SICNA

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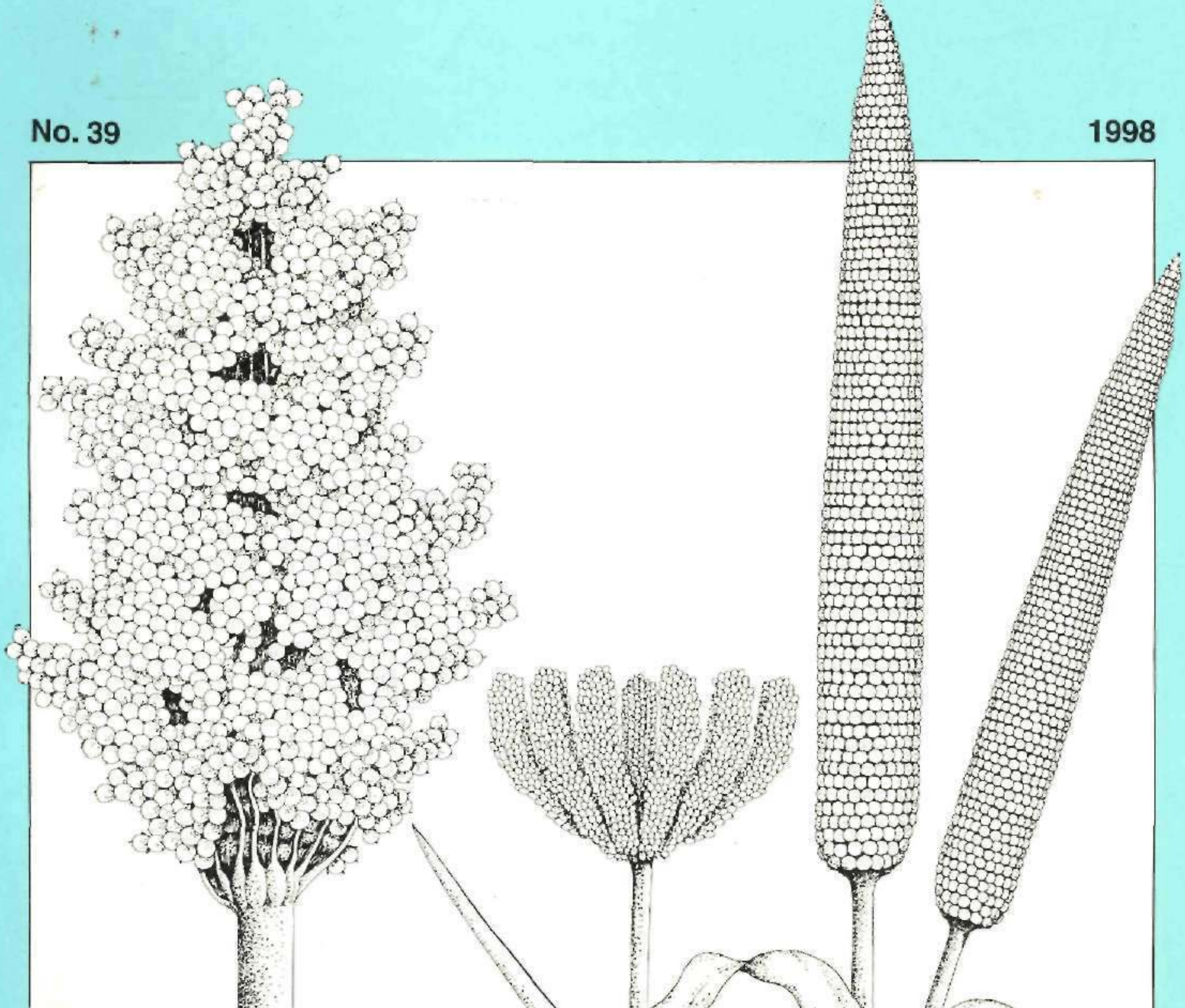

International Sorghum and Millets Newsletter

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, finger millet, chickpea, pigeonpea, and groundnut; these six crops are 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 one of 16 nonprofit, research and training centers funded through the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the World Bank, the United Nations Development Programme (UNDP), and the United Nations Environment Programme (UNEP).

ISMN Scientific Editors 1998

J A Dahlberg C T Hash

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Increasing the Production and Commercialization of Sorghum and Pearl Millet in SADC

Report of the Stakeholder Conference of the SADC/ ICR1SAT Sorghum and Millet Improvement Program, Harare, Zimbabwe, 27-31 Jul 1998

For many centuries, farm families in the drought-prone regions of southern Africa have depended on sorghum and pearl millet to provide reliable harvests and adequate food supplies. These traditional crops will always be important to the region's food security. But their potential as commercial food and feed grain remain under-exploited.

Commercialization of sorghum and pearl millet was the theme of a major 5-day conference organized by the Sorghum and Millet Improvement Program (SMIP) of the Southern African Development Community (SADC) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The Conference, held in Harare during 27-31 July, was inaugurated by the Minister of Lands and Agriculture, Honorable Cde K Kangai. It brought together, for the first time, a wide range of stakeholders involved in sorghum and pearl millet research and development—research scientists and extensionists from seven SADC countries; private firms (seed companies, manufacturers of food products and livestock feed) from six countries; universities; advanced research institutions from USA, UK, and France; policy makers; nongovernmental organizations (NGOs); fanners and farmers' organizations; and major donor agencies. There were a total of 102 participants from 11 stakeholder groups.

SMIP is a region-wide SADC project with its head-quarters at Matopos Research Station near Bulawayo, Zimbabwe. The SMIP Project has played a major role in developing new, highly productive varieties of these crops, thereby helping to improve food security and nutrition throughout southern Africa. The new thrust towards commercialization aims to consolidate these gains and to provide further incentives to sorghum and pearl millet farmers to increase production, by making these crops more productive and marketable, and thus more profitable.

Successful commercialization will present a major challenge, but the potential benefits are enormous. It will provide strong incentives and rewards for increasing production, increase trade and incomes, and create employment. It will help small-scale farmers, including rural women, who depend on these crops in dry, drought-prone areas to make the transition from subsistence to more market-oriented agriculture.

The SMIP Project and its partners (national and international research institutions, universities, extension, NGOs, and industries) are using a three-pronged approach to commercialization: first, by developing varieties that match industrial specifications for milling, brewing, livestock feed, and other uses; second, by developing and promoting adoption of practical systems to increase productivity and ensure supply of good quality grains; and third, by helping to identify markets and new end uses to stimulate demand.

A significant part of the conference was the SMIP display, designed to demonstrate what it is possible to produce from these crops. It featured panicles of sorghum and pearl millet, threshed whole grain, intermediate products such as meal, flour, and bran, and food products along with malts for brewing and silage for livestock feeds. On display were sorghum and pearl millet cultivars released in each SADC country. Baked and popped goods were identified by cultivar so delegates could sample, taste, and determine their own preferences.

Twenty-three companies from six SADC countries, Nigeria, and USA also displayed a very wide range of commercial products ranging from breakfast food to bedtime drinks (beverages, nonalcoholic malt drinks), molasses, and beer of several types. These products attracted considerable interest among delegates and the public who were invited to view the display.

In his Opening Address, the Minister noted that in addressing the challenges of developing technologies for processing and utilization of sorghum and pearl millet, SMIP had teamed up with other organizations to promote their varied uses. He mentioned that the Food and Agriculture Organization of the United Nations (FAO) had declared 1998 the year of "Women Feed the World". In recognition of this, the Conference also included a display from Zimbabwe with the theme "Women Feed the Nation for God's Glory". This display clearly recognized the decisive role that women play in household and national food security, and showed the broad range of food products and preparations that could be made from sorghum, millets, and other indigenous crops.

Cde Kangai said that given the necessary resources of information, technology, and innovations, regional households can attain food security and nutritional balance. These efforts are sure to bring rural men and women into the mainstream of SADC economies and ensure poverty eradication in the long term. He also applauded the work of NGOs, church groups, and farmers' groups, who have played active roles in adapting and promoting new development technologies in small-scale farming areas.

The Minister concluded by expressing his confidence that with the commitment and active support of all stakeholders at the Conference, including the donor community, the next phase of the Project would succeed.

During the inaugural session of the conference the themes were summarized by L K Mughogho, the SMIP Project Manager, who gave an overview of the meeting's main objectives. These were to identify partners with interests and skills for specific activities in SMIP Phase IV, and to elect a Steering Committee composed of a wide range of partners from both the private and public sectors interested in commercializing sorghum and pearl millet.

The Southern African Centre for Cooperation in Agricultural Research (SACCAR) Director, B J Ndunguru, emphasized that SADC recognized that stakeholder partnerships achieved more outputs in line with Article 23 of the SADC treaty approved by the SADC Heads of State. He also noted that the United States Agency for International Development (USAID) did not support the recommendation on a consultancy on the Sustainability Plan for SMIP, recommended by SACCAR in 1994. Instead they preferred a Phase IV run on a project basis with specific results and benchmarks, that should include stakeholders beyond national agricultural research systems (NARS). He noted that a draft proposal for Phase IV was in place, and that SACCAR was keen to establish strategic alliances that enhance the capacity of NARS, and integrate stakeholders with end users of research and extension.

A Merkel from USAID said that USAID's concept of food security is now one where people have enough money to buy food and use their excess income for other needs. In Phase IV the Project should be result-orientated. For commercialization to succeed requires partnerships with a range of stakeholders in which farmers are customers and users of available technology. The future should see increased quantities of sorghum and millet going into the commercial market, increased technology in rural areas, and provision of more farming options.

The next session was an analytical review of the regional impacts of SMIP in terms of sorghum and pearl millet improvement, technology exchange, socioeconomics, and capacity building in the NARS. This was followed by an analytical review of country impacts of SMIP—highlights included a report by M A Mgonja on a community-based food security project in drought-prone areas of northern Tanzania. It showed what can be done by introducing sorghum to farmers who never previously grew the crop, but are now food-secure and able to feed their families with a product they find highly acceptable.

Other reports in this session from Angola, Botswana, Malawi, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe focused on achievements and impacts and also identified ongoing constraints, the potential for future collaborative research, and expectations for Phase IV. Soil fertility problems and seed distribution continue to be recurring needs, as are the exchange of information and the needs for collaborative networking.

The Conference moved on to discuss the future of sorghum and pearl millet in southern Africa in terms of production and trade trends, seed systems, and the delivery of new crop varieties. A well-attended session on producer markets and utilization involved a panel discussion by industry representatives. From this discussion there came a proposal to establish Promotion Fora to encourage utilization of these crops to assist in standardization of grain quality and there was a strong call for a uniform grading system across the region, to assist the purchase of grain and encourage the development of the milling industry.

There was also welcome assurance from processors that they recognized the importance of meeting the product preferences of individual communities, and the need to work with women in rural areas to ensure the acceptability of products.

In a session on commodity networks, L A Navarro from the International Development Research Centre (IDRC), Canada, outlined the successes and failures of past investments in research networks, while M LaGrange from National Grain Sorghum Producers, USA, presented a case study of network functions and impacts. Several issues were highlighted, including the sustainability of networks and the position of donors that networks should move beyond simple acceptance of donor requirements on the value of networks to the private sector, the need to broaden the base of networks' resources, and results that would ensure continued funding. To be sustainable, networks need to encompass a range of stakeholders willing to make complementing investments. Overall, it was concluded that although networks cannot serve all functions, they are necessary to effect economies of scale but they also need to look for markets to survive.

The Conference then split into stakeholder groups to discuss their participation in SMIP Phase IV and Sorghum and Millets Information Network (SMINET). Each group presented their specific comments and recommendations on the Phase IV document. These comments were discussed in plenary session, and carried forward to the Steering Committee for consideration.

The stakeholders took cognizance of the fact that SMIP Phase IV is breaking new ground. It was resolved to go ahead and elect a Stakeholders Steering Committee to advise SMIP, but to let the old Committee continue until the new Committee was approved by SADC.

Steering Committee

In a lively discussion on the constitution of the new Steering Committee, its functions and membership were outlined.

Functions

- Provide guidance to the SMIP program to ensure that project goals are met, implementation is according to agreed plans, and that the program serves the best interests of the region;
- Develop goals, objectives, and structure for SMINET;
- Guide the SMINET Coordinator in the establishment of a sustainable regional sorghum and millet network; and
- Review and approve annual SMIP workplans and annual progress reports.

Membership

The conference proposed that the new SMIP Steering Committee should consist of the following 11 representative members: 2 national sorghum and pearl millet program leaders, 1 university, 1 extension, 2 NGOs, 1 fanner organization, 1 seed industry, 1 milling industry, 1 livestock feed industry, and 1 SMIP Project Manager. In addition, there should be observers: SMIP, Donors, SACCAR and/or Crop Sector Coordinator, and the ICRISAT Program Director. The SMINET Coordinator will be the Secretary, The final membership will be determined after SADC ratification.

The following were elected:

NARS	M A Mgonja	Tanzania
NARS	A J Pretorius	South Africa
University	D N Mbewe	Zambia
Extension Services	R M Kamona	Zambia
NGO	V Parkinson World Vision International (WVI)	Mozambique
NGO	S M Kaionge Cooperative for American Relief Everywhere (CARE)	Zambia
Farmer Organization	E Auino	Namibia
Seed Industry	S B McCarter	Zimbabwe
Milling Industry	V Moiteeiasilo	Botswana
Livestock Feed Industry	A W W Nel (National Foods)	Zimbabwe
SMIP Project Manager		SMIP

Meetings

It was agreed that Steering Committee should hold an annual 5-day meeting.

The next steps

- It was agreed that the SMINET Coordinator should be in office by Jan 1999.
- It was agreed that the SMIP proposal would be finalized after presentation to SACCAR, and that SMIP would make any necessary modifications.

Conclusion

The Conference concluded with votes of thanks to all concerned and delegates left—most of them carrying supplies of publications and reports provided by SMIP. The Steering Committee met on the following day to deliberate Conference recommendations.

Sorghum Improvement

A B Obilana (SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP), Matopos Research Station, PO Box 776, Bulawayo, Zimbabwe)

Abstract

Sorghum improvement in the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP) has used a regional, collaborative, multidisciplinary approach since its inception. In the 15-year period from 1983/84 to 1997/98, improved varieties and hybrids were developed, widely tested, and released in eight SADC countries. Breeding, crop protection, and crop management research focused on drought tolerance, early maturity, grain and fodder productivity, and resistance to downy mildew, leaf blight, sooty stripe, and *Striga.* We also evaluated the grain for food, malting, and feed qualities.

The program has made significant achievements in germplasm movement and utilization; cultivar development, testing, and release; assessment of grain qualities for different end uses; strengthening research capacities in the national programs; and strengthening linkages with NGOs, seed companies in Zimbabwe and South Africa, millers in Botswana and Zimbabwe, breweries and feed companies in Zimbabwe, farmers' organizations, and universities. More than 12 000 sorghum germpiasm accessions were assembled from all over the world and made accessible to NARS for sorghum improvement. From these, 10 075 enhanced breeding lines, 4634 populations, 379 hybrid parents, and 3436 experimental hybrids were developed and samples distributed to Angola (100), Botswana (2398), Lesotho (681), Malawi (1449), Mozambique (322), Namibia (139), South Africa (147), Swaziland (326), Tanzania (3702), Zambia (5330), and Zimbabwe (3930). A total of 27 improved varieties and hybrids were released in eight SADC countries: Botswana (three varieties and one hybrid), Malawi (two varieties), Mozambique (three varieties), Namibia (one variety), Swaziland (three varieties), Tanzania (two varieties), Zambia (three varieties and three hybrids), and Zimbabwe (five varieties and one hybrid). However, of these 27 improved varieties only 9 (33%) are cultivated on about 20-30% of the sorghum areas in six countries. Five sources of resistance to three *Striga* species were identified. Twenty-three drought-tolerant male parents (R-lines) and 36 female parents (A-lines) with their maintainer (B-lines) parents were developed and are presently being used by South Africa, Tanzania, Zambia, and Zimbabwe in their hybrid development programs.

As a result of grain quality assessment of more than 2500 improved sorghum genotypes, including the 27 releases and 100 indigenous varieties used by farmers, more cultivars were released that have been adopted by farmers. Consequent to farmer participatory variety selection outcomes, three countries are now retargeting their breeding approaches. Training in seed production and pollination techniques was provided regionally to country representatives, and in-country training was provided in Botswana, Tanzania, and Zimbabwe. Areas where progress has been difficult include increasing productivity of the improved cultivars, and seed production and distribution. SMIP has also helped identify future research needs and options for commercialization of sorghum in each country.

Introduction

The Southern African Development Community (SADC)/ International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sorghum and Millet Improvement Program (SMIP) has taken a regional approach to sorghum (*Sorghum bicolor* (L.) Mocnch) improvement since its inception in 1983. Its operations can be divided into three 5-year phases. The objectives during Phases I (1983-88) and II (1988-1993) were to:

- Introduce, evaluate, and develop drought-tolerant varieties and hybrids with high yield and resistance to important endemic diseases;
- Develop random-mating populations for the region as a genetic pool for national agricultural research systems (NARS);
- Screen and develop *Striga*-resistant sorghum cultivars; and
- Organize and implement collaborative research, trials, monitoring tours, and training for technicians.

Considerable progress was made in the first two phases in the development of improved breeding lines, varieties, populations, and hybrids (Obilana, in press a, b). In Phase III (1994/95 to 1997/98) the program sought to build on these successes by a change in emphasis from cultivar development to ensuring that these cultivars were adopted by farmers after release. Correspondingly, the objectives for sorghum improvement since 1994 have been to:

- Continue to breed improved varieties, and collect and exchange germpiasm with particular reference to drought tolerance;

- Facilitate the transfer of improved cultivate to fanners through national research and extension systems (NARES) and linkages with NGOs, advanced institutions, and the private sector;
- Evaluate grain quality for various end uses;
- Develop technologies for the management of *Striga,* insect pests, and diseases; and
- Stengthen the capacity of NARS sorghum staff in crop improvement and utilization through in-country and regional training, joint workplans, and collaborative research.

Progress on these objectives was continually monitored and evaluated through a series of clearly defined milestones and expected outputs.

This paper describes the methodologies used and the accomplishments of the SMIP sorghum improvement program, and discusses the future of sorghum improvement within the region.

Methodology

SMIP's strategy has involved the development and testing of improved varieties and hybrids (Phases I and 11), followed by technology transfer and exchange (Phase III), as shown in Figure 1. The focus of genetic improvement was on drought tolerance, early maturity, resistance to diseases (especially leaf blight, sooty stripe, and downy mildew), *Striga,* storage insects and aphids, dual-purpose varieties that could provide both grain and fodder, and acceptability by farmers of the improved cultivars. The increase in emphasis on technology exchange during Phase III was aimed at increasing adoption by farmers and broadening collaboration with a wide range of partners across the region. Throughout, the approach has been multidisciplinary, involving breeders, plant protection and grain quality specialists, and others. Maintenance breeding nurseries and regional/country crossing blocks, on-station and on-farm field testing, farmer verification, and screening at 'hot-spot' locations are key components of collaborative research under SMIP.

Another key component, particularly during Phases I and II, was assessment of grain quality of cultivars under development. This was done in the SMIP laboratory at Matopos, and a database has been compiled, containing grain quality information for over 2500 genotypes. This work has also helped scientists from national programs and the private sector compile and document data to support cultivar releases and promotional efforts.

NARS research capacities were strengthened by a combination of monitoring tours, joint evaluation of field trials, joint workplans, reporting, and joint publications. In-country support focused on training technicians on various aspects—management of trials and breeding nurseries, breeder seed production, field screening techniques for resistance to *Striga* and downy mildew, identification and control of diseases and insect pests, data analysis, and report writing.

Accomplishments

Germplasm movement and utilization. SMIP's genetic improvement efforts are tailored to the needs and capacities of our national program partners. For the stronger NARS (Botswana, Zambia, and Zimbabwe), we developed and provided intermediate outputs (e.g., random mating

Table 1. The sorghum germplasm collection at Matopos, assembled by SMIP for regional use.

Source	Supplier	No of accessions
Worldwide	ICRISAT	6 303
USA	INTSORMIL	652
Southern Africa	National programs and ICRISAT	2 234
Eastern Africa	National programs and ICRISAT	936
Western Africa	National programs and ICRISAT	363
Latin America	National programs and LASIP[1]	1 535
China	National program	15
Asia	National programs	305
Total		12 343

1. ICRISAT Latin American Sorghum Improvement Program.

Figure 1. Progression for breeding, testing and selection of sorghum in southern Africa (SADC region) by SADC/ ICRISATSMIP.

Variety description and production of leaflets	**Cultivar release, seed multiplication, farmer adoption and production**	NARS activity facilitated by SMIP
	↑	
More breeder seed increase (NARS and SMIP); large-scale seed production (NARS and Industry)	**On-farm verification** ↑ **(On-farm testing)**	NARS/SMIP activity; major farmer involvement to identify farmer preferences and release of varieties by NARS; 2 years, multifarm locations
	↑	
Breeder seed increase; seed production training by SMIP regionally and in-country	**National program testing**	NARS activity in national experiment stations, multilocational advanced testing, compilation of data; 2 years
	↑	
	Bilateral cooperative trials (specific to requesting NARS); regional collaborative trials (across all countries)	2-3 years for variety replacement; 6-10 locations in cooperating countries and SMIP
	↑	
NARS selections and promotion of advanced materials into their national variety trials	**Regional advanced cultivar testing**	1st Stage Regional Collaborative Trials of SMIP and NARS; beginning of multilocational trials —SMIP in 4 locations; —NARS in 6-10 country locations; joint NARS/SMIP evaluation
	↑	
NARS specific selections of breeding lines from SMIP test locations	**Preliminary cultivar testing —new varieties, new hybrids -new hybrid parental lines and restorers**	1-2 years 2 locations
	↑	
SMIP test locations	**New line trials/testcross evaluation**	Replicated trial in 2-3 locations; Selection based on visual observation and analyzed data; 1 year duration
	↑	
SMIP nurseries	**F_6/F_7 lines**	Advanced generation testing in 1-2 locations; head bagging of 2-3 plants/line for seed increase
	↑	
Breeding lines SMIP nurseries and semi-finished products selected by advanced NARS into their nurseries	**F_4/F_5 lines Modified pedigree breeding**	Early generation testing in one location
	↑	
SMIP nurseries country crossing blocks	**Crossing program Backcrossing program**	Line development Hybrid parent development
	↑	
	Breeding and observation nurseries —farmer participation	Initial screening Germplasm evaluation
	↑	
	Germplasm acquisition	

Table 2. Classification of sorghum germplasm from eight SADC countries[1].

