India, Fe-deficient soils are characterized as dark brown clays of highly calcarious nature, with thick B-horizons.

The present investigation was based on the presence of patches of plants with chaffy and sterile panicles in sorghum [*Sorghum bicolor* (L.) Moench] seed production plots in Coimbatore district, Tamil Nadu. The study revealed that the soil beneath such patches contained $CaCO_3$ nodules at concentrations of 200-500 g 0.028 m^{-3} of soil. This prompted a study on the possible influence of $CaCO_3$ nodules on the growth, development, seed set, yield, and quality in sorghum genotypes.

Materials and methods

A pot culture experiment was conducted in a factorial randomized-block design (RBD) with four replications each, with 2077 B, CO 21, TNS 30 and COH 3 sorghum genotypes and four levels of CaCO., nodules (200, 300, 400 and 500 g 0.028 nr^{1} of soil). Three sorghum plants were grown in each pot. The experiment was repeated three times.

Plant height (cm), leaf area $plant^{-1}$ (cm^2), seed set (%), mean seed yield (g), and 100-grain mass (g) were recorded. The chlorophyll content of leaves, pollen viability, seed germination and vigor index (computed by multiplying seed germination by root length of seedlings expressed as an absolute value) were measured according to International Seed Testing Association recommended procedures.

Available nitrogen(N), phosphorus (P), and potassium (K) in soil, total micronutrients [Fe, copper (Cu), magnesium (Mn), and zinc (Zn)] in soil and in plant, starch and protein content in the seed, the catalase, peroxidase and cytochrome oxidase activity in plant samples, dehydrogenase and and α-amylase activity in seeds were estimated using standard chemical procedures. The results were analyzed using a factorial RBD as suggested by Sunderaraj et al. (1972).

Results and discussion

Significant increases in pH, available N, P, K and total Cu, Zn, and Mn were observed, while the total Fe in soil and plants decreased with increasing $CaCO_3$ levels (Table 1). As a result, chlorophyll content, plant height, and leaf area $plant^{-1}$ decreased significantly (Table 2). This may be due to accumulation of toxic levels of N (Christie 1979), P (Krastina et al. 1971), K (Klossowski 1977), Cu (Aoba and Skiya 1977), and Zn (Chavan and Banerjee 1979).

Table 1. Effect of calcium carbonate ($CaCO_3$) levels on nutrient status of soil and leaf chlorophyll contents of sorghum

$CaCO_3$ (g 0.028 m;^{3})	Soil pH	Available macro-nutrients (ppm) N	P	K	Total micro-nutrients (ppm) Fe	Cu	Zn	Mn	Chlorophyll (OD)[1]
200	8.5	130.0	18.0	309.5	2.4	36.7	83.0	404.7	0.37
300	8.8	132.0	18.0	313.7	1.8	39.8	82.8	407.5	0.36
400	9.0	136.1	18.4	319.7	0.9	42.7	86.0	410.5	0.34
500	9.9	143.4	19.9	324.3	0.4	45.8	89.3	412.7	0.33
Control (O)	7.6	129.2	17.5	309.6	3.1	36.5	80.8	404.6	0.38
Mean	8.8	134.1	18.4	315.4	1.7	40.3	84.4	408.0	0.36
CD (0.05)	0.02	0.26	0.08	2.48	0.01	0.49	0.55	0.57	0.01

1. Optical density chlorophyll, expressed as mg g^{-1} fresh or dry weight

Table 2. Effect of calcium carbonate ($CaCO_3$) levels on plant and seed attributes in sorghum

$CaCO_3$ (g 0.028 m^{-3})	Plant height (cm)	Leaf area (cm^2)	Pollen viability (%)	Seed set (%)	Seed yield $plant^{-1}$ (g)	100-grain mass (g)	Seed germination (%)	Vigor index
200	123.4	1052.2	72.1	41.2	45.0	2.9	87.2	1477
300	108.1	1018.7	68.9	30.7	29.3	2.2	70.2	1075
400	85.5	945.0	67.6	14.5	21.6	1.5	62.1	1075
500	74.9	844.6	66.7	6.0	12.5	0.7	60.6	993
Control (O)	142.6	1139.6	72.7	82.2	48.5	3.0	88.4	1506
Mean	106.9	1000.0	69.6	34.9	31.4	2.1	72.4	1225
CD (0.05)	1.78	31.63	1.20	0.31	0.31	0.01	0.43	63.09

Table 3. Effect of calcium carbonate ($CaCO_3$) levels on biochemical composition of sorghum

$CaCO_3$ (g 0.028 m^{-1})	Starch (%)	Protein (%)	Seed hydro-genase (OD)[1]	Seed a amylase activity (mm)	Absorbance (min^{-1} g^{-1} fresh leaf mass at flowering)		
					Catalase	Peroxidase	Cytochrome oxidase
200	69.2	10.6	0.41	6.7	1.42	1.38	12.2
300	52.6	8.1	0.30	5.0	1.27	1.31	12.0
400	52.4	7.9	0.28	4.9	1.13	1.22	11.9
500	52.2	7.9	0.27	4.7	1.12	1.16	11.8
Control (O)	69.3	10.7	0.41	6.7	1.46	1.41	12.5
Mean	59.1	9.0	0.33	5.6	1.28	1.30	12.1
CD (0.05)	0.20	0.06	0.02	0.11	0.04	0.02	0.03

1. OD - Optical density chlorophyll, expressed as mg g^{-1} fresh or dry mass

However, significant decline in the Fe *content* in the leaves was mainly due to interference in uptake of Fe by excessive levels of N (Christie 1979), P (Decock et al. 1979), K (Krastina et al. 1971), Cu (Daniel et al. 1973), Mn (Wein-stein and Robbins 1955), and Zn (Chaney et al. 1972) in the root zone, which is the primary site of nutrient absorption. Consequently, there was reduction in plant height and increased leaf chlorosis. Also, increased levels of $CaCO_3$ in soil reduced catalase peroxidase and cytochrome oxidase in leaves sampled at flowering (Table 3).

Since Fe is a constituent of metabolically active compo-unds, it has a catalytic function in biological oxidation- reduction. Due to the non-absorption or inactivation of Fe in the plant system, chlorosis is aggravated, resulting in delayed flowering, and reduced pollen viability, seed set, 100-grain mass and grain yield $plan^{-1}$ (Table 2).

Plants grown in soils with high $CaCO_3$ levels had smaller, shriveled seeds with lower starch and protein contents and reduced dehydrogenase and α-amylase activity (Table 3). Such seeds recorded significantly lower germination and vigor indices reflecting the deleterious effect of high levels of $CaCO_3$ on seed quality components. This is probably due to $CaCO_3$-induced limitation in the flow of assimilates to developing seed due to a cut off in respiration-linked ion uptake.

In the present study, genotypic differences for Fe stress response were more evident in the parental line 2077B followed by CO 21, TNS 30, and COH 3. Genotype 2077B showed significantly lower values for plant height, leaf area at flowering, chlorophyll content, pollen viability, seed set, seed yield $plant^{-1}$, 100-grain mass, seed germination, vigor index, catalase, peroxidase, and cytochrome oxidase activity, starch and protein contents *of seeds* and dehydrogenase and a-amylase *activity in* seeds, followed by CO 21, TNS 30, and COH3. In fact, 2077B did not set any seed at 300-500 g $CaC0_3$ 0.028 m^{-3} of soil. In the remaining three genotypes, there was significant reduction in seed set and seed yield at higher soil levels of $CaCO_3$.

Based on the above findings, genotype 2077B can be classified as 'Fe-inefficient' and CO 21, TNS 30 and COH3 as 'Fe-efficient' as their seed set. yield and quality were significantly superior to that of 2077B. However, the mechanism by which Fe stress in sorghum is overcome by 'Pe-efficicnt' genotypes is not still completely under-stood, except that they have been found to reduce soil pH, probably by the release of hydrogen (H^+) ions (Kannan et al. 1984). The average reduction in pH at flowering was from 8.84 to 8.19 in 2077B, 7.67 in CO 21, 7.53 in TNS 30 and 7.13 in COH3. In addition, Kannan et al. (1984) reported that Fe-efficient genotypes excrete butyl phthalate in addition to releasing of H' reductants that convert ferric ions into more soluble ferrous ions. This probably helps them to overcome Fe stress. In conclusion, it can be said that high levels of $CaCO_3$ in soil lead to 'lime-induced iron stress' that causes disturbance in the physiology and reproduc-tive behavior of sorghum genotypes.

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Pests and Diseases

Fecundity and Longevity of Greenbug Affected by Biotype and Temperature

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Introduction

Greenbug, *Schizaphis graminum* (Rondani), is a major insect pest of small-grained cereals and sorghum, *Sorghum bicolor* (L.) Moench. Originally a pest of winter wheat, *Triticum aestivum* L., the greenbug first became a persistent pest of sorghum in the United States in 1968 (Harvey and Hackerott 1969). Since then, four greenbug biotypes, C, E, I, and K, that damage sorghum have developed. Greenbugs suck juices from and inject toxin into more than 70 grass hosts including sorghum (Michels 1986). Injury can kill seedlings or severely limit the yield of more mature sorghum plants.

Currently, biotypes E and I are dominant on sorghum. Resistant sorghums are the primary defense against greenbug damage. Little is known about how greenbug biotypes develop. Understanding greenbug biology and how biotypes develop is key to developing cultivars with sustainable resistance. The goal of this study was to assess the effect of temperature on the fecundity and longevity of greenbug biotypes E and I to better under-stand greenbug biology, and more accurately evaluate sorghums for resistance to greenbugs.

Materials and methods

Fecundity and longevity of greenbug biotypes E and I were assessed on susceptible RTx430 sorghum plants in an environmental chamber (Precision Model 818 Microprocessor Controlled Low Temperature Illuminated Incubators) set at 14-27 and 22-35 °C and a light.dark cycle of 14:10 h. Seeds were sown in Miracle-Gro Enriched Potting Mix® with Miracle-Gro Plant Food® in 20, 20.3-cm diameter plastic pots in a greenhouse at West Texas A & M University, Canyon. Five pots were used for each combination of temperature and greenbug biotype. Seedlings were thinned to 4 plants pot^{-1}.

Greenbugs were obtained from two pure cultures of biotypes E and I maintained in a greenhouse at West Texas A & M University. A single greenbug enclosed in a 2.5-cm^3 clear plastic clip cage was attached to each of two leaves on a sorghum plant that had seven true leaves. A total of 40 greenbugs of each biotype was used at each temperature. The infested plants were transferred to an environmental chamber set at the desired temperature. The original greenbug in each clip cage was monitored daily and discarded after it had produced a nymph. One nymph, whose birth date was recorded, was retained in each clip cage and allowed to mature to produce offspring. When the greenbug in each clip cage had matured and begun producing offspring, the nymphs produced each day were counted and removed. The greenbug was monitored until death, so total fecundity and longevity could be recorded.

Results and discussion

Significantly fewer greenbugs were produced day^{-1} at the cooler temperature of 14-27°C (1.3) than at the warmer temperature of 22-35°C (Table 1). Overall, significantly more greenbugs were produced at the cooler temperature (47.6 total) than at the wanner temperature (14.0 total). Average longevity was four times greater at the cooler temperature (37.5 days) than at the warmer temperature (9.4 days).

Table 1. Effect of temperature on fecundity and longevity of greenbug biotypes E and I, greenhouse study, West Texas, USA

Temperature (°C)	Average nymphs produced day^{-1}	Aveage fecundity	Average longevity
14-27	1.3 a[1]	47.6 a	37.5 a
22-35	1.5 b	14.0 b	9.4 b

1. Means followed by the same letter within a column are not significantly different at P = 0.05 ($LSD_{fecundity}$ = 5.27, $LSD_{fecundity/day}$ = 0.13, $LSD_{longevity}$= 2.34).

Significantly more nymphs were produced day^{-1} by greenbug biotype E (1.5 nymphs) than by biotype 1(1.2) (Table 2). The average fecundity of biotype E was significantly greater than that of biotype I. Longevity did not differ between the two biotypes, with greenbugs of both biotypes surviving for approximately 23 days.

Table 2. Effect of biotype on greenbug fecundity and longevity, greenhouse study, West Texas, USA

Temperature (°C)	Average nymphs produced day^{-1}	Aveage fecundity	Average longevity
E	1.5 a[1]	33.8 a	23.0 a
1	1.2 b	27.8 b	23.9 a

1. Means followed by the same letter within a column are not significantly different at P = 0.05 ($LSD_{fecundity}$ = 5.27, $LSD_{fecundity/day}$ = 010,$LSD_{longrvity}$ = 2.34).

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Greenbug Fitness on Sorghum and Non-Cultivated Hosts

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Introduction

The greenbug (*Schizaphis graminum* (Rondani)) is a major insect pest of sorghum (*Sorghum bicolor* (L.) Moench) and other small grained cereals. Greenbugs infest more than 70 species of grasses in 44 genera (Michels 1986). Eleven biotypes of greenbug (A-K) have been identified. Biotypes are genetically distinct populations that differ in their response to host plants. Biotype I is currently dominant in Texas. When cultivated cereal crops are not available, greenbugs are thought to survive on wild grasses. The objective of this study was to evaluate the fecundity and longevity of greenbug biotype 1 on sorghum and non-cultivated grass hosts.

Materials and methods

Non-cultivated hosts were Johnsongrass (*Sorghum halepense* (L.) Pers.), Arriba western wheatgrass (*Agropyron smithii* (Rybd.) Love), and jointed goatgrass (*Aegilops cylindricum* (Host) Ces). Sorghum cultivars were RTx 430 (susceptible) and LG 35 (resistant). Seeds were sown on 18 March 2002, in 13-cm-diameter plastic pots filled with Miracle Gro® potting mixture. Each pot was covered by a cylindrical, clear plastic cage covered on top with organdy cloth to allow aeration of the plants. Water was added when the soil was dry. Thirty pots were arranged in a randomized complete-block design (RCBD) with six blocks on benches in a greenhouse; each of the five kinds of grasses was in each block. The temperature in the greenhouse was 21-32°C.

Plants were infested with greenbugs on 1 May 2002. Greenbugs were obtained from a culture of biotype I maintained in a greenhouse at West Texas A & M University, Canyon. One apterous female greenbug was placed in a 2.5-cm^3 clip cage with an organdy-covered hole in each of two sides. A cage was clipped onto a leaf of each of three plants in each pot. Eighteen clip cages were used for each kind of plant. The original greenbug was removed after it produced a nymph. The date the nymph was born was recorded. The nymph was kept in the clip cage until it produced offspring, which were counted and removed each day. The total number of days the greenbug in each clip cage lived was recorded.

Results and discussion

The number of greenbug nymphs produced per day differed significantly among the grass hosts (Wilk's Lambda = 0.045, $F_{(32.52)}$ = 34.73, P < 0. 0001). Significantly fewer greenbug nymphs were produced on western wheatgrass than on the other hosts (a = 0.05, LSD = 11.9) (Table 1). A total of only about 35% as many nymphs (22.8) was produced per greenbug on western wheatgrass as on the susceptible sorghum (64.4 nymphs). The total number of greenbugs produced on resistant sorghum was not significantly different from those produced on susceptible sorghum. Longevities of greenbugs were significantly less (a = 0.05, LSD = 4.6) on jointed goatgrass and western wheatgrass (19.2 days) than on grasses of the genus *Sorghum.* The mechanism of resistance of biotype I-resistant sorghum is not known, but resistance seems to be due to antixenosis or tolerance rather than antibiosis.

Table 1. Mean total number of nymphs produced and longevity per biotype I greenbug

Host	Mean number of nymphs^{-1}	Mean longevity (days)
RTx 430 sorghum	64.4 a	26.9 a
Johnsongrass	60.1 a	27.6 a
LG-35 sorghum	57.4 a	28.2 a
Jointed goatgrass	61.0 a	19.2 b
Western wheatgrass	22.8 b	19.2 b

1. Means followed by the same letter within a column are not significantly different at P = 0.05 (Fisher's LSD).

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Michels, G.J. 1986. Graminaceous North American host plants of the greenbug with notes on biotypes. Southwestern Entomology 11(2): 55-64.

Shoot Bug Incidence on Sorghum in Southern India

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Of the insect pests of sorghum *[Sorghum bicolor* (L.) Moench], shoot bug (*Peregrinus maidis* Ashmead) (Delphacidae: Homoptera) has attained serious pest status due to the introduction of hybrids that mature at different times in certain parts of Andhra Pradesh, Karnataka, and Tamil Nadu. In India shoot bugs can cause 4 1 % losses (Hosmani and Chittapur, 1997). Both nymphs and adults suck the sap of young leaves, resulting in leaf chlorosis that in severe cases causes stunted growth and shrivelled, chaffy grains (Prabhakar et al. 1981). Severe infestation at the boot stage results in the top leaves twisting and preventing the emergence of the panicles (Agarwal et al. 1978). In the Telangana region of Hyderabad, Andhra Pradesh, this pest causes severe damage to sorghum crops. Shoot bug incidence on 20 promising sorghum genotypes was studied.

A field trial was carried out to determine the incidence of shoot bug during the rainy season *(kharif),* 1998 at the farm attached to National Research Centre for Sorghum (NRCS), Rajendranagar, Hyderabad, India. Twenty promising and high-yielding genotypes were sown on 17 July, 1998. The genotypes were sown in 10-m row plots at a 45 x 15 cm spacing in three replications in a randomized-block design. Standard agronomic practices were used to raise the crop successfully. Shoot bug incidence began in the second week of September 1998. The number of shoot bug adults and nymphs plant^{-1} were recorded on 5 plants at 10-day intervals.

The shoot bug incidence is shown in Table 1. Among genotypes, the maximum number of shoot bugs plant^{-1} was recorded on M 35-1 (25.80) followed by Swati (23.40), SPV 462 (22.40) and ICSV 705 (20.00). The smallest number of shoot bugs was registered on DJ 6514 (3.50) followed by ICSV 700 (5.90), IS 2205 (6.40) and CSH 13 (6.80). After an interval of 10 days, the second monitoring was carried out and it was noticed that in all the genotypes the population of shoot bugs was lower than that during first monitoring, except for ICSV 700 on which there was a slight increase over the first monitoring. Of all the genotypes, the highest numbers of shoot bugs plant^{-1} was recorded on M 35-1 (9.50) followed by ICSV 700 (7.60), CSV 15 (6.40), and ICSV 745 (6.10). The smallest number was recorded on DJ 6514 and CSG 9 (1.60) followed by CSH 13 (2.00), and CS 3541 (2.90).

Table 1. Incidence of shoot bug on 20 genotypes of sorghum, Rajendranagar, Hyderabad, India, postrainy (*rabi*) season, 1998

Genotype	Number of shoot bugs plant^{-1}			Plants infested (%)
	64 DAE[1]	74 DAE	Mean	
ICSV 700	5.9	7.6	6.8	18.9
ICSV 705	20.0	5.5	12.8	28.2
ICSV 745	11.6	6.1	8.9	48.1
SPV 462	22.4	4.5	13.5	23.8
SPV 492	9.1	4.7	6.9	11.7
SPV 839	12.5	4.3	8.4	37.5
CSH 6	8.6	4.1	6.4	9.5
CSH 9	13.2	1.6	7.4	31.3
CSH 13	6.8	2.0	4.4	33.3
CSH 14	9.2	4.3	6.8	28.8
CSH 16	8.3	4.6	6.5	26.7
CSV 15	9.3	6.4	7.9	50.5
Swati	23.4	4.4	13.9	41.8
RS 29	17.8	5.4	11.6	44.5
M 35-1	25.8	9.5	17.7	33.2
CS 3541	9.0	2.9	6.0	17.2
DJ 6514	3.5	1.6	2.6	27.1
IS 2205	6.4	3.6	5.0	29.6
IS 2212	8.3	4.2	6.3	38.5
IS 18551	9.1	4.2	6.7	39.8
CD (P = 0.05)	-	-	-	NS[2]

1. DAE = Days after emergence
2. NS = Non-significant

The mean populations in both monitorings clearly indicated that M 35-1 (17.70), Swati (13.90), SPV 462 (13.50), and ICSV 705 (12.80) are genotypes highly susceptible to shoot bug damage. DJ 6514 (2.60), CSH 13 (4.40), IS 2205 (5.00), and CS 3541 (6.00) are less susceptible to shoot bug. When the percentage of plants infested is considered, the maximum number of damaged plants was recorded on CSV 15 (50.5%) and minimum on CSH 6 (9.5%), but the difference among genotypes was not significant. The highest population of shoot bugs (adults and nymphs) was recorded on M 35-1 and the lowest on DJ 6514 in both monitorings. The present experimental results are similar to work by Agarwal et al. (1978) who screened 127 cultivars of sorghum for shoot bug and noticed that I 753, H 109, GIB 3677B, and BP 53 were free from infestation, and Rajasekhar (1989) who evaluated 88 sorghum genotypes and found that hybrids MSH 65 and SPH 3888, and varie-ties SPV 475, 678, 736, 741, 756, 775, 819, 858, and CSV 10 showed promising resistance to shoot bug. Genotypes DJ 6514, CSH 13, IS 2205, and CS 3541 have potential for incorporation in sorghum shoot bug resistance breeding programs.

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Sorghum Diseases in Eritrea - A Survey Report

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Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the main food crops of Eritrea. It is particularly important in the lowlands where rainfall is erratic but it is grown in nearly all Zobas (zones), including the highlands. Average yields are about 0.5 t ha^{-1}. The most common reasons for low yields are drought, pests, diseases and weeds (Shattercane, *Striga,* wild sorghums and their intermedia-tes with cultivated sorghum) and lack of improved practices (Tesfamichael 1999; Obilana et al. 2002). A survey of diseases in major sorghum-growing areas was carried out under the collaborative sorghum and pearl millet research in Eritrea (Danida-Eritrea-ICRISAT collaboration).