Country	Basic races (% of accessions from each country)					Intermediate hybrid races (% of accessions from each country)											Total
	Bicolor (B)	Guinea (G)	Caudatum (C)	Kaffir (K)	Durra (D)	DC	GB	CB	KB	DB	GC	GK	GD	KC	KD	DR[2]	no of accessions
Angola	30	5	5	0	5	0	0	15	0	0	10	0	0	0	0	20	18
Botswana	0	11	4	17	20	14	2	8	0	3	5	1	0	3	12	0	100
Lesotho	0	1	2	14	1	18	1	27	5	2	28	1	0	4	0	0	104
Malawi	1	67	4	0	1	2	5	2	0	1	14	0	4	0	0	0	229
Namibia	0	5	22	2	15	21	0	0	0	0	17	4	2	4	2	2	123
Swaziland	0	2	7	28	0	2	19	26	0	2	9	0	0	2	2	0	43
Tanzania	0	25	18	0	6	4	4	3	2	3	40	0	3	0	0	0	67
Zimbabwe	1	16	11	16	3	11	1	17	1	2	14	1	1	2	5	0	526
Across region	1	23	10	11	5	10	2	12	1	1	15	1	1	2	4	1	1210

1. Does not include germplasm from South Africa (not available with SMIP), Zambia (collection stored at Mt Makulu Research Station), and Mozambique (very long-duration, does not mature at Matopos).
2. DR = drummondii.

populations, segregating lines, breeding stock, and hybrid parental lines) from which national scientists can develop a wider range of finished products. Specialized traits and sources of resistance to biotic and abiotic stresses have been incorporated into these intermediate outputs. Other NARS are provided with finished outputs, i.e., varieties and hybrids. Table 1 shows the diverse germplasm working collection—12 343 accessions—at Matopos assembled by SMIP and used by NARS/SMIP teams throughout the SADC region. Most of these germplasm materials are sourced from ICRISAT (51%), southern Africa (18%), and Latin America (12%).

in order to enable NARS to more effectively use the available genetic material, indigenous sorghum germplasm from the SADC region was characterized at Matopos. As a result, basic information is now available on agronomic traits and race classification of these materials. Table 2 summarizes the classification into the 5 basic and 10 intermediate hybrid races: guinea (23%), kaffir (11%), and caudatum (10%) are the most common of the basic races. The distribution of races was also studied (Obilana et al. 1996). Durra sorghums were recorded (in Botswana and Namibia) for the first time in the region. Among the intermediate races, a wild and weedy group, drummondii, was identified specifically in Angola (20% of the few accessions collected were drummondii), and rudimentarily in Namibia.

The combination of guinea-caudatum as a hybrid race has been most successful in SADC region, together with caudatum-bicolor and durra-caudatum. it would seem, therefore, that the guinea and caudatum races, together with their stable hybrid combinations, guinea-caudatum, durra-caudatum, and caudatum-bicolor, can be successfully used in sorghum improvement programs in the SADC region.

Table 3 shows some important agronomic and grain traits evaluated in the 1354 SADC-indigenous accessions. Almost all the accessions are small seeded, two-thirds have white grain, and nearly half are late-maturing (>85 days to 50% heading). Despite this, however, there is considerable diversity among the indigenous accessions.

Phenotypic correlations were determined among various agronomic and grain traits in the germplasm from southern Africa. Plant height was significantly correlated ($P \leq 0.01$) with days to 50% heading, leaf midrib color, and seed color. Panicle shape was significantly correlated with days to 50% heading.

Massive efforts on germplasm assembly and distribution to NARS have created a favorable base for generation of improved cultivars and impact at both intermediate (for use by scientists) and farmer levels. Both NARS and the private sector in the region now have wider access to world sorghum germplasm, thus increasing the variability and diversity available for improvement. Through a series of regional and national breeding nurseries, crossing blocks, off-season winter nurseries, and preliminary screening; a total of 25 000 breeding lines and enhanced germplasm were generated for regional use between 1983/84 and 1997/98. A total of 18 524 samples, comprising 10075 breeding lines,4634 varieties, 379 hybrid parents, and 3436 hybrids were supplied to national research and extension services, universities, and the private sector (Table 4). During the same period, 244 genetic materials were received from 9 SADC countries, and 608 collaborative sorghum trials were jointly evaluated by 11 countries in the region.

Cultivar development and testing

Extensive multilocational, multiyear, and multidisciplinary screening and testing was done in collaboration with our partners, to develop new improved varieties, hybrids, hybrid parents, and sources of tolerance to drought, and resistance to *Striga,* sooty stripe, leaf blight, downy mildew, and storage insects.

Drought tolerance in improved genotypes. A collaborative study with the Volcani Center, Israel, and the University of Hohenheim, Germany, measured productivity and drought response in 23 hybrids and 21 open-pollinated varieties developed at SMIP. We found that irrespective of the water regime, grain yield and harvest index increased and leaf area decreased in earlier-maturing genotypes (Blum et al. 1992), Hybrids matured earlier (62 days to 50% heading under low stress, 65 days under high stress) and produced more grain (970 kernels per panicle under low stress, 735 kernels under high stress) than varieties (80 days and 547 kernels under low stress, 81 days and 443 kernels under high stress).

In terms of plant water status and mean daily biomass production, varieties were more drought tolerant than hybrids. However, the physiological superiority of the varieties under drought stress did not result in higher grain yields because of their relatively poor harvest index. The drought-tolerant cultivars include SDSH 49, SDSH 409, SDSH 48, and IS 18530-1 (SDS 6785-1).

Hybrid parents were also developed with drought tolerance traits of good tillering, stay green, and early to medium maturity. The objective is to develop and distribute parental lines for further testing by NARS hybrid development programs.

Twenty-three male fertility restorer parents (R-lines) named SDSR 1 to SDSR 23 were selected out of 34 introductions from the International Sorghum/Millet Collaborative Research Program (INTSORMIL) at Texas A&M University during the severe 1991/92 drought, at Matopos and Lucydale in Zimbabwe. The 23 selected R-lines were tested for four years (1992/93 to 1995/96) at these two locations. In comparison with the controls, they gave 15% increased grain yield, 20% lower plant height, 58% harder grain, 10% higher milling yield, similar maturity duration, and zero tannin content for both white and red-seeded types.

Table 3. Agronomic and grain traits in 1354 sorghum germplasm lines[1] from southern Africa, 1988/89.

Trait[2]	Range	Mean	Remarks
Days to 50% heading	46-167	92.4	72% of accessions are medium-maturity (66-105 days)
Plant height (cm)	74-441	221.7	21% of accessions are dwarf types (74-173 cm)
Awns	1 or 2	1.86	90% are awn less
Panicle shape	1-9	4.96	50% are compact or semicompact
Leaf midrib color	1-5	1.85	<1% have brown midrib
Waxy bloom	1-5	1.89	
Seed size	1-3	2.96	96% are small seeded
Seed color	1-5	2.37	65% are white seeded
100-grain mass (g)	0.35-4.33	2.18	
Testa	1 or 2	1.46	

1. Data shown for 1354 SADC-indigenous accessions in the Matopos collection.
2. Awns: 1 = awns present, 2 = awns absent; Panicle shape: 1 = very lax, 2 = very loose drooping branches, 3 = loose drooping branches, 4 = semi-erect branches, 5 = semi-compact elliptic, 6 = compact elliptic, 7 = compact oval, 8 and 9 = broom corn; Leaf midrib color. 1 = white, 2 = dull green. 3 = yellow, 4 = brown, 5 = purple; Waxy bloom: 1 = no waxy bloom, 2 = slightly waxy, 3 = medium waxy, 4 = mostly waxy, 5 = completely waxy; Testa; 1 = present, 2 = absent; Seed cplor; 1 = white, 2 = yellow, 3 = red, 4 = brown, 5 = buff; and Seed size: 1 = large. 2 = medium, 3 = small.

Table 4. Improved sorghum genetic material (number of samples) and collaborative trials supplied to SADC countries, 1983/84 to 1997/98.

Country	No of samples				Total	No of trials
	Breeding lines	Varieties	Hybrid parents	Hybrids		
Angola	0	91	0	9	100	15
Botswana	916	790	60	632	2 398	53
Lesotho	96	212	0	373	681	21
Malawi	411	681	0	357	1 449	42
Mozambique	69	233	0	20	322	20
Namibia	0	87	0	52	139	9
South Africa[1]	0	87	60	0	147	3
Swaziland	13	130	13	170	326	18
Tanzania	2 350	936	0	416	3 702	53[2]
Zambia	4 032	551	96	651	5 330	39[2]
Zimbabwe	2 188	836	150	756	3 930	335[2]
Total	10 075	4 634	379	3436	18 524	608

1. SMIP started responding to South Africa's requests from 1994/95.
2. Includes breeding, pathology. entomology, and *Striga* hot spot trials and observation nurseries.

Similarly, 36 female (A/B pairs of male-sterile lines and their maintainers) parents, named SDSA/B 1 to SDSA/B 36 were developed by SM IP through four back-crosses and selection for grain quality, stay green, and productivity. They are slightly taller than the controls, slightly earlier (2%), superior in grain yield (8%), and 5-10% superior in milling quality. All have white grains that are 15% harder than the hybrid controls. Field visual assessments show the new male-sterile lines can be grouped into three categories: (1) dwarf (<1 m) with broad drooping leaves, tan plants, and resistance to leaf blight and sooty stripe; (2) semidwarf (1.0-1.6 m) with thin upright leaves, purple plants, and susceptibility to both diseases; and (3) semidwarf to semitall (1.7-1.9 m) with broad leaves, tan plants, and susceptibility to both diseases.

***Striga* resistance.** In collaboration with breeders, weed scientists, and pathologists in Botswana, Tanzania, and Zimbabwe, and a student from Old Dominion University, Norfolk, Virginia, USA, we screened and evaluated 490 SADC sorghum germplasm accessions and 12 introduced *Striga asiatica* (white-flowered)-resistant (SAR) lines from ICRISAT-Patancheru, Screening was done between 1985/86 and 1993/94 at five hot-spot locations—one location in Botswana and two each in Tanzania and Zimbabwe—using the 'checker board method' developed by ICRISAT (Vasudeva Rao 1987). We identified five resistant sources to three endemic *Striga* species in the region (Riches et al. 1986; Obilana et al. 1991; Mbwaga and Obilana 1994). In particular, two sources, SAR 19 and SAR 29, showed resistance to multiple *Striga* species. These findings need further confirmation. The sources of resistance are:

- *S. asiatica,* red flower: SAR 16, SAR 19, and SAR 35 in Botswana; SAR 19 in Zimbabwe; SPL 38A x SAR 29 in Tanzania;
- *S. hermonthica:* SAR 29 in Tanzania; and
- *S.forbesii:* SAR 19, SAR 29, and SAR 33 in Zimbabwe.

Meanwhile, in Zimbabwe and Tanzania, NARS/SMIP teams evaluated components of an integrated control package that included resistant cultivars, cultural practices, and use of fertilizers and herbicides between 1992/93 and 1994/95. SAR 19, SAR 29, and SAR 33 seem to supress *S. asiatica* emergence in on-station experiments, and this resistance was confirmed on farmers' fields at hot-spots in Zimbabwe and Tanzania (Mabasa 1996). However, the resistant SAR lines gave poor yields in both Zimbabwe and Tanzania, averaging 30-40% less than the improved but susceptible cultivars. Herbicide control of *Striga* was also studied, and the results show that the postemergence herbicide 2,4-D-amine could be effective.

Diseases and insect pest resistance. Using the infestor and spreader row screening method (Leuschner 1996) five sources of downy mildew resistance were identified at Matopos (Zimbabwe) and Golden Valley (Zambia). These are ICSV 112 (synonym SV-1 and MRS 12), ICSV 2, SDS 2620 deriv., SDS 2658, and PAN 172 (a selection from ZSV I made at Panmure, Zimbabwe). In a series of 15 trials in 1989/90 and 1990/91, more than 80% of the 375 test entries were resistant to downy mildew, while 42-49% were resistant to leaf blight. Resistance to sooty stripe was found in 22-49% of the entries (Obilana 1990).

Another area of particular importance in hybrid development and seed production was control of ergot (*Claviceps africana*). Preliminary results at Matopos (ICRISAT 1994) suggested that: (1) seed-set is more variable between rows of six A-lines than between rows of four A-lines; (2) under intense disease pressure from nearby sporulating sources, seed-set in a four-row plot of A-lines is significantly greater than in a six-row plot; and (3) the rate of disease increase (severity) is characteristically sigmoidal in hybrid production plots just as in A-lines alone.

We developed a methodology to screen for resistance to storage pests in sorghum (Leuschner 1996). The grain-insect egg combination of 15 g of grain infested with 40 eggs was found to be optimal (ICRISAT 1994). Using this method, we routinely screened all improved sorghum varieties derived from the breeding program for resistance to *Sitophilus* spp and *Sitotroga cereatella.* From among 270 cuitivars, we selected several, based on mean number of insect progeny, as having intermediate resistance to the two pests. Seven *Sitophilus-resistant* cuitivars were selected that showed 22-63 progeny compared with 105 progeny in the resistant control Segaloane. The 10 *Sitotraga-resistant* cuitivars had 18-26 progeny, compared with 25 progeny in the resistant control Segaloane.

Productivity, adaptation, and farmer participation

Improved cuitivars generated from collaborative NARS/ SMIP research show yield improvements ranging from 9 to 85%, and improved earliness (7-23%) over the local controls across six SADC countries (Table 5). Feedback from farmers who participated in breeding and selection showed that SMIP's breeding objectives are in line with what farmers want.

Farmers' participation was a novel exercise, launched with the objective of allowing farmers to identify preferred traits and genotypes, and helping us refine breeding objectives. For the exercise, we assembled a new type of nursery known as the Diverse Germplasm Observation Nursery (DGON). Farmers worked with NARS/SMIP scientists to evaluate the DGON, which consisted of 40 improved genotypes, indigenous varieties, and popular commercial varieties. Two years of farmer-participatory testing, 1993/94 and 1994/95, in two drought-prone locations in Zimbabwe, Matopos, and Lucydale showed

Table 5. Grain yield (t ha^{-1}) and maturity (days to 50% heading) of released and promising sorghum cultivars compared to controls in six SADC countries, 1987/88 to 1997/98.

		Grain yield (t ha^{-1})			Maturity (days to 50% heading)		
Country	No of environments	Range	Mean	Superiority over controls (%)	Range	Mean	Superiority over controls (%)
Botswana	12 on-station	0.69-7.00	2.56	+9	58-86	67	-22
Botswana	14 on-farm	0.45-1.01	0.66	+29			
Malawi	6 on-station	1.55-2.28	1.88	+33	76-87	79	+7
Namibia	4 on-station	1.57-3.93	1.95	+56	68-79	75	-7
Namibia	7 on-farm	0.66-1.35	1.16	+ 1			
Tanzania	20 on-station	1.20-4.40	2.40	+85	60-86	69	-23
Tanzania	22 on-farm	2,43-3.09	2.96	+65			
Zambia	12 on-station	1.03-6.11	3.63	+9	74-86	79	+3
Zimbabwe	30 on-station	1.33-7.07	3.81	+40	63-79	70	-11
Zimbabwe	>45 on-farm	0.94-4.05	1.52	+22			

that farmers prefer, in order of priority, short to medium plant height (0.95-1.54 m), drought tolerance, early maturity (63-86 days to 50% pollen shed), medium-large grain size, and good grain yield (1.66-2.83 t ha^{-1}) (Fig. 2). The range of farmer-acceptable values for the priority traits were calculated using data from the 12 best genotypes.

Improved cultivar releases

Twenty-seven improved sorghum varieties and hybrids have been released in eight SADC countries since the inception of SMIP in 1983/84 (Table 6). The eight countries are: Botswana (4 releases), Malawi (2), Mozambique (3), Namibia (1), Swaziland (3), Tanzania (2), Zambia (6), and Zimbabwe (6). Additional information on these releases is available in Obilana, in press (b), Setimela et al. 1997, and Chintu et al. 1996.

A systematic process of development and testing helps esure that the best varieties are selected for release. Following 3-4 years of on-station regional and national testing, the NARS select three to five varieties for on-farm verification trials. These trials are carried out in 5-10 farmers' fields/locations for one or two years by the national scientists, extension officers, and farmers' groups. Meanwhile, SMIP produces breeder seed of varieties under on-farm testing, and other varieties with potential for release, to facilitate further multiplication by the NARS, NGOs, and seed companies. The one or two varieties most preferred by farmers are then released by NARS. SMIP also assists national scientists with data assembly and drafting of release proposals, for example, by providing data on field performance and grain quality.

Process leading to cultivar release. Cultivar releases were the culmination of a lengthy process of collaborative technology development and exchange, as described below and summarized in Figure 1. Germplasm movement and collaborative selection and testing were backed up by technology exchange activities. SMIP also provided technical support and assistance for breeder seed production and training to ensure that seed production is adequate, and that technologies developed or tested in one country lead to spillover benefits in other countries in the region. In addition, SMIP catalyzed the development of stronger linkages between research and extension, and between research, extension, and the private seed sector on one hand and NGOs on the other, to facilitate seed production and distribution of the released cultivars.

Activities in the first four years included the development of breeding nurseries and a regional crossing program. Regional breeding nurseries were developed at two locations at Muzarabani and Aisleby in Zimbabwe, one location at Golden Valley in Zambia, two locations at Ilonga and Ukiriguru in Tanzania, one location at Kasinthula in Malawi, and two locations at Sebele and Pandamatenga in Botswana. The regional crossing program to test early-generation and advanced-generation materials is based in SMIP and involves collaboration with breeders in Botswana, Zambia, Zimbabwe, and Tanzania. During this period SMIP also assisted NARS in maintaining country crossing blocks at Aisleby.

The on-station testing program included a series of trials: new line trials (1 year), preliminary trials (1-2 years), and regional advanced trials (2-3 years), together with bilateral cooperative trials conducted (in response to specific requests) at eight locations across five countries. These included Matopos and Lucydale in Zimbabwe, and six other locations in four countries.

Assessment of grain quality for several end uses

Grain quality assessments by SMIP have made an important contribution to regional food security (Obilana 1997). Grain quality of the improved material under development was tested in the SMIP food technology laboratory at Matopos. We have compiled a database on physical, physico-chemical, and chemical traits for more than 2500 genotypes (including the 27 cultivars released in eight SADC countries) and produced a manual of laboratory procedures for grain quality evaluation of sorghum and pearl millet (Gomez et al. 1997). In addition, SMIP provides technical assistance on request to NARS and private firms to analyze advanced and promising materials, and to support proposals for cultivar release. SMIP also collaborates with the seed sector, milling and malting industry, and commercial feed growers to assess grain quality and identify new options for commercialization of sorghum (e.g., for use in composite flour). The emphasis in these analyses is on flour color and quality, milling yield, malting quality, and tannin content. Table 7 (see also ICRISAT 1994) summarizes some of the results on grain quality testing.

In 1995/96, SMIP conducted a detailed 10-country review of food technology research in the region. The study, which involved a consultant and partners from the University of Pretoria and from each participating country, covered various areas, including assessment of NARS interest in sorghum and pearl millet food technology, and an inventory of skills and facilities available in the region. The report of the study (Oniango 1996) was published by ICRISAT, and formed the basis

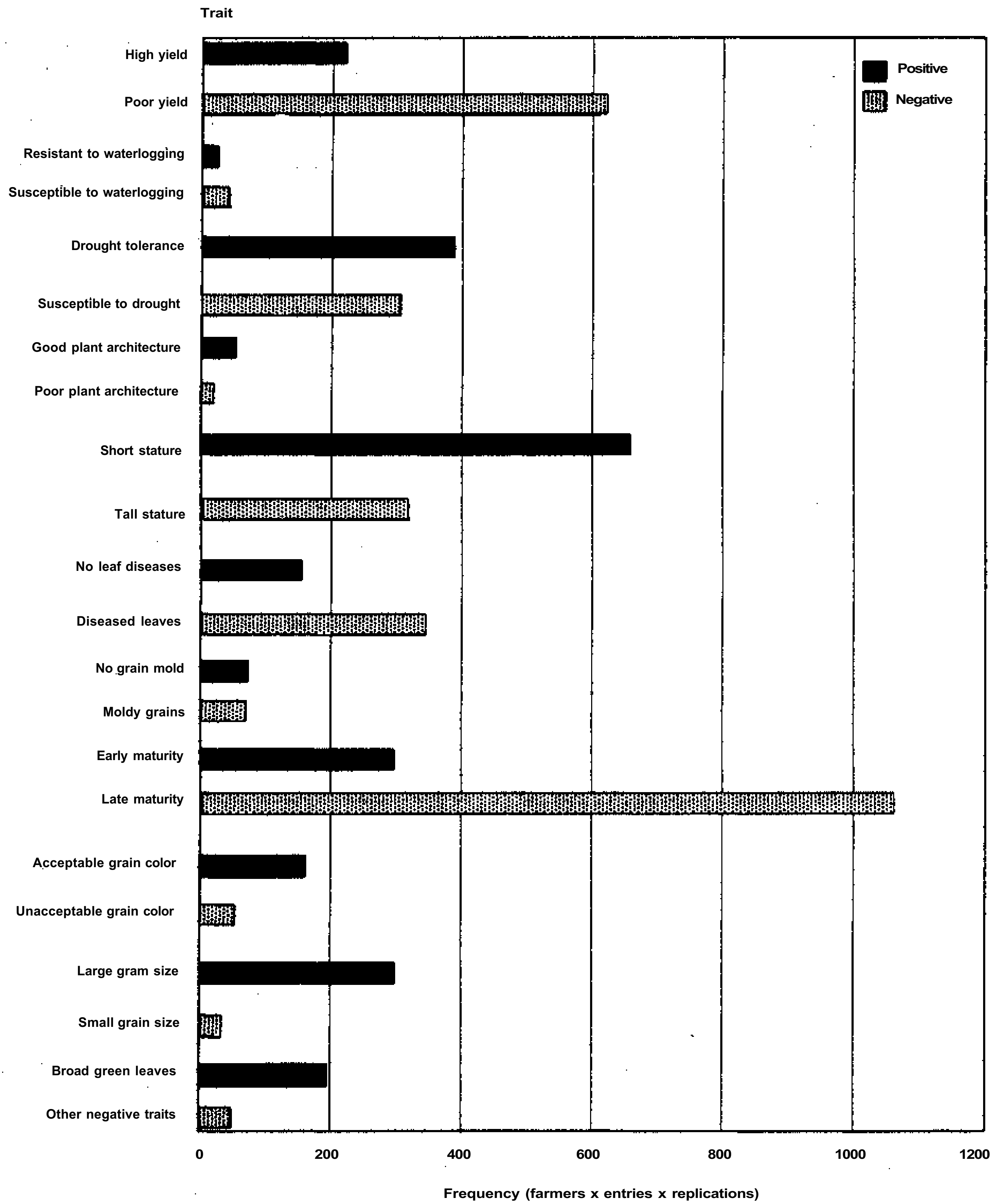

Figure 2. Positive and negative traits of sorghum cultivars most frequently mentioned and identified by farmers at Matopos and Lucydale, Zimbabwe, 1993/94 and 1994/95 (ICRISAT 1997).