Materials and methods

The survey covered highland (Debub zone) and lowland (Gash Barka zone) sorghum-growing areas, excluding the Northern Red Sea zone, it was conducted with the assistance of plant protection personnel from the Eritrean Department of Agriculture. Thirty-five fields (approximately 207 ha) at 15 locations in the lowlands, and 13 fields (approximately 15 ha) at 8 locations in the high-lands were surveyed for sorghum diseases. At each location information on site identification, cultivar, area sown, number of fields, latitude and longitude using a global positioning machine (Garmin GPS 12XL®, Garmin International, 1200 East 151st Street, Olathe, Kansas 66062, USA), crop stage, and cultural practices was collected from farmers. Information on cropping sequence for the last three seasons was also noted.

The disease incidence was based on the percentage of diseased plants in five randomly selected subplots (4 m^2) in each field. Both incidence and severity were recorded for leaf diseases and smuts, only incidence for *Striga,* and severity for foliar diseases based on mean percentage area damaged on the top four leaves.

Results and discussion

Sorghum was grown mainly in the western lowlands and highlands (altitude range 610-2075 m; latitude 14°19'-15°09' Nand longitude 36°31'-38°52' E). In most areas the crop was at the soft to hard dough stage. In highland areas, local landrace cultivars, such as Shiketi, Ammal, and unknown locals were predominant whereas in lowland ares local landrace cultivars, such as Wediaker, Faterita, Hariray, Hugurtay, Wediferege, Arfaghedemes, Wediaker-keihafu, Bazenay, and Wediahmad were predominant (Table 1). Shattercanes and their intermediate types with cultivated sorghum were observed as contaminants in most fields. *Striga hermonthica* (Del.) Benth. was predominant in and around fields of sorghum.

The diseases recorded included such foliar diseases as leaf blight *(Exserohilum turcicum* (Pass.) K.J. Leonard & E.G. Suggs), anthracnose (*Colletotrichum graminicola* (Ces.) GW. Wilson), zonate leaf spots (*Gloeocercospora sorghi* D. Bain & Edgerton ex Deighton), gray leaf spots (*Cercospora sorghi* (Ellis & Everh.), oval leaf spots (*Ramulispora sorghicola* E. Harris), sooty stripe (*Ramulispora sorghi* (Ellis & Everh), downy mildew [*Peronosclerospora sorghi* (W. Weston & Uppal) C.G Shaw]; and panicle diseases including head smut [*Sporisorium reilianum* (Kuhn) Langdon & Fullerton], covered kernel smut *[Sporisorium sorghi* (Link in Willd.)l, loose kernel smut *[Sporisorium cruentum* (Kuhn) K. Vanky], and long smut *{Sporisorium ehrenbergii* Vanky).

Table 1. Distribution of sorghum diseases on local cultivars grown in two zones of Eritrea surveyed during the 2001 rainy season

Zone	Sub-zone	Cultivars grown	Diseases identified
Debub	Mendefera	Locals	Covered smut, Head smut, *Striga*
	Adi Quala	Shiketi, Ammal	Anthracnose, Covered kernel smut
Gash Barka	Shambuko	Wediaker	Anthracnose, Leaf blight, Head smut, Loose kernel smut, *Striga*
	Gogne	Bazenay	Loose kernel smut, *Striga*
	Goluj	Wediaker, Faterita, Hariray, Wediferege, Hugurtay, Arfaghedemes, Wediaker-Keihafu, Locals	Leaf blight, Anthracnose, Zonate leaf spot, Gray leaf spot, Sooty stripe, Oval leaf spot, Loose kernel smut. Head smut, Covered kernel smut. Stalk rot, *Striga*
	Tessenei	Wediaker, Hugurtay, Hariray, Wediahmad	Leaf blight, Anthracnose, Zonate leaf spot. Gray leaf spot. Sooty stripe, Oval leaf spot, Loose kernel smut, Head smut. Covered kernel smut, Long smut, Downy mildew. Maize Dwarf Mosaic Virus, *Striga*

Table 2. Mean disease reactions[1] across local landrace cultivars grown in farmers' fields in Eritrea surveyed during the 2001 rainy season

Disease	Fields	Disease incidence (%)		Disease severity (%)	
		Mean	Range	Mean	Range
Leaf blight	18	23 ± 4.2	5-60	16 ±2.5	5-40
Anthracnose	17	43 ± 6.6	10 100	24 ± 3.5	10-50
Gray leaf spot	7	25 ± 9.3	10-80	20 ± 5.7	5-50
Zonate leaf spot	9	36 ±10.5	10 90	32 ± 9.9	10-80
Oval leaf spot	2	35 ± 15.0	20-50	20 ± 0.0	20-20
Sooty stripe	5	11 ±2.4	5-20	10 ±3.9	5-25
Loose kernel smut	13	29 ± 4.8	1-50	58 ± 6.8	20-100
Covered kernel smut	7	19 ±5.2	1-35	58 ± 2.9	50-70
Head smut	8	2 ± 0.6	1-5	100 ±0.0	100-100
Long smut	4	4 ±2.1	1-10	2 ± 0.3	1-2
Striga	17	44 ±7.5	2-100	-	-

1. Across 10 predominantly grown cultivars: Faterita, Hariray, Hugurtay, Wediaker, Wediahmad, Wediakerkeihafu, Wedeferage, Bazenay, Gcdamhamam, and Arfaghedemes

In highland areas covered kernel smut was predominant with mean incidences of 5-8% and 35-50% severity on Shiketi and some other local cultivars, followed by head smut with 5% incidence and 100% severity on local cultivars. About 10% incidence *of Striga* was recorded on local cultivars. Local cv. Ammal was free from both leaf diseases and smuts.

In lowland areas the occurancc of individual diseases and their incidence and severity across cultivars are summarized in Table 2. Among leaf diseases, leaf blight (prevalence 50%, incidence 23% and severity 16%), anthracnose (prevalence 50%, incidence 43% and severity 24%) and zonate leaf spot (prevalence 27%, incidence 36% and severity 32%) were important. Among smuts, loose kernel smut (prevalence 37%; incidence 29% and severity 58%) and covered kernel smut (prevalence 20%, incidence 19% and severity 58%) were important. Wediaker was found to be the most susceptible cultivar to all the leaf diseases and smuts except long smut followed by Hariray. Bazenay was free from leaf blight, anthracnose, zonate leaf spot, sooty stripe, oval leaf spot, covered kernel smut and head smut followed by Hugurtay and Faterita which were free from gray leaf spot, oval leaf spot, sooty stripe, covered kernel smut, head smut and long smut. Stalk rot caused by *Colletotrichum graminicola* (Ces.) GW. Wilson was also observed on Wediaker with 60% incidence.

Striga was recorded on all the cultivars with a range of 2-100% incidence. *Striga* incidence was comparatively lower in highland areas that receive more rainfall than on the cultivars grown in lowlands where rainfall was less, indicating that drought stress may enhance the incidence of *Striga.* The Eritrean farmers were of the opinion that *Striga* appears mostly at the flowering stage and drought enhances *Striga* infestation. Heavy rains and fertilizer application reduce *Striga* infestations. Farmers observed reduction in *Striga* infestation when sorghum is grown in rotation with sesame (*Sesamum indicum* L). Fallowing land for 2-3 years reduced *Striga* infection. Since shattercanes and their intermediate types had all leaf diseases including downy mildew and smuts, their role as collateral or alternate hosts for sorghum diseases need investigation.

Because sorghum after sorghum cropping sequence was the most common practice, its impact as a primary source of inocula for several diseases requires further investiga-tion.

The average rainfall in area under survey was about 500 mm. About 10 local cultivars are grown pre-dominantly indicates that there is limited genetic diversity in the local sorghum gcrmplasm of Eritrea. Treatment of seeds with cow's urine (stored for 3 days in a closed container) is thought to reduce infection by smuts. These local practices require further investigations. Breeding for resistance to the most economically important foliar and panicle diseases coupled with improved agronomic and seed treatment practices could help to reduce losses in yield and fodder.

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Leaf Blight of Sorghum Caused by *Drechslera australiensis*—a New Report from India

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Foliar diseases of sorghum (*Sorghum bieolor* (L.) Moench] are potential yield reducers as they cause premature drying of leaves that results in considerable reduction in grain and fodder yields. The widely prevalent common leaf blight is incited by *Exserohilum turcicum* (Pass.) Leonard & Suggs (Frederiksen 2000). We have observed a leaf blight on grain sorghum cultivars in Rajasthan, India, caused by a different pathogen, *Drechslera australiensis* as described below.

Severely blighted leaves of local landrace cultivars grown in a farmers' field near Udaipur were collected in the rainy season, 2001. The characteristic symptoms were narrow (1-5 mm) lesions of varying (2-71 mm) length. The lesions had reddish brown margins and straw-colored centers, and coalesced to cover the leaf lamina (Fig. 1). Isolation from the diseased leaves on potato dextrose agar (PDA) medium yielded a culture with brownish-grey mycelium and pale brown, small, 3-septate conidia resembling *Drechslera* sp. Pathogenicity of the purified culture was tested by spray inoculating (1 x 10^5 conidia mL^{-1}) on

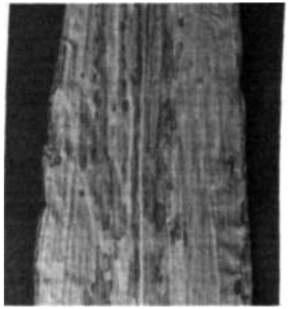

Figure 1. Symptoms on sorghum due to *Drechslera australiensis*.

the leaves of 21-day old plants of known susceptible sorghum cultivar, Kekri local. The characteristic lesions developed within 7 days of inoculation.

The cultural and morphological characters of the isolate were studied in details in slide culture. The conidiophores were geniculate, measuring 90-300 x 3-6 mm. Conidia were solitary and arranged in a verticillate manner, straight, ellipsoidal to oblong, rounded at the base, pale brown, 3-pseudoseptate with slightly protruding hilum, and measured 15.5-31.8 x 7.5-15.7 mm. The pathogen resembled *Drechslera australiensis* (Bugnicourt) Subramanian and Jain ex M.B. Ellis. A search through the literature revealed that *D. australiensis* has so far been reported from living leaves of *Sorghum halepense* L. (Kushawaha et al. 1999), and ours is the first report of it causing severe leaf blight on grain sorghum. Similar cultures were subsequently recovered from leaf samples received from Surat and Parbhani, and further studies on these are in progress.

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Bacterial Leaf Streak of Sorghum— a New Report from India

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Introduction

At least 10 bacterial diseases have been reported on sorghum *[Sorghum bicolor* (L.) Moench] of which bacterial stripe [*Pseudomonas andropogonis* (Smith) Stapp], bacterial leaf streak (BLS) [*Xanthomonas campestris* pv. *holcicola* (Elliott) Starr & Burkholder], and bacterial spot (*Pseudomonas syringae* pv. *syringae* van Hall) Claflin et al. (1992) are considered to be economically important. In southern Africa, BLS of sorghum has reported from Angola, Lesotho, Malawi, Tanzania but the pathogen's identity was not confirmed, whereas from the Republic of South Africa, BLS has been reported with confirmed identity (de Milliano 1992). Occurrence of BLS was also reported from West Africa, South America, Mexico, North America, Iran, and Japan. Noble and Richardson (1968) reported the seedborne nature of BLS; however experimental data were not presented. Rao et al. (1990) have detected *X. campestris* pv. *holcicola* in sorghum leaves by dot immunobinding assay in a sorghum sample imported to India from Yemen in 1987. *X. campestris* pv. *holcicola* is a pathogenic and quarantined organism. In several countries this bacterium is used as trade barrier. Bacterial leaf streak has not previously been reported from India. This paper reports the occurrence of the disease on sorghum in field conditions at the ICRISAT research farm, Patancheru, Andhra Pradesh, India, and in several farmers' fields surveyed in Karnataka, India, from August 1999 to March 2001 and in elite germplasm accessions evaluated for resistance to foliar and panicle diseases during the 2001 rainy season at ICRISAT, Patancheru.

Material and methods

BLS-infected leaves of cultivar H 112 were collected from the field in the first week of July 2000. Infected portions of leaves were cut in to 1 -cm^2 pieces, surface-sterilized in 1% sodium hypochlorite and washed three times in sterile distilled water. The pieces were plated on nutrient agar medium. The plates were incubated at 25±1°C for 4 days. Subsequent sub-culturing and multiplication was done on sucrose peptone agar medium (sucrose 20 g, peptone 5 g, potassium hydrogen phosphate 0.5 g, magnesium sulphate heptahydrate 0.25 g, and 15 g agar in 1000 mL water). The antiserum to X. *campestris* pv. *holcicola* obtained from L E Claflin, Kansas State University, Manhattan, USA, which had a titer of about 1500, was used to test against the bacterium following an ELISA technique.

To prove the pathogenicity of the bacterium, 30-day-old sorghum seedlings were inoculated with freshly grown bacterium following carborundum powder, vacuum pump, and other methods described below. In the carborundum powder method, 10 30-day-old potted seedlings of variety H 112, were sprayed with carborundum powder (BDH Chemicals, UK, about 300 grit) to create wounds on either side of the leaf surface, and 15 minutes later, absorbent cotton dipped in bacterial suspension was smeared over the leaf surfaces. Seedlings were incubated in a growth chamber for 24 h with a 12-h light cycle. Later the pots were moved to greenhouse benches. Two controls were maintained, one with only carborundum spray, and another with carborundum spray followed by swabbing with sterile distilled water.

In the vacuum pump method, lids of two bottles were marked and cut to an appropriate size to insert a leaf and the plastic pipe of a vacuum pump (Charles Austen Pumps Ltd, 100 Roystan Road, Byfleet Weybridge, Surrey UK). The leaf edges of the seedling were either clipped or left intact. Seedlings with their leaves intact were inserted into a bottle containing bacterial suspension. The container was sealed using wax. The vacuum pump was operated for 3-4 minutes for each leaf dipped in the suspension. Entry of the bacterial suspension into the leaf was ensured by observing of air bubbles emerging from stomata and the cut leaf edges. The leaves were air-dried and incubated in a growth chamber for 24 h. Next day the pots of seedlings were moved to a greenhouse so symptoms could develop. The other methods tried were spray, injection, and drop-inoculation similar to those followed when testing for pearl millet downy mildew [*Sclerospora graminicola* (Sacc.) J. Schrott] (Singh et al. 1997). For control treatments sterile distilled water was used instead of bacterial suspension. The experiment was repeated twice.

Results and discussion

The BLS symptoms observed on H 112 at the ICRISAT research farm were similar those described by Frederiksen and Odvody (2000). Small water-soaked, reddish-brown necrotic streaks appeared in the early stages that later elongated and darkened. Later still the lesions broadened and developed tan centers with a narrow red margin. These symptoms were delimited by the veins (Figure la). Occasionally, tiny, yellow, bead-like exudations were found on lesions. The narrow, long or short translucent lesions coalesced forming large patches (Figures 1b and 1c). In severe cases, affected leaf parts acquired a burned appearance (Figures 1d and 1e). At this stage the leaves withered, and turned brown. The most-prominent symp-toms were elongate lesions or areas of discoloration, usually of limited length, parallel to the leaf veins (Figure 1b). Out of 1014 elite germplasm accessions (originating from 45 countries) evaluated for various foliar and panicle diseases during the 2001 rainy season at ICRISAT, Patancheru, BLS was observed in seven accessions [IS 21977 (India), IS 14008, IS 14305, IS 24497 (South Africa), IS 29389 (Lesotho), IS 13177 (Argentina) and IS 25428 (Kenya). The BLS incidence was 4- 10% and the severity 2-20%. BLS was also observed in several farmers' fields in the state of Karnataka, during rainy and postrainy seasons (August 1999 to March 2001) while conducting disease surveys. The locations where BLS was observed were Ainapur [16° 49' 40" (N), 75° 46' 19" (E)], Kannolli [16°50' 84" (N), 76° 08' 24" (E)] and Bijapur [16° 49' 40" (N), 75° 46' 19" (E)] in Bijapur district; Hunagund [16° 18' 33" (N), 75° 54' 57" (E)] in Bagalakot district, Attigullapura [11° 50' 00" (N), 76° 59' 94" (E)], and Seenappanadoddi [11° 48' 88" (N), 77° 00' 17" (E)] in Chamarajnagar district; Dandinakuru-barahatti [14° 13' 82" (N), 76° 27' 70" (E)] in Chitradurga district; and Sege [13° 06' 69" (N), 76° 04' 73" (E)] in Hassan district. BLS incidence varied from 0.5-20% and its severity from 5-60%. The occurrence of BLS in various farmers' fields and on the research farm appears to be the first record from India (Frederiksen, R A, and Rajasab, A H, personal discussion).

The bacterium was consistently isolated from naturally infected sorghum plants grown in an experimental field at ICRISAT, Patancheru, in June 2000 and was identified as *Xanthomonas campestris* pv. *holekola* based on the reaction to the lyophilized antiserum to *X. campestris* pv. *holcicola* in ELISA plates. However, attempts to prove pathogenicity following several methods were unsuccessful.

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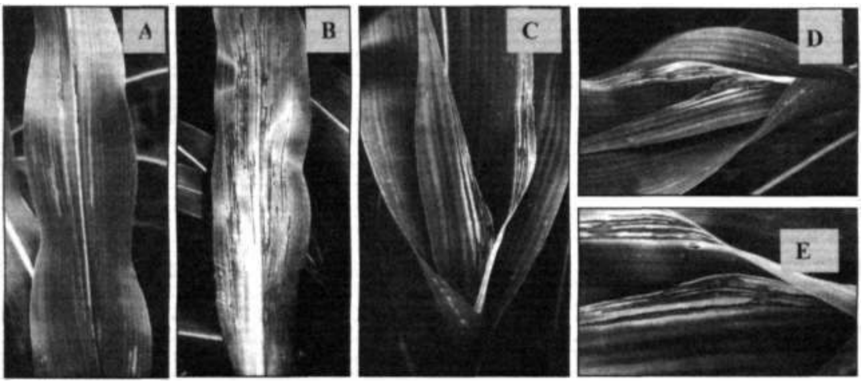

Figure 1. Symptoms of bacterial leaf streak *(Xanthomonas campestris* pv. *holcicola)* of sorghum, la. Streak delimited by the veins, lb. Elongate lesions or areas of discoloration, usually of limited length, parallel to veins, 1c. Narrow, long or short translucent lesions coalesced forming large patches, 1d and e. Burnt appearance similar to that of anthracnose and leaf blight.

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Usefulness of Non-senescent Parents for Charcoal Rot Resistance Breeding in Sorghum

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Introduction

Charcoal rot of sorghum (*Sorghum bicolor* (L.) Moench) is caused by the fungus *Macrophomina phaseolina* (Tassi) G Goid. The disease has a great destructive potential, particularly in postrainy (rabi)-scason sorghum. The ability of non-senescent genotypes to remain physiologically active during all growth stages of a crop may contribute to the overall tolerance and disease resistance mechanism, by minimizing the predisposition to charcoal rot infection, and its spread inside the stem (Duncan 1984).

Materials and methods

The Purdue population containing recombinant inbred lines (RILs) derived from a cross between non-senescent parent B 35 and senescent parent TX 7078 (100 lines) and the Queensland population based on non-senescent parent QL 41 and senescent parent QL 39 (144 lines including parents) were evaluated in an Alfisol field at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, during Nov 1995 Apr 1996. Withholding irrigation before flowering created drought conditions suitable for disease development. Each set of RILs and their parents, along with a few controls were sown in three replications in single-row 4-m long plots with a row spacing of 60 cm. Plant density was maintained at 11 plants m^{-2}. Recommended doses of fertilizers was applied to the plots along with carbofuran granules 4 kg ha^{-1} to protect the crop from stem borer [*Chilo partellus* (Swinhoe)].

To study plant senescence two criteria, leaf senescence (observations recorded for 6 days during the later phases of maturity till harvest), and the number of green leaves $plot^{-1}$, together with such other parameters as charcoal rot infection (%) and extent of disease spread were recorded at harvest, i.e., 10 days after physiological maturity. Soft stalk and lodging were scored using a 0-9 point disease-rating scale, where 0 is no disease, 1 is 10%, and 9 is 90% disease incidence.

To study the relationship between plant senescence and charcoal rot development, simple correlation and regression estimates were calculated for RILs of both populations. Further, to study the critical relationship between plant senescence and charcoal rot development, the 10 most-green genotypes, and 10 least-green genotypes were considered from each population and simple correlation and regression estimates calculated.

Results and discussion

In the Purdue population, correlation and regression analyses of different disease resistance characters, leaf senescence, and the number of green leaves $plot^{-1}$ revealed positive and significant correlations between lodging, soft stalk, extent of disease spread, charcoal **rot** (%) and leaf senescence, and negative and significant correlations between lodging, soft stalk, length of spread of disease, charcoal rot (%), and number of green leaves plot[1]. The coefficients of determination (γ^2) for correlation between lodging, soft stalk, extent of disease spread, charcoal rot (%), and leaf senescence were comparatively high (55-77%) compared to the correlation between lodging, soft stalk, extent of disease spread, charcoal rot (%), and green leaves plot^{-1} (30-54%) (Table 1). Based on 100 genotypes, the correlation and regression coefficients were highly significant.

One unit increase in leaf senescence corresponds to 1.34 units increase in percentage lodging, 1.56 units in soft stalk, 25.68 units in extent of disease spread, and 17.69 units increase in percentage charcoal rot infection. Whereas one unit increase in green leaves plot^{-1} corresponds to a 0.22 unit decline in lodging (%), 0.20 unit in soft stalk, 0.11 unit in length of disease spread, and a 4.41 unit decline in charcoal rot (%) was observed (Table 1). Extent of disease spread was highly affected by leaf senescence and number of green leaves plot^{-1}.