Table 6. Sorghum varieties released in eight SADC countries as a result of collaborative NARS/ICRISAT research, 1984/85 to 1997/98.

Country	Variety designation	Pedigree	Year of release	Recommended production/adaptation zones	Remarks[1]
Botswana (4)	BSH 1	F_1 hybrid (Syn: SDSH 48)	1994	Short season, 250–750 mm rainfall	White, DT
	Mahube	IS 2923 (Syn: SDS 2583)	1994	Very short season, 200–600 mm rainfall	Red, SE
	Mmabaitse	Bot 79	1994	Short season, 250–750 mm rainfall	White
	Phofu	F3A-115-2 (Syn: M91057 SDS 3220)	1994	Short season, 250–750 mm rainfall	White, DT, SG
Malawi (2)	Pirira 1	(SC108-3 × CS3541)19-1 (Syn: SPV 351, ICSV 1)	1993	Interm. season, hot-humid areas 400–850 mm rainfall	White, TSB
	Pirira 2	[(IS 12622C × 555) × (IS 3612C × 2219B)5-1 × E-35-1]5-2 (Syn: SPV 475, ICSV 112, SV-1)	1993	Interm. season, 400–850 mm rainfall	White, SLD, SSB
Mozambique (3)	Chokwe	Selection from SV-1 (Syn: SPV 475, ICSV 112)	1993	Interm. season, 400–850 mm rainfall	White, SSB
	Mamonhe	IS 8511	1989	Interm.-to-long season, 750–950 mm rainfall	White
	Macia	F3A-115-2 (Syn: M91057, SDS 3220)	1989	Short season, 250–750 mm rainfall	White, DT, SG
Namibia (1)	Macia	F3A-115-2 (Syn: M91057, SDS 3220)	1998	Short season, 250–750 mm rainfall	White, DT, SG
Swaziland (3)	MRS 12	Selection from SV-1 (Syn: SPV 475, ICSV 112)	1992	Interm. season, 400–850 mm rainfall	White
	MRS 13	IS 2391 (Syn: SDS 1513)	1989	Interm. season, 400–850 mm rainfall	Red
	MRS 94	IS 3693 (Syn: SDS 1594)	1989	Interm. season, 400–850 mm rainfall	Brown, RSS, RLB
Tanzania (2)	Tegemeo	2K × 17/B/1	1988	Interm.-to-long season, 450–850 mm rainfall	White
	Pato	IS 23496 (Syn: SDS 2293-6)	1995	Interm. season, 400–800 mm rainfall	White
Zambia (6)	Kuyuma	MR4/4606 T11 (Syn: WSV387, SDS 3136-2)	1989	Interm. season, 450–900 mm rainfall	White
	Sima	IS 23520	1989	Interm. season, 450–900 mm rainfall	White
	MMSH 413	F_1 hybrid	1992	Interm. season, 450–900 mm rainfall	Brown
	MMSH 375	F_1 hybrid	1992	Interm. season, 450–900 mm rainfall	Brown
	WSH 287	F_1 hybrid	1987	Interm. season, 450–900 mm rainfall	White
	ZSV 12	IPA-47-38-2-C8203 (Syn: SDS 4358-1)	1995	Interm. season, 450–900 mm rainfall	Mainly white
Zimbabwe (6)	SV-1	[(IS 12622C × 555) × (IS 3612C × 2219B)5-1 × E-35-1]5-2 (Syn: ICSV 112)	1987	Interm. season, 400–850 mm rainfall	White
	SV-2	(IS 24704 × IS 10558)1-3-BWK-2-BK-BK (Syn: A6460, ICSV 88060)	1987	Short season, 250–750 mm rainfall	White, DT
	Macia	F3A-115-2 (Syn: M 91057, SDS 3220)	1998	Short season, 250–750 mm rainfall	White, SG, DT
	ZWSH 1	F_1 hybrid	1992	Interm. season 400–850 mm rainfall	White speckled
	SV-3	43-1-1-2 (Upper Volta) × 10 CR-2-2 (Syn: NL 499)	1998	Short-to-interm. season 300–900 rainfall	White
	SV-4	(9/97 × MR844-1-1) (Syn: NL 330)	1998	Short-to-interm. season 300–900 rainfall	White

1. DT = drought tolerant; SE = super early; SG = stay green trait; TSB = tolerant of stemborer; SLD = susceptible to leaf diseases; SSB = susceptible to stemborer; RSS = resistant to sooty stripe; and RLB = resistant to leaf blight.

Table 7. Grain quality traits in different sorghum types.

	Range of values		
Grain trait	White sorghums	Red sorghums	Brown sorghums
Testa	Absent	Absent	Present
Hardness score[1]	2.6-4.8	1.7-4.7	1.4-3.8
Flour yield (%)	72.60-90.82	69.23-88.20	64.20-86.20
Water absorption (%)	3.8-11.8	4.2-13.1	5.1-14.8
Flour color:			
Dry Agtron reading	68.2-82.5	59.5-76.8	50.7-72.1
Wet Agtron reading	48.8-63.6	32.2-55.4	24.4-48.8
Malting quality (SDU values)	14.68-73.34	15.90-72.62	28.28-74.17
Tannin content (% ce)	0	0.0-0.5	0.5-5.0
Crude protein (%)	10.9	10.9	10.9
Popping quality			
Visual hardness	2.4-3.0	3.0-3.4	-
Grain size[2]	medium-large	medium-large	

1. Hardness score on a 1-5 scale where 1.0-2.5 = soft, 2,6-3.4 = intermediate, and 3.5-5.0 = hard.
2. Grain size: large = grains >4.00 mm, medium = grains 4.00-2.60 mm, small = grains <2.60 mm.
3. Brown sorghums do not pop well as the grains are too soft.

for a 1996 regional workshop on the same subject. The proceedings of the workshop (Obilana 1996), which include specific recommendations to strengthen food technology research, were also published by ICRISAT.

Networking in SMIP

SMIP is founded on a networking approach, pooling the skills of a wide range of partners. Over the years, the nature of these partnerships has been continually modified, in line with growing NARS strengths and changing national and regional priorities. Progress in initiating and strengthening regional sorghum networks can be summarized as follows.

Regional networking

- Regional collaborative testing and selection through breeding nurseries, crossing blocks, trials, and monitoring tours;
- Training for scientists and technicians in pollination techniques, breeding nursery management, and breeder seed production; and
- Assessment of needs in food technology research and development.

New linkages

- With seed companies (Seed Co and National Tested Seeds in Zimbabwe, Pacific Seeds and Pannar in South Africa) for cultivar testing and seed production;
- With NGOs [e.g., World Vision International in Mozambique, Angola and Zimbabwe; CARE (Cooperative for American Relief Everywhere) and AFRICARE (Care for Africa) in Angola, ActionAid in Malawi, and ENDA (Environment and Development Activities) in Zimbabwe], and church organizations (e.g., Christian Council, Mvumi Rural Training Centre, and Bihawana Farmers Training Centre in Tanzania) for seed production and distribution;
- With food and feed industries in Zimbabwe (National Foods, Chibuku Breweries, and Induna Mills), for commercialization of sorghum for meal, composite flour, malt, and brewing;
- With farmers' organizations (Commercial Farmers Union, Zimbabwe Farmers Union, SADC/Deutsch Gesellschaft fur Technische Zusammenarbeit (GTZ) Small Scale Seed Production Project) for seed production and commercialization of sorghum;

- With universities and advanced research institutes including the University of Pretoria, South Africa; University of Zimbabwe; and Centre de cooperation Internationale en recherche agronomique pour le developpemment (CIRAD), France, for grain quality research; and University of Hohenheim, Germany, Volcani Center, Israel, and Old Dominion University, USA, on drought tolerance and *Striga* resistance; and
- With the SADC Plant Genetic Resources Centre, Lusaka tor regional germplasm conservation, exchange, and utilization.

Bilateral cooperation

- With individual SADC countries for collaborative annual workplanning, varietal testing, special projects, and promotion of sorghum. This collaboration is tailored to needs and research capacities of each NARS.

Implications for impact

In summary, sorghum improvement work at SMIP has generated impact via both intermediate (genetic material and new methodologies for use by researchers) and finished products (directly benefiting farmers and consumers).

Direct impact. Collaborative SMIP/NARS research has resulted in the release of 27 improved sorghum varieties and hybrids in eight SADC countries. These releases are a substantial improvement over the 16 releases in five countries during the period 1968-1983. While adoption is constrained by several factors (often institutional rather than research-related), these cultivars cover an estimated 20-30% of the national sorghum area in many countries (Obilana et al. 1997). The returns on donor investment for SMIP research have been substantial. For example, internal rates of return of 27-34% and a stream of net benefits ranging from US$ 7.8 to 28.9 million in Zimbabwe have been reported (Anandajayasekeram et al. 1995).

Intermediate products. Intermediate-level impacts include the following:

- Technical assistance provided to all SADC NARS (except Mauritius) in cultivar testing and compilation of documentation that led to the release of 24 out of 27 new varieties and hybrids that were proposed for release;
- Better targeting of NARS breeding programs (and thereby improved chances of adoption) through farmer-participatory variety selection;
- Annual collaborative research workplans of NARS and SMIP scientists have helped accelerate progress, for example, in improving resistance to diseases and insect pests, and identification of options for alternative end uses;
- Development of drought-tolerant male and female parental lines for hybrid development in Botswana, South Africa, Zambia, and Zimbabwe; and
- Identification of sources of resistance to three endemic *Striga* species, and incorporation of resistance into genotypes with improved agronomic backgrounds from Botswana, Tanzania, and Zimbabwe.

Areas of concern

Progress has been limited in three areas.

- Significant yield increases have been demonstrated in the new varieties, but yields must increase still further before the crop can be successfully commercialized.
- More effort is needed to develop NARS capacities to produce required quantities and quality of breeder seed of released varieties.
- Additional training and advisory assistance should be provided to more NARS in the region, with a focus on seed production, handling, and distribution.

The future

Phase IV (1998-2003) will focus on increasing productivity and stimulating commercialization. Correspondingly, specific objectives and activities are being reviewed and refined. Future emphasis will be placed on:

Productivity increases through

- Improvement of hybrids and varieties using limited population improvement with alternative sorghum groups (e.g., guinea sorghums) by toperossmg and the use of biotechnology; and
- Better production practices including soil fertility improvement and crop-water-environment management.

Increased commercialization through

- Better marketing strategies;
- Targeting new hybrids/varieties for specific use in milling, malting, and feed; and
- Improving and broadening linkages and partnerships.

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15 Years of Pearl Millet Improvement in the SADC Region

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Abstract

Pearl millet improvement under the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP) originally focused on two major objectives. The first was to lay the foundation for making improved varieties widely available to farmers in the region. This was to be achieved by supplying national breeding programs with enhanced germplasm and information they could use to stabilize yields in their specific environments. The second was to raise the level of expertise available for the breeding, production, and utilization of pearl millet, contributing to development of strong national programs with the capacity to generate and test elite germplasm.

Significant progress has been made towards these objectives. The pearl millet germplasm from southern Africa have been collected, characterized, and conserved. The regional facility holds well over 7000 pearl millet germplasm accessions from around the world, 3082 of which are of SADC origin. Sixteen pearl millet varieties originating from this project have been released in five SADC countries: Malawi (2), Namibia (4), Tanzania (2), Zambia (4), and Zimbabwe (4). These varieties currently occupy 2-45% of the total pearl millet area in these countries. Functional millet breeding programs

have been established in nine countries, among them Namibia where a successful seed development and delivery system was developed from scratch, Malawi, Namibia, and Tanzania are now in the process of redefining their breeding priorities through farmer-participatory methods. An IPM package for control of the armored bush cricket has been successfully implemented in Namibia and Zambia. Over 80 scientists and 200 technicians have been trained in crop improvement, agronomy, crop protection, seed production, and quality control; and this training has helped national programs upgrade their skills and experience.

SMIP recognizes that a strong regional scientific capability and the technical advances made in the development and dissemination of improved varieties provide a solid foundation for increasing farm-level productivity and incomes. If the full potential of this foundation is to be realized and the ultimate goal of the program fulfilled, SMIP must now address three important issues: seed delivery systems, broader stakeholder input into technology development, and commercialization of pearl millet.

Introduction

The request of the Southern African Development Community (SADC) heads of government to the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to set up a regional center clearly stated the need to rapidly step up the production of sorghum and millets in the SADC region. This reflected the intent of the SADC governments to direct attention to deliver new technologies to the semi-arid parts of the region with a view to improving the well being of the less privileged living in communal lands. This shift in policy was expected to redress prevailing inequalities in income distribution and elevate the status of the subsistence farmer.

ICRISAT responded to the request by setting up a regional crop improvement program—the Sorghum and Millet Improvement Program (SMIP)—based in Bulawayo, Zimbabwe. This multidisciplinary program aimed to develop genotypes that matched the sorghum (*Sorghum bicolor* (L.) Moench) and pearl millet (*Pennisetum glaucum* (L.) R. Br.) production environments of the SADC.

SMIP has so far completed three 5-year phases—Phase I (1984-89), Phase II (1989-1993), and Phase III (1994-98). Pearl millet improvement in Phase I focused on the initiation of a regional research program sensitive to collaborating national needs, identification of varietal materials, and development of evaluation procedures. Genotype development through crossing was established as a service to national agricultural research systems (N ARS) in several countries with the provision of field supplies and in some cases technicians. Monitoring tours and annual workshops served to enhance networking and information exchange. Under Phase II, progress was made in strengthening NARS' research capabilities in the following areas:

- Collection, introduction, evaluation, and conservation of local and exotic germplasm and breeding materials from various sources;
- Development of improved varieties, hybrids, and random-mating populations with drought tolerance;
- Establishment of regional crossing activities including country crossing blocks to make a range of genetic stocks more accessible to NARS breeders; and
- Dissemination of selected cultivars into national programs through regional collaborative trials and nurseries.

Phase II culminated with the release of seven improved pearl millet varieties in three SADC countries. During Phase III, technology development continued but the emphasis shifted to technology exchange. In this phase, nine more improved pearl millet varieties were released in the region, bringing the total number to 16.

Summary of achievements

Germplasm exchange. SADC pearl millet genetic resources were collected, characterized, and conserved—a total of 3082 accessions from all countries except Angola, Mozambique, and South Africa. Global germplasm was introduced and widely distributed to NARS. The Matopos facility now holds over 7000 pearl millet germplasm accessions.

Development of improved genetic material. NARS-SMIP collaboration has led to the release of 16 improved pearl millet varieties in five SADC countries. Hundreds of pearl millet breeding lines, germplasm lines, varieties, and hybrids have been developed and supplied to NARS, for use in their breeding programs. Ten composite populations have been bred, targeted at the two major semi-arid crop/livestock production systems in the SADC region.

Strengthening NARS capacities. Functional pearl millet improvement programs were established in all SADC countries except Lesotho and Swaziland. Prior to SMIP, only Botswana, Malawi, Tanzania, and Zimbabwe had active breeding programs.

Other areas. SMIP contributed to the development of a successful seed delivery system for improved pearl millet varieties in Namibia. It also introduced and promoted farmer-participatory variety selection methods, thereby assisting NARS in Namibia, Tanzania, and Malawi to redefine breeding priorities to respond more closely to farmers needs and preferences. We also helped establish a functional pearl millet downy mildew (*Sclerospora graminicola*) screening facility with the Zambian NARS for regional use, and helped to develop and test an integrated pest management (IPM) package to control the armored bush cricket (*Acanthoplus speiseri* (Orthoptera: Tettigoniidae)) in Namibia and Zambia.

Germplasm exchange

SADC germplasm

The regional program currently maintains 3082 germplasm accessions collected from the region, with origins distributed as follows: Angola (21), Botswana (46), Malawi (273), Mozambique (28), Namibia (1024), South Africa (3), Tanzania (373), Zambia (88), and Zimbabwe (1317). This germplasm was collected through joint missions mounted by ICRISAT and the concerned national programs between 1985 (Botswana, Tanzania, and Zimbabwe) and 1992 (Namibia, Zambia, and Zimbabwe). This SADC germplasm contains a good range of variation for plant type, maturity, grain type, grain color, etc. It has a good proportion of pearly white and corneous endosperm accessions from Namibia, which contribute useful traits for grain quality, and it is an invaluable resource of useful traits for future improvement of the crop for the region. We found noticeable un-relatedness between improved introduced varieties and SADC local landrace varieties. Crosses between these two sources resulted into very high heterosis values [e.g., with Tanzania landraces values as high as 99% were recorded and yield superiority of 90% over the then improved released variety Serere 17 (Monyo et al. 1996a)]. SMIP and collaborating NARS scientists in Zimbabwe, Botswana, Tanzania, and Namibia evaluated. a total of 4527 germplasm accessions and introductions at the regional center and NARS research stations between 1985/86 and 1991/92. These evaluations served to characterize the regional germplasm and were used as the basis for selection of genotypes used in the constitution of breeding populations and formation of a working collection for SMIP.

International germplasm and breeding lines

Between 1976 and 1980, only five countries, Botswana, Malawi, Tanzania, Zambia and Zimbabwe, had any research activities on sorghum and/or millet improvement. Out of these, improved pearl millet variety releases had occurred only in Botswana and Tanzania. Serere 6A in Botswana and Serere 17 in Tanzania, both released in the 1960s, were products from the former East African Agricultural and Forestry Research Organization (EAAFRO). After the collapse of the East African Community in 1979 the only viable source of germplasm-then available in the region was cut off. ICRISAT tried successfully to fill this gap and during 1976-1995 a total of 14 821 pearl millet germplasm accessions and breeding lines were introduced from the Genetic Resources and Genetic Enhancement Divisions of ICRISAT to SADC. SMIP made it much easier for ICRISAT to bring germplasm into the region because most of these (57%) came in through the SADC-SMIP project. Zambia, the second greatest beneficiary, received 28% of the total germplasm, the significance of which shows up in the progress achieved by the national program in the use of this germplasm to develop new cultivars. Zambia alone has released 4 of the SADCs total 16 released pearl millet varieties (Table 1) over the last 15 years.

Role of SMIP in the supply of germplasm to SADC

One of SMIP's greatest achievements has been that of supply of genetic materials to the SADC NARS. The effectiveness of ICRISAT to supply this valuable resource to NARS increased tremendously from 1984 onwards because ICRISAT was now able to work through SMIP to reach NARS more effectively. For the past 15 years SMIP has supplied a total of 45 456 pearl millet accessions (germplasm, breeding lines, varieties, and hybrids) to the SADC countries. Botswana, Malawi, Namibia, Tanzania, and Zimbabwe were the great beneficiaries of pearl millet germplasm through SMIP. As an indication of the value of this resource, each of these countries except Botswana has developed (with the assistance of SMIP) and released 2-4 improved pearl millet varieties. With the establishment of SMIP, there has also been an extra dimension to germplasm exchange, in that it became a two-way system. SMIP also started receiving genetic materials from NARS for use in

Table 1. Pearl millet cultivars released in SADC countries, 1984-1998.

Country	Total improved cultivars released per country	Release name	Year of release	Target Production System[1]	Spillover
Namibia	4	Okashana 1 (ICTP 8203)	1989	19	20
		Okashana 1 (ICMV 88908)	1990	19	20
		Okashana 2 (SDMV 93032)	1998	19	20
		Kangara (SDMV 92040)	1998	19	20
Zambia	4	ZPM-871 (WC-C75)	1987	20	
		Kaufela (ICMV 82132)	1989	20	
		Lubasi	1990	20	
		Sepo	1997	20	
Zimbabwe	4	PMV-1	1987	19	20
		PMV-2	1992	19	20
		SDMV 93032	1996	19	20
		PMV-3	1998	19	
Tanzania	2	Okoa(TSPM 9018)	1994	20	
		Shibe	1994	20	
Malawi	2	Tupatupa (SDMV 89005)	1996	20	
		Nyankhombo (ICMV 88908)	1996	19	20
Total	16				

1. Production Systems (PS) definitions:
PS 19: Lowland, rainfed, short season (less than 100 days), sorghum/miilet/rangeland. Covers sub-Sahelian eastern Africa and the margins of the Kalahari Desert in southern Africa.
PS 20: Semi-arid, intermediate season (100-125 days), sorghum/maize/rangeland. Covers substantial parts of eastern and southern Africa.

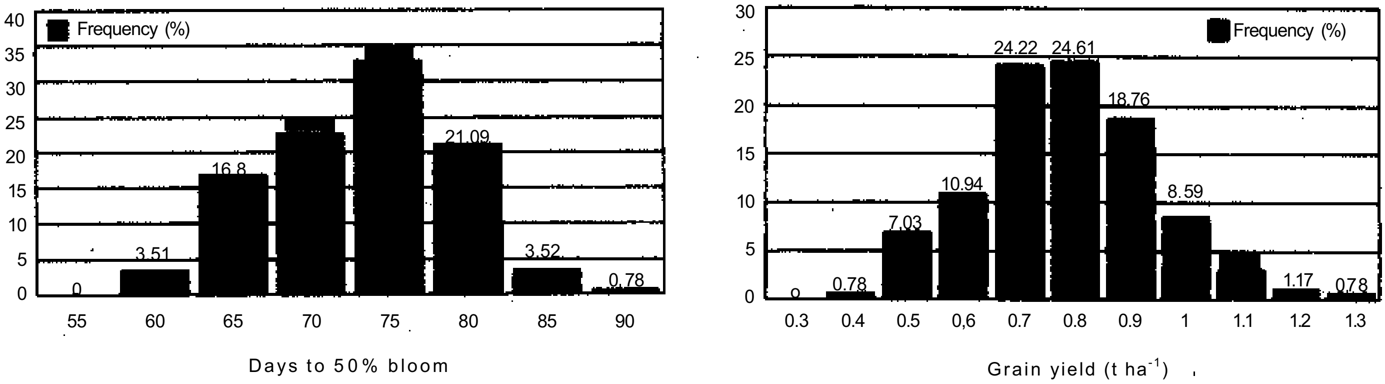
regional breeding programs. During the past 15 years, SMIP has acquired from NARS a total of 3599 different accessions (germplasm and breeding lines) for use in breeding: Zimbabwe (1362), Namibia (994), Tanzania (527), Malawi (467), Botswana (96), Zambia (77), and Mozambique (76).