Based on a total of 144 genotypes in the Queensland population, it was observed that the simple correlation and regression analyses of different disease characters with leaf senescence and number of green leaves plot^{-1} revealed highly significant correlations and regressions (Table 1). A highly significant and positive correlation for leaf senescence, and a negatively significant correlation for number of green leaves plot^{-1} with lodging, soft stalk, extent of disease spread, and charcoal rot infection (%) were observed.

A set of 23 lines comprising 10 genotypes with maximum, and 10 of minimum leaf senescence scores, number of green leaves plot^{-1}, and their parents were considered for further critical studies on correlation and regression analyses (Table 1). From the simple regression analysis, it was observed that positive and highly significantly regression coefficient estimates existed between leaf senescence and different charcoal rot parameters. Negative and highly significant regression coefficients were also observed between the number of green leaves plot^{-1} and charcoal rot development. Very high g^2 percentages ranging from 38.9-51.3% for leaf senescence and 27.0-47.2% of green leaves plot^{-1}.

Duncan (1984) indicated that since the non-senescent (stay-green) sorghum genotypes remain physiologically active during the later stages of growth, this characteristic contributes to overall tolerance as a disease resistance

Table 1. Simple correlation and regression estimates[1] in Purdue and Queensland sorghum populations

Dependent variables (disease characters)	Independent variables (senescence parameter)	Regression coefficients: Purdue a	Purdue b	Queensland a	Queensland b	Correlation coefficients (T): Purdue	Queensland	Coefficient of determination (γ^{20}%): Purdue	Queensland
Lodging	Leaf senescence	-4.96	1.03[3]	-4.25	0.96	0.64[3]	0.61	42.1	38.2
		(-6.65)[2]	(1.34)	(-3.29)[2]	(0.87)	(0.88)	(0.65)	(77.6)	(42.7)
Soft stalk	Leaf senescence	-6.34	1.25[3]	-4.40	1.00	0.68[3]	0.57	47.0	32.6
		(-8.05)	(1.57)	(-3.91)	(1.00)	(0.83)	(0.62)	(65.7)	(38.9)
Extent of	Leaf senescence	-11.60	0.32[1]	-9.31	1.82	0.56[1]	0.53	31.6	27.8
disease spread		(-122.7)	(24.66)	(-103.4)	(21.06)	(0.75)	(0.71)	(55.8)	(51.3)
Charcoal rot	Leaf senescence	91.90	18.88[3]	69.1	14.16	0.60[1]	56.21	37.2	31.6
(%)		(-81.40)	(17.69)	(-72.6)	(15.40)	(0.75)	(0.71)	(56.2)	(49.7)
Lodging	Leaf number	2.08	-1.17[3]	2.27	-0.94	-0.32[3]	-0.54	10.6	28.8
	plot^{-1}	(2.82)	(-0.22)	(2.48)	(-0.82)	(-0.57)	(-0.52)	(33.3)	(27.0)
Soft stalk	Leaf number	2.15	-1.34[3]	2.48	-1.04	-0.32[3]	-0.53	10.5	27.7
	plot^{-1}	(2.60)	(-0.20)	(3.06)	(-0.11)	(-0.55)	(-0.66)	(30.1)	(43.2)
Extent of	Leaf number	3.87	-3.56[3]	3.21	1.92	-0.40[3]	-0.49	16.4	24.1
disease spread	plot^{-1}	(57.42)	(-6.11)	(52.23)	(-2.80)	(-0.70)	(-0.60)	(49.5)	(36.1)
Charcoal rot	Leaf number	38.40	-27.79[5]	28.52	-15.8	-0.43[3]	-0.56	19.0	31.2
(%)	plot^{-1}	(49.47)	(-4.41)	(33.52)	(-1.68)	(-0.74)	(-0.69)	(54.6)	(47.2)

1. Regression equation Y = a + bx (n = 100 Purdue; n = 21 Queensland)
2. Observation based on cntreme tail-end observations (top 10 and bottom 10 genotypes including parents arranged in ascending order of leaf senescence magnitude)
3. Significant at 1% level

mechanism and also helps to minimize predisposition to stalk rot (caused by *Fusarium moniliforne* Sheld.) in sorghum. Pedgaonkar and Mayec (1990) also discussed the role of stalk rot potential in relation to charcoal rot development in sorghum. Rosenow (1980) and Pande et al. (1989) found negative correlations between plant lodging and non-senescence. In the present study, the correlation and regression analyses clearly indicated that different senescent levels have positive correlations with disease development. The stay-green character means plants are not disposed the disease, and hence increase in stay-green level is an important factor in charcoal rot resistance. It is therefore possible that high-yielding non-senescent, charcoal rot-resistant offsprings could result from a crossing program involving B 35 or QL 41 (non-senescent) with high-yielding genotypes.

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Effects of Crop Season, Storage Conditions, Cultivars, and Fungicide on Postharvest Mold Fungi Infecting Sorghum Grain

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Introduction

Field fungi often invade grains before harvest in the field and affect the quality of grain. The damage caused by fungi is often neglected until it reaches an advanced stage. In addition to direct losses some of these fungi produce mycotoxins that contaminate food and feed, and thus create health hazard for humans and cattle. The association of *Fusarium* spp. and *Aspergillus* spp. with grain has been a major cause of concern because of their ability to produce toxins (Bhat et al. 2000). Little information is available on frequency of fungi associated with postharvest sorghum grains and their management. We report here the fungal frequency recorded in grain samples collected from various storage systems, cultivars, seasons, and fungicide-treated grains, and suggest strategies to protect postharvested grain from mold fungi infestations.

Materials and methods

A total of 26 sorghum grain samples of hybrids, varieties and local cultivars were collected during surveys in 1997 in rural areas in the Indian states of Andhra Pradesh, Karnataka, and Maharashtra. The samples were drawn from sorghum grain stored by fanners for food in five different types of storage. Fifteen samples were collected from the 1996 rainy-season crop and 11 from the 1996/97 postrainy-season crop from gunny bags, mud-lined baskets (MB), polypropylene bags (PB), open storage in the corner of a room, and a mixture of MB and PB.

Using compartment probes (80 cm long x 2.5 cm diameter and 27 cm long x 1.5 cm diameter) 5-kg grain samples were drawn from each lot. Each grain sample was assessed for its fungal profile in a representative sample of 800 grains that were equally distributed in four treatments: 1. grains surface-sterilized in 1% sodium hypochlorite (NaOCl), and not treated with benomyl, 2. grains surface-sterilized and treated with benomyl (0.05%), 3. grains not surface-sterilized, but treated with benomyl, and 4. control, no surface-sterilization and no benomyl treatment. The treated grains were transferred to pre-sterilized petridish humid chambers (25 grains petridish^{-1}) and were incubated at 28±1°C with a 12-h light/dark cycle for 5 d. Individual grain in all the four treatments were examined and the identity of the fungi were confirmed (Navi et al. 1999). The frequency offungi found was determined using a Statistical Analysis System (SAS) procedure.

Results and discussion

The major fungi observed with mean fungal frequency of >5% in various storages, cultivars, seasons, and treatments were—*Alternaria alternata* (Fr.) Keissler; *Aspergillus flavus* Link; *A. niger* van Tieghem; *Bipolaris australiensis* (M.B. Ellis) Tsuda & Ueyama; *Curvularia lunata* (Wakker) Boedijn; *C. lunata* var *aeria* (Bat., Lima, & Vasconcelos) M.B. Ellis; *Fusarium moniliforme* J. Sheld. *Lisea fujikuroi* Sawada, *Penicillium citrinum* Thorn; *Phoma sorghina* (Sacc.) Boerema, Dorenbosch, & van Kesteren; and *Rhizopus stolonifer* (Ehrenb:Fr.) Lindner. 39 other fungi (Navi et al. 1999) with <5% mean frequencies recorded in the study are not reported.

Effect of season. In 15 samples collected during the rainy season the mean grain germination was only 52% compared to 99% in 11 postrainy-season samples (Table 1). In addition, the frequency of the potentially toxin-producing fungus *F. moniliforme* was higher (15%) in the rainy season samples than in the postrainy samples (9%). The frequencies for *A. flavus* were 3% in the rainy and 2% in the postrainy season samples. Similarly, the spectrum of other major fungi varied depending on the season during which grain samples were drawn. The fungi with high frequencies were *A. alternata, C. lunata, C. lunata* var. *aeria,* and *F. moniliforme.*

Effect of storage types. Storage types also influenced the grain germination and fungal frequency (Table 2). Higher grain germination (86-92%) was recorded from gunny bags and MB-stored grain than from that stored in in other containers (21-43%). Grain stored in the corner of a room, had 0.1% *A. alternata* compared with 12-16% in

Table 1. Effect of season on frequency of mold fungi in sorghum grain samples

Haravesting season	Samples	Germi-nation (%)	Major fungal[1] frequency (%)[2] AA	AF	AN	BA	CL	CLA	FM	PC	PS	RS
Rainy	15	52	13	3	6	5	19	16	15	0.3	5	6
Postrainy	11	99	16	2	3	4	12	10	9	2	3	11
SE (M)i.		23.5	1.5	0.5	1.5	0.5	3.5	3.0	3.0	0.9	1.0	2.5

1. AA = *Alternaria alternata,* AF = *Aspergillus flavus,* AN = *A. niger,* BA - *Bipolaris australiensis,* CL = *Curvularia lunata,* CLA = *C. lunata* var *aeria,* FM = *Fusarium moniliforme,* PC = *Penicillium citrinum,* PS = *Phoma sorghina,* and RS = *Rhizopus stolonifer*
2. Across treatments, cultivars, and storage conditions

Table 2. Effect of storage type on frequency of mold fungi in sorghum grain samples

Storage type	Samples	Germi-nation (%)	Major fungal[1] frequency (%)[2] AA	AF	AN	BA	CL	CLA	FM	PC	PS	RS
Corner of a room	1	21	0.1	0.2	7	0	16	1	25	0	2	6
Gunny bag	14	92	16	3	7	4	6	5	6	2	2	9
Mud-lined baskets (MB)	7	86	12	3	3	8	16	22	15	1	6	9
Polypropylene bags (PB)	3	37	16	4	4	1	29	9	14	0.2	2	7
PB/MB	1	43	13	0	1	4	20	42	24	0	13	7
SE (M)±		14.5	2.9	0.8	1.2	1.4	3.7	7.4	3.5	0.4	2.1	0.6

1. A A = *Alternaria alternata,* AF = *Aspergillus flavus,* AN = *A. niger,* BA = *Bipo laris australiensis,* CL = *Curvul aria lunata,* CLA = C. *lunata* var *aeria,* FM = *Fusarium moniliforme,* PC = *Penicillium citrinum,* PS = *Phoma sorghina,* and RS - *Rhizop us stolonifer*
2. Across treatments, cultivars, and storage conditions

Table 3. Effect of sorghum cultivars on frequency of mold fungi in sorghum grain samples

Genotypes	Samples	Germination (%)	Major fimgal[1] frequency (%)[2] AA	AF	AN	BA	CL	CLA	FM	PC	PS	RS
CSH 9	6	60	24	1	1	5	37	19	17	0.1	6	3
Dagri local	1	100	10	0	6	5	6	1	8	0	0.1	23
JK 22	2	44	1	4	4	7	4	16	13	0	3	20
Local	1	91	1	3	0.2	0	3	0	10	0	22	6
Maldandi/ Dagri local	1	93	12	1	6	2	8	6	3	9	0	16
Maldandi	11	98	16	3	5	4	3	4	7	3	2	10
MSH 51	3	54	4	8	14	4	8	18	17	0.1	2	6
SPH 468	1	68	12	2	7	6	15	37	16	0	2	0
SE(M)±		7.8	2.8	0.9	1.5	0.8	4.0	4.4	1.8	1.1	2.6	2.9

1. AA = *Alternaria alternata,* AF = *Aspergillus flavus,* AN = *A. niger,* BA = *Bipolaris austral tensis,* CL = *Cunwlaria lunula,* CLA = *C. lunata* var *aeria,* FM = *Fusahum moniliforme,* PC = *Penicillium citrinum,* PS = *Phoma sorghina,* and RS = *Rhizopus stolonifer*
2. Across treatments, cultivars, and storage conditions

Table 4. Effect of seed treatment with benomyl on frequency of mold fungi in sorghum grain samples

Grain treatment	Germination (%)	Major fungal[1] frequency (%)[2] AA	AF	AN	BA	CL	CLA	FM	PC	PS	RS
1.. Surface-sterilized not treated with benomyl	79	13	1	2	4	11	8	17	0.1	5	0.4
2. Surface-sterilized and treated with benomyl	81	15	1	1	4	11	11	1	0	1	1
3. No surface-sterilization but treated with benomyl	79	17	0.2	1	6	13	18	1	0	2	11
4. Control, no sterilization or benomyl	76	12	10	17	4	17	9	27	6	7	23
SE(M)±	1.0	1.1	2.3	3.9	0.5	1.4	2.3	6.4	1.5	1.4	5.3

1. AA = *Alternaria alternata,* AF = *Aspergillus flavus.* AN = *A. niger,* BA = *Bipolaris australiensis,* CL = *Curvularia lunata,* CLA = *C. lunata* var *aeria,* FM = *Fusarium moniliforme,* PC = *Penicillium citrinum,* PS = *Phoma sorghina,* and RS = *Rhizopus stolonifer*
2. Across treatments, cultivars, and storage conditions

other types of storage. Similarly, the frequencies of other fungi differed with types of storage. The major fungi were the same four reported above.

Effect of sorghum cultivars. Among the eight sorghum cultivars, higher grain germination was observed in local cultivars (91-100%) than in hybrids (44-68%) (Table 3). On the contrary, CSH 9 had highest frequency of *C. lunata* (37%), followed by *A. alternata* (24%), *C. lunata* var *aeria* (19%) and *F. moniliforme* (17%). The frequency of *F. moniliforme* was higher in the hybrids (13-17%) than in Maldandi and local cultivars (3-10%). While the frequency of *A. flavus* in MSH 51 was 8% and that of *P. citrinum* in Maldandi/Dagri local was 9%. However, the frequency of other major fungi varied between hybrids and local cultivars.

Effect of benomyl seed treatment. Of the four treatments, the highest grain germination (81%) was recorded from grains surface-sterilized with NaOCI and treated with benomyl compared with the control (76%) (Table 4). However, surface-sterilization of grains with NaOCI did not eliminate all the fungi, indicating that most of the major fungi were internally seedborne. Grains treated with benomyl with or without surface sterilization considerably reduced the frequency of *A. flavus, F. moniliforme* and *P. citrinum.* Benomyl treatment (0.05%) greatly reduced the frequency o f f *F. moniliforme* from 27% in the control to 1 % in treated grains. Besides *F moniliforme,* benomyl was also effective against *A. flavus, A. niger, P. citrinum,* and *P. sorghina,* but it was not effective against *Alternaria, Bipolaris,* and *Curvularia* spp.

Conclusion

In storage, fungi can develop if grains are stored without sufficient drying, if grain is damaged during harvest, handling, threshing, and drying, and if the moisture content of grains increases during storage. In this study it was observed that, most of the fungi appeared to have come from field infestation. *A. flavus,* and *P. citrinum* have also been recorded in storage. Based on the results of this study, it is suggested that grain is stored either in gunny bags or jute bags rather than in other containers mainly to minimize the damage from *Fusarium* spp., or that mold-tolerant/resistant genotypes are grown during the rainy season. Benomyl-treated grains could be used as seed for the next season's crop.

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An Outbreak of Sorghum Ergot in Parts of Andhra Pradesh, India

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Introduction

Ergot (*Claviceps sorghi* P. Kulkarni et al. and *C. qfricana* Frederickson, Mantle, and de Milliano) of sorghum (*Sorghum bicolor* (L.) Moench) is a serious limiting factor in hybrid seed production, particularly if seed set in male-sterile lines is delayed due to lack of viable pollen caused by non-synchronous flowering in male-sterile and restorer lines. Further, environmental conditions favorable for disease development are not congenial to rapid seed set, thus making spikelets more vulnerable to ergot attack (Bandy opadhy ay 1992). In this paper we report the occurrence of ergot in epidemic form in Maachinenipalli village towards the end of the rainy season (1-8 October 1999) and its further spread in 12 administrative zones of Mahbubnagar and two zones of Ranga Reddy districts in Andhra Pradesh from a survey conducted in 2000.

Materials and methods

A total of 28 farms were surveyed in Andhra Pradesh during an ergot epidemic in the rainy season 2000. The areas represent the major sorghum-growing belt of Mahbubnagar district where sorghum was grown on over 130,000 ha (Source: Associate Director of Research, Regional Agricultural Research Station (RARS), Palem 509 215, Mahbubnagar District). Most of the farmers sow local Yellow Jowar, local White Jowar and ICSV 745 as dual-purpose sorghums during the rainy seasons, and SSG 777 and SSG 878 are exclusively grown for fodder in areas of Kalwakurthy administrative zone all year round.

The incidence and severities of ergot was recorded from each field in an area of approximately 12-m^2 in each of three randomly selected subplots. Based on the number of infected plants and the total plants the incidence (%)

was recorded, and the severity was noted on a 0-100% scale from individual panicles.

Results and discussion

The incidence and severity range of ergot in the epidemic areas surveyed is given in Table 1. ICSV 745 sown in Kalwakurthy and Bhootpur zones remained free from ergot. The survey of 12 administrative zones in Mahbubnagar district representing 22 farmers' fields in 15 villages revealed the occurrence of ergot in epidemic form during September 2000. The incidence of ergot in 15 villages was higher than 50%. In most villages the sorghum crop had high ergot incidence and severity (up to 100%) suggesting that farmers could harvest little grain from these fields. Forage sorghum hybrids SSG 777 and SSG 878 were also highly susceptible to ergot.

When farms in Maachinenipalli village were surveyed during 3-10 September 1999 they had no ergot. However, a month later towards the end of the rainy season (1-8 October 1999) none of the fields was free from ergot. The pathogen infected forage and local sorghums that were sown in late June 1999. In contrast, fields in adjacent Bhootpur administrative zone (within 40-50 km) were free from ergot. During the survey ergot incidence in Maachinenipalli village was 80-100% with 100% severity. In addition, the ergot incidence range in 10 adjacent administrative zones was 10-100% with 50-100% severity (Table 1). In Bhootpur administrative zone the ergot prevalence was similar to that in 1999.

The farmers in Maachinenipalli witnessed epidemics of ergot only during 1999 and 2000. A thorough discussion on sorghum ergot history, the fodder storage

Table 1. Sorghum ergot scenario in Mahbubnagar and Ranga Reddy districts of Andhra Pradesh, India during 2000/1

District/ddministrative zones	Village	Cultivar	Incidence range (%)	Severity range(%)
Ranga Reddy				
Maheswaran!	Tukkuguda	Yellow Jowar	90-100	100
Maheswaram	Mankal	Yellow Jowar	70-80	80-100
Kandakur	Kottur	Yellow Jowar	5-30	80-100
Mahbubnagar				
Amanagal	Kadathal	White Jowar	10-50	100
Amanagal	Ramuntala	White Jowar	10-35	80-100
Amanagal	Amanagal	White Jowar	50-100	100
Veldanda	Velladandi	Yellow Jowar	50-100	100
Veldanda	Tandra	Yellow Jowar	25-50	100
Veldanda	Tandra	White Jowar	50	100
Vangoor	Maachinenipalli	Yellow Jowar	80	100
Vangoor	Maachinenipalli	SSG 878	100	100
Vangoor	Vangoor	Yellow Jowar	25	100
Vangoor	Vangoor	Yellow Jowar	100	100
Kalwakurthy	Kalwakurthy	Yellow Jowar	100	100
Mahbubnagar	Appannapalli	Yellow Jowar	25-40	100
Jadcherla	Nakkalabanda	Yellow Jowar	50	100
Thimmajipet	Timmajipet	White Jowar	80-90	100
Bijinapally	Bijnapalli	White Jowar	75	100
Bijinapally	Palem	SPV 351	90	50-60
Midjil	Ranipet	White Jowar	60-70	100
Midjil	Wadiyal	White Jowar	50	100
Shadnagar	Rayakal	Yellow Jowar	25-50	100
Shadnagar	Rayakal	Bhoojonna	100	100
Shamshabad	Palmakul	Yellow Jowar	30-40	100
Bhootpur	Amisthapur	Yellow Jowar	0	0
Bhootpur	Amisthapur	ICSV 745	0	0

system, and losses due to the disease revealed that farmers take one or more of the following actions to avoid the disease: 1. Select only healthy panicles for food, and feed ergot-infected panicles and stover to animals; 2. Allow infected plants to dry in the field for future use as fodder, or 3. Allow cattle to graze without harvesting or drying the stover.

The possible sources of infection for sorghum ergot spread from an epidemic area of Maachinenipalli in 1999 to other administrative zones in the distriet could be either postharvest-infected panicles stored or dumped in pits, or ergot-contaminated seed movement frorn one village to another. Therefore, based on this information it is assumed that pathogen, might have moved from an area of ergot epidemic in Maachinenipalli to other locations in the district. It appears that the pathogen development was favored by the cloudy weather and high rainfall during flowering (Anahosur and Patil 1982; McLaren and Wehner 1990) and subsequently spread by wind currents (Frederickson et al. 1993). On the contrary, in Amistapur village of Bhootpur administrative zone about 80 km from Maachinenipalli the crop was absolutely free from ergot probably because there was no rain during flowering in 1999 and 2000. Even though the farmers in this village observed ergot in 1996, there was no further spread in the subsequent cropping seasons.