Varietal improvement

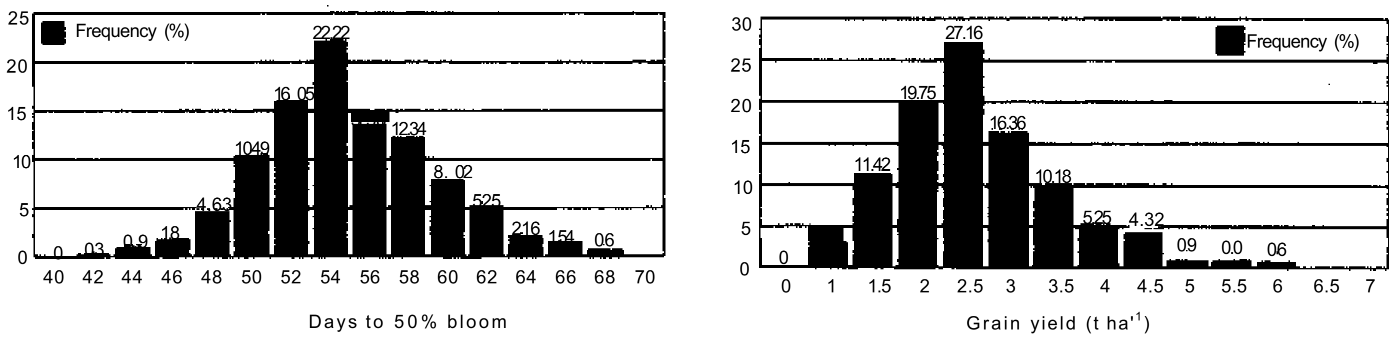
Genetic diversification and population breeding

Pearl millet varieties grown in the region are variable types. In Malawi and Zambia you will find tall, late maturing types that, irrespective of their origin, are morphologically very similar. In Botswana, Zimbabwe, and Namibia you mainly find early to medium maturing types, whereas in Tanzania the photoperiod-sensitive types predominate. However, in all cases growth durations of the local landrace accessions were always relatively longer than the season length in their localities. In general, the local landrace accessions have been caught up by the changing climate and weather patterns in addition to their inherent low yield potential (Figs. 1 and 2).

The regional program has developed composite populations based on maturity groups to satisfy the needs of these variable agroecologies. To respond to the danger *of* drought and short season, the program targeted early maturity and improved grain yield in these composite populations. Whereas typical local landraces could take 110-130 days to reach maturity, the longest growth duration of any of the SMIP developed composite population progenies is 110 days (Table 2). The majority reach 50% bloom in 55 days. However, for Tanzania, where long season pearl millet cultivars are grown, the season length extends to 120 days. Progenies that can mature in 80-90 days constitute the majority of the SADC Early Composite population (Fig. 3), Attempts were also made to couple early maturity with yield improvement (Fig. 4). The yield superiority of the Early



Figures 1 and 2. Frequenciy distributions of flowering (days to 50% bloom) and grain yield (t ha^{-1}) in Namibian pearl millet germ plasm accessions (n=750).



Figures 3 and 4. Frequency distributions of flowering (days to 50% bloom) and grain yield (t ha^{-1}) in pearl millet S_1 progenies (n=324) from the SADC Early Composite.

Composite progenies are usually more apparent during seasons of severe drought when most local landraces fail to yield anything due to early termination of rains (Monyo et al. 1996b).

Breeding varieties, hybrids, and hybrid parents

The population improvement program is an important source of new varieties. Out of the 301 pearl millet varieties developed by the SADC/ICRISAT program during the past 15 years, 148 originated from composite populations, 109 from backcross breeding, and 44 from mass selection of introductions, landraces, or recombination and selection.

Breeding hybrids

Interest in hybrid pearl millet has been shown by at least four countries in the region: Namibia, Zimbabwe, Zambia, and Tanzania. The yield advantages of hybrids over open-pollinated varieties have been quite evident in the absence of diseases. The regional program is thus putting some efforts into the development and identification of superior hybrids and good parents.

The vulnerability of single-cross hybrids to diseases [downy mildew, ergot (*Claviceps fusiformis*), and smut (*Moesziomyces penicillariae*)] in the region has long been recognized (De Milliano 1989). Breeding efforts are currently devoted to finding a solution for this. It is a well recognized phenomena that the advantage of hybrid vigor in pearl millet is worth pursuing. However, we somehow have to go round the disease problems associated with genetic uniformity brought about in the process of developing single-cross hybrids. The regional program has pursued this through two approaches:

1. Variety cross hybrids. The ideal combination is when the female is a late dwarf, and the male (pollen) variety is slightly earlier but tall. The hybrid is expected to be much earlier and taller than any selfed female plants. We have not been very successful thus far with seed production mainly due to drought and problems of synchronization of flowering.

2. Topcross hybrids. This approach requires that at least one of the parents is a variety. Topcross hybrids are more heterogeneous than single crosses and thus are expected to be less vulnerable to diseases. Topcross hybrids are already proving to be popular, especially

Table 2. SADC Pear! Millet Composite Populations and their zones of adaptation.

Composite population	Days to maturity	Season developed	Zones of adaptation
SADC Early Composite	75-90	1985/86	Botswana, Namibia, Zimbabwe (PS 19)
SADC Dwarf Composite	90-110	1985/86	Malawi, Zambia (PS 20)
SADC Bristled Composite	80-100	1985/86	Zimbabwe, Malawi, Mozambique (PS 19 and 20)
SADC Late Maturity Composite	90-110	1985/86	Malawi, Zambia, Tanzania (PS 20)
SADC Bold Grain Composite	75-90	1989/90	Botswana, Namibia, Zimbabwe, Angola (PS 19)
New SADC White Grain Composite	80-100	1995/96	Namibia, Zimbabwe, Malawi, Mozambique (PS 19 and 20)
Tanzania SADC Late Maturity Composite	100-120	1990/91	Tanzania, Zambia (PS 20)
Namibia Composite 90	80-90	1989/90	Namibia, Zimbabwe, Botswana, Angola (PS 19)
Maria Kaherero Composite	75-90	1995/96	Namibia, Botswana, Zimbabwe, Angola (PS 19)
Tanzania SADC Photoperiod-sensitive Composite	100-120	1995/96	Tanzania (PS 20 photoperiod sensitive)

in Namibia where there is an established seed industry. Seed growers like this approach because both the hybrid and pollinator parent seed are marketable.

Male steriles. Seed parent ICMA 87001 normally produces the highest yielding hybrids, which are also relatively later in maturity. ICRISAT-Patancheru has put more emphasis on the early to extra early type of materials. The fact that late maturing A-lines seemed to work better for SADC, and that there are so few of that maturity group available from other programs, prompted SADC to put some emphasis into developing pearl millet A/B pairs. Utilizing parents developed at Patancheru as sources of maintainer genes and male-sterile cytoplasms, SMIP is developing a series of A/B pairs in the A_1 and A_4 cytoplasmic male-sterility systems. These pairs are currently in their final stages of development They will be evaluated regionally for plant and grain traits of value and their suitability as hybrid parents, to identify the best 5-10 pairs for the two major Production Systems of the region.

Grain quality evaluation in pearl millet

Grain quality characteristics of all varieties under on-farm verification and advanced on-station testing are routinely evaluated. This data is useful and is included to support release documents jointly prepared with collaborating NARS. Table 3 shows grain quality traits in some selected pearl millet varieties released by SADC NARS.

As can be seen from the table, varieties like SDMV 92040 with cream/white colored grain can produce white flour as opposed to the traditional gray pearl millet product (see Agtron reading of 56% as compared to 47-49% for Okashana 1). It is anticipated that flour of this variety can be easily composited with wheat and other white flours to produce baked products. This possibility has already been tried on a small scale in the lab and it is possible to blend up to 50% pearl millet flour with wheat flour for cookies and up to 20% for bread without much loss in product quality.

Palatability, taste, and food acceptance are intrinsic values embedded in the local germplasm that have been selected by farmers over the centuries. For any food grain breeding program to be successful the grain qualities of what farmers already have must be characterized and as much as possible of this incorporated into new varieties. Through screening for grain hardness we are now able to identify those varieties that are closer to the farmers' local cultivars as a source of germplasm for breeding. Table 3 clearly reveals the superiority of the farmers' local for grain hardness traits as measured by visual scoring, lower proportion of floury endosperm, lower particle size index, and better milling yields. Visual hardness score, particle size index, and water absorption have been identified as indicators of grain hardness.

Table 3. Grain quality characteristics of the 16 improved pearl millet varieties released by SADC NARS for the region.

Cultivar	Visual hardness score[1]	Proportion floury endosperm	Particle size index	Kernel weight (g 100^{-1})	Floaters (%)	Dehulling loss (%)	Milling yield (%)	Water absorption (%)	Size fraction large[2]	Size fraction medium[3]	Size fraction small[4]	Agtron reading dry	Country of release
Tupatupa (SDMV 89005)	2.7	0.43	9.88	0.96	75	4.80	93.30	10.40	15.82	82.19	1.79	50.50	Malawi
Nyankhombo (ICMV 88908)	2.3	0.51	11.00	1.20	89	11.90	83.70	12.50	72.07	27.71	0.20	48.80	Malawi
SDMV 90031	3.0	0.35	10.19	1.11	81	4.90	93.15	11.50	29.57	69.83	0.53	48.80	Mozambique
Okashana 1 (ICTP 8203)	2.4	0.35	-	1.41	48	8.40	81.10	12.80	55.30	44.38	0.13	46.80	Namibia
Kangara (SDMV 92040)	2.7	0.44	10.59	1.17	86	4.90	91.85	11.80	55.25	44.31	0.36	56.40	Namibia
Okashana 2 (SDMV 93032)	2.5	0.51	10.82	1.24	91	5.45	90.80	10.00	57.41	42.31	0.15	49.20	Namibia
Okashana 1 (ICMV 88908)	2.5	0.53	11.05	1.26	93	5.60	89.75	10.70	55.07	44.55	0.29	48.90	Namibia
Okoa (TSPM 91018)	3.1	0.32	9.94	0.94	65	4.95	92.50	9.20	19.91	78.82	1.20	50.80	Tanzania
Kaufela (ICMV 82132)	2.8	0.38	-	0.93	21	9.20	85.30	9.70	8.51	91.18	0.26	49.00	Zambia
PMV-2 (SDMV 89004)	2.6	0.47	12.14	1.13	79	7.20	89.25	10.00	24.17	75.04	0.47	51.10	Zimbabwe
Local cultivar	3.3	0.25	9.17	0.92	53	4.60	91.85	8.50	13.67	84.53	1.60	48.10	Zimbabwe

1. Grain hardness scale of 1–5, where 1 = very soft and 5 = very hard.
2. % >2.6 mm.
3. % 2.6–1.77 mm.
4. % <1.7 mm.

Network activities

Bilateral collaborative research

Where faster progress appeared to be likely under collaborative bilateral arrangements, special projects were developed between SMIP and the concerned NARS.

Improvement of breeding lines and varieties for the long season pearl millet production zones of Tanzania. A particularly difficult area in which to make progress was that of developing varieties adapted to Tanzania because of the photoperiod-sensitive nature of the Tanzanian germplasm. True, they could benefit from the regional program through supply of insensitive germplasm but these lacked local adaptation. A good mix of both to transfer useful traits from one to the other was seen as the ideal (Monyo et al. 1996a) but this work could only be done in Tanzania because the Tanzanian materials would not flower outside their zone of adaptation.

Tanzania and SMIP therefore embarked on a joint project to develop breeding lines and varieties particularly adapted to the long season pearl millet production zones.

The main components of the project included:

- Collection, introduction, and evaluation of genetic materials;
- Development and improvement of full season composite populations;
- Development of full season inbreds and varieties; and
- Conversion of selected local landraces into better agronomic backgrounds.

Achievements

- Evaluation of Tanzanian germplasm was completed in 1988/89 and selected genotypes channeled to the breeding program.
- Selected superior local landraces were converted into better agronomic background through limited backcrossing (using elite regional varieties) and they now constitute entries for the Tanzanian National variety testing program.
- The first full season composite was developed in the 1990/91 season and is being utilized by the NARS.
- Two pearl millet varieties, Shibe (of Tanzanian local landrace extraction) and Okoa (of Zimbabwean local

Table 4. Plant characteristics and grain yields of improved pearl millet varieties Okoa and Serere 17, and the local cultivar in on-farm trials, Tanzania, 1991-94.

Variety	Days to flowering[1]	Plant height[2] (cm)	Panicle length[3] (cm)	Mean grain yield[4] ($t\ ha^{-1}$)	Superiority over local (%)
Okoa	62	198	43	2.31	42
Serere 17	53	175	24	1.62	0
Local cultivar	67	211	36	1.62	-

1,2,3,4, Based on an average of 17,11,16, and 21 nonreplicated environments, respectively.

landrace extraction) were developed and released in Tanzania in 1994 through this project, after on-farm evaluation for farmer preferences (Letayo et al. 1996).

- A new photoperiod-sensitive composite was developed during 1995/96 as a source of varieties for Tanzania.

The release of Okoa and Shibe in Tanzania in 1994 marked the first release of any pearl millet variety developed through joint collaboration with ICR1SAT through SMIP. The only other improved pearl millet in Tanzania, Serere 17, was released in the mid 1960s and was a product of research of the former Eastern African Agricultural and Forestry Research Organization—a regional research umbrella of the East African Community, As can be seen, Okoa has 42% grain yield advantages over both the farmers' local cultivar and Serere 17 (Table 4).

Assistance in establishing a pearl millet breeding program for Namibia. Pearl millet is the most important cereal in Namibia. It is grown in an estimated 355 000 ha (Ipinge et al. 1996a) and contributes 24% of the total caloric intake of the country's population (SADC Food Security Bulletin 30 Jun 1991). In spite of this importance, Namibia had no research program on pearl millet prior to independence in 1990. Soon after independence, Namibia became a member of SADC and the Government requested ICRISAT to assist in the initiation of a pearl millet National Research program. The following are the components of the Namibian breeding program developed with ICRISAT's assistance:

- Collection and evaluation of the Namibian pearl millet germplasm;
- Evaluation of new sources of variability for utilization to improve pearl millet for Namibia;
- Generation of variability for national exploitation;
- Systematic exploitation of the local Namibian landrace accessions;
- Development and use of low cost, widely applicable methodologies for involvement of farmers in the development and selection of pearl millet varieties;
- Improvement and exploitation of pearl millet composite populations with farmer participation; and
- Development of strong linkages with the SADC/ ICRISAT SMIP regional program.

Achievements

- The National germplasm has been collected, evaluated, characterized and conserved; a total of 1024 accessions are in storage.
- The breeding program has been decentralized to involve fanners in all aspects of cultivar development/ selection. New breeding products (populations, experimental varieties, and breeding lines) have been developed with active farmer participation (Ipinge et al. 1996b).
- Four pearl millet varieties have been released within a span of eight years!
- A functional seed program was developed, resulting in formation of a farmers' seed cooperative with responsibility for supply of inputs, seed production, and distribution.
- As a result, adoption levels of improved pearl millet varieties in Namibia now stand at 45% (Rohrbach et al., in press).

Regional collaborative trials

Through this activity SMIP ensures that technology developed by the regional center and jointly with National Programs is tested multilocationally in the region.

Multinational testing enables SMIP to make correct inferences about a certain technology (new variety) and a reading on the stability of genotypes over a wide range of environments. Entries exhibiting superior performance in these trials are selected by individual National Programs for their own national testing programs. Such trials have led to the identification of the many NARS releases of pearl millet in SADC.

Regional Collaborative Trials have facilitated exchange of germplasm between and among NARS, free flow of germplasm from the regional program SMIP to NARS and vice versa, and identification of widely adapted germplasm for regional/multinational release.

Below are a few examples of important regional releases and their advantages relative to the farmers' local cultivars in their areas of release.

ICMV 88908 [= Nyamkhombo = Okashana 1] (popular in Namibia, Zimbabwe, Angola, and Botswana);

SDMV 93032 [= Okashana 2] (Namibia, Zimbabwe, Angola);

SDMV 89004 [= PMV-2] (Zimbabwe, also adapted in Malawi and Botswana); and

SDMV 92040 [= Kangara = PMV-3] (Zimbabwe, Namibia).

Pearl millet accounts for 42.3% of area under cereals and 42.7% of total cereals production in Namibia. SMIP assisted Namibia to initiate a breeding program in 1991, which is now fully operational. Namibia has made big strides in involving farmers in their variety selection efforts, which has contributed substantially to their successful program. Okashana 1 (ICMV 88908) released in 1990 (Witcombe et al. 1995) currently occupies more than 45% of the total area under pearl millet production (Rohrbach et al., in press) and provides a 25% yield advantage over the local landraces on the long term average. In seasons of severe drought when the local varieties fail to produce anything, Okashana 1 still manages to produce something—a factor that has made it Namibia's first choice for food security. Two other varieties, both developed with active farmer input, were released in 1998: Okashana 2 (SDMV 93032) with similar yields to Okashana 1 but with stronger stalks and better storing grain, and Kangara (SDMV 92040), which provided a 40% yield advantage compared to the farmers' local cultivars, and has an edge over Okashana 1. All the

Table 5. Plant characteristics and grain yield of pearl millet varieties Okashana 1, Okashana 2, Kangara, and the local cultivar in research station trials, Namibia 1993-96.

Variety	Days to flowering[1]	Plant height[2] (cm)	Panicle length[3] (cm)	Plant lodging[4] (%)	Mean grain yield[5] ($t\ ha^{-1}$)	Superiority over local (%)
Okashana 1	55	167	23	31.25	1.481	25
Okashana 2	56	169	23	20.50	1.361	15
Kangara	53	162	22	-[6]	1.667	40
Local cultivar	63	206	33	16.25	1.187	-

1,2,3,4,5. Based on an average of 40,39,39,8, and 40 environments, respectively.
6. Data not available.

Table 6. Plant characteristics and grain yield of pearl millet varieties Tupatupa, Nyankhombo, NC-Tall, and the local cultivar in research station trials, Malawi 1989-1994,

Variety	Days to flowering[1]	Plant height[2] (cm)	Panicle length[3] (cm)	Mean grain yield[4] ($t\ ha^{-1}$)	Superiority over local (%)
Tupatupa	59	214	26	1.464	72
Nyankhombo	52	191	23	1.169	37
NC-Tall	60	265	30	1.049	23
Local cultivar	67	294	33	0.850	-

1,2,3,4. Based on an average of 32 environments.

improved cultivars are 2-3 weeks earlier in maturity than the Namibian local landrace varieties (Table 5).

More than 600 000 people live in the lower Shire valley of Malawi and depend on pearl millet and sorghum for their staple food. Average grain yields are 600 kg ha^{-1} and there is no possibility for increasing land under cultivation (Malawi is one of the most densely populated countries in the SADC). It is estimated that to make these people self sufficient in food, yields must increase to 41 ha^{-1}, which is not possible. This region is thus endemically food deficit. To help the situation a good combination of appropriate genotypes and management must be sought.

Two varieties were released by the NARS in 1996. One of these varieties (SDMV 89005), locally known as Tupatupa, offers 72% higher grain yields than the farmers' local cultivar under on-station conditions and a 55% advantage under farmer-managed conditions. The second one (ICMV 88908), released under the local name Nyankhombo, offers a 37-48% yield advantage compared to the farmers' local landraces and is up to 3 weeks earlier in maturity (Tables 6 and 7).

Targeting NARS breeding programs to farmers' needs

A number of Diverse Genotype Observation Nurseries (DGON) were conducted in collaboration with NARS in some selected countries from 1994-98. Three regional workshops on participatory involvement of farmers in technology development were also held under the auspices of better targeting NARS breeding programs.

DGONs were conducted with NARS with the participation of their farmers in Zimbabwe, Namibia, Tanzania, and Malawi. The trials were sown adjacent to on-farm trials in the farming community to expose farmers to the range of variability in traits among pearl millet cultivars. Farmers were also invited to research stations to assess varieties. Using these diverse genotypes, farmers assisted breeders in selecting traits that they preferred in the cultivars. Surveys on farmer-demand for alternative grain and plant traits were also conducted in Namibia and Zimbabwe.

SMIP staff participated with their collaborating NARS counterparts to analyze the farmer selection criteria using a participatory approach and informal discussions. In virtually all sites farmers seemed to be fairly unanimous in preferring the traits of early maturity, bold grain, drought tolerance, hard endosperm for ease of processing and resistance to storage pests, white grain for food, good taste, large panicles, medium height, strong stems, and high yield. They did not like late maturing cultivars, small-seeded varieties, or those that were difficult to thresh and process into meal, Soft grain was also not preferred because of its poor milling yields and susceptibility to storage pests.

In Namibia we involved a group of 20 women farmers with interest in millet food products for three consecutive years and about 100-200 fanners once each year on specially organized field days at Mahenene research station. Similar information was also collected from two other research stations (Okashana and Mashare) in Namibia. In Zimbabwe we involved a group of 10 farmers (6 women and 4 men) for two seasons at Matopos research station and supplemented this with information from farmers' field days organized once a year and involving 100-150 farmers. Supplementary information in Zimbabwe was also collected from special nurseries sent to one communal area, Tsholotsho.

We conducted a workshop on farmer participation and input at different stages of the breeding process at Mahenene, Namibia, from 25-28 Apr 1995 for national scientists. Its aim was to facilitate sharing of infonnation on new infonnal techniques of increasing farmer participation in the development of improved cultivars. The workshop, which was attended by participants from

Table 7, Plant characteristics and grain yield of pearl millet varieties Tupatupa, Nyankhombo, NC-Tali, and the local cultivar in on-farm farmer managed trials, Malawi 1995-94.

Variety	Days to flowering[1]	Plant height[2] (cm)	Panicle length[3] (cm)	Mean grain yield[4] ($t\ ha^{-1}$)	Superiority over local (%)
Tupatupa	46-50	217	-	1.44	55
Nyankhombo	38-48	184	-	1.38	48
NC-Tall	55-65	259	-	1.00	7
Local cultivar	65-70	280	-	0.93	-

1,2,3,4. Based on an average of 18 nonreplicated environments.

Botswana, Namibia, and SMIP, concentrated on the evaluation of the effectiveness of several methods of soliciting farmer input into the breeding program. Among some novel methods evaluated were the use of Morphologically Diverse Germplasm Observation Nurseries (MDGON) for traits selection by farmers, structured group interviews, matrix scoring and ranking involving Participatory Rural Appraisal (PRA) techniques, and pairwise scoring and ranking.

We also consulted 59 farmers—50 women and 9 men from the Namibian North Central region (Owamboland)—on their preferences. This exercise exposed us to the different types of local varieties and to what farmers liked in each of them.

During the 1995/96 season, after two years of farmer involvement with breeders in the nurseries in Zimbabwe and Namibia in particular, the NARS and SMIP breeders have prioritized the pearl millet ideotype sought after by farmers in the region as that which is early maturing, drought tolerant, and with large bold grains that are hard and resist storage pests, and have good grain quality for food. Similar results have been documented elsewhere in the SADC (Chintu et al. 1996; Ipinge et al. 1996b; Letayo et al. 1996; and Monyo et al. 1996a).

Fifty genotypes were evaluated, and the characteristics of the 10 most popular genotypes indicate that each of the preferred traits has a range of values within which it is considered acceptable. These ranges are as follows:

- 55-65 days to 50% flowering;
- Grain size above 14 g kernels 1000^{-1};
- Grain yield above 1.50 t ha^{-1}; and
- Grain color light gray to creamy-white.