Acknowledgments

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Prevalence of Ergot of Sorghum in India

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Introduction

Ergot (*Claviceps sorghi* P. Kulkarni et al.. and *C. africana* Frederickson, Mantle, & de Milliano) is a serious limiting factor, in the production of sorghum [*Sorghum bicolor(L.)* Moench] hybrid seeds. Ergot can also cause widespread damage to cultivars in farmers' fields when environmental conditions favorable to the pathogen prevail at flowering (Kukedia et al. 1982). In this article we report the incidence and severity of ergot, in sorghum-growing areas in the states of Andhra Pradesh, Gujarat, Tamil Nadu, Maharashtra, Karnataka, Rajasthan and Uttar Pradesh in India.

Materials and methods

On-farm sorghum ergot surveys were conducted from August 1999 to February 2000 (Year 1), August 2000 to March 2001 (Year 2) and November 2001 to April 2002 (Year 3). A total of 250 farms in Andhra Pradesh, one in Gujarat, 413 in Maharashtra, 451 in Karnataka, 127 in Tamil Nadu, 3 in Rajasthan, and 10 in Uttar Pradesh were

Table 1. Mean incidence and severity range (%) of sorghum ergot in India from August 1999 to April 2002

	Fields		Mean ergot range[1]	
Indian states	Surveyed	With ergot	Incidence (%)	Severity (%)
Andhra Pradesh	250	92	13-61	23-93
Kamataka	451	54	27-60	36-100
Maharashtra	413	40	2-30	5-83
Tamil Nadu	127	13	0-22	0-52
Rajasthan	3	3	Trace[2]	Trace
Uttar Pradesh	10	10	52.0	45.5
Gujarat	1	1	Trace	Trace

1. Mean of 3 years' survey from August 1999 to April 2002 except for Rajasthan, Uttar Pradesh and Gujarat wherein survey was conducted only during cropping season 1999
2. < 1 % incidence and severity

surveyed. The latitude, and longitude, of each of the field surveyed was recorded using a hand-held global positioning system instrument (®1993 Magellan System Corporation, San Dimas, California, USA).

The cropping patterns in Andhra Pradesh, Kamataka, Maharashtra and Tamil Nadu included predominantly local cultivars followed by improved varieties and hybrids of sorghum. The crops were surveyed at vegetative to physiological maturity stages. Ergot incidence and severity from each field were recorded in approximately 12-m^2 areas randomly selected at three different places. Disease incidence was recorded based on the number of plants infected out of the total plants counted, and the severity on a 0-100% scale based on the number of infected florets in individual panicles. A total of 152 ergot samples (10-15 infected panicles from each field) were collected from all the three survey. The samples were placed separately in brown paper bags, air-dried and stored under laboratory conditions (25± 1 °C) for further studies at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the United States Department of Agriculture (USDA) laboratories.

Results and discussion

The most obvious external symptom of ergot observed in panicles was honeydew exudation from infected florets (Frederiksen and Odvody 2000). Honeydew was either uniformly yellow-brown to pink or superficially white matt. Sclerotial formation was observed in only a few panicles.

In Kamataka, (Table 1) ergot was observed during the first week of October (late-sown rainy-season crop) and the second week of December 1999 (early-sown postrainy-season crop). A farmer of Chitradurga, Kamataka, mentioned the occurrence of severe ergot on MSH 51 every year since 1998 in both seasons. On another farm in Talaku village (14° 27' N and 76° 40' E), in the same district, sorghum hybrid MSH 51 was heavily affected by ergot (80-90% incidence and 90-100% severity) resulting in about 70% loss in grain yield during the 1999 postrainy season. It became essential to clean grains by washing them in water to remove honeydew and to separate black structures prior to sale in the local market.

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Iterative Germination of Secondary Ergot Conidia in Sorghum

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Introduction

Ergot, caused by *Claviceps africana* Frederickson, Mantle & de Milliano is a disease of unfertilised gynoecia of some *Sorghum* spp, including *Sorghum bicolor* (L.) Moench. It has great potential to damage sorghum nurseries and cause significant irreplaceable damage to breeding material and hybrid seed production blocks. Losses have been estimated at 10-80% in India and South Africa and US$ 3 million in Brazil with losses in the range of 10-100% (Bandyopadhyay et al. 1998).

Macroconidia are produced on the surfaces of sphacelia, which replace the ovaries, and are immersed in honeydew that oozes from infected spikelets (Bandyopadhyay et al. 1990; 1998). During periods of moderate temperatures and high humidity, macroconidia near the surface of the honeydew germinate, and single secondary conidia develop at the apices of sterigmata above the honeydew surface. These secondary conidia are responsible for the rapid spread of the pathogen (Frederickson et al. 1989; 1993). Despite their importance in the epidemiology, little is known about their biology. In this paper we report on the capacity of conidia of *C. africana* for successive germination, and discuss the biological implications.

Materials and methods

Secondary conidia of the Australian *C. africana* isolate 10765 were collected by blowing air at 0.2 m sec^{-1} over the surface of water agar on which secondary sporulation was occurring, inverting the agar surfaces over freshwater agar, and tapping the bottom of the plates to dislodge the conidia (Tonapi et al. 2002). The dimensions of 150 conidia in six plates @ 25 conidia $plate^{-1}$ were measured. These latter plates were left unsealed and transferred to a temperature gradient table at temperatures of 7.4°C, 14.6°C, 23°C, 28°C, 33.4°C, and 39.2°C, 2 plates $temperature^{-1}$. The germination of 100 secondary conidia in each of the four plates was evaluated after incubation times of 24, 48, 72, and 96 h. The tertiary conidia on all plates were harvested using the methods outlined above, and their germination in the range of above temperatures was assessed. Subse-quent generations of conidia were generated and treated in the same manner.

Results and discussion

Conidia of *C. africana* produced up to seven generations of sibling conidia. Frederickson (1989) reported that R Bandyopadhyay had observed the iterative germination of secondary conidia to produce tertiary conidia, but no further information was provided. The dimensions of the seven generations of conidia are presented in Table 1. The dimensions of secondary conidia in different generations ranged from 10.92-10.13 urn (length) and 5.49-5.13 urn (width). However no definite trend in the decline in length and width of secondary conidia was evident.

Table 1. Morphology of sibling conidia of *C. africana* in successive generations

	Conidial size (µm)[1]	
Generation	Length	Width
1	10.92	5.49
2	10.25	5.33
3	10,13	5.13
4	10.15	5.21
5	10.20	5.16
6	10.21	5.19
7	10.18	5.29
SD	0.55	0.36
SE	±0.25	±0.16

1. Mean of 150 secondary conidia in each generation

The mean germination (%) of conidia across seven iterative germinations was optimal at 14.6°C (100%) (Fig. 1). There was no germination recorded for any generation of conidia at temperatures <7.4°C and >28°C. These results contrast with the findings of Bhuiyan et al. (2002a) who found that the optimum temperature for germination of secondary conidia of Australian isolates of *C. africana* was close to 20°C. It is quite possible that the high rates of germination would have been achieved if the conidia had been incubated at temperatures between 14.6°C and 23°C, and that this would have changed the shape of the temperature response curves (Fig. 1). When secondary conidia that had initially been incubated at 7.4°C for 24 h, were transferred to temperatures of

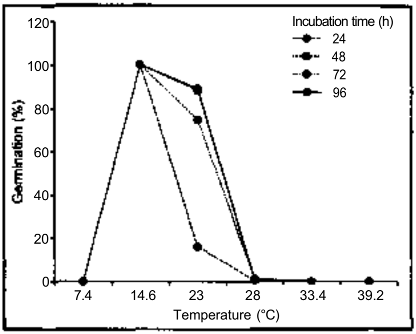

Figure 1. Effect of temperature on germination of secondary conidia

14.6°C, 92.7% germina-ted, and at 20°C 92.3% of them germinated after 24 h. Hence, the optimum temperature range for germination of secondary conidia of the Australian *C. africana* isolate 10765 was 14.6-20°C.

Our findings have a number of implications for the biology and epidemiology of *C. africana.* Firstly, it is evident that conidia of *C. africana* have the capacity for successive generation of sibling conidia. It is highly likely that secondary conidia that are deposited on spikelets before they flower can survive, perhaps by repeated germination of these conidia, until flowering occurs and conditions are conducive for infection. This occurrence may explain the high levels of ergot infection on panicles that are covered at emergence with paper bags to inhibit outcrossing. Secondly, the finding that conidia that are incubated at low temperatures that are not conducive to germination, but are then transferred to germination-conducive temperatures may provide another survival mechanism. Secondary conidia on panicles and/or flowering spikelets could survive overnight at low temperatures until temperatures increase, and those in cold air currents could survive long distance dispersal. Bhuiyan et al. (2002b) and others have demonstrated that macroconidia of C. *africana* can survive low temperatures for long periods, so this trait might be common for all conidia of the pathogen.

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Influence of Temperature and Relative Humidity on Pollen Traits and Ergot Severity in Sorghum

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Introduction

Ergot disease of sorghum *[Sorghum bicolor* (L.) Moench] caused by *Claviceps africana* Frederickson, Mantle & deMilliano, is a disease of gynoecia in which the ovary is replaced with a sphacelium (Bandyopadhyay et al. 1998). Macroconidia, produced on sphacelia, are released into honeydew, which oozes from the infected florets. Secondary conidia, which are believed to be responsible for the rapid spread of ergot within a crop and perhaps for long-distance dispersal (Bandyopadhyay et al. 1998; Ryley et al. 2000), are produced on short sterigmata above the surface of the honeydew. Fertilised ovaries are, for the most part, resistant to infection (Bandyopadhay et al. 1998), so the availability of viable pollen is critical in ergot epidemics (Bandyo-padhyay et al. 1998; Ryley et al. 2000). The viability and/or quantity of pollen can be affected by temperature during flowering (Ryley et al. 2000).

Temperatures near 20°C during flowering are reported to favor ergot development (Anahosur and Patil 1982; McLaren and Wehner 1990; Ryley et al. 2000). Relative humidity (RH) also influences ergot outbreaks. Cool, wet weather during flowering favours infection of sorghum by *Clavicep sorghi* Kulkarni, Seshadri & Hegde. Futrell and Webster (1966) reported that relative humidity near 100% for 24 h during flowering was optimal for infection. Significant infection has also been reported to occur at RHs lower than 100% (Anahosur and Patil 1982).

The interrelationships between environmental parameters, host factors such as pollen traits, pathogen factors such as production and dispersal of secondary conidia, and infection are complex (Ryley et al. 2000). Most of the published information on these interactions is based on field experiments and observations. In this paper we report on experiments, conducted under controlled conditions, to study the effects of temperature and relative humidity on infection and on pollen characteristics.

Materials and methods

Isolate maintenance The Australian *C. africana* isolate 10765 used in the study was maintained by sequential inoculation onto flowering panicles on plants of the sorghum A-line, AQL 33. The plants were grown in a greenouse, and panicles at 50% flowering were inoculated with an aqueous suspension of macroconidia and secondary conidia (approximately 1×10^6 conidia mL^{-1}), and covered with a paper bag for 2 d. Honeydew oozed from infected spikelets 7-10 d after inoculation, and honeydew was collected for further studies within 7 days.

Infection studies. AQL 33 was used in the infection studies. Secondary conidia of isolate 10765 were collected by blowing air at 0.2 m sec^{-1} over the surface of water agar on which secondary sporulation was occurring, inverting the agar surfaces over freshwater agar, and tapping the bottom of the plates to dislodge the conidia. Conidia were collected from the lids of the inverted agar plates with a 1.5-cm wide flat brush and were brushed onto 100 stigmas per flowering panicle, which had been moistened by a fine spray of deionised water before inoculation. Three replicates each of 12 plants were placed in a randomized complete block design in controlled environment cabinets at 10°C, 20°C, 25°C, 30°C, 35°C, or 40°C, each with a relative humidity of 60% ±2, and a 10 h daylight/14 h night cycle. Half the panicles in each replicate were covered with plastic bags, which were sealed to maintain a RH of approximately 100%, for 3 days. After 14 days, each panicle was rated for infected spikelets (%), using the presence of a sphacelium as the criterion.

Pollen number, germination, and viability. The B-line 23326-3-1 was used in the pollen studies. At 50% flowering, the upper and lower branches of the panicles were removed, leaving approximately 200 spikelets with newly emerged anthers. Four replicates each of four plants were placed in a randomized complete block design in controlled environment cabinets at 10°C, 20°C, 25°C, 30°C, 35°C, or 40°C, each with a RH of 60% ±2 and a 10 h daylight/14 h night cycle. Half the panicles in each replicate were covered with plastic bags, which were sealed to maintain a RH of approximately 100%., for 3 days. After that time, pollen for the pollen number and germination studies was collected at 7.00 am by tapping the panicle with the middle finger. The pollen was deposited on the surface of germination agar medium (Tuinstra and Wedel 2000) in petri dishes, which were held vertically 60cm from the panicles, one plate $panicle^{-1}$. The plates were sealed with Parafilm and incubated at 20°C in the dark for 4 h. With the aid of a compound microscope the total number of pollen grains, and the number of germinated pollen grains in each of 10 x 1.23 mm^2 microscope fields, was counted. A pollen grain was considered to be germinated when the length of the pollen tube was greater than the diameter of the grain. The pollen number data were adjusted to pollen grains cm^2.

Pollen for the viability test was collected on glass slides at the same time as the collection of pollen on agar plates. A drop of 0.2% MTT [3-(4,5-dimethylthiazolyl-2)-2, 5-diphe-nyl tetrazolium bromide] in 60% sucrose was placed on each slide and the pollen was mixed into the solution. The percentage of viable pollen grains [those stained magenta (Norton 1966)] was then determined with the aid of a compound microscope. One hundred pollen grains on each of four slides per treatment were counted.

Seed set. Plants whose panicles were used in the pollen studies were incubated in growth cabinets for a further 10 d, and then transferred to a greenhouse. Seed set (%) was determined a further 15 d later.

Results and discussion

Our results indicate that the optimum temperature for infection of the male-sterile line AQL 33 by secondary conidia of *C. africana* isolate 10765 was 20°C, and that no ergot developed at 10°C, or at 35°C (Fig. 1). This result confirms the earlier field observations of a number of researchers. Ergot severity was higher at 100% RH than at 60% RH at all temperatures (Fig. 1).

There was a statistically significant positive correlation (r^2 = 0.98) between pollen germination and

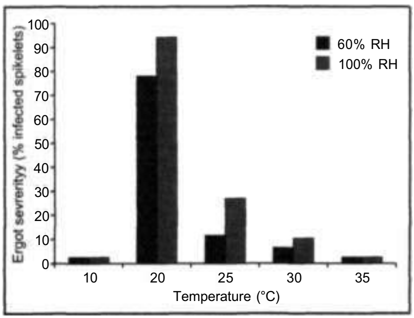

Figure 1. Effects of temperature (V) and relative (RH) humidity on infection of the sorghum A-line AQL33 by an Australian isolate of *Claviceps africana.*

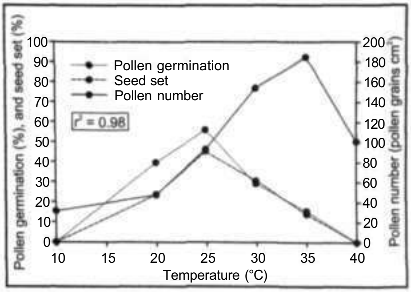

Figure 2. Effects of temperature on pollen number, pollen germination and seed set of the sorghum B-line 23326-3-1 at 60% RH.

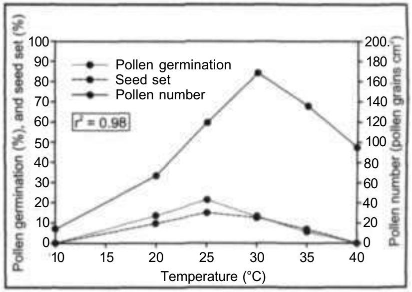

Figure 3. Effects of temperature on pollen number, pollen germination and seed set of the sorghum B-line 23326-3-1 at 100% RH.

pollen viability, so only pollen germination is displayed in Figures 2 and 3. The responses of pollen number, pollen germination, and seed set of the male-fertile line 23326-3-1 to temperature and RH were similar (Figs. 2 and 3). The optimum tempera-ture for all three parameters was 25°C, with values of 0% at 10°C and 40°C. At 60% RH there was a gradual increase in pollen number from 31 pollen grains cm^{-2} at 10°C to 154 pollen grains cm^{-2} at 35°C, then a decrease to 101 pollen grains cm^{-2} at 40°C (Fig. 1). At 100% RH, the temperature with the highest number of pollen grains (73 cm^{-2}) was 30°C. The values of all the pollen parameters at 100% RH were less than the corresponding values at 60% RH.

Under optimum day (>28°C) and night temperatures (>17°C) (depending on host adaptation) pollen germinates within 30 minutes and fertilization occurs within 2-12 h (Stephens and Quinby 1934). In contrast, at similar temperatures conidia require 8-12 h for germination on the stigma and 36-48 h to reach the ovary (Bandyopadhyay et al. 1998). Consequently, any factor, which reduces the viability or amount of pollen reaching the stigmas, will contribute to successful infection by conidia of *C. africana.* The results presented in this paper indicate that both temperature and RH influence infection of AQL 33, and the amount and germination of pollen that is released from the anthers of 23326-3-1. Low temperatures (20°C) and high humidity (100% RH) favored infection of AQL 33, but reduced pollen germination, viability and number of pollen grains released from anthers, and seed set 23326-3-1. The mechanism(s) responsible for the reduction in pollen viability and germination are unknown. However, the mechanism responsible for reduced pollen grain numbers may be due to the effects of these parameters on anther dehiscence.

Genotypes differ in the sensitivity of their pollen to temperature (Brooking 1979), so it is possible that the reactions of other male-fertile lines will differ from that of 23326-3-1. Studies on the interactions between pollen, infection by conidia, and such factors as temperature and RH, are needed on a range of male-fertile germplasm. Information from these and other investiga-tions, such as the effects of environmental factors on the production, dispersal, and deposition of secondary conidia of *C. africana,* will greatly improve our knowledge of some of the important interactions that contribute to ergot epidemics.

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The authors acknowledge the grant of a fellowship from the J N Tata Endowment, Mumbai, India and provision of facilities by the University of Queensland, Gatton to undertake this research during a postdoctoral visit by the senior author. The isolate of *C. africana* was provided by Sukumar Chakraborty and Birty Koomolong, Cooperative Research Centre (CRC) for Tropical Plant Protection, University of Queensland, St. Lucia, Queensland, Australia. R Henzell and D Jordan, DPI Hermitage Research Station, Warwick, QLD provided the sorghum lines AQL 33 and B23326-3-1 used in this study. Special thanks are due to M Man and H Robertson, Technical Officers, School of Agriculture and Horticulture, University of Queensland, Gatton, Australia, for their help and assistance during the course of investigation.

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Jinza N0.18-A Somaclonally Developed, Head Smut Resistant Sorghum Hybrid

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Introduction

The use of biotechnology as a breeding technique had resulted in extensive work on somaclonal variation in sorghum [*Sorhgum bicolor* (L.) Moench] since 1988. A sorghum hybrid, developed by this technique recorded a significantly better performance than other entries in a provincial regional yield test. Subsequently, it was registered and released in 1999 by Shanxi Provincial Variety Committee as Jinza No. 18.

Breeding procedure

Jinliang No. 5 is an R-line with good combining ability and several superior performance characteristics. Several widely used hybrids have been developed using it as a restorer, but is highly susceptible to head smut [*Sporisorium reilianum* (Kuhn) Langdon and Fullerton] and has a few other short-comings. Hence, it was felt necessary to improve by tissue culture.

Shoot tips including the first node were excised from the germinating R-line seeds. Murasige-Skoog (MS) medium enriched with 2,4-D and KJ (potassium iodide) was used as a callus-induction medium, and MS medium enriched with KI and indole acitic acid (IAA) was used as the regeneration medium. Regenerated plants (R_o generation) were transplanted into the field. Harvested R_o seed was advanced to the R_1 generation. Somaclonal lines harvested individually were the R_2 generation. Somaclonal lines R_{111} and R_{119} differed from Jinliang No. 5. They were short, with deep green leaves, tight panicles, and were highly resistant to head smut. These lines were used as R-lines to create hybrids. The cross 7501 A x R_{111} was high-yielding and resistant to lodging and head smut in initial yield evaluation. The hybrid produced 9180 kg ha^{-1}, outyielding the check hybrid by 13.5 kg ha^{-1} in the provincial-level regional yield trial 1996/7.

Hybrid characteristics

Jinza No. 18 is a highly uniform and genetically stable hybrid. It matures in about 130 days, has an average plant height of 185 cm and a 1000-grain mass of 36 g. It is characterized by strong hard stems, tight panicles, and big red grains with black glumes. Compared to currently cultivated commercial hybrids, it has higher 1000-grain mass, shorter and more resistant to lodging, head smut, and leaf diseases.

Seed production and cultural points

The parental lines can be sown at the same time during hybrid seed production although the restorer line R_{111} flowers 3-5 days later than the male-sterile line.

The hybrids yields well on irrigated highly fertile land. The optimum plant density is 90,000-100,000 plants ha^{-1}. It is necessary to spray to reduce aphid incidence and infestation.

Effectiveness of the somaclonal breeding technique

Research has demonstrated that sorghum plants can be successfully produced by tissue culture. It also indicated the existence of somaclonal variations in the filial generations of R-plants that can be used to improve sorghum. This technique enables the breeding period to be shortened, and genetical variants to be stabilized rapidly. Somaclonal variants were screened, successfully projecting somaclonal breeding as an effective supplementary breeding technique.

New Sources of Resistance to Grain Mold in Converted Zerazera Sorghum

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Introduction

Although 49 fungal species have been reported to be associated with the grain mold complex the species of *Alternaria, Aspergillus, Curvularia, Drechslera, Fusarium, Penicillium,* and *Phoma* have been identified as major ones (Navi et al. 1999). The association of *Fusarium* spp. and *Aspergillus* spp. with grain mold has been a cause of concern because of their ability to produce toxins (Bhat et al. 2000). Fumonisin toxicity to humans and poultry was reported for the first time in India by Bhat et al. (1997).

Zerazera landraces of sorghum that are distributed in the eastern region of Sudan are medium tall with tan color, and look relatively clean in the field. Their grain shape is of the Caudatum type with short glumes, mostly ivory yellow to cream in color. The grain color is yellow, straw, or white, and their endosperms are highly corneous and flinty and white to yellow in color. Zerazera sorghums have been extensively used in various sorghum improvement programs because of their agronomic desirability, superior grain quality and tolerance to diseases and drought (Prasada Rao and Mengesha 1981). Hence, attempts were made to screen some of the converted Zerazeras for resistance to grain molds. Both field (Bandyopadhyay and Mughogho 1988a), and in vitro screening techniques (Singh and Navi 2001) were used to identify high levels of resistance in sorghum with straw-colored grain, particularly in the Guinea alleles background. Accessions that were resistant to mold under artificial epiphytotic conditions and with good agronomic traits are reported in this paper.

Table 1. Evaluation of 43 Zerazera sorghum selections both in vitro and in field nurseries at three Indian locations (Bhavanisagar (BVS), Mysore (MYS) and Patancheru (PTN)J for grain mold resistance during the 1993 and 1994 rainy seasons

IS No.	Pedigree	Origin	DTF[1]	PLHT[2]	LAB[3]	Mean field grain mold score[4] BVS	MYS	PTN	Locations mean	TGMR[5]
41376	IS 956C-13	Sudan	54	90	2.2	5.8	4.0	2.6	4.1	2.3
41402	IS 18758C-164	Ethiopia	79	175	2.5	3.0	2.6	2.5	2.7	2.0
41403	IS 18758C-170	Ethiopia	73	160	2.5	2.7	3.1	2.3	2.7	2.0
41412	IS 18758C-234	Ethiopia	73	165	2.5	2.5	2.3	2.4	2.4	2.3
41413	IS 18758C-242	Ethiopia	73	140	2.5	2.2	2.5	4.2	3.0	3.4
41424	IS 30469C-286	Ethiopia	70	125	2.5	2.5	4.4	3.9	3.6	3.0
41437	IS 2579C-342	Sudan	72	110	2.7	2.3	2.7	3.8	2.9	2.5
41473	IS 24695C-544L	Ethiopia	79	135	2.7	2.6	2.6	5.1	3.4	3.0
41488	IS 18758C-597S	Ethiopia	79	110	2.7	3.3	2.5	3.2	3.0	3.0
41489	IS 18758C 597T	Ethiopia	77	200	2.8	2.7	3.0	2.3	2.7	2.2
41720	IS 18758C 618	Ethiopia	54	125	2.8	3.6	3.0	2.1	2.9	2.0
41509	IS I8758C -698	Ethiopia	86	215	2.8	3.1	3.0	1.9	2.7	2.0
41510	IS 30469C 718	Ethiopia	79	230	3.0	3.5	3.0	3.9	3.5	3.5
41512	IS 24695C 730	Ethiopia	70	105	3.0	2.3	2.3	2.4	2.3	2.0
41513	IS 24695C - 734	Ethiopia	72	95	3.0	3.6	2.5	3.7	3.3	3.5
41530	IS 24695C -808	Ethiopia	74	115	3.0	2.5	5.4	3.6	3.8	3.4
41538	IS 24695C-842	Ethiopia	87	140	3.0	3.2	3.3	3.7	3.4	3.5
41543	IS 24695C-858	Ethiopia	77	150	3.0	2.7	2.0	3.2	2.6	3.0
41549	IS 18758C 886	Ethiopia	72	145	3.2	4.7	3.6	4.5	4.3	4.0
41550	IS 18758C 890	Ethiopia	70	115	3.2	2.4	3.2	4.8	3.5	4.3
41551	IS 18758C-894	Ethiopia	72	130	3.2	2.0	2.3	2.9	2.4	2.2
41564	IS 6248C-952	India	83	220	3.2	3.4	4.3	3.6	3.8	3.2
41596	IS 24695C-1085	Ethiopia	81	155	3.2	3.5	2.8	4.3	3.5	3.5
41598	IS 24695C-1089	Ethiopia	75	140	3.2	2.0	2.4	3.4	2.6	3.0
41601	IS 24695C-1101T	Ethiopia	81	200	3.2	2.3	4.4	3.3	3.3	2.7
41602	IS 18758C-1107S	Ethiopia	83	155	3.3	3.8	4.4	5.6	4.6	4.5
41603	IS 18758C-1107T	Ethiopia	83	185	3.3	3.0	3.3	3.0	3.1	3.0
41607	IS 18758C-1131	Ethiopia	75	150	3.3	1.8	2.5	2.9	2.4	2.3
41608	IS 30469C-I137	Ethiopia	72	120	3.3	2.3	2.5	3.4	2.7	3.0
41609	IS 30469C-1143D	Ethiopia	77	130	3.3	3.3	2.3	4.1	3.2	3.4
41612	IS 30469C-1157	Ethiopia	79	150	3.3	3.0	3.4	2.8	3.1	2.1
41613	IS 30469C - 1161	Ethiopia	85	215	3.3	2.5	3.1	2.9	2.8	2.4
41614	IS 30469C-1167	Ethiopia	83	200	3.5	2.8	2.5	2.3	2.5	2.0
41617	IS 30469C 1179	Ethiopia	70	170	3.5	4.0	2.8	1.8	2.9	2.0
41620	IS 30469C - 1199	Ethiopia	72	110	3.5	3.0	2.8	2.7	2.8	2.5
41621	IS 30469C - 1205	Ethiopia	81	135	3.5	2.0	3.0	3.1	2.7	2.6
41669	IS 18758C - 1476	Ethiopia	81	140	3.5	2.0	4.4	5.2	3.9	4.5
41673	IS 30469C -1502	Ethiopia	70	195	3.5	3.3	3.0	2.3	2.9	2.2
41674	IS 30469C-1508D	Ethiopia	79	225	3.5	1.7	2.5	3.0	2.4	3.0
41695	IS 30469C 1649D	Ethiopia	80	195	3.5	3.1	2.5	3.3	3.0	3.0
41696	IS 30469C I649T	Ethiopia	61	145	3.5	5.2	3.0	2.7	3.6	2.2
41703	IS 24695C 1679T	Ethiopia	79	195	3.5	2.3	2.3	2.5	2.4	2.0
41706	IS 24695C - 1695	Ethiopia	75	205	3.5	2.2	2.7	2.3	2.4	2.0
9471	(Resistant check)	S. Africa	60	245	3.2	2.3	2.1	1.8	2.1	2.0
18452	SPV 104 (Susceptible check)	India	63	190	8.5	3.5	6.7	8.2	6.1	8.0
		SE±	1.14	60.1	0.13	0.13	0.14	0.18	0.11	0.16

Mean of two repetitions each with 10 plants in 4-m long plots in field screening

1. DTF = Days to 50% flowering in the rainy season
2. PLHT=Plant height (cm) in rainy season
3. Mean of two replications, each of a petridish containing 25 grains using three fungi (*Fusarium moniliforme* , *F. pallidoroseum,* and *Curvular ia lunata*)
4. Mold scores on 1-9 scale, where 1= no mold, and 9 - > 75% mold
5. Threshed grain mold score was recorded only at Patancheru

Materials and methods

The most predominantly occurring grain mold fungi *Fusarium moniliforme* J. Sheld. *F pallidoroseum* (Cooke) Sacc. and *Curvularia lunata* (Wakker) Boedijn] were isolated on oatmeal agar and multiplied on presoaked autoclaved sorghum grains at 28±1°C under 12 h light cycles for 10 days. A spore suspension (1 x 10^6 spores mL^{-1}) prepared by mixing equal volumes of spore suspension of each of the three fungi was used for in vitro tests.

A total of 347 selections derived from 12 photoperiod sensitive Zerazera accessions [IS 956, IS 2579, IS 3443 and IS 6928 (Sudan), IS 18758, IS 24695 and IS 30469 (Ethiopia), IS 6248, IS 18484, IS 18790 and IS 18791 (India) and IS 18522 (USA)] through a conversion program were used for in vitro screening. IS 9471 a resistant cultivar with brown pericarp and IS 18452 a susceptible cultivar with straw-colored pericarp were included as checks in all the tests.

A preliminary evaluation of 347 selections was carried out in 1992 following an in vitro screening technique developed at ICRISAT (Singh and Navi 2001). Twenty-five seeds of each selection were dipped in a spore suspension described above for 1-2 min. They were air dried and transferred to a 9-cm pre-sterilized petridish humid chambers and incubated at 28±1°C for 5 days. Seeds were evaluated on a 1 9 mold severity rating scale where 1 = no mold, 2 = 1-5, 3 = 6 10, 4 = 11-20, 5 = 21 30, 6 = 31-40, 7 = 41- 50, 8 = 51-75 and 9 = >75% grain surface areas covered by the mold).

Forty-three resistant selections made from in vitro tests were evaluated in a field grain mold nursery using overhead sprinklers during the 1993 and 1994 rainy seasons at Patancheru in Andhra Pradesh, and under natural conditions at Bhavanisagar in Tamil Nadu and Mysore in Karnataka. In each selection 10 panicles with uniform flowering were tagged and were evaluated for mold resistance using the 1-9 rating scale at grain maturity, and again 14 days after maturity. All the tagged panicles were harvested, threshed, and threshed grain mold scores were recorded on a 1-9 scale.

Results and discussion

Under in vitro test, none of the selections was totally free from mold, while 43 showed mean mold ratings between 2.2 and 3.5, 88 were rated between 3.7 and 4.5, and 216 had ≥4.7 mold ratings. The 43 selections with ≤3.5 ratings from in vitro screening were tested in sorghum grain mold nurseries during the rainy seasons 1993 and 1994 the mean mold rating across the locations was ≤4 on 1-9 scale for most test entries (Table 1). The mean mold score of susceptible check IS 18452 was 6.1 and that of a resistant check IS 9471 with brown pericarp was 2.1. The threshed mold scores of the 43 selections were below 4 and that of resistant check 2 and the susceptible check 8. The days to 50% flowering (DTF) ranged from 54 to 87 while plant height varied from 90 to 220 cm in the selected 43-converted zerazera selections. Eight accessions with in vitro mold ratings of ≤3.7-4 and field mold ratings of <4 at Patancheru were selected as

Table 2. Evaluation of eight Zerazera sorghum selections for resistance to grain molds both in vitro and a field grain mold nursery at Patancheru during the 1994 rainy season

					Mean mold score[4]		
IS No.	Pedigree	Origin	DTK[1]	PLHT[2]	LAB'	PTN	TGMR[5]
41720	IS 18758C -618-2	Ethiopia	54	125	2.1	2.2	2.0
41720	IS 18758C-618-3	Ethiopia	54	125	2.4	2.4	2.0
40657	IS 18758C-710-4	Ethiopia	-[6]		2.5	2.3	2.0
40657	IS 18758C-710-5	Ethiopia	-	-	2.5	2.3	2.0
41397	IS 30469C-140-2	Ethiopia	79	130	3.0	3.9	3.5
41397	IS 30469C 140-4	Ethiopia	79	130	3.0	3.9	3.2
41618	IS 30469C - 1187-5	Ethiopia	79	205	3.0	3.9	3.4
41675	IS 30469C 1508T-2	Ethiopia	80	235	3.0	3.9	3.3
9471	(Resistant check)	S. Africa	60	245	3.2	1.8	2.0
18452	[SPV 104 (Susceptible check)]	India	63	190	8.5	8.2	8.0
	SEf±	3.75	16.32	0.59	0.59	0.58	

1 5 See Table 1 footnotes
6. = Data not available

promising. Two selections each of IS 18758C--618 , IS 18758C-710, and IS 30469C-140, and one selection each of IS 30469C-1187, and IS 30469C-1508T showed consistently high levels of mold resistance (<3) in both the tests (Table 2). Additionally, these selections were also found to have very high levels of resistance to anthracnose [*Colletotrichum graminicola* (Ces.) GW. Wilson] and leaf blight [*Exserohilum turcicum* (Pass.) Leonard & Suggs] at all the three locations (data not reported).

Several sources of resistance have been reported in late-maturing white-straw, brown-, and red-pericarp sorghums (Bandyopadhyay and Mughogho 1988b) and in photoperiod-sensitive germplasm accessions (Singh et al. 1995; Singh and Navi 2001). These new sources identified are photoperiod-insensitive, early to medium-maturing with straw-colored grain. Therefore, it is proposed to further test them in variable environments to determine their resistance stability.

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Millet Research Reports

Genetics and Breeding

Selection of Superior Female Parents Utilizing B x R Crosses for A-line Development in Pearl Millet

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Introduction

When breeding pearl millet [*Pennisetum glaucum* (L.) R. Br] the development of superior B-lines can have more impact on increasing grain and/or forage yield than any other type of inbreeding, especially if the B-lines are used to develop cytoplasmic male-sterile (CMS) lines (Hanna and Rai 1999). A desirable B-line should perform well so as to reduce the cost of seed production, maintain complete male sterility, have good general combining ability (gca), produce adequate pollen to maintain its isogenic A-linc, and have the much-needed resistance to biotic and abiotic stresses that will make it a successful inbred line. In the process of developing new CMS lines, it would be advantageous to determine the combining ability of potential B-lines before committing time and effort to sterilize all of the potential females (Schert and Johnson 1984; Rai and Singh 1987; Lee et al. 1992). The work reported here was an attempt to assess combining ability of newly developed downy mildew [*Sclerospora graminicola* (Sacc.) J. Schrot] (DM)-resistant B-lines and to identify the B-lines suitable for conversion into male-steriles and for use.

Materials and methods

The material consisted of five pollinators D 23, PPMI 301, ICMP 451, M 46, and PPMI 469. Most of these are parents of released hybrids. They were used as testers to assess the combining ability of eight newly developed DM-resistant maintainer lines: 2136B, 2142B, 2174B, 2222B, 2188B, 2197B, K 310B, K 297B, and 514IB (control) that were used as females in line x tester mating. The new main-tainers were developed from a population produced by intermating the DM-resistant B-lines in the pearl millet improvement program at the Division of Genetics, Indian Agricultural Research Institute (IARI), New Delhi. The maintainer 5141B (female parent of eight commercial hybrids produced during 1977-84) was included as a control maintainer against which to compare the suitability of new B-lines for conversion into male-sterile lines. Forty-five hybrids, their 14 parents (B-lines and pollinator parents), and Pusa 23 as a standard control were sown in a randomized-block design with two replications during the 1995 rainy season at the Division of Genetics, IARI, New Delhi. The parents, F_1s and control were randomized separately and sown in adjoining blocks (Arunachalam 1974). Each entry in a replication was represented by a single 3-m row spaced 45 x 15 cm. The mean values recor-ded on 10 randomly chosen plants for eight quantitative characters (Table 1) were used for statistical analysis. Estimates of combining ability were computed following Kempthorne (1957).

Results and discussion

The analysis of variance revealed that significant variability existed in the experimental material for all the characters. The variation due to parents vs. hybrids was significant for all the characters, implying the pre-sence of substantial heterosis in the material. The parents (lines and testers) also differed markedly for various characters.

Performance of hybrids. The overall mean grain yield of hybrids (77 g plant^{-1}) was 167% higher than the overall mean grain yield of parents (28.79 g plant') (Table 1). Individual plant grain yields of the F_1 hybrids ranged from 32 g (5141B x PPMI 469) to 117 g (2197B x D 23). Three hybrids were significantly superior to Pusa 23, while 33 hybrids were at par. Observations for other components of grain yield were similar. When the new B-lines were compared for their hybrid potential against the control (5141B), the new B-line 2197B, was the best as it produced two hybrids (2197B x D 23 grain yield 117 g plant^{-1} and 2197B x PPMI 301 grain yield 111 g plant^{-1}) that were significantly superior to Pusa 23, while its other three hybrids were at par. On the other hand, 5141B produced two hybrids (5141B x D23 grain yield 67 g plant^{-1} and 5141B x ICMP 451 grain yield 100 g plant^{-1}) that were at par while its other three hybrids produced grain yields signi-ficantly lower than that of Pusa 23. Two hybrids based on 5141B, and 33 hybrids based on new B-lines were at par, three were significantly better, and four were significantly worse than Pusa 23. This indicated that the new B-lines have better heterotic ability, i.e., the ability to impart hybrid vigor to their offspring when crossed with genetically diverse pollinators (Burton 1982) and are therefore more suitable for use than 5141B.

General combining ability (gca) The estimates of gca (Table 2) showed that inbreds 2136B, 2174B, and 2188B that had significantly negative gca estimates, were good general combiners for time to 50% flowering, and possessed genetic architecture that was suitable for imparting earliness to their progenies. The B-line parents: K 310B and K 297B for plant height; 2174B and 2222B for spike length; K310B and K297B for spike girth; 2142B, 2197B, and 5141B for grain density; K310B and K297B for 1000-grain mass; and 2222B, 2188B, and 2197B for grain yield plant^{-1} showed significantly desirable gca effects. Compared to 514IB (which has negatively significant gca effects for all the characters except for grain density, the new B-lines; 2197B, 2188B, and 2222B that have signifi-cantly positive gca effects have better gca, not only for grain yield, but also for other components.

Among restorers, D 23 was identified as the best general combiner for grain yield plant[1], grain density, 1000-seed mass, spike girth, and effective tillers plant^{-1}. Other good restorers, were PPMI 301 and ICMP 451. The genotype M 46 is poor combiner for all characters except earliness.

Table 1. Mean of parents, hybrids, range, and standard heterosis (% over Pusa 23) of best three hybrids resulting from B x R crosses

Character	Mean of parents	B x R hybrids Mean	B x R hybrids Range	Pusa 23	Over Pusa 23 At par	Over Pusa 23 Significantly superior	Best three B x R hybrids[1] 1	2	3
Time to 50% flowering (days)	58	56	50-60	53	23	2	2136B x PPMI 469 [-1.88]	2136B x D23 [-3.77]	2142B x M46 [-5.66]
Plant height (cm)	151	200	145-233	190	41	4	2142B x ICMP 451 [22.63]	2142B x PPMI 469 [18.94]	K310B x ICMP 451 [17.36]
Effective tillers	2.4	2.5	1.7-3.6	3.2	26		2188B x M46 [12.5]	2174B x M46 [9.37]	K310B x M46 [6.25]
Spike length (cm)	21.8	27.3	23-31	26.6	30	11	2136Bx PPMI 469 [16.69]	2222B * D23 [14.21]	2188B x PPMI 469 [13.64]
Spike girth (cm)	1.9	2.3	1.86 2.72	2.2	34	9	97Bx PPMI 301 [23.63]	K310Bx D23 [20.90]	K310B x PPMI 301 [19.54]
Grain density cm^2	23.6	24.2	15.5-32.1	21.3	21	18	2142B x PPMI 469 [51.07]	5141Bx D23 [49.29]	5141B x PPMI 469 [45.531
Grain yield plant^{-1} (g)	28.8	77.6	32-117	83	33	3	2197B x D23 [41.87]	2197B x PPMI 301 [34.25]	2142B x D23 [32.33]
1000-seed mass (g)	7.68	10.2	7.1-14.3	9.5	22	15	K310B x ICMP 451 [50.84]	K310B x PPMI 301 [45.57]	K310B x D23 [36.94]

1. Values in parentheses are heterosis values (%) over standard control Pusa 23

Table 2. General combining ability (gca) effects of tested pearl millet lines (B-lines) and testers (R-lines), IARI, New Delhi, rainy season 1995

Lines	Time to 50% flowering (days)	Plant height (cm)	Effective tillers	Spike length (cm)	Spike girth (cm)	Grain density (cm^2)	Grain yield $plant^{-1}$ (g)	1000-grain mass (g)
B-Lines								
2136B	-2.75[1]	-9.76[1]	0.08	-0.12	-0.12[1]	-1.70[1]	-11.02[1]	-0.20
2142B	1.24	-0.36	-0.91[1]	-0.91[1]	-0.03	2.28[1]	-0.36	-0.82[1]
2174B	-2.85[1]	3.93	0.11	1.38[1]	-0.15[1]	-0.08	-5.59	0.35
2222B	1.84	2.43	-0.09	1.31[1]	-0.03	-0.08	7.00'	0.24
2188B	-0.65[1]	-9.96[1]	0.04	0.36	0.10	0.47	8.44[1]	-1.40[1]
2197B	2.44	0.23	0.19	-0.04	-0.03	3.33[1]	19.70[1]	-0.74[1]
K-93-310	-1.65	6.23[1]	0.07	-0.46	0.16[1]	-5.66[1]	-2.84	2.41'
K-93-297	-0.14	8.13[1]	-0.31[1]	0.44	0.22[1]	-3.95[1]	1.67	1.79'
Check								
5141B	2.24	-0.84	-0.28[1]	-1.96[1]	-0.14[1]	5.39[1]	-17.00[1]	-1.62[1]
R-Lines								
D23	0.23	1.25	0.36[1]	0.08	0.08[1]	3.47[1]	9.44[1]	0.56[1]
PPMI 301	0.87[1]	0.02	-0.30[1]	-0.97[1]	0.20[1]	0.07	4.72	0.58[1]
ICMP 451	0.32	6.70[1]	-0.11	0.79[1]	-0.008	-1.03[1]	3.95	0.48[1]
M 46	-0.95[1]	-18.14[1]	0.48[1]	-2.44[1]	-0.17[1]	1.52[1]	-6.07[1]	-0.90[1]
PPMI 469	0.01	9.96[1]	-0.42[1]	1.81[1]	-0.10[1]	2.91[1]	-2.60	--0.73[1]
CD at 5%								
Lines	0.99	5.80	0.23	0.80	0.07	1.29	6.95	0.39
Testers	0.74	4.31	0.17	0.58	0.05	0.96	5.19	0.29

1. Significant at *P* = 0.05

Comparing both the gca effects of the new B-lines and the performance of their hybrids with 5141B, B-lines 2197B, 2188B, and 2222B were identified as females poten-tiality suitable for conversion into male-sterile versions that could be further used in hybrid programs to **enhance** the yield levels of hybrids.