During 1996/97, in our endeavors to develop a plant ideotype sought after by farmers, we revisited our experiences of farmer participation in plant breeding with Namibia and analyzed the trait variability in materials developed by Participatory Plant Breeding (PPB) methods against those developed conventionally. Preliminary returns reveal unquestionable priorities for early maturity, grain size, and drought tolerance. PPB-derived materials were superior in all these traits (Monyo et al. 1997b). Detailed results of the Namibian case in particular are published in "Farmer participatory research in practice: experiences with pearl millet farmers in Namibia" in the NARS/SMIP workshop on PPB approaches held in Harare from 6-11 Jul 1997 and made available to all SADC NARS (Monyo et al. 1997a).

Currently three SADC countries, Namibia (Ipinge et al, 1996b), Tanzania (Letayo et al. 1996), and Malawi (Chintu et al. 1996), have retargeted their breeding programs to incorporate farmer input in the development of new cultivars encompassing priority plant and grain traits as identified by farmers. Five more countries, Angola, Botswana, Mozambique, South Africa, and Zambia, have expressed willingness to start.

Plant protection

Identification of major diseases and their hot spots

Disease samples have been collected for identification of pathogens in Mozambique, Swaziland, Tanzania, Zambia, and Zimbabwe (CAB International Mycological Institute 1989). Collaborating institutes in addition to national institutes in the region included Imperial College, Wye College, and Reading University in the UK; Purdue University and Texas A&M University in the USA; ICRISAT-Patancheru, India; and the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), Harare, Zimbabwe.

In trip reports during 1989 and 1990, the disease situation in the region was documented for Angola, Botswana, Malawi, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe (De Milliano 1990; 1991). Special reports were made about smut by Faux (1989b), ergot by Faux (1989a, b) and Mbwaga and De Milliano (1990); and false mildew in Zimbabwe by Mtisi and De Milliano (1990). A report on diseases of millet in the SADC region was prepared for a training course (De Milliano 1989).

Internationally, progress was made with the identification of bacteria (Claflin et al. 1989; Qhobela and Claflin 1988), ergot research (Thakur et al 1989; Thakur and Sharma 1990), and smut research (Thakur 1989).

Causual organisms for leaf spot disease of pearl millet, currently becoming of concern in the SADC region, were identified as bacteria, *Pantoe aglomerans* and *Pseudomonas syringae* (Frederickson et al. 1997; Frederickson et al. in press).

Five diseases were of importance:

1. Ergot (*Claviceps fusiformis*), with epithytotics in farmers' fields and on research stations in Tanzania and at research stations in Malawi and Zimbabwe;
2. Leaf spot diseases (several types, some unidentified) in farmers' fields in Botswana, Tanzania, and Zambia, and at research stations in Malawi, Tanzania, and Zambia;

3. Downy mildew (*Sclerospora graminicola*) in farmers' fields in Malawi, Tanzania, Zambia, and Zimbabwe;
4. Rust (*Puceinto penniseti*) in farmers' fields in Tanzania, and Zambia and at research stations in Malawi, Tanzania, Zambia, and Zimbabwe; and
5. Smut (*Moesziomyces penicillariae*) in farmers' fields in Zambia and at Ngabu, Malawi.

False mildew (*Beniowskia sphaeroidea*) occurred on research stations in Malawi, Zambia, and Zimbabwe, but is considered to be of minor importance. Hanlin (1987) concluded that *Beniowskia* and *Clathotrichum* are synonymous. Huda and Thakur (1989) made an attempts to characterize the environment for ergot disease development in pearl millet.

Not one of the research stations with pearl millet in Zimbabwe had a downy mildew epiphytotic in the last 10 years, though epiphytotics occurred in farmers' fields. As this is the most important disease of pearl millet in the world, this fact deserved attention. SMIP, working with Zambian NARS, established a screening facility in Kaoma, which is a hot spot site for downy mildew in the region. Disease resistance testing of newly developed germplasm can be done effectively at hot spot locations—locations with effective screening for diseases resistance, during three out of four years. The following hot spot locations have so far been identified:

1. Downy mildew—Mongu and Kaoma, Zambia; and Ukiriguru, Tanzania;
2. Ergot—Ngabu, Malawi; Panmure, Zimbabwe; and Ukiriguru, Tanzania;
3. False mildew—Panmure, Zimbabwe;
4. Leaf spot disease—Mongu, Zambia; and
5. Smut—Ngabu, Malawi; Mongu, Zambia; and Ukiriguru, Tanzania.

Adaptation and development of screening techniques

The techniques are only tested at locations where the diseases are endemic, usually at disease hot spots. Research was carried out on three diseases:

Ergot. At Henderson (with assistance of J Benza, Plant Protection Research Institute, Zimbabwe), and Panmure, Zimbabwe, and at Ilonga, Tanzania (with assistance from A Mbwaga).

Smut. At Matopos, Zimbabwe with assistance from L Faux (Wye College, UK, funded by ODA).

Leaf spots. *Pantoe aglomerans* (Frederickson et al. 1997) and *Pseudomonas syringe* (Frederickson et al. in press) were identified as causual organisms for leaf spot and streak diseases of pearl millet in Zimbabwe.

Identification of sources of resistance

Ergot. Both ICMPES 28 and ICMPES 29 had very low ergot severities under natural epiphytotics in Malawi, Tanzania, and Zimbabwe (four years' data). At Matopos the two entries became affected after artificial inoculation, as during other years. However, severities remained moderate to low. ICMPES 45, however, had low severities. Entries screened for ergot susceptibility were monitored daily to ascertain their flowering sequence, 30 panicles per entry. There was a range of flowering sequences, from protandrous (anthers emerge before or at the same time as the stigma), e.g., ICMPES 45, to many days of protogyny (stigmas exposed to pollen, spores, etc), e.g., ICMH 451. ICMPES 28, and ICMPES 29 had a protogyny period of about 2 days. Susceptible varieties flowered earlier in the season (fewer number of days to flowering), which could coincide with the end of the rains and relatively low pollen availability, whereas those that were classified as resistant flowered 2-3 weeks later, with stigma emergence at a time of greater pollen availability and escaping some of the high humidity and rainfall (at Matopos). A correlation appeared to be present between a short protogyny period and escape from infection, as was found at ICRISAT-Patancheru. ICMPES 28 and ICMPES 29 had reasonably good agronomic adaptation at locations in Botswana, Malawi, Tanzania, Zambia, and Zimbabwe.

Smut. When tested in hot spot locations ICMPES 2, ICMPES 45, ICMSR 270, and ICMSR 284 had mean smut severities below 5% whereas susceptible controls had severities well over 42%.

False mildew. Resistance screening was effective at Muzarabani, Zimbabwe. Several late locals as well as some late introductions had low severities. 81B, 863B, 862B, and 852B (the latter is resistant to rust in India) had severities above 15%. 861B and ICMB 87001 had severities below 5%. Hybrids of resistant parents were resistant but not immune, e.g., ICMA 87001 x SDPC 40 and ICMA 87001 x SDPC 22. Therefore, it appears that resistance to false mildew can be bred for.

Insect pests

The most serious field pest of pearl millet in the region is the armored bush cricket. This pest causes massive crop losses in Namibia, Zambia, and Botswana. It has also been reported to be of potential importance in Zimbabwe and Tanzania. During phases II and III, SMIP devoted considerable resources to the understanding and control of this pest.

Biology of the armored cricket. Considerable information on the biology and ecology of the armored bush cricket was generated from studies conducted in Zambia (1988-1990) and Namibia (1993-95).

Cricket life cycle and pearl millet development. At the beginning of the rainy season in January, first-instar nymphs start to hatch from the egg pods. The rate of hatching is dependent on soil moisture. The top soil layer (15 cm deep) has to be moist for at least 3 days, 11-20 days after which hatching starts. This finding has to be verified, and could be used for forecasting hatching of cricket nymphs.

Hatching coincides with germination of pearl millet. After hatching the cricket develops over six nymphal stages before reaching the adult stage after about 70 days. Crickets can develop only on generative plant parts (flowers and grain), although they are able to maintain themselves for some time on leaves without further development. As long as pearl millet is in the vegetative growth stage cricket nymphs depend for food on the generative plant parts of grasses and broadleaf weeds.

The first damage on pearl millet appears only at flowering. The most serious damage will be caused by the nymph stages 4-6 and by adult crickets. Pearl millet is most sensitive to cricket damage during the milk stage (Fig. 5). Most serious damage can be expected when the milk stage coincides with cricket stages 5-7. Later, at grain maturity, pearl millet grain will be too hard for the mouthparts of the cricket and therefore less attractive to all cricket stages. At the end of the season the cricket lays its egg pods in the shaded soil of perennial trees and shrubs that do not shed leaves and at the base of pearl millet plants in the field. The eggs remain in diapause in the soil until embryonic development starts in October. Fully developed embryos remain in eggs until moisture conditions are right for hatching.

Yield loss caused by different cricket development stages. Daily losses of 5 kg potential grain harvest can be expected if an arbitrary population of 10 000 crickets ha^{-1} is taken into consideration. Comparatively, cricket stage 4 does not contribute much to the yield loss except

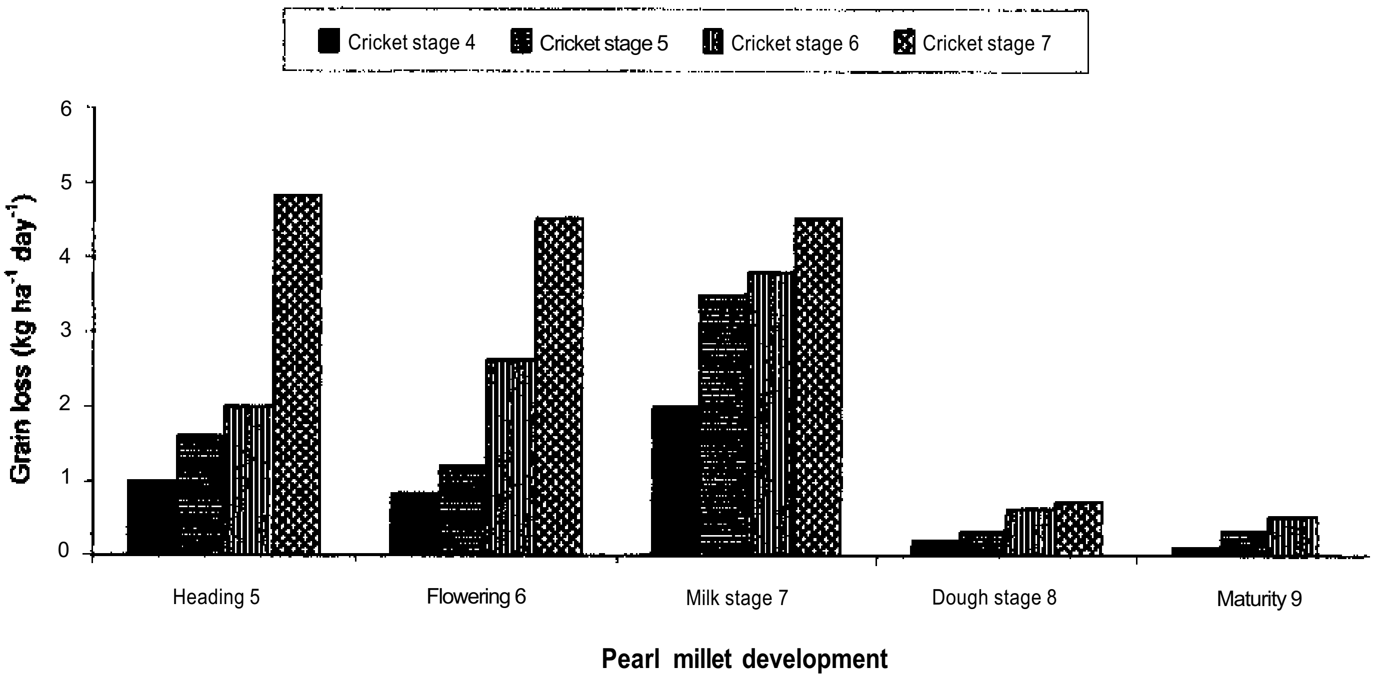


Figure 5. Grain damage, i.e., food intake (kg ha^{-1}) day^{-1}, by cricket stages 4-7 at pearl millet development stages 5-9 (Wohlleber 1996).

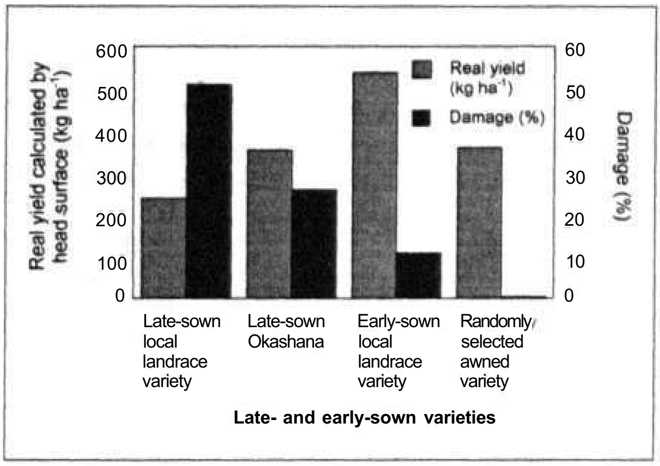


Figure 6. Yield loss in pearl millet caused by crickets for different sowing dates and varieties expressed in percentage and kg ha^{-1}.

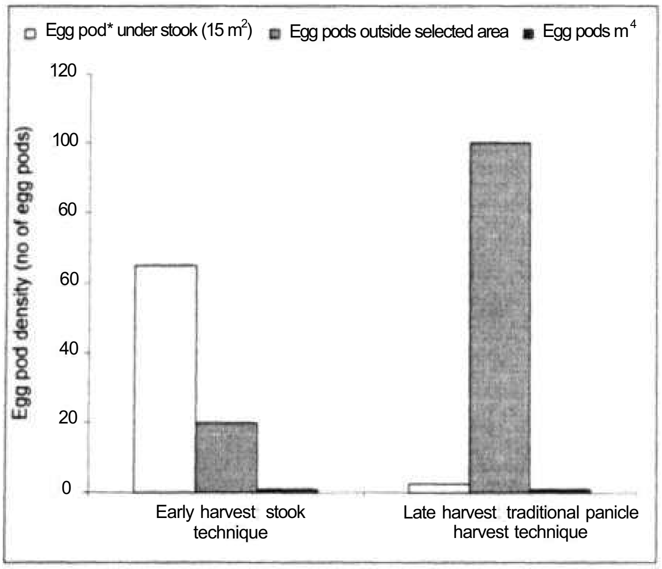


Figure 7. Number of egg pods found under stooks (15 m^2) and surrounding area (385 m^2) compared with egg pods found in a traditionally harvested area (15 m^2, selected) and the surrounding area (385 m^2) (Wohlleber 1996).

at the milk stage. Modest yield losses from physiological maturity onwards could be explained by difficulties experienced by crickets in cracking the grain (Fig. 5).

The results indicate that major grain damage could be avoided if the milk and soft dough grain development stages of pearl millet (Maiti and Bidinger 1981) do not coincide with the most voracious feeding stages of the cricket (Wohlleber 1996). This is possible to achieve if extra-early varieties are sown. The cricket feeds on wild grass outside the field borders and only gets into the millet fields if there is soft grain to feed on. If grain fill is faster than cricket development, as in the case with extra-early maturity varieties, then by the time the cricket is most damaging, the grain is too hard, and hence receives minimal damage.

Integrated pest management strategies. Options deriving from earlier studies have been tested and options for cricket control are now available. A proposed IPM system involves the following components:

- Record of rainfall data for predicting hatching of nymphs;
- Population monitoring using ground cages for trapping emerging nymphs and monitoring population density;
- Choice of variety (early/late maturing) depending on rainfall and sowing date;
- Weed management, especially around field borders;
- Baiting (maize/millet meal + insecticide + water);
- Hand-picking of crickets;
- Border treatment with insecticide;
- Digging of border ditch (labor-intensive activity);
- Early harvesting and possibly stocking; and
- Collection and destruction of egg pods.

To understand how yield losses are caused by crickets, the pest's life cycle and the damage potential of its different stages must be considered. If a 120-day variety is sown late, the sensitive pearl millet stages 5,6, and 7 will coincide with the older cricket stages that cause the most damage. If the same variety is sown at an earlier date, severe damage can be prevented through earlier maturing of the grain. The Okashana variety takes 90 days to maturity, an intermediate position because the time required for grain development to maturity is shorter (Wohlleber 1996).

The results indicate that if sowing dates are well managed and varieties are selected for their time to maturity, cricket damage can be avoided or reduced (Fig. 6). And initial data suggest there is some effect by awns, in the awned variety, that reduces cricket damage. This needs to be investigated further.

Change in harvest procedure

The reason why farmers leave their pearl millet crop in the field after grain maturity is to let the grain dry to a low moisture content suitable for storage. Such drying is also possible with early harvesting and the stooking of whole plants. So, as the stooks attract adult crickets for mating and oviposition, aggregated adults could be hand-collected from the stooks, and egg pods could be destroyed later in the season by digging them up.

The two methods of control described-early sowing in combination with early maturity and stooking after harvesting are promising components of a possible integrated pest management system (see Fig. 7). Other components are clean-weeding and control with bait.

Future directions

Significant progress was achieved in pearl millet improvement during the past 15 years of SMIP (see the achievements section). These gains need to be sustained in order to achieve impact in Angola, Mozambique, Botswana, and South Africa, where millet releases have yet to occur. We hope this will be achieved during Phase IV because all these countries have improved materials at different stages in the pipeline, from materials awaiting formal release in Mozambique and Botswana to materials in advanced national trials in Angola and South Africa.

The development of a strong regional scientific capability and the technical advances in the development and dissemination of improved pearl millet varieties provide a solid foundation for increasing farm level productivity and incomes. If the full potential of this foundation is to be realized and the ultimate goal of the program fulfilled the following crop improvement related issues still need to be addressed.

1. **Seed systems.** The existing seed systems are inadequate to produce and distribute required quantities and quality of seed of improved pearl millet varieties. This is **a** key constraint to the greater adoption of improved pearl millet varieties in participating SADC countries. This constraint will continue to slow the impact of the joint breeding activities if not tackled in **a** systematic manner. It is very important now to find partners and methods to address the issue of improving seed production and dissemination of improved cultivars.

2. **Stakeholder input in breeding.** Initially, farmers were not involved in selection of the plant and grain traits of the new varieties. Choices were made by SMIP and national program breeders. Fortunately, the emphasis on early maturity and drought tolerance, rather than primarily on maximmizing yields, has paid off in terms of varieties that perform well and are acceptable to farmers. However, greater input by fanners and the commercial sector in setting priorities for the next generation of improved varieties is now seen as vital to the continued success of the program.

3. **Commercialization.** At present, less than 2% of pearl millet production in the region enters the commercial market. Although commercial demand for pearl millet is limited, southern African countries, especially Namibia, would like pearl millet flour to be available on the shelf in supermarkets for urban consumers. This is the needed stimulant for increasing productivity through use of improved seed and improved farming practices. However, pearl millet has a problem that must first be addressed before it is possible to mill and put on the supermarket shelf. Once the grain is decorticated and ground into flour, the quality of the resulting meal deteriorates rapidly, often developing a unique acidic odor within a few hours. Investigation of this objectionable odor indicates that it does not result from classical oxidative changes in lipids but rather is a result of enzymatic activity (Hoseney et al. 1992). Ultraviolet scans of this water-soluble compound indicated that it is related to C-glycosylflavone present in pearl millet. Identification of this relationship is a major breakthrough and paves the way to the development of genotypes with low levels of this odor-generating compound. Further research into this area is necessary if pearl millet is to be a viable commercial commodity.

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Sorghum and Pearl Millet Production, Trade, and Consumption in Southern Africa

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Abstract

A review of regional production and trade data for sorghum and pearl millet in southern Africa reveals that while these crops remain important in the production system, they are being slowly replaced by maize and wheat in the average diet. The area sown to sorghum and pearl millet is still increasing in most SADC countries. Contrary to popular opinion, there is little evidence that these crops are being replaced by maize in the semi-arid farming system, at least since 1980. However, the production growth derived from rising crop areas has been largely offset by declining grain yields. Productivity levels remain so low that sorghum and pearl millet have difficulty competing in national and regional grain markets. One result is that, except in South Africa, sorghum and pearl millet remain largely semisubsistence crop enterprises. In addition, low sorghum and pearl millet yields have contributed to SADC's growing dependence on maize and wheat imports. The prospects for expanding sorghum and pearl millet production in the SADC region are briefly considered.

Introduction

Sorghum (*Sorghum hicolor* (L.) Moench) and pearl millet (*Pennisetum glaucum* (L.) R. Br.) account for 15% of cereal grain area and 9% of cereal grain production in the Southern African Development Community (SADC) region of southern Africa. The dominant grain is maize (*Zea mays* L.), accounting for 70% of cereal grain area. The remaining area is largely made up of wheat (*Tritium aestivum* L.) and rice (*Oryza sativa* L.). In much of the region, maize competes directly with sorghum and pearl millet in the cropping system. Farmers will commonly grow sorghum or pearl millet in addition to maize. If rains are favorable, maize offers higher yields. If rains are poor, sorghum or pearl millet assures at least a minimum quantity of food production necessary to avoid starvation. As rainfall levels decline and become more variable, the proportion of sorghum or pearl millet in the cropping systems rises.

Sorghum and pearl millet must also compete with maize in the regional market. Since maize is the dominant cereal grain, the supply and demand for this commodity largely determine trading prices. Sorghum and pearl millet have difficulty competing on the industrial market because of their relatively low and variable productivity. Also, industry in many countries is unaccustomed to the use of these inputs. In the rural market, industrially processed maize is sometimes cheaper than locally produced sorghum or pearl millet.

To become competitive, the productivity of sorghum and pearl millet must improve. Limited gains may be derived from improved varieties. Larger gains must be derived from improvements in soil and water management. But investments in improved management need to offer competitive returns with alternative uses of farm capital and labor. If productivity fails to improve, southern Africa appears likely to become increasingly dependent on maize and wheat imports.

Sorghum and pearl millet area

Farmers in southern Africa sow over 1.9 million ha of sorghum and approximately 0.9 million ha of pearl millet [Table 1; the production and trade data used in this paper are derived from the Food and Agriculture Organization of the United Nations (FAO) 1998 unless otherwise indicated]. However, the accuracy of estimates of pearl millet area is lower than those for sorghum because national databases tend not to differentiate between alternative types of millet. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) estimates that about 70% of the millet area reported by FAO in southern Africa is sown to pearl millet (ICRISAT and FAO 1996). Virtually all of the remainder is sown to finger millet. In comparison, maize, the dominant cereal grain throughout most of the region, is grown on almost 12 million ha. Wheat and rice are grown on about 3.5 million ha, while finger millet is sown on about 0.4 million ha.