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Assessment of Inbred Lines as Seed Parents of Top-cross Hybrids in Pearl Millet

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Introduction

Pearl millet [*Pennisetum glaucum* (L.) R.Br.] single-cross hybrids are grown for their grain over large areas of India. Setbacks initially due to devastating downy mildew [*Sclerospora graminicola* (Sacc.) J. Schrot.] (DM) disease and the adherence to using only single-cross hybrids led to slow progress in developing high-yielding and disease-resistant hybrids (Andrews and Bramel-Cox 1994). Top-cross hybrids—an inbred seed parent pollinated by an open-pollinated variety of broad genetic nature - are practical in pearl millet and have yield advantages in terms of durability of resistance and stability of adaptation that are difficult to obtain in single-cross hybrids (Andrews et al. 1996). The present study was attempted to assess a set of newly bred DM-resistant male-sterile (A) and maintainer (B) lines for their suitability as seed parents of top-cross hybrids in pearl millet.

Material and methods

Eight pearl millet CMS lines of 1CRISAT, Patancheru origin (841A, 81A, ICMA 91333, ICMA 91444, ICMA 91777, ICMA 92444, ICMA 92777, and ICMA 92888) and one CMS (5141 A) and 11 maintainers from the Pearl Millet Improvement Programme of the Indian Agricultural Research Institute (IARI), New Delhi (2136B, 2142B, 2203B, 2216B, 2174B, 2222B, 2188B, 2197B, 2155B, K310B and K297B) were used as potential seed parents. Pollen collected from at least 100 plants of different pollinators (D 23, 1CMP 451, J 104, B110, PPMI 469, PPMI 301, M46, H77/833-2, and K 560-230) and of two F_1 hybrids, Pusa 23 and Pusa 322 was mixed and used to pollinate the 20 seed parents during the summer season, 1995 at the Central Institute of Cotton Research (CICR), Regional Station, Coimbatore. The bulk pollen as such is of broad genetic nature, but, each of the resultant hybrid plants is a cross between two inbreds only. Hence, the so-called top-cross hybrid is not a true top-cross hybrid in genetic terms, but is only a mixture of single-cross hybrid plants. The protogynous nature of pearl millet was effectively used to make hybrids on maintainers (Andrews et al. 1996). These 20 test hybrids (each of the test hybrids was a mixture of many single-cross hybrid plants making it heterozygous and heterogeneous mixture) were sown during the rainy season of 1995 at the Division of Genetics, IARI, New Delhi. The experiment was grown in three replications, with spacing of 45 cm between rows and 15 cm between plants in a 3-m rows plot^{-1}. Thirty plants were randomly selected from each plot and from them, data for eight quantitative traits, time to flowering (days), plant height (cm), effective tillers plant^{-1}, panicle length (cm), panicle girth (cm), grain density cm^{2}, grain yield plant^{-1} (g) and 1000-grain mass (g) were recorded. The superiority (%) of test hybrids over the commercial single-cross hybrid check, Pusa 23 (CC) was calculated as $[(F_1\text{-CC}) \times 100] / \text{CC}$ where F_1 was the mean of test hybrids, and CC was the mean of commercial check, Pusa 23.

Results and discussion

The ranges, genotypic variances and superiority (%) for grain yield and its components of the hybrids relative to the commercial check Pusa 23 (Table 1) clearly indicated that the test hybrids differed significantly in their performance per se, and that a great amount of variability existed in the material. The mean time to flowering of the hybrids was 54 d ranging from 50 (hybrids made on 841 A) to 60 (hybrids made on ICMA 92444). Only one hybrid on 841A was significantly earlier than Pusa 23 (mean time to flowering 50 d with -5.7% superiority) while other hybrids based on ICMA 91333, ICMA 92444, 2222B, 2155B, and 2197B were significantly later in flowering than Pusa 23.

For plant height, the test hybrids were, in general, tall (mean height 210 cm). The hybrids based on 841 A, 81A, ICMA 92444, ICMA 91444, ICMA 91777, ICMA 92777, ICMA 92888, 2174B, 2216B, 2222B, 2155B, 2142B, K297B, and K310B were significantly taller than Pusa 23. These females could be used to develop dual-purpose hybrids for both grain and fodder. Similar to the ranges and genotypic variances of time to flowering and plant height, such other traits as effective tillers plant^{-1}, panicle length, panicle girth, grain density, and grain mass also indicated wide variability in the test hybrids (Table 1). For grain yield, the most important character, the genotypic variance (347) was high, while mean grain yield plant^{-1} ranged from 54 g (female ICMA 91333; superiority = -39%) to 127 g (female ICMA 91777; superiority = +43%). Seven of the 20 test hybrids were significantly superior in grain yield to Pusa 23. Observations for individual component traits were also similar. The seed parents of hybrids made on ICMA 91777, ICMA 92777, 2203B, 2174B, 2222B, 2155B, and

Table 1. Superiority (%) of single–cross test pearl millet hybrids over Pusa 23 (check), rainy season, 1995, IARI, New Delhi

Hybrids with male-sterile	Time to 50% flowering (d)		Plant height (cm)		Effective tillers		Panicle length (cm)		Panicle girth (cm)		Grain density (cm^{2})		Grain yield plant^{-1} (g)		1000-grain mass (g)	
	Mean	Superiority (%)	Mean	Superiority (%)	Mean	Superiority (%)	Mean	Superiority (%)	Mean	Superiority (%)	Mean	Superiority (%)	Mean	Superiority (%)	Mean	Superiority (%)
841A	50	–5.7*[1]	216	13.7*	2.5	–13.8	29	15.8*	2.3	–4.2	22.3	–9.2	85.0	–4.5	9.8	3.8
81A	53	0.0	211	11.1*	2.8	3.4	28	12.5*	2.1	–12.5*	26.5	7.8	87.0	–2.2	9.8	2.8
ICMA 91333	58	9.4*	150	–21.1*	2.26	–22.1*	29	15.2*	2.1	–12.5*	28.3	15.3*	54.3	–39.0*	8.8	–6.8
ICMA 91444	52	–1.9	216	13.7*	2.8	–3.4	27	6.7	2.3	–4.2	24.2	–1.7	81.7	–8.2	10.4	9.4
ICMA 91777	53	0.0	211	11.1*	3.46	19.3*	29	14.3*	2.4	0.0	21.7	–11.7*	127.3	43.1*	12.3	29.6*
ICMA 92444	60	13.2*	258	35.8*	2.33	–19.7*	27	9.0	2.6	8.3*	24.5	–0.1	72.7	–18.4*	10.6	11.8*
ICMA 92777	54	1.9	211	11.1*	3.6	24.1	28	11.8*	2.5	4.2	20.4	–17.0*	112.0	25.8*	12.4	30.3*
ICMA 92888	53	0.0	211	11.1*	2.46	–15.2	28	13.2*	2.7	12.5*	20.3	–17.4*	76.0	–14.6	10.3	8.9
5141A	53	0.0	200	5.3	2.06	–29.0*	28	13.2*	2.8	16.7*	19.8	–19.3*	81.0	–9.0	13.5	42.8*
2136B	54	1.9	192	1.1	3.06	5.5	27	8.0	2.2	–8.3*	20.8	–15.4*	65.0	–27.0*	10.5	11.2
2142B	54	1.9	216	13.7*	3	3.4	24	–2.2	2.1	–12.5*	29.0	17.9*	86.0	–3.4	8.5	–10.1
2203B	55	3.8	195	2.6	3.31	14.1	25	–0.6	2.3	–4.2	26.5	7.7	119.0	33.7*	10.2	7.6
2216B	54	1.9	226	18.9*	2.8	–3.4	27	7.7	2.6	8.3*	22.8	–7.1	91.0	2.2	11.3	18.9*
2174B	52	–1.9	226	18.9*	3.33	14.8	28	13.3*	2.1	–12.5*	25.6	4.2	104.0	16.9*	9.7	2.2
2222B	57	7.5*	222	16.8*	2.6	–10.3	29	14.6*	2.5	4.2	26.8	8.9	108.0	21.3*	10.4	9.4
2188B	52	–1.9	190	0.0	2.33	19.7	30	19.9*	2.2	–8.3*	24.4	–0.9	69.0	–22.5	8.9	–6.3
2197B	59	11.3*	199	4.7	2.26	–22.1	29	16.9*	2.3	–4.2	32.4	31.7*	92.0	3.4	8.8	–7.3
2155B	56	5.7*	220	15.8*	2.8	–3.4	27	9.5	2.4	0.0	23.6	–4.1	107.0	20.2*	11.3	19.1*
K310B	54	1.9	224	17.9*	3.53	21.7	28	10.3*	2.4	0.0	22.4	–8.8	116.0	30.3*	11.9	25.5*
K297B	54	1.9	214	12.6*	2.53	–12.8	28	12.0*	2.3	–4.2	23.5	–4.3	71.0	–20.2*	10.2	8.0
Pusa 23	53	–	190	–	2.90	–	25	–	2.4	–	24.57		89		9.48	–
Mean	54		210		2.79		28		2.4		24.3		90.2		10.5	
Range	50–60		150–258		2.06–3.60		24–29		2.1–2.8		19.8–32.4		54.3–127		8.5–13.5	
CV (%)	5.22		391.5		0.14		1.07		0.04		9.24		347.5		1.42	
CD (5%)	2.64		12		0.54		2.22		0.10		2.35		15		1.14	
CV (%)	4.83		9.84		16.67		4.14		8.95		13.40		18.1		12.58	

1. * = significant at 5%

K310B that showed significant superiority over Pusa 23 could be exploited further for the development of true top-cross hybrids involving landraces, elite populations etc., and their yield advantages assessed for commercial exploitation. Since only male-sterile inbreds (A-lines) are commercially used as seed parents for making and exploiting top-cross hybrids, the potential B lines identified in this study (2203B, 2174B, 2222B, 2155B, and K310B) need conversion into their male-sterile versions. The use of locally adapted landraces in breeding top-cross hybrids on high-yielding, male-sterile lines could provide an opportunity to produce top-cross hybrids with high grain yield potential and DM resistance without any apparent loss of adaptation to the marginal environments in which the parent landraces evolved (Bidinger et al. 1994).

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Heterosis in Pearl Millet: A Physiological Assessment

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Introduction

Pearl millet is a C_4 species with a very high photosynthetic efficiency and dry matter production capability. The traditional landraces are often tall, have thick stems and are excessively leafy. The biomass production in these landraces even under the prevailing low-resource farming systems is very high (6-12 t ha^{-1}), while the harvest index (HI) is often below 20% compared to over 30% for the improved cultivars (Anand Kumar 1989). Improvement in HI is a major thrust in breeding for higher grain yield.

Following the discovery of a cytoplasmic-genic male sterility (cms) system in pearl millet (Burton 1958) grain hybrids with shorter plant height were developed in India. These had a HI of 40% and produced 8 t ha^{-1} of experimental grain yields in 85 days. Hybrid vigor in pearl millet is expressed phenotypically as the production of greater amounts of plant tissue, grain or derived products. Obviously then the hybrid forms exhibit more growth than their inbred parents. Since growth is the product of biochemical reactions, heterosis will be manifested either by increased rates of metabolic reactions or by a more efficiently organized metabolic system. Increased reaction rates are achieved by enhanced enzyme activity. Enhanced activity must result from the presence of more enzyme (Hageman et al. 1967).

A study was taken up in the Department of Crop Physiology, Tamil Nadu Agricultural University (TNAU), Coimbatore to assess hybrid vigor in pearl millet in terms of some important biochemical parameters, e.g., N-fixing enzyme (nitrate reductase, N Rase) activity, carbon-fixing enzyme (soluble protein) content, and light-harvesting pigment (chlorophyll) content.

Materials and methods

The male-sterile line 732-A is medium-short (90 cm), profusely tillering (7-10 productive tillers), and flowers in about 50-54 days. The panicle is cylindrical and thin (5-6 cm in diameter) and medium long (20-25 cm). It yields 0.75-1.0 t ha^{-1} of medium-sized grains and has a 1000-grain mass of 7.0- 7.5 g, it is resistant to lodging and possesses adequate field resistance to downy mildew (DM) [*Sclewspora graminicola* (Sacc.) J. Schrott]. This line was used for crossing with inbred line PT4450 which has the following characters, tall plant type (160-170 cm), medium tillering (4-6), flowering in about 45-50 days, and has high grain productivity of 3-4 t ha^{-1}. The hybrid (CoHCu-8) produced by crossing these two parents is more productive and resistant to DM. CoHCu-8 and its parents were used for physiological assessment.

The parents and hybrid were sown in June 2001 and harvested by September 2001. The trial plot size was of 12 m^2. The plants were sampled at critical growth stages of crop growth, i.e., vegetative, flowering, and maturity and their chlorophyll content (Yoshida et al. 1971), soluble protein content (Lowry et al. 1951), and NRase activity (Nicholas et al. 1976) were estimated.

The heterotic values of the physiological parameters were estimated by adopting the formula.

$$\text{Standard heterosis} = \frac{F_1 \text{ value - Mid-parental value}}{\text{Mid-parental value}} \times 100$$

Results and discussion

Chlorophyll content. More chlorophyll$_a$ (Chl$_a$), chlorophyll$_b$ (Chl$_b$), and total chlorophyll were found in the hybrids than in their parents throughout the crop growth period. The heterotic value of Chl$_a$ was higher at maturity (29.00%) and at vegetative stages (26.97%) while it declined at the flowering stage (25.12%). A similar trend was observed in total chlorophyll content (Table 1). Chl$_b$ content showed an increasing trend of heterosis throughout crop growth. Miflin and Hageman (1963) reported a contradictory effect in the chloroplast activity of F_1 corn (*Zea mays* L.), where the F_1alue was lower than the mid-parental value.

Soluble protein content. The soluble protein content in the plants averages to 6-9 mg g^{-1} of fresh weight. Carboxylating enzymes constitute >70% of the soluble protein. The carboxylating enzymes are RuBPcase which principally fixes CO_2 in C_3 plants and PEPcase in C_4 plants. In the present study the soluble protein content was higher in the hybrid CoHCu-8 than in its parents 732-A and PT-4450 and the F_1 value was higher than the mid-parental value at all critical growth stages (Table 1).

NRase activity. The assimilatory reduction of nitrates absorbed by plants is converted to nitrite by an important key rate limiting enzyme NRase during nitrogen (N) metabolism.

NRase activity was higher in the F_1 hybrid CoHCu-8 than in its parents 732-A and PT-4450 in all the three tested stages. Highest heterosis was recorded at maturity (77.11%) followed by vegetative (52.22%) and flowering (29.14%) stages (Table 1). Maheshwari and Nair (1991) observed the heterotic vigor in hybrid pearl millet for NRase and noted that excised shoots of hybrids showed heterosis for NRase induction potential over their parents. Joshi et al. (1995) were of the view that the NRase in the

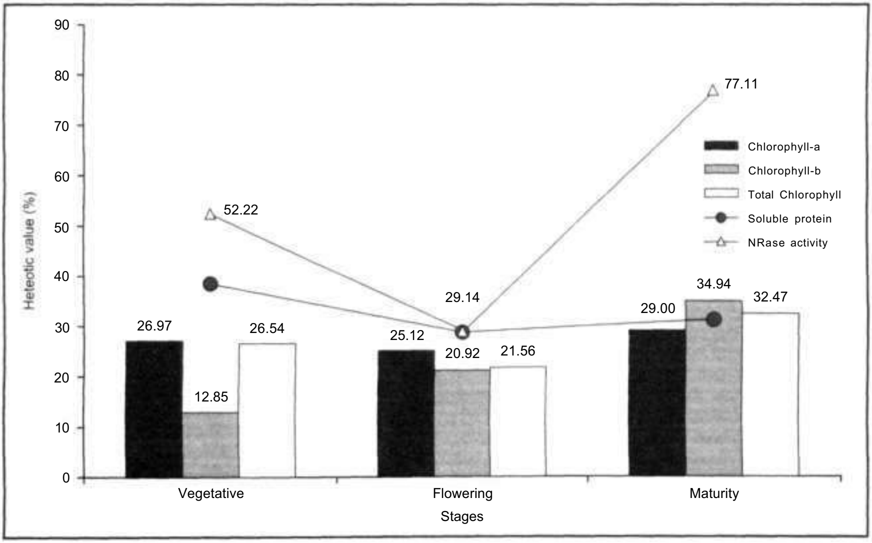

Figure 1. Standard heterosis of physiological parameters in pearl millet.

Table 1. Chlorophyll content (mg g^{-1}), Soluble protein content (mg g^{-1}) and NRase activity (μ mole NO_2 $g^{-1}h^{-1}$) of F_1 hybrid and parents and standard heterotic value

	Stages		
Physiological parameters	Vegetative	Flowering	Maturity
Chlorophyll$_a$ (Chl$_a$)			
732 A	0.930	2.025	0.908
PT 4450	1.039	2.417	1.013
CoHCu-8	1.250	2.779	1.239
Heterotic value (%)	26.97	25.12	29.00
Chlorophyll$_b$(Chl$_b$)			
732 A	0.358	0.684	0.315
PT 4450	0.397	0.836	0.349
CoHCu-8	0.426	0.919	0.448
Heterotic value (%)	12.85	20.92	34.94
Total chlorophyll			
732 A	1.320	2.826	1.235
PT 4450	1.487	3.273	1.380
CoHCu-8	1.776	3.707	1.732
Heterotic value (%)	26.54	21.56	32.47
Soluble protein content			
732 A	3.35	4.49	3.55
PT 4450	3.92	6.12	4.01
CoHCu-8	5.03	6.82	4.96
Heterotic value (%)	38.38	28.56	31.22
NRase activity			
732 A	2.20	4.38	1.64
PT 4450	2.53	4.85	2.03
CoHCu-8	3.60	5.96	3.25
Heterotic value (%)	52.22	29.14	77.11

hybrid mainly followed the mid-parental value. The heterosis phenomenon of these hybrids might be based on the concept that the intermediate nature of these enzymatic components of the assimilatory system represented a balanced status producing an optimum level of reduced leaf N that is responsible for the enhanced efficiency of the hybrid's photosynthetic system and in turn their productivity and yield.

The present study on the pearl millet hybrid CoHCu-8 and its parents 732-A and PT-4450, however showed an increasing content of soluble protein, chlorophyll, and NRase activity over both mid-parents and parents. The heterotic phenomenon is an explanation that the hybrid between two inbred parents is likely to have a better-balanced metabolic system. The major enzymes like soluble protein content (RuBPcase) and NRase activity, and the chlorophyll content should be at optimum levels of activity to produce optimum growth and yield in the hybrid.

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Pollen Drying Techniques in Pearl Millet

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Introduction

Improved techniques to preserve pollen are continuously being developed and should be exploited in crop improvement programs. Pollen can be stored after drying, or in organic solvents. Reasons for declining viability during storage among plant species and cultivars are not well understood. The condition of pollen at time of collection and subsequent processing before, during, and after storage could determine how long pollen remains viable to effect seed set. Temperature and moisture have the greatest influence on pollen longevity (Visser 1955;

Stanley and Linskens 1974; Hanna 1990). In general, lower temperatures and moisture content increase longevity.

Although pearl millet [*Pennisetum glaucum* (L.) Br.] is trinucleate, its pollen tolerates the desiccation (Hanna and Towill 1995) and viability of dried pollen can be maintained in storage for long periods (Hanna 1990). Studies to deter-mine the optimum moisture content of pollen for storage are few although it is understood that pollen collections from the field differ in moisture content that should be adjusted prior to storage. Greenhouse-collected pollen contains less moisture than field-collected pollen and therefore, required less drying time. Air-drying pearl millet pollen for 3 h at 24°C and 38% relative humidity reduced the moisture content of field-collected pollen to 7.5-12% and greenhouse-collected pollen to 2.2%. Pearl millet pollen usually required 1 or 2 h of drying attain a suitable moisture content for storage (Hanna and Towill, 1995). Connor and Towill (1993) reported that equilibrium mois-ture contents for a given relative humidity will differ among plant species and are dependent on pollen compo-sition.

Pearl millet pollen was successfully stored for 7 at -8°C and 8 years at -73°C, and continued to be viable (Hanna, 1990). However, loss of viability during storage tended to be faster in reclosable plastic bags than in glass vials due to increase in moisture accumulation in plastic bags (Hanna 1994). Thawing and refreezing pearl millet pollen for short intervals did not seem to affect viability in either a frostless or conventional freezer and pollen longevity can be extended if it is stored in airtight containers (Hanna et al. 1983; Hanna 1994).

The objective of this research was to determine if a pollen drying could be simplified, and the use of a forced-air drying oven avoided.

Materials and methods

Pollen was collected in 7 x 30 cm glassine bags from indivi-dual inflorescences of HGM, 100 at 13:30 on 21 August 2000. Bags were randomly assigned to each treatment below. Drying treatments were as follows:

A. Place bags on their side (in accordion style) on a black paper surface for 2 h
B. Place bags on their side (in accordion style) on a foil surface for 2 h
C. Place bags on their side (in accordion style) on asphalt surface for 2 h
D. Place bags in a forced air oven for 2 h at 38°C (standard drying treatment).