Tanzania accounts for about 35% of SADC's sorghum area (Table 1). Mozambique, Zimbabwe, South Africa, and Botswana are also significant producers.

Table 1. Sorghum and pearl millet production areas in SADC countries, 1995-97 averages.

Country	Sorghum		Pearl millet	
	Area ('000 ha)	SADC area (%)	Area ('000 ha)	SADC area (%)
Angola	82.6	4.2	66.1	6.8
Botswana	150.0	7.7	9.3	1.0
Congo	80.0	4.1	42.0	4.3
Lesotho	17.7	0.9	0.0	0.0
Malawi	74.7	3.8	13.8	1.4
Mauritius	0.0	0.0	0.0	0.0
Mozambique	439.8	22.5	69.9	7.2
Namibia	34.6	1.8	269.8	27.7
South Africa	172.5	8.8	21.0	2.2
Swaziland	2.0	0.1	0.0	0.0
Tanzania	683.2	34.9	263.3	27.1
Zambia	44.4	2.3	30.8	3.2
Zimbabwe	174.9	8.9	186.7	19.2
SADC total	1956.5	100	906.7	100

Source: FAO 1998.

Table 2. Sorghum, pearl millet, and maize area as a proportion of total cereal grains area in SADC countries, 1995-97 averages.

Country	Total cereal grains area ('000 ha)	Sorghum (%)	Pearl millet (%)	Maize (%)
Angola	789.4	10.5	8.4	75.6
Botswana	178.2	84.2	5.2	10.3
Congo	2086.1	3.8	2.0	64.6
Lesotho	147.5	12.0	0.0	56.5
Malawi	1390.5	5.4	1.0	90.4
Mauritius	0.2	0.0	0.0	100.0
Mozambique	1756.2	25.0	4.0	61.5
Namibia	335.9	10.3	80.3	9.4
South Africa	6177.0	2.8	0.3	60.7
Swaziland	62.8	3.2	0.0	96.2
Tanzania	3194.5	21.4	8.2	50.2
Zambia	748.1	5.9	4.1	80.0
Zimbabwe	2025.5	8.6	9.2	75.4
SADC total	18887.5	10.4	4.8	63.3

Source: FAO 1998.

Table 3. Growth rates in area sown to to sorghum, millet, and maize in SADC countries, 1980-1997.

Country	Sorghum (%year^{-1})	Millet (% year^{-1})	Maize (% year^{-1})
Angola	na[1]	5.2	1.0
Botswana	4.3	0.3	-0.2
Congo	5.9	4.0	4.2
Lesotho	-7.4	-	-2.2
Malawi	6.0	5.4	1.1
Mauritius	-	-	-6.5
Mozambique	1.9	9.7	2.1
Namibia	1.1	3.9	2.4
South Africa	-1.6	-0.3	-0.6
Swaziland	-1.8	-	-0.3
Tanzania	1.5	0.5	1.5
Zambia	5.0	9.6	1.5
Zimbabwe	-1.7	-4.2	0.4
SADC total	1.0	2.1	0.8

1. na = not available.
Source: FAO 1998.

The remaining eight SADC countries account for less than 20% SADC's sorghum area.

Namibia and Tanzania each account for about 27% of SADC's pearl millet area (Table 1). The area of land sown to this crop has been increasing in Namibia, but has changed little in Tanzania over the past 10 years. Zimbabwe sows almost one-fifth of the region's pearl millet area. The remaining 10 SADC countries account for only 27% of the total. Three of these countries, Lesotho, Swaziland, and Mauritius, produce no millet.

The importance of sorghum and pearl millet within each country can be measured in tenns of the proportion of total cereal grain area sown to each crop (Table 2). Sorghum accounts for the majority (84%) of cereal grain area only in Botswana. Sorghum accounts for 25% of cereal grain area in Mozambique and 21% in Tanzania. In all other counties the crop accounts for less than 15% of cereal grains area.

Pearl millet provides a major source of livelihood only in one country, Namibia, where it accounts for 81% of cereal grains area. The crop accounts for almost 10% of grains area in Tanzania, Zimbabwe, and Angola. Elsewhere, this crop is of relatively minor importance.

Though sorghum and pearl millet are not major components of the cropping systems of most SADC countries, these grains are critically important for the food security of many small-scale farmers. Sorghum and pearl millet are generally grown in some of the poorest and most drought prone agricultural regions of each SADC country. These tend to be isolated regions, distant from capital cities and major grain markets. They also tend to be regions attracting larger investments in public food distribution during periods of drought.

SADC's sorghum area has been increasing, since 1980, at an average annual rate of 1% (Table 3). Area growth has been recorded in all SADC countries growing sorghum except Lesotho, Swaziland, South Africa, and Zimbabwe. In general, area gains reflect the continuing growth of rural populations. Larger gains in Botswana reflect the impact of government efforts to promote expanded production with subsidies on land clearing and preparation. The gains in Malawi and Zambia reflect a shift from maize toward the production of more drought-tolerant crops.

SADC's millet area has also been increasing since 1980, at an average annual rate of 2%. (We are unable to differentiate the growth rates of pearl millet and finger millet.) Millet area is recorded by FAO databases to be increasing in every millet growing country except Zimbabwe and South Africa. As in the case of sorghum, these gains reflect the combined effects of drought and population growth.

The common view that maize has been replacing sorghum and pearl millet during the past two decades is incorrect. Regional maize area has, in fact, been growing at a slower rate than the area growth of sorghum and pearl millet, Maize remains an important crop in many semi-arid areas. However, periodic droughts have reinforced sowings of the more drought-tolerant coarse grains.

Unexpectedly, the growth rate in coarse grains area as a whole is less than one-half the average 3.0% annual population growth rate in SADC. This reflects the relatively slower rates of farm population growth due to population movements from rural to urban areas. The limited area gains also reflect rising land constraints. Future increases in production will need to be derived primarily from improving yields.

Sorghum and pearl millet yields

Sorghum yields are low by global standards in all SADC countries except South Africa. Sorghum yields across the SADC region averaged only 0.8 t ha^{-1} during the 1995-97 period (Table 4). This compares with a average global sorghum yield of 1.4 t ha^{-1}. Grain yields in the more commercialized South African production system averaged 2.1 t ha^{-1}. The grain yields achieved in the remaining SADC countries averaged only 0.7 t ha^{-1}. No SADC country, other than South Africa, registered sorghum yields greater than 1.0 t ha^{-1}. In Botswana, where sorghum dominates the cropping system, sorghum yields averaged only 0.2 t ha^{-1}.

Pearl millet yields average even less than those of sorghum. In the SADC region as a whole, millet yields averaged only 0.6 t ha^{-1} over the 1995-97 period. (Again, the FAO data do not differentiate between pearl millet and finger millet yields.) Tanzania achieved an average millet grain yield 1.0 t ha^{-1}. In contrast, Namibia, which relies on pearl millet as the main national crop enterprise, achieved grain yields averaging only 0.2 t ha^{-1}. Zimbabwe's yields average only 0.3 t ha^{-1}.

While we would expect the grain yields of sorghum and pearl millet to be lower than those for maize, given the production of these crops in drier agroecologies, the magnitude of the difference provides the main justification for the dominance of maize in the southern African cropping system. Across the SADC region as a whole, maize yields an average 1.5 t ha^{-1}, more than double the average level of sorghum and pearl millet yields. In semi-arid agroecologies, where sorghum and pearl millet are most important, farmers still commonly sow maize in the expectation of a favorable harvest if rainfall is consistent through the season. In southern Zimbabwe, for example, farmers reason that if rainfall is favorable, maize will yield more than sorghum or pearl millet. If rainfall is poor, the maize may fail. But these risks are offset by the availability of drought relief, and alternative sources of income (Hedden-Dunkhorst 1993).

Table 4. Average grain yields for sorghum, millet, and maize in SADC countries, 1995-97.

Country	Sorghum (t ha^{-1})	Millet (t ha^{-1})	Maize (t ha^{-1})
Angola	n.a.	0.5	0.5
Botswana	0.2	0.3	0.6
Congo	0.6	0.6	0.8
Lesotho	1.0	-	1.4
Malawi	0.7	0.6	1.4
Mauritius	-	-	2.6
Mozambique	0.5	0.4	0.9
Namibia	0.2	0.2	0.8
South Africa	2.1	0.6	2.1
Swaziland	0.7	-	1.7
Tanzania	0.9	1.0	1.4
Zambia	0.5	0.3	1.7
Zimbabwe	0.5	0.6	1.2
SADC total	0.8	0.6	1.5

Source: FAO 1998.

Table 5. Growth rates in grain yields of sorghum, millet, and maize in SADC countries, 1980-1997.

Country	Sorghum (%year^{-1})	Millet (% year^{-1})	Maize (% year^{-1})
Angola	n.a.	-3.1	-0.7
Botswana	3.3	5.1	2.3
Congo	-2.6	-0.9	-0.1
Lesotho	2.2	-	3.3
Malawi	-1.1	1.0	0.2
Mauritius	-	-	0.3
Mozambique	-2.8	3.6	2.3
Namibia	-1.0	-1.4	-2.6
South Africa	-0.7	-0.9	0.3
Swaziland	-0.7	-	1.1
Tanzania	-0.3	-1.6	0.3
Zambia	-0.2	0.6	-1.0
Zimbabwe	0.9	-4.2	-0.9
SADC total	-1.0	-1.8	-0.2

Source: FAO 1998.

Over the 1980-1997 period, SADC's average yields of all three major coarse grain crops have been declining. Pearl millet yields were declining at an average annual rate of 1.8% per year (Table 5). Sorghum yields were declining at an average annual rate of 1.0% per year. Maize yields declined at an average annual rate of 0.2%. The justification for these losses cannot simply be attributed to poor rainfall. Estimates derived from FAO databases in the early 1990s indicate farmers in southern Africa use less than 27 kg of chemical fertilizer per hectare (Heisey and Mwangi 1996). Virtually none of this fertilizer is applied to sorghum and pearl millet, except in the commercialized sorghum sector of South Africa. As a result, soils are being mined of nutrients.

A growing array of experimental evidence highlights the magnitude of the gap between the average grain yields small-scale fanners are achieving, and the yields obtainable with even small improvements in crop management. Table 6 summarizes a few of these comparisons. In most cases, trial yields for 'local' varieties average more than twice the level of average grain yields on the fields of neighboring farmers. This gap is apparent even when variety trials are implemented in the fields of small-scale farmers and under the management of these producers. When seed varieties are changed, farmers may be able to obtain 0-25% yield gains depending on the cultivars involved and the character of the season (Rohrbach and Makwaje, in press; Rohrbach, in press). In severe drought years, the early maturity offered by recently released sorghum and pearl millet varieties may offer up to a 50% yield advantage. However, most of the yield gap apparent in experiment station and on-farm trials data is the result of differences in crop management.

Sorghum and pearl millet production

The distribution of sorghum and pearl millet production roughly matches the distribution of area sown. The SADC region as a whole produces about 1.5 million t of sorghum and an estimated 0.5 million t of pearl millet (Table 7; this estimate, derived from the aggregate FAO millet database, assumes the average yields of pearl millet and finger millet are similar). This compares with an production level of 17.7 million t of maize over the 1995-97 period. Given its higher average yields, Tanzania accounts for 42% of the region's sorghum production. South Africa accounts for 23% and Mozambique accounts for 15% of the SADC region's sorghum production.

Tanzania accounts for one-half of SADC's pearl millet production. Though Namibia grows about the same area of land to this crop, this country only produces 13% of the region's pearl millet production due to its low grain yields. Zimbabwe accounts for 11% of the region's pearl millet production.

The growth in SADC's area sown to sorghum and pearl millet has offset the decline in average grain yields over the 1980-1997 period. As a result, the region's sorghum production levels have remained essentially unchanged. Pearl millet production is marginally increasing at a rate of 0.3% per year. However, on a per

Table 6. Cap between trial yields and average farm yields for sorghum and pearl millet.

Country	Type and period of trials	Trial yields of local varieties ($t\ ha^{-1}$)	Average national grain yield ($t\ ha^{-1}$)	Yield gap ($t\ ha^{-1}$)
Botswana[1]	Sorghum on station (1993-95)	1.6	0.3	1.3
	Sorghum on farm (1993-96)	0.5	0.3	0.2
Malawi[2]	Sorghum on station (1984-87)	1.4	0.6	0.8
	Pearl millet on farm (1994)	0.9	0.4	0.5
Namibia[3]	Pearl millet on farm (1993)	1.4	0.2	1.2
Zimbabwe[4]	Sorghum on farm (1993)	1.8	0.7	1.1
	Pearl millet on farm (1993)	1.3	0.4	0.9

1. Source: Rohrbach and Makwaje, in press.
2. Source: Chintu and Chigwe undated, Chintu and Monyo undated.
3. Source: Matanyaire and Gupta 1996.
4. Source: Heinrich and Mangombe 1995.

Table 7. Sorghum and pearl millet production in SADC countries, 1995-97 averages[1].

Country	Sorghum Production ('000 t)	Sorghum SADC production (%)	Pearl millet[1] Production ('000 t)	Pearl millet[1] SADC production (%)
Angola	37.5	2.4	30.0	5.8
Botswana	36.7	2.4	2.7	0.5
Congo	50.0	3.2	25.8	5.0
Lesotho	16.8	1.1	0.0	0.0
Malawi	53.2	3.4	7.8	1.5
Mauritius	0.0	0.0	0.0	0.0
Mozambique	235.5	15.1	30.4	5.9
Namibia	7.3	0.5	66.9	13.0
South Africa	356.9	22.9	13.0	2.5
Swaziland	1.5	0.1	0.0	0.0
Tanzania	648.6	41.7	255.7	49.7
Zambia	31.0	2.0	22.7	4.4
Zimbabwe	80.7	5.2	59.4	11.5
SADC total	1555.6	100	514.5	100

1. Production estimates for pearl millet are derived from FAO estimates for all millets and joint FAO and ICRISAT estimates of proportion of area sown to pearl millet.
Source: FAO 1998.

capita basis, the availability of both crops is declining by more than 2.5% per year. In effect, food security in the region's semi-arid regions is worsening. Declining production levels must be offset by increasing reliance on food grain imports.

The contribution of sorghum and pearl millet to SADC cereals production has also remained roughly constant since 1980. Sorghum accounts for about 6% of SADC cereal grain production and pearl millet accounts for only 2%. The relative contribution of maize to SADC cereal production is slowly increasing at about 0.6% per year, because declining maize yields are more than offset by rising area sown.

Sorghum and pearl millet trade

In all countries except South Africa, most of the sorghum and pearl millet being harvested is consumed on the farm. SADC/ICRISAT SMIP sponsored surveys (Hedden-Dunkhorst 1993; Rohrbach 1995; Minde and Mbiha 1993) indicate that little grain enters the market, and most of these transactions involve sales between neighboring households. In the rural market, sorghum is commonly priced about the same as maize. Pearl millet is commonly priced 10-30% more than maize.

Commercial market deliveries of sorghum and pearl millet are estimated to average less than 10 000 t in all SADC countries except Zimbabwe and South Africa. In Zimbabwe, the opaque beer industry purchases approximately 15 0001 of sorghum per year for malting. However, most of this is derived from large-scale farmers. In South Africa, 1995 estimates indicate industry purchases of about 300 000 t for use in animal feed (41%), opaque beer brewing (43%), and the manufacture of a range of other food products. Most of this is purchased from about 600 large-scale commercial fanners.

Botswana has a growing sorghum-based milling industry manufacturing sorghum meal for the retail market. Small-scale millers purchased around 30 000 t of sorghum grain in 1997 (Rohrbach and Makwaje, in press). However, at least three-quarters of this was based on sorghum imports, largely from South Africa. Smaller quantities of sorghum grain were imported from commercial farmers in Zambia and from small-scale farmers in Zimbabwe.

The magnitude of regional sorghum and pearl millet trade has been minuscule compared with trade in maize and wheat during the mid-1990s. Sorghum and pearl millet account for roughly 2% of the total volume of grain traded in the SADC region and only 1% of the

Table 8. Net imports ('000 t) of alternative cereal grains in SADC countries, 1994-96 averages.

Country	Sorghum	Millet	Maize	Wheat
Angola	0.4	0.3	193.0	242.1
Botswana	37.5	0.0	50.6	63.2
Congo	14.7	0.0	47.7	228.2
Lesotho	5.4	0.0	99.6	76.3
Malawi	6.7	0.0	294.3	60.0
Mauritius	0.0	0.1	49.0	102.2
Mozambique	1.4	0.8	227.9	227.4
Namibia	0.0	0.0	38.0	35.8
South Africa	-23.1	0.6	-1400.6	786.7
Swaziland	0.0	0.0	20.1	50.1
Tanzania	0.0	0.0	62.5	0.0
Zambia	13.3	0.0	60.2	40.8
Zimbabwe	-2.4	-0.9	-557.4	74.8
SADC total	53.9	0.9	-815.1	1987.5

Source: FAO 1998.

total value of grain traded (Table 8). Seven of the 12 SADC sorghum producers registered net sorghum imports between 1994 and 1996, though all but one country imported less than 15 000 t. Botswana imported almost 40 000 t of sorghum due to the country's domestic production shortfall.

The FAO statistics indicate very small net imports of pearl millet in six SADC countries during the mid-1990s. These averaged less than 500 t. Zimbabwe annually exported an average 900 t of pearl millet. Much of this was pearl millet seed for Mozambique and South Africa.

In comparison, all SADC countries had large trade volumes of maize and wheat. During the 1994-96 period, Zimbabwe and South Africa were net maize exporters. Each of the remaining 11 SADC countries were net importers of maize. All SADC countries, except Tanzania, were net importers of wheat.

The SADC region as a whole spent over US$280 million per year on maize and wheat imports over the 1994-96 period. This does not include the value of trade within the region. If South Africa is excluded, regional grain import costs totaled US$ 440 million per year. The import bill is increased by the high costs of transporting grain across much of the region. National import costs for wheat, the most significant regional commodity import, commonly average more than US$ 200 per t. Import prices for maize are commonly over US$ 175 per t.

The combination of declining aggregate cereal grain production and rising population levels have contributed to a rising dependence on grain imports. During the early 1980s, SADC exported an average 3.2 million t of maize per year. A decade later, the SADC region had become a net maize importer. During this same period, SADC's wheat imports more than doubled. Six of the 13 SADC countries now import at least 30 kg of maize or wheat per person. This is about 20% of the average calorie supply for a country primarily dependent on grains.

Sorghum and pearl millet utilization

In the SADC region as a whole, sorghum consumption has remained constant as a proportion of total coarse grain (maize, sorghum and pearl millet) consumption for food. Sorghum accounts for about 7% of the region's coarse grain calories. Pearl millet consumption has marginally declined from supplying about 3.5% of the region's coarse grain calories during the early 1980s to about 3.0% in the mid-1990s. Maize consumption has marginally increased. Wheat and rice consumption are rising more quickly.

Given the limited regional trade in sorghum and pearl millet, consumption levels for these crops closely reflect the levels of production. If production rises, consumption increases. If production falls, sorghum and pearl millet calories are replaced with those from maize and wheat. Since sorghum production levels have remained relatively steady in most SADC countries, aggregate consumption levels have not changed much. The major exception is Lesotho, where the contribution of sorghum to coarse grain calories declined by 50% between the early 1980s and the mid-1990s.

The declining regional contributions of pearl millet to SADC diets reflects the decline in production in two major producers—Tanzania and Zimbabwe. In a number of other countries, pearl millet consumption is marginally increasing as a result of the expansion of land area sown to this crop.

While more than 90% of SADC's sorghum and pearl millet production are consumed directly for food, increasing quantities are used for livestock feed. The feed industry as a whole absorbs approximately 4 million t of grain per year. However, almost all of this is maize. Sorghum and pearl millet account for less than 4% of the region's grain allocations to feed.

South Africa has the largest feed grain industry in the region. This industry accounts for 80% of SADC's feed grain utilization. Yet even here, where sorghum production is highly commercialized, this grain only accounts for only 3% of the total quantity of feed grains consumed. Most of the remainder is maize.

Sorghum accounts for about 20% of estimated feed grain utilization in Mozambique and 10% in Tanzania, but the total quantities of cereals being used for livestock feed in these countries are low.

The prospects for expanding industrial utilization are weakened by the continuing low productivity of these crops. Sorghum and pearl millet must ultimately compete with maize in terms of quality, consistency of supply and price. In industries where substitution is limited, such as opaque beer, demand may increase despite high grain costs. However, if substitution with maize is possible, industry will generally choose the cheaper input To date, this has generally been maize.

Future trends

The SADC sorghum and pearl millet sector has changed little over the past 15 years. In regional production systems, these crops are neither increasing nor decreasing in importance. However, declining per capita production levels have necessitated a growing dependence on cereal grain imports. A growing share of these imports is made up of wheat.

If sorghum and pearl millet are to have a future in the SADC food and feed system, current trends in declining grain yields must be reversed. These simply reinforce the competitive disadvantage of these crops. Pearl millet yields are already so low in northern Namibia that it is cheaper for consumers to purchase imported maize (Rohrbach 1995). Sorghum yields remain so low in Botswana that the domestic sorghum milling industry relies on sorghum imports from South Africa. Within a few years, wheat appears likely to overtake sorghum as the second most important source of cereal calories in this country. Maize has already become more important than sorghum (Rohrbach and Makwaje, in press). In Zimbabwe, most sorghum and pearl millet farmers have long resolved their food production deficits with industrially processed maize meal (Hedden-Dunkhorst 1993).

The prospects for a reversal of these trends are mediocre. Productivity gains will not be derived simply from changing in varieties. Larger yield gains require associated improvements in soil and water management. These investments are risky in the semi-arid environment. The investment returns must compete with the returns to alternative investment opportunities, including the migration of labor to urban, wage employment.

The best prospects for promoting investments in improved crop management probably lie in expanding production and trade for the industrial market. Sorghum is globally competitive with maize and wheat as a feed grain. Small gains in productivity, or marketing efficiency, could sharply increase the quantities of grain used by the SADC feed industry. Pearl millet and sorghum will retain a niche as industrially processed food grains, though the size of this market is difficult to estimate. If the costs of these grains remain relatively high, this market is unlikely to grow.

The largest and most immediate prospect for expanding utilization is in resolving continuing production deficits on the farm. Opportunities for improving the level and stability of semi-subsistence production should not be ignored. However, the long term future of these crops depends on the success of their commercialization.

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Socioeconomics in SMIP: Research Highlights, Impacts, and Implications

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Abstract

Economics research under the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP) has targeted an evolving diagnosis of the main constraints to improving productivity in the sorghum and pearl millet based cropping systems of southern Africa. The research began by examining whether product market constraints limited the incentives to produce sorghum and pearl millet. These investigations considered policy, institutional, and technological factors influencing industry demand for these crops. The results provided analytical input into national debates about grain market liberalization. Since more than 95% of sorghum and pearl millet trade was in the rural market, SMIP's analyses evolved to consider opportunities for improving grain flows from surplus to deficit rural regions.