After drying, pollen was screened, placed in screw-cap vials and stored at -18°C. After drying, the moisture content of the pollen was determined from three sub-samples of each treatment (Table 1). Temperature 12 mm above the drying surfaces averaged (3 measurements) 43° for Treatment A, 44° for Treatment B, and 43°C for Treat-ment C.

At 15 and 47 days after storage (DAS), four, 0.5-mL subsamples (replications) of pollen from each treatment were placed in glassine bags and each bag was used to pollinate a cytoplasmic-nuclear male sterile (CMS) Tift 23AE inflorescence. Fresh pollen was also used to pollinate the CMS at each DAS pollination to test the receptivity of the female parent. Seed set (%) was deter-mined and used to estimate the viability of the stored pollen.

Results and discussion

All data are summarized in Table 1. Results show that all drying treatments reduced the original pollen moisture by about 50%. However, the seed set data indicates that there were differences in the effectiveness of drying treatments in maintaining pollen viability. Both Treatment B (reflective foil) and the forced-air oven drying (Treatment D) reduced the moisture of the pollen to 5.7% and both produced about the same amount of seed set at 15 and 47 DAS. These two drying treatments maintained acceptable pollen viability for the time period tested. The black drying surfaces of both Treatments A and C resulted in the lowest pollen moisture contents and also the lowest seed sets. Previous studies showed that pollen moisture of <7% was favorable for maintaining pollen viability (Hanna et al. 1983).

These data indicate that the black drying surface treatments somehow had a early effect on reducing pollen viability since the drying surface temperatures were similar for Treatments A, B, and C, yet, seed set from Treatment B at 15 DAS was 100% compared to 30% or less for Treatments A and C. Seed-set data immediately

Table 1. Pollen moisture and seed set characteristics of pollen dried using various techniques

Treatment	Pollen moisture	Seed set (%) 15 DAS[1]	Seed set (%) 47 DAS
Fresh	9.9	100.0	100.0
A	4.2	8.0	13.0
B	5.7	100.0	78.0
C	4.4	30.0	24.0
D	5.7	100.0	74.0
LSD (5%)	0.1	6.0	36.0

1. DAS = days after storage

after drying (not obtained) would have helped to answer this question. The differences between Treatments B, A, and C appear to be related to the reflective and absor-ptive heat of these treatments. At Tifton, pollen is routinely dried for 2 h at 38°C in a forced-air oven (Treat-ment D) before storage at -18°C. The reflective drying surface of Treatment B was as effective in maintaining the viability of pearl millet pollen as the standard drying treatment. The reflective drying Treatment B has implica-tion for use in drying pollen at locations where forced-air ovens may not be available.

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Agronomy

On-farm Seed Priming Increases Yield of Direct-sown Finger Millet in India

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Introduction

Finger millet (*Eleusine coracana* (L.) Gaertner) is a crop that is popular with resource-poor farmers in Africa and Asia because it is adaptable, resilient, and yields well on marginal land without irrigation. It may be transplanted, as in some parts of India and Nepal, but most is direct-sown, often by broadcasting. Establishing adequate stands of direct-sown crops can be a problem in marginal areas where timely access to resources for land preparation is sometimes difficult. Improved stand establishment and increased yield following 'on-farm' seed priming has been reported recently in a number of crops (Harris et al. 1999 for upland rice (*Oryza sativa* L), chickpea *(Cicer arietinum* L), and maize (*Zea mays* L.); Harris et al. 2001b for wheat *(Triticum aestivum* L.); Musa et al. 2001 for chickpea). Two trials of the effect of seed priming on six finger millet cultivars are described below.

Materials and methods

Trials were implemented at the Birsa Agricultural University/GVT research farm, Ranchi, Jharkhand, India in the rainy seasons (*kharif*) of 2000 and 2001. In each year, seeds of six varieties of finger millet (A-404, Birsa Marua-2, HR 374, VL 149, KARRA 1, and ZAH 1) were sown in a randomized-block design with three replicates. Seeds of each variety were either sown after priming in water for 8 h, followed by surface drying to facilitate handling, or were sown as usual without priming. Sowing dates were 22 July in 2000 and 20 July in 2001 and net plot size was 3.5 m x 1.0 m. Seed was sown by hand at a rate of 8 kg ha^{-1} into a furrow opened with a hoe, with 20 cm between furrows. Twenty kg of N (as urea) ha^{-1}, 30 kg of P_2O_5 (as single superphosphate) ha^{-1} and 20 kg of K_2O (as potassium chloride) ha^{-1} were incorporated as a basal dressing, and a further 20 kg N ha^{-1} was applied as a top dressing 30 days after sowing. In 2000, plant height, finger length, number of fingers plant^{-1}, number of effective tillers plant^{1}, panicle length, days to 50% flowering and to maturity, and grain yield were measured. In 2001, only grain yield was measured.

Results

In 2000, priming significantly reduced both the mean time to 50% flowering and the mean time to maturity by about 6 days and increased mean plant height by 9 cm (Table 1). There were significant differences between varieties in plant height, finger length, number of fingers plant^{-1}, panicle length, days to 50% flowering and to maturity, but there were no significant variety x priming interactions for any of the variables in Table 1. Priming was associated with significant yield increases, averaged over the six varieties, of 17% in 2000 and 11% in 2001 (Table 2). The yield of varieties in 2000 ranged from 1.25 t ha^{-1} to 2.87 t ha^{-1} and there was a significant interaction with priming ($P < 0.001$) where one variety (KARRA 1) failed to respond positively. Yields were similar in 2001 (1.921 ha^{-1} to 2.49 t ha^{-1}) but were not significantly different between varieties. A 404 was the highest-yielding variety in both years but there were no consistent patterns for the others. There were also significant interactions between year x variety ($P<0.004$) and year x variety x priming ($P<0.009$).

Discussion and conclusions

There were large differences in performance amongst the diverse range of genotypes tested. Time to maturity varied in 2000 from 98 to 111 days, and there were significant differences between varieties in all components of yield except the number of effective tillers plant^{-1}. Priming seeds for 8 hours resulted in taller, earlier-maturing plants that produced more yield than plants from non-primed seed in both years. Such positive effects have been widely reported in a number of other crops (Harris et al. 1999; Harris et al. 2001 b; Musa et al. 2001). However, this is the first time that on-farm priming has been successfully demonstrated in such a small-seeded crop as finger millet, although a positive response has been reported in sorghum [*Sorghum hicolor* (L.) Moench] (Harris 1996). This low-cost, low-risk technology can be adopted by fanners once they have tried it for themselves and these on-station experiments should be confirmed using farmer-participatory approaches (Harris et al. 2001a).

Table 1. Effect of seed priming and variety on the phenology and yield components of finger millet in Jharkhand, India, rainy season 2000

Variety	Priming[1]	Plant height (cm)	Finger length (cm)	Fingers plant^{-1}	Effective tillers plant^{-1}	Panicle length (cm)	Time to 50% flowering (d)	Time to maturity (d)
A 404	NP	99	6.3	6.5	4.4	15.3	75	111
	P	113	6.0	6.6	4.1	16.6	70	103
Birsa Mama 2	NP	101	7.0	6.9	3.9	19.5	50	100
	P	114	7.1	7.4	4.1	20.4	45	95
HR 374	NP	109	6.4	6.7	4.5	18.1	72	105
	P	118	6.9	6.2	4.7	19.2	65	101
VL 149	NP	115	8.3	8.1	4.7	21.5	68	98
	P	120	8.1	8.9	3.9	22.0	60	90
KARRA 1	NP	111	5.8	6.5	4.5	18.2	72	105
	P	120	6.4	5.8	4.3	18.1	65	100
ZAH 1	NP	114	6.2	6.8	4.4	16.6	70	105
	P	119	6.1	7.0	4.4	16.9	65	100
CV(%)	6.7	4.9	7.5	16	7.5	2.6	1.3	
SE mean	Priming	1.8	0.08	0.12	0.16	0.33	0.4	0.3
LSD (5%)	Priming	5.5	0.24	0.38	0.50	1.01	1.2	1.0
SE mean	Variety	1.8	0.18	0.35	0.35	0.53	1.1	0.5
LSD (5%)	Variety	5.5	0.56	1.07	1.09	1.63	3.5	1.7

1. NP = seed not primed; P = seed primed in water for 8 h

Table 2. Combined analysis of finger millet yields from Jharkhand, India, rainy seasons 2000 and 2001[1]

	Factor	Yield	SE mean	Significance	LSD (5%)
Year		45	NS	126	
	2000	2207			
	2001	2133			
Variety			78	0.001	220
	A 404	2526			
	Birsa Marua 2	2127			
	HR 374	1968			
	VL 149	2157			
	KARRA 1	2189			
	ZAH 1	2055			
Priming			*45*	*0.001*	*125*
	Not primed	2031			
	Primed	2310			

1. Main effects only. Overall CV (%) = 12

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Pests and Diseases

Long Smut in Pearl Millet—A New Record from Eritrea

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Long smut was observed on pearl millet [*Pennisetum glaucum* (L.) R. Br.] panicles (Fig. 1) in two fields at Megareh (15°47'N, 38°25'E) in Keren subzone, and at Bogu (15°25'N, 38°25'E) in Hagaz subzone of Anseba zone, Eritrea, during the 2000 rainy season. There are no references to this disease in the scientific literature on pearl millet. The incidence of long smut varied from 1% at Bogu to 60% at Megareh. The sorus was long, cylindrical, sometimes with a slight curve at the middle or at the tip, and contained a black mass of spores covered by a whitish to dull yellow, fairly thick membrane (Fig. 2). The sorus was 3-4 times larger than a normal grain of pearl millet. The disease is very well differentiated from grain smut caused by *Tolyposporium penicillahae* (Bret.) by its size and shape. The fungus causing the long smut in pearl millet was identified by Kalman Vanky as *Sporisorium ehrenbergii* (Kuhn)

Figure 1. Long smut on pearl millet in Eritrea

Figure 2. Long smut on pearl millet in Eritrea showing the shape and size of sori

K. Vanky (syn. *Tolyposporium ehrenbergii* (Kuhn) Patouillard) (personal communication). Vanky, an authority on the taxonomy of smut fungi, confirmed this as a first record on pearl millet. The authors have heard anecdotal reports of long smut on pearl millet in dry regions of Kenya and the Sudan.

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Prevalence of Pearl Millet Downy Mildew in Eritrea

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Introduction

Pearl millet [*Pennisetum glaucum* (L) R.Br.] is the second most important food crop grown mainly by small-scale farmers in low and mid elevations in Eritrea. Downy mildew (DM) caused by *Sclerospora graminicola* (Sacc.) J. Schrot., a major constraint to pearl millet production in much of the semi-arid tropics (Singh et al. 1993) is widely distributed in Eritrea where it often occurs in epidemic form on farmers' landraces. A systematic survey of the prevalence and severity of DM in farmers' fields was carried out under an ICRISAT-Danida-Eritrea project to better understand its distribution and develop control measures.

Materials and methods

A roving survey was conducted in 8 subzones: Keren, Hamemalo and Hagaz of Anseba Zone, and Mogolo, Barentu, Gogne, Haycota, and Dghe of Gash Barka Zone. Local administrators and personnel from the Eritrea Ministry of Agriculture accompanied the team in their respective zones. The survey covered 32 fields sown with pearl millet landraces, and 7 fields sown with an improved open-pollinated ICRISAT variety, ICMV 221 (4 in Keren, 1 in Hamemalo, and 2 in Hagaz). The latitude, longitude and altitude of the sites visited were recorded using Geographic Positioning System (GPS) equipment (GPS 12 XL*, Garmin International, Olathe, Kansas 66062, USA). In each field DM incidence was recorded in five random subplots (1 m^2) with 40-50 plants in each. DM incidence (%) was calculated from the ratio of diseased to total plants. At the time of survey the crops were at anthesis to soft dough stages.

Data on total rainfall and number of rainy days from sowing to soft dough stage in each subzone were collected from the Department of Agriculture. Rainfall and crop sequence data were used to ascertain if there were relationships between these factors and disease development. Diseased leaf samples were collected to assess variations in the pathogenicity of DM isolates.

Results and discussion

DM was present in most fields, incidence was low to high on landraces in the Keren (40-78%), Hagaz (32-86%), Hamemalo (36-56%) subzones of Anseba Zone, and in Barentu (13-48%), Gogne (5-94%) and Haikota (1-46%) subzones of Gash Barka Zone (Table 1). In contrast. DM incidence was very low (<1%) in Mogolo and Dghe. Twentyseven samples of infected tissue were collected from landraces at different locations and sent to the University of North Wales, Bangor, UK for studies on pathogenic variability.

Table 1. Downy mildew (DM) incidence on local landrace cultivars across eight subzones of two Zones in Eritrea, rainy season, 2000

Zone	Subzone	Number of fields[1]	DM incidence (%)[2] Mean	Range
Anseba	Keren	4	54	40- 78
	Hamemalo	4	44	36-56
	Hagaz	4	53	32 86
Gash Barka	Mogolo	1	1	1-1
	Barentu	3	25	13-48
	Gogne	7	41	5-94
	Haikota	4	13	1-46
	Dghe	4	<1	0-1

1. Field size varied from 0.2-0.5 ha
2. Based on the mean of 5 subplots $field^{-1}$, 1-m^2 $subplot^{-1}$

Pearl millet variety, ICMV 221 was introduced to Eritrea in 1999 by ICRISAT and DARHRD, as a DM-resistant, early-maturing and high-yielding cultivar. It showed < 1 % incidence at Sutur and Bogu, but up to 28% across 4 fields in Halib Mentel in Keren subzone. Because it matures early, ICMV 221 is more vulnerable to bird damage than local landraces.

Total rainfall varied from 109 mm in Hagaz to 303 mm in Barentu and the number of rainy days varied from 5 in Gogne to 18 in Hamemalo and Barentu (Table 2). The variation in DM incidence at different locations did not directly relate to either the variation in total rainfall, or to the number of rainy days. This indicates a likely variation in the virulence within populations of the pathogen in the region.

Table 2. Total rainfall (mm), number of rainy days and mean downy mildew (DM) incidence in eight subzones, Eritrea, July-September, 2000

Zone	Subzone	Rainfall Total (mm)	Days	DM incidence (%)
Anseba	Keren	245	15	40-78
	Hamemalo	116	18	36-56
	Hagaz	109	12	32-86
Gash Barka	Mogolo	261	12	<1
	Barentu	303	18	13-48
	Gogne	155	5	5-94
	Haikota	206	14	1-46
	Dghe	-[1]	-	0-1

1. Data not available

The pearl millet after pearl millet was the predominant cropping sequence, practiced by most farmers. The cropping sequence sorghum [*Sorghum bicolor* (L.) Moench]-sorghum-pearl millet had 42-48% DM incidence, pearl millet-sorghum-pearl millet had 48 78% DM incidence, onion *(Allium cepa* L.)-onion-pearl millet had 80% DM incidence, compared to 47-86% incidence in pearl millet followed by pearl millet. Although there was variation in disease incidence among different cropping sequences, there was no consistent effect of cropping sequence on disease incidence. This needs to be studied further.

To effectively manage DM, the development of cultivars with genetic resistance to the disease should be a primary objective of the local pearl millet breeding program. To facilitate breeding for resistance, a DM 'sick plot' (oospore-infested field) could be developed for screening breeding lines at the Hagaz Research Station. A brief (1-2 months) training period for a pathologist and technical staff in DM screening can be provided at ICRISAT, Patancheru. Surveys of DM incidence in farmers' fields should continue to document variation in spatial and temporal virulence patterns on landraces and improved cultivars. The International Pearl Millet Downy Mildew Virulence Nursery, co-ordinated by ICRISAT, could be useful in assessing variation in the pathogen population. A number of new resistant cultivars should be made available to farmers to reduce both the losses from DM and the likelihood of the pathogen overcoming the resistance of any single variety. Ultimately, greenhouse facilities for screening seedlings for DM resistance should be established at the agricultural research headquarters, Halhale.

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Pearl Millet Downy Mildew in Gujarat

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Introduction

Downy mildew (DM) caused by *Sclerosporagraminicola* (Sacc.) J. Schrott., is the most serious disease of pearl millet (*Pennisetum glaucum* (L.) R.Br.), particularly when it affects hybrids. In recent years due to the large-scale cultivation of hybrids in India, several new pathotypes of *S. graminicola* have evolved, and some promising ones have succumbed to DM (Thakur and Rao 1997; Thakur et al. 1999). Monitoring the DM resistance of pearl millet hybrids and virulence in the pathogen is critical for effective utilization of resistance genes. During a collaborative project on characterization of pathogenic variability in the pearl millet DM pathogen between ICRISAT and the All India Coordinated Pearl Millet Improvement Project (AICPMIP) of the Indian Council of Agricultural Research (1CAR), field surveys were conducted in Gujarat. The results of a systematic field survey undertaken to monitor DM incidence on various hybrids in farmers' fields in major pearl millet growing areas of Gujarat during the 2001 rainy season are reported.

Materials and methods

The survey involved 18 *talukas* (subdivisional revenue units) of Jamnagar, Rajkot, Surendranagar, Kheda, Anand, and Panchmahal districts of Gujarat during the 2001 rainy season. It covered 88 fields (17 fields in Anand, 30 in Jamnagar, 3 in Rajkot, 18 in Kheda, 7 in Panchmahal, and 13 in Surendranagar), ranging between 0.25-1 ha per field and encom-passing 21 different hybrids. DM incidence was recorded in five 2-nr random subplots where 50 plants subplot^{-1} were examined for disease symptoms. Disease incidence (%) was calculated from the ratio of diseased to total plants.

Information on cultivars, seed treatment, sowing date, fertilizer application, weeding, latitude and longitude, and cropping sequence were recorded to ascertain the relationship between these components and disease development. Seeds of most hybrids were available on time, facilitating sowings to be completed by the 2nd week of June. Many farmers applied 30-40 kg P_2O_5 ha^{-1} as a basal dose and 80 kg ha^{-1} of urea (46% N) as top dressing. The crop was at the soft-dough to hard-dough stages during the survey.

Results and discussion

The average rainfall was >500 mm, which was above normal. Its distribution was uniform in most of the areas surveyed. There were 21 hybrids from public and private seed companies grown by farmers (Table 1). Some seed lots were treated with Apron® (metalaxyl) as indicated on the seed bags.

DM incidence in general was only a trace in Jamnagar, Rajkot and Surendranagar districts, but the mean incidence was 30% in Kheda with a range of 1-86%; 45% in Anand with a range of 0-92%, and 36% with a range of 4-77% in Panchamahal districts. Of the 15 private-sector hybrids, seven (Amul, MRB 2210, Nandi 3, PAC 931, Proagro 7501, - 9330, and Vikram 51) were free from DM and the remaining eight recorded mean incidences from 9% on JKBH 26 to 55% on Super Prashanth 44 (Table 1). Of the six public-sector hybrids only GHB 235 was free *from DM and the remaining* five hybrids (GHB 316, GHB 526, Pusa 23, BK 560, and ICMH 451) recorded mean incidence of 2% on GHB 316 to 68% on ICMH 451.

Table 1. Downy mildew (DM) incidence of pearl millet hybrids grown in farmers' fields surveyed in Jamnagar, Surendranagar, Rajkot, Kheda, Anand and Panchamahal districts, Gujarat, India, rainy season, 2001

Cultiva	Fields	Mean	Range[1]
Private sector			
Nava Moti	1	2 ±0.0	2-2
JKBH 26	2	9 ±2.4	0-30
Proagro 7701	1	18 ±2.2	12 14
PBH 47	1	27 ± 1.9	20-30
MLBH 308	3	28 ± 1.8	20-40
Pioneer 7777	3	34 ± 4.8	10-60
Swaminath	1	42 ± 6.2	28-60
Super Prashanth 44	1	55 ± 4.5	40-66
Public sector			
GHB 316	1	2 ± 0.5	0-6
GHB 526	1	16 ±2.1	10-20
Pusa 23	10	20 ±3.1	0-70
BK 560	2	24 ± 5.3	10-50
ICMH 451	12	68 ± 3.6	24 100

1. Across subplots in fields suryeved.

Different cropping sequences were followed during the rainy and postrainy seasons based on the availability of irrigation. DM incidences in cropping sequences were 37% in pearl millet-tobacco (*Nicotiana tabacum* L.)-pearl millet, 92% in pearl millet-wheat (*Triticum aestivum* L.)-castor (*Ricinus communis* L.)-pearl millet, *and 29% in pear*] millet-vegetables -pearl millet, 10% in pearl millet-cowpea (*Vigna sinensis* Endl.)-maize (*Zea mays* L.)-pearl millet, compared to 55-77% DM incidence in pearl millet after pearl millet. The pearl millet-cowpea-maize-pearl millet sequence had the comparative advantage of reducing DM incidence that needs further investigation.

It is necessary to constantly monitor the performance of hybrids for DM incidence. Since the cultivation of pearl millet during summer has increased in central Gujarat, a similar survey could be useful to assess DM incidence on different cultivars.

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Incidence of Downy Mildew on Pearl Millet Male-sterile Lines at Jodhpur, Rajasthan, India

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Introduction

Since the release of the first series of pearl millet [*Pennisetum glaucum* (L.) R. Br] hybrids in India during the late 1960s, downy mildew (DM) [*Sclerospora graminicola* (Sacc.) J. Schrot.] has assumed national standing as a disease of significant economic importance. During the last 3 decades, considerable efforts have been made to manage this disease. The recurrence of DM in 1995, after a gap of 7 years indicated the limitations of exploiting single-cross F_1 hybrids. Single-cross hybrids are genetically uniform, and become susceptible to DM within 3-5 years of their release because strains of the pathogen, specifically adapted to the new hybrid multiply rapidly (Thakur et al. 1999). To successfully cultivate a hybrid for a longer period in a given area it is imperative that the hybrid and both its parents posses resistance to the DM pathotypes existing in that region; failing which it would be risky to introduce a hybrid. To check the rapid multiplication and spread of a virulent pathotype, it is essential to broaden the genetic base of hybrids already in cultivation. This led to efforts to diversify the genetic base of male-sterile (ms) lines by transferring A_1 cytoplasm to other genetic backgrounds, and to develop new ms lines based on different sources of male-sterility-inducing cytoplasm. However, the majority of available pearl millet ms lines are still based on A_1 cytoplasm, because it is easier to obtain restorers for A_1 cytoplasm than from other sources of stable pearl millet cytoplasmic male-sterility.

About 47% of the total pearl millet growing area in India is in Rajasthan. Of this, 80% is cultivated in the harsh agroclimate of western Rajasthan that is still a hot spot for DM (Arya and Kumar 1976; Thakur et al. 1998). Significant differences in DM incidence because of differences among pathotypes of Indian origin have been reported (Thakur et al. 2001). Several hybrids and their parental lines that were resistant to DM in other states are susceptible to DM in western Rajasthan, probably because a different and highly virulent pathotype occurs there (Thakur et al. 1998).

The objective of the present study was to identify ms lines resistant to the naturally available DM inoculum at the Central Arid Zone Research Institute (CAZRI) research station, Jodhpur, Rajasthan, without using artificial inoculation. Such genotypes could then be effectively used in hybrid development programs specifically targeted to western Rajasthan.

Materials and methods

The study was spread over 3 years (1999-2001) and in three different environments (Table 1). In 1999, during the crop growing period (July-October), 214 mm of rain fell; 195 mm of this fell in July, and only 19 mm from August to October. This resulted in severe drought when the pearl millet crop was tillering and flowering, and only few lines flowered successfully. During 2000, there was 263.5 mm total rainfall, of which only 46.4 mm fell during August, and 3 mm in September resulting in terminal drought stress. During 2001, there was 327.9 mm total rainfall during the crop growing period, most of it was well distributed and an excellent crop resulted.

Table 1. Mean rainfall, temperature, relative humidity and downy mildew (DM) incidence (%) on male-sterile lines, rainy seasons, 1999-2001 at the Central Arid Zone Research Institute (CAZRI), Jodhpur, Rajasthan, India

Variables	1999	2000	2001
Rainfall (mm)	214.0	263.5	227.9
Daily mean (temperature °C)			
Maximum	36.1	35.1	34.6
Minimum	26.6	25.8	24.8
Relative humidity (%)	71.5	72.7	78.1
DM incidence (%)			
Mean	2.6	9.03	22.9
Range DM (%)	0 10	0-26	0-67

The incidences of DM recorded at CAZRI over the 3 consecutive years (at the 30-day stage in 1999, and 60-day stage in 2000 and 2001) on 16 pearl millet ms lines obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), 6 ms lines from the Punjab Agricultural University (PAU), Ludhiana, and 2 ms lines from the Gujarat Agricultural University (GAU), Jamnagar, are given in Table 2.

Results and discussion

The mean DM incidence (%) across 16 ms lines increased from 2.6% in 1999 to 9.03% in 2000, and 22.89% in 2001. During 1999, 10 out of the 16 ms lines were DM-free, while during 2000 and 2001, only two escaped the

Table 2. Downy mildew (DM) incidence (%) on pearl millet male-sterile lines from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Punjab Agricultural University (PAU), Ludhiana, and Gujarat Agricultural University (GAU), Jamnagar, the Central Arid Zone Research Institute (CAZRI), Jodhpur, Rajasthan, India, rainy seasons, 1999-2001

Male-sterile lines	Source	DM incidence (%)			
		1999	2000	2001	Mean
841A	ICRISAT	0	1	5	2.0
843A	ICRISAT	10	12.5	50	24.1
ICMA 91444	ICRISAT	10	17	17	147
ICMA 92111	ICRISAT	0	10	16	8.7
ICMA 93111	ICRISAT	0	19	64	27.7
ICMA 93333	ICRISAT	0	0	0	0.0
ICMA 94222	ICRISAT	0	26	67	31.0
ICMA 95444	ICRISAT	0	7	11	6.0
ICMA 95555	ICRISAT	0	0	0	0.0
ICMA 96111	ICRISAT	5	8	34	15.7
ICMA 96555	ICRISAT	0	18	20	12.7
ICMA 97111	ICRISAT	2.1	5	6	4.4
ICMA 97555	ICRISAT	10	5	59	24.7
ICMA 98111	ICRISAT	0	11	2	4.3
ICMA 98222	ICRISAT	4.5	2	5	3.8
ICMA 98333	ICRISAT	0	3	10	4.3
Mean		2.6	9.03	22.89	11.5
LSD ($P<0.05$)					9.5
Pb 218A	PAU	-	59	93	76.0
Pb 220	PAU	-	11	74	42.0
Pb 310	PAU	-	68	100	84.0
Pb 313	PAU	-	24	19	21.5
Pb 315	PAU	-	17	70	43.5
Pb 406	PAU	-	47	60	53.5
9901A	GAU	-	33	92	62.5
2072A	GAU	-	11	79	45.0
Mean[1]		-	33.75	73.38	53.5
LSD ($P<0.05$)					21.85

1. Mean of male-sterile lines from PAU Ludhiana and GAU Jamnagar.

pathotypes of Indian origin in greenhouse experiments (Thakur et al. 2001).

Based on this study, 7 of the 16 ICRISAT ms lines can be considered resistant, or moderately resistant to the DM pathogen population of CAZRI, and could therefore be considered for use in hybrid development programs targeting western Rajasthan.

Another set of 8 ms lines obtained from Punjab (*the* Pb-series) and Gujarat (9901A and 2072A) were evaluated for 2 years, but the DM incidence data suggested that all these lines were highly susceptible at this location, and thus not suitable for Use in developing hybrids for Rajasthan.

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Research Highlights

All India Coordinated Pearl Millet Improvement Project, Indian Council of Agricultural Research: Research Highlights 2001/2

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Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the fourth most important cereal crop in India, where it covers around 7.4% of the total food grain area of the country and contributes to nearly 3.4% of the total production of food grains. Considering the 5-year means, pearl millet was cultivated on 9.43 m ha during 1995-2000, a decrease of 12% compared to the 1985-90 period. However, despite this reduction in area, pearl millet production has recorded a commendable gain by 30% in 1995-2000 over 1985-90.

The 2001 rainy season was particularly favorable for pearl millet cultivation in the major northern pearl millet growing states. According to the estimates, pearl millet achieved the highest national productivity of 844 kg ha^{-1} in the rainy season 2001. This enhanced productivity resulted in increased production by 33% in Rajasthan, 35% in Gujarat, and 15% in Haryana.

Varietal improvement

As India enters the Tenth Plan, it is worth mentioning that the AICPMIP made some outstanding achievements during the Ninth Plan period (1997-2001) as reflected by the release and notification of as many as 23 hybrids and 7 varieties for general cultiva-tion in different pearl millet growing regions of the country. During 2000/1, four pearl millet hybrids and two varieties were released and notified for general cultivation by the Central Sub-Committee on Crop Standards in July 2001 (Table 1).

Organization of yield evaluation trials

Rainy-season trials. In zone A (dry zone up to 600 mm annual rainfall), the following coordinated hybrid/population yield evaluation trials were conducted successfully; 34 in Rajasthan, 20 in Gujarat, 8 in Uttar Pradesh, 12 in Haryana, 7 in Madhya Pradesh, 4 in Punjab, and 2 in Delhi. In zone B (>600 mm annual rainfall), successful trials were 18 in Maharashtra, 7 in Andhra Pradesh, 4 in Karnataka, and 4 in Tamil Nadu.

Performance of new hybrids. The performance of some new dual-purpose hybrids was outstanding in initial trials in terms of both grain yield and stover (dry fodder) yield. Based on three years' (1999-2001) performance in coordinated trials, two hybrids GHB 559 and GHB 558 excelled their respective checks substantially and recorded 22-23% higher grain yield (>2.8 t ha^{-1}) over the check hybrid Pusa 23, and more than 8 t ha^{-1} of stover in zone A. Also in zone B, these two hybrids recorded over 30% higher grain yield than the check hybrid Shradha. In

Table 1. New pearl millet hybrids and varieties released in India

Hybrid/ variety	Pedigree	Mean grain yield (t ha^{-1})	Maturity (days)	Recommended for States
RHB 121	89111A x RIB 3235-18	2.7	75	Rajasthan, Haryana, Gujarat, Madhya Pradesh, Uttar Pradesh, and Delhi
PB 112	PSP 35 x PP1	2.7	77	Rajasthan, Haryana, Gujarat, Madhya Pradesh, Uttar Pradesh, and Delhi
Nandi 35	NMS 11A x NMP 42	2.9	82	Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu
COH (cu) 8	732A x PT 4450	0.8[1] and 3.6[2]		Tamil Nadu all seasons
MP 383	Pusa Composite 383	2.1	75-78	Rajasthan, Haryana, Gujarat, Madhya Pradesh, Uttar Pradesh, and Delhi
Samrudhi	AIMP 92901	2.0-2.5	75-78	Maharashtra

1. Rainfed; 2. Irrigated

advanced hybrid trials, hybrid MH 1021 (3.07 t ha^{-1}) and MH 1019 (2.89 t ha^{-1}) were the most promising in zone A and produced more grain than a recently released high-yielding hybrid, PB 106.

Progress in breeding for early-maturing hybrids is encouraging. Three hybrids HHB 176, HHB 177, and GHB 538 in zone A, and XM 0793 in zone B were superior in grain yield to early-maturing check hybrid 1CMH 356 in the same maturity range. Two hybrids in the arid zone trial were found to have similar maturity and grain yield levels as that of very early maturing hybrid HHB 67.

Performance of open-pollinated variety. The population improvement program has shown significant gain in developing early-maturing varieties with high yield levels. MRC 1 was the most promising early population, it flowered 4 days earlier, and was superior in grain yield to Raj 171. Other promising varieties were G1CV 98771, HMP 9711, and HMP 9701.

Summer trials. Summer pearl millet hybrid trials conducted during Feb-Jun under irrigation at 10 locations across five states (7 locations in Gujarat, and one each in Rajasthan, Maharashtra, and Tamil Nadu) clearly identified some promising hybrids for release. Hybrids PB 172 and GHB 526 in three years of testing recorded, on average, nearly 25% more grain than Pusa 23 (3.23 t ha^{-1}). Initial entries MSH 132 and MSH 136 have also recorded high mean grain yields of more than 3.9 t ha^{-1} across locations. These hybrids matured in 82-87 days across locations.

Improvement in hybrid parental lines

The development of hybrids utilizing diverse parental lines is the key to success in enhancing grain yield and managing downy mildew (DM) [*Sclerospora graminicola* (Sacc.) J. Schrot.] through genetic resistance. A number of new male-sterile lines (A-lines) with the A_1 cytoplasmic source developed at ICRISAT and the AICPMIP project centers were evalu-ated in hybrid combinations at various locations. Currently, hybrids in different stages of evaluation are composed of nearly 15 A-lines from ICRISAT, 3 A-lines each from Rahuri and Jamnagar, and 2 A-lines each from New Delhi and Hisar. In addition to the on-going research program for genetic diversification in the A_1 cytoplasmic source for early maturity and downy mildew resistance, efforts are being made to develop A-lines with the A_4 cytoplasmic source of male sterility in a partnership project with ICRISAT.

The breeding program to develop diversified restorer lines is making good headway. In addition to the on-going program, the development of inbreds from a broad-based Mandor Restorer Composite has been initiated at various centers to breed hybrids specifically adapted to zone A.

Pearl millet germplasm

A large number of germplasm accessions collected jointly by ICRISAT and ICAR institutes in India is conserved in the ICRISAT gene bank at Patancheru, and is freely accessible for crop improve-ment work. Recently, in a very significant move, these germplasm accessions are being restored to the National Bureau for Plant Genetic Resources (NBPGR). Thus, a large number of germplasm accessions is being regenerated under an ICRISAT-NBPGR partnership project. AICPMIP is actively collaborating in this process and in the current summer season (2002), 163 accessions are being multiplied at Jamnagar and Coimbatore.

Agronomic investigation

Studies on various agronomical aspects were carried out at five centers in all three zones (A, A1, and B) in the rainy season and four centers in zones A and B during the summer season. New hybrids and populations clearly expressed positive response to nitrogen application in both seasons. As compared to the application of 30 kg N ha^{-1}, application of 90 kg N ha^{-1} in the rainy season hybrid trial increased grain yield by 26.7% in zone A and 23.6% in zone B. In a summer hybrid trial, the application of 120 kg N ha^{-1} showed a 24.8% increase in grain yield over 60 kg N ha^{-1} application.

In integrated nutrient management studies, the grain yield obtained after the application of 40 kg N + 30 kg P_2O_5 + bio fertilizer [*Azospirillum* + *Phosphobacterium* (PSB)], was close to the best responsive dose of 60 kg N + 40 kg P_20_5 ha^{-1} in both zones. This result further substantiated the earlier findings that 10-20 kg N ha^{-1} can be saved through application of bio-fertilizers (*Azospirillum* + PSB) in pearl millet.

Less than optimum plant stands are a major cause of low productivity under sub-optimal conditions in the rainfed region. Among different treatments studied, spreading of 5 t FYM ha^{-1} over the sown rows resulted in better plant stands and produced the highest grain and fodder yields.

Frontline demonstrations. Frontline demonstrations of the newly developed hybrids/varieties and agronomic practices, such as intercropping systems, use of bio-fertilizers and optimum sowing dates were organized at all the project centres. A total of 241 demonstrations in the rainy, and 19 during the summer seasons were conducted on 139 ha of farmers' fields. The results clearly demonstra-ted gains from the adoption of improved technology over the farmers' practices.

Management of diseases

Hybrids and varieties in different trials were screened for DM and smut [Tolyposporium *penicillariae* Bref.] diseases under artificial inoculation in 11 DM and 4 smut disease nurseries. A total of 94 initial hybrids and varieties, 48 advanced hybrids and varieties, 22 released hybrids and varieties, and 8 A-lines were tested for their resistance to different diseases. Four hybrids (MH 1085, MH 1013, MH 1014 and MH 1022) in zone A and another four hybrids (MH 946, MH 949, MH 1003 and MH 1007) in zone B possessed high degrees of DM resistance (<1%). These hybrids also recorded <5% DM incidence across the zones. Further, four hybrids MH 1061, MH 1069, MH 1070, MH 1105 and one variety MP 403 recorded resistance to both DM and smut.

Released hybrids Pusa 23, Pusa 605,7688, and PB 106 continued to maintain high DM resistance (<1%) in zone A, whereas hybrids ICMH 356 and Shradha, and variety ICMV 155 maintained resistance to DM (<3% incidence) in zone B.

To evaluate and monitor pathogen diversity in the DM pathogen, 13 resistant and susceptible lines were evaluated in the disease nursery at 12 locations. None of the lines showed high level of resistances across all locations. Highly resistant line, IP 18292 recorded a susceptible reaction at certain locations, but IP 18293 maintained its consistently high resistance level (<5% incidence) across all the locations. Variation in virulence levels in the pathogen populations at different locations was evident.

The use of such biotechnological tools as marker-assisted selection is now being employed successfully at ICRISAT for deployment of DM resistance QTLs in hybrid parents. The AICPMIP project is also building research capabilities in this direction within the project and it has initiated work on the isolation of resistance gene homologues in the highly resistant source (IP 18292) at University of Mysore.

Management of insect pests

Advanced hybrids and populations were screened for resistance to such important insect pests, such as shoot fly [*Atherigona soccata* (Rondani)], stem borer (*Chilo partellus* Swinhoe), grey weevil [*Myllocerus subfasciatus* (Guerin-Meneville)], chaffer beetle [white grub (*Phyllophaga* spp.)] and leaf roller (*Marasmia trapezalis* Guen] at four centers. The most promising entries were identified against each of the insects during field screening. The results of integrated pest management of white grub showed that neem-based treatments were ineffective, whereas treatments including biological agents were significantly more effectiv e than the control. However, insecticide treatment using carbosulfan @ 8 g $100g^{-1}$ seed was found most effective in controlling damage caused by white grubs [*Phyllophaga crinita* (Burmeister)].

Book Reviews

Bhatnagar, S.K., Khairwal, I.S., and Pareek, S. 2002. Pearl millet nucleus and breeder seed production manual. Jodhpur, India: All India Co-ordinated Pearl Millet Impro-vement Project (AICPMIP), Indian Council of Agricultural Research (ICAR). 8 pp.
This manual compiled and edited by the Project Coodinator (Pearl Millet) of the All India Coordinated Pearl Millet Improvement Project (AICPMIP), Indian Council ofAgricultural Research (ICAR) provides useful information on the production and maintenance of nucleus and breeder seeds of pearl millet, and is an official publication of the Project Coordinating Cell of AICPMIP.

The high quality of commercial seed of varieties and hybrids depends on the genetic purity of nucleus and breeders seed stock. This necessitates the adoption of technically sound procedures for seed multiplication of parental lines of hybrids, and of open-pollinated varieties. Since published procedures were only available for production of foundation and certified seed of pearl millet, the manual is welcome. In preparing it, information on pearl millet and/or related cross-pollinated crops was compiled from various sources. The compiled draft was discussed with breeders from public- and private-sector organizations and seed production agencies at AICPMIP annual group meetings prior to publication.

The manual very briefly describes the floral biology and mode of pollination in pearl millet, since these ultimately determine seed production. For nucleus seed production of open-pollinated varieties, the suggested procedure includes step-wise work starting from the selec-tion of individual plants in an isolation nursery, progeny evaluation, and growing remnant seed of selected progeny in nucleus seed nurseries.

For nucleus seed production of parental lines of hybrids, it is suggested that maintainer B-lines should be produced by the outlined procedure, and that this B-line seed should then be used to produce male-sterile A-lines. Making paired crosses, progeny evaluation, and bulking remnant seed of A-lines of pure pairs is the recommended way to produce the required quantity of nucleus A-line seed. The procedure takes five seasons, and an explana-tory flow chart is included in the manual.

To produce breeder seed of male-sterile A-lines, it is suggested that A and B lines are sown alternately in a 4:2 ratio in isolation. Bulk sowing in isolation is suggested as the way to produce breeder seed of B-lines, restorer (R) lines, and open-pollinated varieties (OPVs) from nucleus seed stocks.

The procedures detailed in the manual should help breeders to adopt uniform ways of producing nucleus and breeder pearl millet seed in India.

ICRISAT. 2001. Factfile on poor peoples' staples in the semi-arid tropics: area, production and yield trends. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). 8 pp.

A useful free brochure that provides basic data on ICRISAT mandate crops including sorghum and pearl millet; and emphasizes ICRI SAT-assisted improvement in breeding and cultivars that help to boost yields.

McGaw, E.M. 2002. Fine tuning the progeny: more miralces with millet molecules. Bangor and London, UK: Centre for Arid Zone Studies (CAZS), Department for International Development (DFID). 40 pp.

Following the 1998 ICRISAT/DFID/CAZS joint publica-tion *Tempest in a test tube.* This book explains progress in research on resistance to downy mildew of pearl millet and how results are now reaching farmers' fields in India. Over the past decade the use of DNA makers to map useful genes for resistance has enabled remarkable progress to be made, using marker-assisted backcrossing to transfer resistance to economically important hybrid seed parents. Downy mildew resistant pollinations and pyramiding QTLs associated with resistance all helped, and have now provided the opportunity to produce resistant hybrids not only for India, but also for the Sahalian regions of Africa, where they will help fight hunger among the world's poorest people fighting to survive in marginal environments.

Schioler, Ebbe. 2002. From the rural heart of Latin America - Farmers, agricultural research and livelihoods. Washing-ton, USA: Future Harvest. 85 pp.
ISBN 87-7964-201-2

Published first in Danish by the Royal Danish Ministry of Foregin Affairs and cofinanced by Danida, this English translation of Ebbe Schieler's stories' illustrates how the Future Harvest Centers supported by the CGIAR are developing technologies and empowering rural Latin Americans to improve their lives and communities.

Sulaiman V., Rasheed, and Hall, A.J. 2002. Beyond technology dimension - can Indian agricultural extension re-invent itself? NCAP Policy Brief 16. New Delhi, India: National Centre for Agricultural Economics and Policy Research (NCAP), Indian Council of Agricultural Research (ICAR). 4 pp.

The last decade witnessed an accelerated decline in the credibility of pubic sector extension. Unless extension grows beyond technology transfer, and clearly articulates its role in facilitating broader changes supportive of evolving rural livelihoods, its ability to remain relevant in the future is extremely doubtful. While the reform process is heading in this direction, planners need to face up to the need for considerable institutional change and learning if extension is to escape from the shackles of a technology dissemination role. This Policy Brief tackles the issues head-on and provides clear and direct messages for plan-ners and policy makers that are pcrtinant not only to India, but in the wider global scenario where many countries' agricultural systems face similar challenges.

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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 [P*ennisetum glaucum* (L.) R. Br.], 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.).

How to format contributions—deadline 15 September

- Keep the items brief. 4-6 pages (double-spaced) including data tables and figures
- 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 the correct Latin name with authority of every crop, pest, or pathogen at the first mention
- Submit 2 hard copies (original + photocopy) of the manuscript in the correct format to the Scientific Editor of the respective regions at the address given below
- Include the full address of all authors, and telephone, fax, and e-mail of the corresponding author.

ISMN will carefully consider all submitted contributions and will include in the Newsletter those that are of acceptable scientific standard and conform to its 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 reports in this issue. Wherever substantial editing is required, we will send a draft copy of the edited version to the corresponding author lor approval before printing.

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