Most market analyses indicated the importance of productivity growth in order for sorghum and pearl millet to become competitive with maize. Such analyses encouraged the allocation of greater resources in the third phase of the SMIP project toward technology transfer—in particular, the dissemination of new varieties developed during the previous project phases. Complementary analyses were initiated on seed market policies, and alternative strategies for seed multiplication and distribution. Results from these studies are contributing to the search for more sustainable methods of seed supply for open-pollinated varieties.

SMIP-supported assessments of the impacts of variety adoption offered mixed evidence of productivity gains. The yield gaps between on-station and on-farm trials and farmers' fields remain large. These analyses encouraged greater emphasis on the development of complementary, yet practical, fertility management options suited to the investment capabilities of small-scale farmers.

This review of some of the major products of SMIP's economics research highlights the difficulties of technological change and productivity improvement in the semi-arid cropping system. This has set the basis for the emphasis of the fourth phase of the SMIP project on developing more sustainable seed delivery systems, facilitating improvements in sorghum and pearl millet management, and exploiting market opportunities where these crops are most competitive. Priorities for economic analysis during this coming phase of the project are briefly summarized.

Economics research mandate

In 1988, an economist was hired under the Southern African Development Community (SADC)/International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sorghum and Millet Improvement Program (SMIP) to conduct studies of sorghum (*Sorghum hicolor* (L.) Moench) and millet marketing and utilization. SMIP hypothesized that the main constraint to the adoption of improved sorghum and millet technologies was the lack of demand for these crops. The evidence of mounting sorghum and pearl millet (*Pennisetum glaucum* (L.) R. Br.)

stocks held by Zimbabwe's Grain Marketing Board was used to justify this claim. The primary mandate of the economist was correspondingly to diagnose marketing and associated policy constraints to industry use of sorghum and pearl millet. These analyses were to complement the efforts of a food technologist hired to develop alternative sorghum and pearl millet based food products.

Preliminary analyses of national food and feed markets highlighted high sorghum and pearl millet prices as the main factor limiting industrial demand—maize (*Zea mays* L.) grain was generally cheaper and more consistently available on national markets. Improvements in productivity were viewed necessary to increase the competitiveness of these crops. Correspondingly, the focus of economics research during SMIP Phase 111 shifted toward impact assessment and the evaluation of constraints to technology transfer. Particular emphasis was placed on diagnosing constraints to seed distribution and adoption of new sorghum and pearl millet varieties. Variety adoption rates and impacts were evaluated in countries where these new varieties had been grown for several years.

However, early analyses of impact revealed that only limited productivity gains would be achieved from the introduction of new varieties. These also highlighted the gap between yields being achieved on experiment stations and in on-farm trials, compared with those achieved by small-scale farmers in their own fields. SMIP's initial efforts were correspondingly directed toward diagnosing constraints to investments in improved crop management practices—fertility management in particular.

This evolving research agenda was matched by efforts to improve the research capacity of economists in the region. Early training programs targeted policy analysis. Later ones targeted the strengthening of skills in crop management modeling. SM1P funding for postgraduate degree training was complemented by the pursuit of collaborative research and data analysis with young scientists throughout the SADC region.

Grain market research

SMIP-sponsored analyses of grain market policies and performance sought first to assess opportunities for expanding industrial demand for sorghum and pearl millet. One objective was to advise governments on options for improving the competitive position of sorghum and millet through market-related institutional and policy reforms. Some of these results provided input into ongoing national discussions about grain market liberalization.

As market policy reforms were implemented, the research focus shifted toward analysis of the competitive position of sorghum and millet in the rural grain market. This included consideration of the impact of grain dehullers on incentives to produce these crops.

Collaborative studies on grain marketing and competitiveness were conducted in Botswana, Lesotho, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe.

Evaluating industry demand

Zimbabwe. Early research examined the potential demand for sorghum and pearl millet by the national food and feed industry (Rohrbach and Mbwanda 1989). This revealed that the apparent surplus of sorghum and pearl millet on the national market was largely a result of unfavorable product pricing. The national Grain Marketing Board selling price for sorghum and pearl millet was higher than the selling price for maize. In consequence, only the opaque brewing industry purchased sorghum, and these purchases were limited to the 15 000 t per year necessary to make beer malt. The remainder of the food and feed industry used maize, the cheaper grain. The companies interviewed indicated that sorghum prices would have to drop 10-50% below the price of maize before they would buy any significant quantities. This and related analyses were used in discussions about grain market liberalization with the United States Agency for International Development (USAID) and the Government of Zimbabwe. Partly as a result of these discussions, Zimbabwe started its grain market reforms by liberalizing the trading of sorghum and pearl millet.

Zambia. SMIP's economist organized a related study, under the auspices of Zambia's National Commission for Development Planning, to evaluate opportunities for expanding industrial use of sorghum and pearl millet. This objective was viewed as a means to encourage diversification of the nation's agricultural economy and reduce grain imports. The analysis highlighted the opportunity to use 15 000 t of sorghum in the national baking industry as a partial (15%) replacement for wheat flour (Ministry of Finance and National Commission for Development Planning 1989; Rohrbach and Mwila 1989). The study also identified the opportunity for using up to 88 000 t of sorghum in the brewing industry, and 55 000 t of sorghum or pearl millet in the livestock feed industry. The main constraints to industrial use of sorghum and pearl millet were high subsidies on maize marketing and wheat imports. Recommendations were provided for reducing these subsidies and promoting the processing and marketing of sorghum and pearl millet. The report encouraged liberalization of grain trading.

Botswana. SMIP's economist also contributed an analysis of the market demand for sorghum in Botswana (Rohrbach 1988) in the context of a USAID-funded Agricultural Sector Assessment. The analysis highlighted the growing importance of maize imports in this sorghum-based economy, and recommended policy options for improving the competitiveness of sorghum in the domestic food processing industry. These included the need to maintain import parity pricing for all major grains, and to reduce parastatal marketing costs. The report advised the Botswana government to lift restrictions on sorghum imports in order to encourage use of this grain in the milling industry. Botswana's grain market has now essentially been liberalized, though the Botswana Agricultural Marketing Board (BAMB) remains a high-cost operation. The small-scale milling industry has sharply grown during the past few years, largely on the basis of sorghum imports. The low productivity of domestic sorghum production remains a problem. Average sorghum yields in Botswana are only 10-20% of those achieved in neighboring South Africa.

Tanzania. SMIP's economist developed a collaborative project with the Sokoine University of Agriculture, examining the prospects for expanding the marketing and utilization of sorghum, pearl millet, and finger millet in Tanzania. The research highlighted the fact that less than 1% of the national harvest flows into the commercial market. Approximately 5000 t per year of red sorghum is used by the opaque brewing industry. Only around 1000 t per year is used by the livestock feed industry. Once again, the main constraint to the expansion of industrial utilization was the high grain price, itself due to low productivity and high marketing costs. While the liberalization of national grain markets during the late 1980s increased the number of traders and grain transporters serving the sorghum- and millet-growing areas, most transactions remained small. The research culminated in a national conference on sorghum and millet utilization (Minde and Rohrbach 1993) and the establishment of a national committee of research, extension, and industry representatives to liaise on subsector development.

Swaziland. A sorghum subsector reconnaissance was conducted in 1990 with representatives of the Research Division of the Swaziland Ministry of Agriculture (Rohrbach and Malaza 1993). This reviewed production and market trends and discussed the competitive position of sorghum with farmers and representatives of the milling and livestock feed industries. The analysis highlighted the fact that only 1500 ha of sorghum is now grown in Swaziland. This is unlikely to increase without significant improvements in the productivity of the crop relative to maize. The analysis indicated that the best prospect for promoting sorghum use is to improve the productivity of higher-tannin red sorghum for brewing. This analysis encouraged the thesis research of M Malaza on "The displacement of sorghum as a major staple food crop in Swaziland."

Namibia. SMIP worked with Namibia's Directorate of Planning, Pricing, Marketing and Cooperatives to analyze the competitive position of pearl millet. Prospects for the commercialization of pearl millet were also assessed during the study (Keyler 1995b). The analysis highlighted two main constraints to expanding the production and sale of pearl millet flour. First, pearl millet yields are extremely low—generally less than 300 kg ha^{-1} on average. Low and variable rainfall limits productivity growth, and causes high variability in production levels. Second, maize can be readily imported at competitive prices. In effect, the price of imported maize sets a floor under the pearl millet market. The preferred local grain generally sells for a 20-45% price premium over maize, depending on the levels of government purchases and local stocks. As a result, households facing a grain supply and income constraint purchase the cheaper imported maize. The study again concludes that the competitiveness of pearl millet on the domestic market can be improved primarily by increasing productivity (Rohrbach 1995a). This increase will have to be derived from improvements in water-use efficiency and soil fertility. Yet investments in new technology will have to be competitive with the returns to investments in livestock production, or the pursuit of off-farm employment.

Rural markets

Recognizing that more than 95% of sorghum and pearl millet in the SADC region never reaches the commercial market, several of these analyses of grain demand were extended to include assessments of grain flows through rural markets. These include the trade of grain between neighboring farm households and between rural communities. This analysis was particularly concerned with the fact that most sorghum and pearl millet farmers are net grain buyers in most years. Much of the grain being purchased in various communities is industrially milled maize, A logical first target for the marketing of surplus sorghum and pearl millet is then the rural consumer who is unable to produce enough to meet household food security requirements.

Zimbabwe. A SMTP review of the sorghum and pearl millet production in Zimbabwe showed that at least two-thirds of the farm households producing these crops face a consistent grain production deficit (Hedden-Dunkhorst 1993). In drier years, roughly half of all households farming in semi-arid regions have to reduce their calorie intake. Virtually all farmers rely heavily on purchases of maize meal to meet production deficits (Rohrbach et al. 1990). These analyses proposed the development of intrarural grain markets as a good means to encourage trade in sorghum and pearl millet. Regions with sorghum and pearl millet grain surpluses need to be linked with regions experiencing grain deficits. Grain trade restrictions prior to grain market liberalization prevented the development of these trading patterns. The national Grain Marketing Board was advised to become more actively involved in selling grain back into rural markets.

Shortly after Zimbabwe's grain markets were liberalized, SMIP examined the impact of the market reforms on sorghum and millet trade (Mazvimavi 1995a,b). The underlying hypothesis was that the removal of maize subsidies and associated restrictions on grain movements would encourage private traders to invest in grain trade. In semi-arid areas, private investment would be led by small-scale commercial grain millers. We found, however, that small-scale millers face strong competition from large-scale millers capable of negotiating favorable terms on input costs and exploiting economies of scale. Further, the profitability of small-scale milling operations depends highly on the costs and consistency of their grain input. Correspondingly, the most successful operations are based in peri-urban areas. At the time of the study these were only milling maize. Small-scale millers interviewed did not believe there was a market for sorghum or pearl millet flour. A key problem underlying the development of this market was the inconsistency of grain supplies. These findings have generally been confirmed by investment patterns in small-scale milling since 1985. However, one Bulawayo-based entrepreneur has initiated milling of sorghum flour.

Zambia. SMIP worked with the National Commission for Development Planning to examine the competitive position of sorghum, pearl millet, and finger millet on the rural market (National Commission for Development Planning 1991). This study highlighted the dependence of rural consumers on purchases of industrially processed maize meal. National maize subsidies encouraged the production of maize in drought-prone regions. The costs of low and variable maize productivity in these areas were offset by the low costs and consistent availability of industrially manufactured maize meal. The study recommended policy support for the development of private sector markets, particularly markets facilitating grain trade from surplus to deficit rural areas, and the removal of maize subsidies. A set of 26 recommendations were provided to the government relating to production support, grain processing, storage, transport, and trade. These recommendations and the underlying baseline information on rural grain trade provided an input into national discussions on grain market liberalization.

Tanzania. The analysis of sorghum and pearl millet marketing and utilization with Sokoine University of Agriculture also examined grain flows on the rural market. Farm surveys revealed that, like Zimbabwe, more than three-quarters of Tanzania's sorghum and pearl millet producers face grain production deficits almost every year. Grain purchases are funded through the sale of household labor, livestock, and through involvement in petty retail trade. This reduces the labor and cash available for investment in the farming system. The reliance on grain imports into sorghum and pearl millet growing areas is problematic because of the high transaction costs associated with grain movements from surplus to deficit regions. Grain prices commonly differ by 200-400% across distances of 500-1000 km. In addition, price margins are higher for less heavily traded grains like sorghum and pearl millet. This encourages households growing sorghum and pearl millet to resolve their production deficits by purchasing maize. The study concluded that the first priority for improving food security in most sorghum and pearl millet producing zones must be to improve productivity. More than three-quarters of sorghum and pearl millet growers have never tried improved varieties. Less than 5% have ever tried chemical fertilizer.

Namibia. The analyses of commercialization prospects in Namibia were similarly complemented by a review of the prospects for expanding intrarural trade of pearl millet. As in the case of Zimbabwe and Zambia, the objective would be to replace purchases of imported maize with purchases of domestically produced grain. The study indicated that most of Namibia's small farmers are net buyers of grain. In the principal pearl millet growing region of Ovambo, 74% of small fanners indicate they never sell grain, most commonly because they never produce a surplus. Most of those sales occurring are in the form of small transactions (averaging only 16 kg) between neighboring households. While most households express a taste preference for pearl millet, limited availability and relatively high prices encourage consumption of maize. Options for facilitating greater private sector millet trade are offered (Keyler 1995b). The primary efforts need to be directed toward improving grain flows from surplus to deficit regions and improving productivity (Rohrbach 1995a). This study provided the first major database on pearl millet production and marketing in the country (Keyler 1995a).

Impact of sorghum and pearl millet dehuliers

Zimbabwe. During the late 1980s and early 1990s, sorghum and pearl millet dehuliers were being promoted in Zimbabwe (as well as Botswana, Zambia, Tanzania, and Swaziland) in the view that processing constraints were the main deterrent to the expansion of sorghum or pearl millet production. These correspondingly discouraged the adoption of improved cropping technologies. However, an assessment of the impact of dehuliers in Zimbabwe found they had little effect on sorghum or pearl millet production (Mazvimavi 1993). Most of the throughput for these dehuliers was maize. While farmers commonly stated a taste preference for mechanically dehulled and pounded sorghum and pearl millet, many were unwilling to pay the extra costs of dehulling. Over 50% of respondents within a 10 km radius of a dehuller still manually dehull their sorghum or pearl millet grain before taking it to a hammermill for pounding. The study found no significant change in the area sown to alternative crops associated with the introduction of dehuliers. The analysis concluded that the prices of dehulling services may need to drop relative to the opportunity cost of female labor in order to encourage greater use of these machines. In addition, the study suggested that improvements in sorghum and pearl millet productivity will be required before these crops begin replacing maize in the local cropping system.

Lesotho. SMIP worked with representatives of the Agricultural Research Division to conduct a reconnaissance of the coarse grains market, to help set the terms of reference for an International Development Research Centre (IDRC)-funded analysis of the demand for dehulled sorghum and the financial viability of sorghum dehuliers. The preliminary analysis indicated that dehuliers were unlikely to reduce reliance on imports of maize, wheat, and sorghum from South Africa (Rohrbach et al. 1989). However, dehulling services could encourage expansion of sorghum production relative to maize in the southern parts of the country, where sorghum has a productivity advantage. The analysis encouraged complementary research on the competitiveness of sorghum by a national economist, N Moletsane, working on a Masters degree with SMIP funding.

Adoption and impact studies

A series of adoption and impact studies were conducted in Botswana, Malawi, Namibia, and Zimbabwe. These studies assessed the justification for further investments in the crop breeding programs while highlighting targets for future breeding efforts.

Drought relief seed

SMIP first assessed the impact of the free distribution of sorghum and pearl millet seed in response to the severe 1991/92 drought in southern Africa (Friis-Hansen and Rohrbach 1993). With special USAID funding, ICRISAT contributed to the production of more than 490 t of white sorghum seed and 160 t of pearl millet seed for Zimbabwe, Namibia, and Malawi. This investigation highlighted the value of the emergency production of varieties well adapted to the region. Farm surveys revealed that much of the seed being imported into southern Africa by donors and NGOs for drought relief was poorly adapted to the region. Though expensive, the effort to produce locally adapted varieties under winter irrigation provided large numbers of farmers (including 30% of sorghum growers and 20% of pearl millet growers in Zimbabwe) with initial access to newly released varieties of sorghum and pearl millet. The locally developed sorghum varieties offered grain yields five times greater than ill-suited sorghum seed imports. The study also revealed that, contrary to government and donor perceptions, rural seed stocks were not wiped out by the drought. Most fanners had retained sorghum or pearl millet seed in stock. Seven recommendations were provided for future seed distribution schemes associated with drought relief.

Zimbabwe's sorghum and pearl millet breeding

SMIP, in collaboration with a national economist, conducted a follow-up assessment of the impact of sorghum and pearl millet breeding in Zimbabwe. This calculated an internal rate of return (IRR) of 27-34%, and a stream of net benefits ranging from US$ 7.8-28.9 million, on the combined investments of the Zimbabwe national program and ICRISAT in the development and dissemination of two varieties, SV-2 sorghum and PMV-2 pearl millet. This IRR is competitive with the returns to other investments in the Zimbabwe economy and compares favorably with the returns to agricultural research calculated elsewhere in Africa. Additional benefits accrue in the form of enhanced food security to some of the most drought-prone regions of the country. Interestingly, however, farmers do not cite productivity gains as the main reason for adopting these new varieties. According to on-farm trials, the yield gains from changes in variety average less than 20%. Farmers indicate the earlier maturity of these varieties is the main justification for their adoption. This offers a better chance of a harvest when rains fail. If larger or more consistent yield gains are to be achieved, improvements are necessary in crop management practices, particularly in fertility management.

Namibia's pearl millet breeding

A SMIP-led impact assessment of Namibia's breeding program (Rohrbach et al., in press) indicates the IRR to public investments in the development and dissemination of new pearl millet varieties in this country has been 60%. This high rate of return reflects the importance of pearl millet in the Namibian cropping system, and the rapid delivery and acceptance of the Okashana 1 variety. Research costs were low because of the timely evaluation of a wide range of germplasm delivered by ICRISAT through SMIP. The returns were also improved by the quick release of Okashana 1 in response to farmer interest expressed during early participatory evaluations of this cultivar. In addition, seed was delivered rapidly to farmers because of complementary public investments in building a semicommercial seed multiplication and distribution facility. Most Namibian farmers are now well aware of the opportunity to obtain new varieties of pearl millet. Correspondingly, the prospects for adoption of two additional pearl millet varieties released in April 1998 are favorable.

Botswana's sorghum breeding

A recent assessment of the adoption of newly released sorghum varieties in Botswana highlights the need to link improvements in sorghum productivity with the exploitation of the commercial grain market (Rohrbach and Makwaje, in press). Botswana released three open-pollinated sorghum varieties and one sorghum hybrid in 1994. One of the varieties, Phofu, has already been widely disseminated. Within 2 years of its release, more than 90% of the nation's small-scale farmers were aware of this cultivar, and almost 50% had planted it. This success is attributable to government support for the multiplication of this variety, and the distribution of Phofu under national drought relief programs. Much smaller quantities of the other three cultivars (Mahube, Mmabaitse, and BSH 1) were produced and distributed. However, farm surveys and a review of variety trial data indicate no yield gains are offered by three of the four cultivars. The hybrid cultivar offers the promise of yield gains, but Botswana has been unable to produce the seed of this hybrid. The study highlights the fact that larger gains in productivity will only be derived from improvements in crop management. However, these are unlikely to occur without stronger efforts to commercialize production. The country now imports most of the sorghum used by its milling and brewing industries. Research and extension need to work with these industries to pursue a strategy explicitly linking technology change and commercial grain market demand.

Zambia' sorghum breeding

SMIP provided assistance to the Department of Research and Specialist Services in Zambia for an impact assessment of its sorghum research program (Chisi et al. 1997). Since 1987, seven new sorghum varieties and hybrids were released for distribution to farmers. According to survey results, adoption levels for new sorghum varieties reached 20% in 1993 and 35% in 1995, Adoption in the smallholder sector is largely the result of the initiatives of nongovernmental organizations and public drought relief schemes to distribute the seed of released cultivars. Most of this distribution was free of charge. The calculation of the IRR depends critically on assumptions regarding future rates of adoption and the ceiling level at which adoption peaks. If the 1995 adoption rate continues without farther expansion, the returns to sorghum research in Zambia will be marginal. However, this appears unlikely given the level of acceptance of the new varieties. An adoption rate of 50% would yield an IRR of 15.4% and a net present value (NPV) at a 5% discount rate of US$ 6.4 million, This study also highlights the fact that the level of research costs can significantly influence the returns to these investments. in Zambia, considerable manpower and capital expenditure through special project support contributed by an external donor reduces the average rate of return. The relative cost of these investments was particularly high given that Zambia produces less than 50 000 ha of sorghum. Nonetheless, Zambia benefited from exploitation of a range of sorghum germplasm already characterized and initially developed by ICRISAT and other international breeding programs. By implication, returns to future research investments may improve with further exploitation the this international technology base.

Seed market analysis

By the beginning of Phase 111, SMIP's collaborative research and development efforts had stimulated the release of more than 20 sorghum and pearl millet varieties in southern Africa. Yet few farmers had access to this seed. Correspondingly, several regional studies, and more detailed investigations in Zimbabwe, targeted the diagnosis of constraints to sorghum and pearl millet seed production in the formal seed sector, and opportunities for expanding seed flows through informal seed markets. SMIP also organized a major international conference reviewing alternative seed supply strategies.

Formal seed markets

Surveys of variety adoption, and associated efforts to monitor seed multiplication and distribution through commercial seed markets indicate few small-scale fanners have consistent access to sorghum or pearl millet seed varieties released by national agricultural research systems (NARS) in southern Africa (cf. Rohrbach 1995b; Rohrbach et al. 1997). Most of the seed distributed during the past 10 years has been given out free of charge under government and donor funded drought relief or refugee resettlement programs. This includes over 3 000 t of sorghum and pearl millet seed produced for the 1995/96 cropping season. Commercial companies consistently express doubts about the existence of significant retail market demand for open-pollinated varieties. They expect that once fanners obtain new varieties from drought relief programs, they will continue to retain this seed from their harvests. In consequence, the returns to investment in building retail market channels are perceived to be low. Fanners still complain about the lack of sorghum and pearl millet seed in local markets. But private companies remain unconvinced about the size and consistency of this demand.

The persistence of seed delivery under national drought relief and resettlement programs has, however, encouraged private companies to multiply large stocks of sorghum and pearl millet seed for sale to the public sector. A review of SADC seed stocks conducted in early 1998 revealed a regional seed surplus of more than 7000 t of sorghum and 2500 t of pearl millet (Rusike and Rohrbach 1998). Most of this is held by seed companies in South Africa, Zimbabwe, and Zambia. The stocks were built up in anticipation of donor support for seed distribution following the 1997/98 season *el nino* drought.

Interest in drought alleviation strategies has also encouraged nongovernmental organizations (NGOs) to initiate small-scale seed production projects in Zimbabwe, Zambia, Malawi, Mozambique, and Tanzania (Mitti 1997; Msimuko 1997). Early evidence indicates, however, that the efficiency and financial sustainability of many of these efforts is questionable.

Informal seed markets

The limited commercial interest in the development of retail markets for sorghum and pearl millet seed encouraged SMIP to investigate the structure and conduct of informal, village seed markets. Studies in Zimbabwe (Rohrbach and Mutiro 1997; Rohrbach 1997) reveal that roughly one-third of all farm households participate in the local trade of seed. The largest share of these transactions take the fonn of gifts to neighboring households and to relatives in more distant villages. However, the degree of quality control in this seed market is limited. Much of the seed being traded is derived from household grain stocks.

The surveys provide virtually no evidence of field isolations to maintain varietal purity. While most farmers select seed in the field prior to harvest, the tendency to sow multiple varieties leads to genetic mixtures. Seed prices do not appear related to clear quality standards. These analyses have encouraged a PhD study on the impact of commercialization and seed market development on sorghum varietal diversity in Zimbabwe, SMIP is providing advisory assistance for this study.

Regional seed policies

A SMIP-sponsored regional study of constraints to the release, production, and distribution for sorghum and pearl millet seed provides a comparative review of the structure and performance of seed sectors in Tanzania, Malawi, Zambia, Botswana, Mozambique, and Zimbabwe (Musa and Rusike 1997). The report notes that intellectual property rights have been used to preclude the entry of small-scale seed producers into the seed industries of some countries. Parastatal companies linked with government research units have sought to retain monopoly control over seed production, but failed to broadly market sorghum or pearl millet seed. Private seed companies are starting to compete with public agencies, but the lack of enforceable plant breeders rights discourages multiplication by some of these companies. In addition, mandatory certification of seed restricts multiplication of varieties by NGOs and farmers' groups. In some countries, mandatory varietal registration has also limited seed release and multiplication. The report provides recommendations on variety release procedures, intellectual property rights, seed inspection procedures, seed registration and certification procedures, the role of NGOs, and highlights the opportunities for further developing a competitive private seed sector. Shortly after the preparation of this report, sorghum and pearl millet seed trade was liberalized in Zimbabwe.

This analysis led to SMIP leadership in organizing an international conference on Alternative Strategies for Smallholder Seed Supply in March 1997. Twenty-seven papers on alternative public and private sector seed supply strategies were presented and discussed. The conference offered recommendations for further development of seed systems in southern Africa and for the establishment of a regional seed network. The procedures for establishing this network are currently under discussion.

Fertility management research

Survey evidence has consistently revealed that less than 5% of the farmers in the semi-arid regions of southern Africa use chemical fertilizer (Rohrbach and Makwaje, in press; J Doughty, Rural Development Support Programme, personal communication; Minde and Mbiha 1993). Yet significant productivity gains are unlikely without this input. Studies in Zimbabwe are evaluating the range of factors influencing technology adoption and strategies for defining more practical fertility management recommendations.

Diagnosing the problem

A reconnaissance survey on fertility management by small-scale farmers in semi-arid areas of Zimbabwe (Ahmed et al. 1997) indicates that while manure use is widespread, the rates of application are declining due to the loss of cattle during recent years of drought. Increases in the harvesting and selective feeding of crop stover have reduced the availability of residues to the soil. While farmers are aware of the value of some crop rotations, the application of these rotations is restricted by the need to sow most land to cereals. Many farmers are also using anthill soil as a nutrient supplement. But this has contributed to a rapid decline in the number of anthills in some areas. Use of humus and leaves from nearby wooded areas has also increased. Farmers commonly complain about the high cost of fertilizer. Some claim that fertilizer use may be detrimental to their soils. Such findings suggest knowledge and education constraints may be as severe as cash constraints in limiting the adoption of chemical fertilizer.

The evolving use of crop residues

The analysis of crop management practices at a single point in time commonly neglects the fact that practices are constantly changing. In semi-arid areas with semisubsistence cropping systems, some of the largest changes are resulting from growing pressures on limited resources. For example, the growth of rural populations has led to the reallocation of grazing land to crop production across much of southern Africa. But cattle numbers have continued increasing and land degradation due to over-grazing represents a rising threat. An investigation of resource use trends in Zimbabwe (Takavarasha 1993) reveals that farmers have responded to growing land pressures by sharply increasing the collection and use of crop residues. During the past three decades the amount of grazing land per livestock unit has declined by 50%. During this same period the proportion of households beginning to collect and selectively feed crop residues has more than doubled. According to cross-sectional survey data, by the early 1990s over 90% of small farmers had started collecting crop residues from their fields. Correspondingly, the relative value of grain stover has sharply increased. The value of sorghum, pearl millet, and finger millet stover ranged from 38 to 53% of the value of the respective grain harvests over the 1988-1992 period. These results suggest the value of considering stover yields in national breeding programs. They also highlight growing pressures on limited soil resources. When residues were openly grazed, crop fields gained both a portion of the stover and manure from the feeding animals. The incorporation of both sets of resources into crop soils has declined.

Modeling fertility options

SMIP's farm surveys reveal that few farmers receive extension advice related to soil and water management, and most of the limited advice being offered is ignored. This advice is largely irrelevant to the investment priorities of most small-scale farmers. In a pilot exercise, economic and bio-physical modeling are being combined with field surveys to develop more practical extension recommendations for fertility management in Zimbabwe (Ahmed and Rohrbach, in press; Rohrbach, in press). The initial analyses emphasize fertility management options for households facing severe cash constraints. Rather than evaluating how to maximize crop yields or profits, these analyses target improvements in the returns to application of the limited quantities of fertilizer or manure farmers have available. If a farmer is only able to purchase one bag of chemical fertilizer, what should be the nutrient mix and how should this be applied in order to maximize returns to this limited investment? The modeling also aims to ask how the contributions of legume rotations and intercrops can be maximized in these drought-prone environments.

This research is only at an initial stage. However, the early results are promising. These suggest that farmers can increase average sorghum yields by 25% simply by better targeting the fertilizer received under recent drought relief programs. Fanners can also increase the returns to manure use by combining this input with small quantities of chemical fertilizer (Ahmed and Rohrbach, in press). While further work is needed to verify the accuracy of simulations with manure, the results are promising enough to encourage initial testing of such low input (but high return) management options with small-scale farmers.

Human resource development

During Phase II and the first part of Phase III, SMIP provided degree training for seven economists through INTSORMIL-related programs in the United States. These have now returned to research and development programs in southern Africa. Three have returned to posts in national agricultural research institutes and two are in university positions. The whereabouts of the remaining two are unknown. Two of these economists are still working on sorghum and millet related issues at least part of their time. The high mobility of economists, and strong, varied demand for their services, results in limited attention being directed toward economic analysis relating to sorghum and pearl millet.

A SMIP-led analysis of economics research capabilities reviewed this situation in 1993 (Heisey and Rohrbach 1995). This identified 37 economists employed in 8 of the 10 NARS in the SADC region (not including South Africa). More than half of these economists were employed in Tanzania alone. Several countries, including Namibia and Mozambique, had no economists in their agricultural research institutes. There were no economists in the SADC NARS with PhD degrees. Only one-third of these economists had MSc degrees. The survey indicated there are no consistent sources of in-service training for economists in the region. Economists in all countries sought assistance with applied techniques of economic analysis. There was particular interest in training in methods of technology adoption and impact assessment.

SMIP, in collaboration with the Centro Internacional de Mejoramento de Maiz y Trigo (CIMMYT), established a Policy Analysis Initiative (PAI) in 1990 as a pilot program designed to encourage economists from NARS to incorporate policy analysis into their work. The PAI sought to encourage consideration of how agricultural policies affect technology adoption and use. The PAI also provided a mechanism for economists based in the NARS of eastern and southern Africa to discuss technology and policy issues of common concern, examine common analytical problems, and to learn from the work of their peers in other national programs. The PAI was launched with a planning and methodology workshop for 15 economists from eastern and southern Africa in late September of 1990. These included participants from Botswana, Ethiopia, Kenya, Malawi, Swaziland, Tanzania, Zambia, and Zimbabwe. During this workshop, analytical methods for evaluating technology adoption, fertilizer use, grain marketing, and research resource allocation policy were outlined. Over the next year, the PAI provided analytical support for these sorts of studies and, in a few cases, small research grants. In March of 1992, the PAI sponsored a reporting workshop incorporating the presentation of 15 papers and a seminar on methods of fertilizer policy analysis. The papers were published in a book (Mwangi et al. 1993).

Efforts to extend this PAI were hindered by disagreement about what institutions should take charge of policy analysis training in southern Africa. The SADC Food

Security Unit eventually established its own policy analysis training program. The University of Zimbabwe is working to establish a policy analysis network.

SMIP worked with the Southern African Centre for Cooperation in Agriculture and Natural Resources Research and Training (SACCAR) to provide training in methods of impact assessment during regional workshops held in 1994, 1995, and 1996. Over 40 socioeconomics and biophysical scientists from all SADC countries were trained in techniques of impact assessment.

Implications for the future

Analyses of the demand for sorghum and pearl millet in the product market consistently highlight the need for these crops to be competitive in price and availability with maize. Sorghum and pearl millet commonly cost more than maize or are only inconsistently available to industry buyers. The quality of grain available on national markets tends to be highly variable. Industries requiring sorghum for particular products, such as opaque beer, have learned the value of contracting with farmers for varieties and grain quality standards meeting their requirements. When maize cannot be used, sorghum contracts may even attract a premium price. Where substitution is possible, sorghum must be available at prices 10-30% below the price of maize. This requires that sorghum be produced and transported to the factory at costs lower than those for maize.

Sorghum and pearl millet trade is also disadvantaged by the fact that most producers are small in scale and distantly located from industrial consumers. Further, production levels are highly variable due to the frequency of drought. This raises the costs of grain assembly and transport, relative to competing inputs like maize. Industry in South Africa and Zimbabwe has sought to reduce this uncertainty by contracting for its needs. However, efforts to minimize contracting costs encourage transactions with fewer larger scale farmers. We know little about opportunities for extending these contracts to small-scale farmers.

A small premium market exists for sorghum and pearl millet grain or flour priced higher than the costs of maize, This is evident in the sale of sorghum flour by a small miller in Zimbabwe and the prevailing costs of pearl millet grain and flour on the Namibian market. Sorghum flour often sells for more than the price of maize flour in Botswana. However, little information is available about the size of this market and the potential for market expansion.

The main determinant of the competitiveness of sorghum and pearl millet, both in the rural food system and the industrial market, is the productivity of these crops. Prior to the liberalization of national grain markets in southern Africa, sorghum and pearl millet were often disadvantaged by a range of implicit and explicit subsidies on the trade of maize. Now that these markets have been largely liberalized, the relative competitiveness of alternative crops in domestic production and regional trade has become even more important. If Botswana, for example, can import sorghum from South Africa more cheaply than it can produce this grain, comparative advantage suggests domestic resources ought to be allocated to more productive farm enterprises like livestock. Farmers in southern Zimbabwe may be better off producing cotton and buying their grain supply. While sorghum and pearl millet production may remain essential for household food security, low yields will inhibit trade on domestic and regional markets.

Assessments of the adoption of new varieties reveal strong interest in adopting new sorghum varieties offering earlier maturity than traditionally grown cultivars. This trait improved the probability of grain harvests in years of drought. However, the average yield gains being achieved with the new cultivars are smaller than expected. These range from zero to 35%, Survey evidence indicates farmers are not changing their crop management practices as they adopt new varieties. In effect, they are failing to take advantage of the greater responsiveness of new cultivars to improvements in fertility and water management. This remains a challenge for sorghum and pearl millet technologists.

In most SADC countries, the main determinant of variety adoption has been the free distribution of sorghum or pearl millet seed for the purposes of disaster relief. Indeed, commercial seed companies in Zimbabwe, Zambia, and South Africa have geared up production to feed the emergency market. Virtually all sorghum and pearl millet seed distribution north of South Africa has been subsidized, and little seed flows through retail trade channels. The lack of commercial interest in developing rural seed trade and continuing demand for seed for emergency relief has encouraged a range of NGOs to pursue village seed production projects. However, the sustainability of these efforts, once donor subsidies are withdrawn, remains open to question.

The economics research funded during the early stages of SMIP encouraged the pursuit of grain market liberalization. As markets were being liberalized, this research argued for continuing support for the development of intrarural grain trade promoting the movement of grain from surplus to deficit regions. But most liberalization strategies simply targeted the reduction of market regulation and public investments. The economic research highlighted the value of continuing public support for seed production in order to promote the rapid dissemination of new varieties. At the same time, this has started to outline a range of alternative seed supply mechanisms. Finally, recognizing that larger productivity gains will only be achieved with improvements in crop management, the economics unit has initiated pilot analyses of how to better orient advice on alternative fertility management strategies to the investment matrix farmers are willing to consider. The target is to maximize returns on the more limited investments farmers are willing to make. This, too, remains a challenge for continuing work.

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Technology Exchange in Phase HI of SMIP

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Abstract

The first two phases of SMIP led to the development of a range of improved technologies. During Phase III (1993-98), the priority was therefore to promote the transfer of these technologies (primarily improved sorghum and pearl millet varieties) to smallholder farmers. The three key components of technology exchange activities were: verification of technology under farmers' conditions; backstop support for national seed production and distribution; and review and revision of extension recommendations. These activities were implemented largely by the national research and extension programs. SMIP acted as catalyst and facilitator, focusing on areas where the regional program could be of greatest assistance to national initiatives.

On-farm variety trials involving national research and extension staff, NGOs, SMIP, and farmers were conducted in nine SADC countries to evaluate varieties developed during the previous two phases of SMIP. In five countries (Botswana, Namibia, Malawi, Mozambique, and Tanzania), the trials led directly to national recommendations for release of sorghum and/or pearl millet varieties. In Swaziland, Zambia, and Zimbabwe the trials served to verify performance and farmer acceptance of varieties that had been released but not widely tested on farmers' fields.

SMIP provided training in seed production techniques to research, extension, and/or NGO staff in five countries (Botswana, Malawi, Mozambique, Namibia, and Zimbabwe), and financial support for national seed production efforts in Tanzania, Zambia, and Lesotho. Seed availability, though still a major constraint to variety adoption, has improved considerably. Regional seed stocks (excluding seed retained by farmers) at the end of the 1997/98 season were over 4400 t for improved sorghum varieties and 965 t for improved pearl millet varieties.

Another key area was the review of extension recommendations. SMIP cosponsored a major regional workshop that examined current management recommendations in each country, and reviewed available information on farmers' production systems, adoption levels, and constraints to the adoption of crop management

recommendations. Adoption rates for management recommendations were low throughout the region. The workshop consensus was that poor adoption was due to a lack of farmer input into technology development, leading to inappropriate or impractical recommendations, and poor understanding among researchers of farmers' production systems and constraints. The consensus was that there is an urgent need to redirect research to focus more directly on 'real' problems, and involve fanners more closely in technology development. Correspondingly, SMIP has supported workshops specifically aimed at promoting the use of farmer-participatory research in both crop management and crop improvement research.

Another crucial SMIP contribution was in developing and strengthening linkages among various stakeholders. Benefits from linkage development are likely to persist well beyond SMIP. In several countries, partnerships developed for on-farm testing were later extended to address the issue of seed systems.

Introduction

The Sorghum and Millet Improvement Program (SMIP) has been implemented in three 5-year phases, beginning in 1984. The third phase of SMIP covered the years 1993-1998. The primary goal of Phase III of SMIP was "to improve food security through increasing productivity of sorghum (*Sorghum bicolor* (L.) Moench) and pearl millet (*Pennisetum glaucum* (L.) R. Br.) grown by resource-poor farmers in drought-prone regions" (ICRISAT 1993, p. 15).

The first two Phases of SMIP focused on developing research infrastructure, human resources, and technology. For Phase III, the SMIP Steering Committee, composed of representatives from each of the SADC national agricultural research programs participating in SMIP, ranked regional research priorities as (1) technology transfer, (2) development of improved varieties, germplasm collection, and exchange, (3) management of diseases, pests, and the parasitic weed *Striga,* (4) human resource development, and (5) evaluation of grain quality. Technology transfer was listed as the first priority, and the specific purpose was to promote the transfer of technologies to smallholder farmers. The strategy proposed for the transfer of technologies (ICRISAT 1993) included:

- Verification of technology under farmers conditions;
- Backstop support for national seed production and distribution;
- The review and revision of extension recommendations;
- The review and evaluation of constraints to technology adoption; and
- The evaluation of research and technology impact.

All aspects of the proposed strategy were followed, with good results, particularly in regard to the release and adoption of improved varieties. This paper describes the approaches, activities, and achievements in technology transfer, in relation to the verification of technology, support to national seed production and distribution efforts, and the review and revision of extension recommendations. Activities and outputs related to the review and evaluation of adoption constraints and the evaluation of impacts are discussed in a separate paper.

Principles and approaches in technology exchange

Since its inception, SMIP has endeavored to work with partners in achieving program goals. Partnerships have been particularly important in the technology exchange activities, since these require input and support from numerous stakeholders. Thus, the most important principles and approaches that have been used in the technology exchange program in Phase III of SMIP relate to interactions among partners, and include the following.

Technology exchange vs technology transfer

The successful development and adoption of technology is dependent on a two-way flow of information. Feedback from farmers, extensionists, and other stakeholders to commodity and systems researchers is as crucial to success as is testing, demonstration, and adaptation of improved technologies by research. In developing and disseminating improved technology, SMIP and its partners have strongly encouraged the two-way flow of information. To better reflect this two-way interaction, the term technology exchange was adopted in place of 'technology transfer'.

Key role of national programs in impact generation

It was recognized that for genuine impact to occur at the farm level, direct implementation could only be done by the national agricultural research and extension systems (NARES), considered here in the broadest sense to include research, extension, nongovernmental organizations (NGOs), and other stakeholders in the process of technology development and dissemination. In fact, for technology exchange in general, implementation can only effectively be carried out by national systems, and the role of the international agricultural research centers (IARCs) is as a partner, to encourage, assist, and facilitate this activity. Thus SMIP held discussions with each national program to identify where the regional program could be of most assistance to the national program, and then contributed within those areas.

Joint planning

The key to effective collaborative action is joint planning. All participants in the process must be included in the identification of mutually agreed objectives, and in the development of implementation plans for all collaborative activities to achieve those objectives.

This approach has worked well. At the regional leyel, SMIP and NARES scientists met annually to discuss program priorities for the region as a whole, and for activities at the national level for each country. This process clarified the regional priorities according to the SMIP program mandate (ICRISAT 1993). Regional meetings were followed by work planning meetings with each of the participating national programs. At the national level, priorities of the national programs were put forward by national scientists. Areas of overlap with the regional priorities for SMIP were then identified. These areas of overlap became the focus for regional collaborative activities, and joint planning with all relevant parties was initiated. There was usually considerable commonality between national and regional priorities because the overall objective at both levels was to benefit farmers, and thus regional priorities followed national interests.

Linkage development. SMIP has always encouraged and catalyzed national efforts in linkage development. For example, SMIP funded national level meetings in all participating Southern African Development Conference (SADC) countries in 1993, where many different departments and organizations were able to come together to consider ways of strengthening collaboration. Provision was always made to include as many of potential stakeholders as possible in national meetings, so that collaborative approaches could be developed from the start. The national level linkages that have developed through these collaborative activities may be one of the most important and lasting contributions of SMIP.

The concept of 'stewardship'. To generate on-farm impact, technologies and information must move from the 'problem definition' stage through the design, testing and dissemination stages, without interruption. It is important to monitor and facilitate this process, or in other words, provide *stewardship* for the progress of the technology through the system to the end user. The most appropriate source of this stewardship is the national research program, which is most familiar with the application and uses of the technology, and will have the greatest vested interest in making it available to end users.

SMIP has promoted this concept of stewardship in Phase III. Stewardship of their own technologies is strongly in the interest of national research programs. An important contribution of SMIP has been to ensure that technical assistance and limited funding were available to support key national initiatives at critical junctures, such as supporting national level meetings for planning and coordination of activities among all the relevant partners.

Activities and outputs—improved sorghum and pearl millet varieties

During Phases I and II of SMIP, regional and national plant breeders were very successful in developing early-maturing, high-yielding sorghum and pearl millet varieties for food use. One of the main objectives of the technology exchange program of SMIP Phase III was to make these materials widely available to farmers, and facilitate adoption. The approach involved three main activities:

- On-farm testing of the varieties;
- Formal variety release at the national level; and
- Seed production and dissemination.

On-farm testing of improved varieties was necessary because prior to Phase III, most participating countries were testing sorghum and/or pearl millet varieties on-station. Before investing resources in promoting the new varieties, it was necessary to detenuine whether they would perform well under the typically more stressful conditions in farmers' fields, and identify which varieties were acceptable to, and/or preferred by, farmers.

Formal variety release at the national level was necessary in most participating countries before seed of a variety could be legally produced and sold to farmers.

Seed production and distribution systems are obvious prerequisites for making new varieties of sorghum and pearl millet widely available. In the medium to long term, these need to be sustainable rather than the present ad hoc efforts initiated in response to disasters.

The activities and outcomes related to on-farm testing, variety release, and seed production/dissemination in SMIP Phase 111 are discussed below.

On-farm variety testing

Systematic on-farm testing was initiated in the 1992/93 season in three countries. By 1994/95, on-farm variety trials with these crops had been expanded to cover ail of the original nine participating SADC countries (Table 1). In all countries, the on-farm trials were conducted by the national research programs in collaboration with national extension services (except Mozambique, where the trials were conducted by World Vision International, with support from the national research and extension programs) and SMIP. In five of the nine countries, NGOs also participated in the on-farm trials programs. Farmers were directly involved with implementing and assessing the trials. On-farm trials peaked in 1994/95, and subsequently declined as adapted varieties were identified in most countries, and SMIP's emphasis shifted to seed production and dissemination (Table 1).

In all countries the trials were jointly designed and implemented by national research and extension personnel, and participating NGOs. Farmers were not always involved in the planning, but were always involved with implementation. In some cases, changes in trial designs were initiated to accommodate farmers requirements (e.g., Tanzania). In many, but not all, cases SMIP provided technical support at planning meetings and/or provided partial funding to support national efforts. SMIP scientists monitored on-farm trials jointly with national scientists. The trials followed the same general format, but each national program designed and

Table 1. SMIP-NARS collaborative on-farm sorghum and pearl millet variety trials in SADC/ICRISAT SMIP.

Year	Country	Crops	Trial types[1]	Collaborators[2]	Farm evaluations?[3]
1992/93	Malawi	Sorghum/pearl millet	RM,FM	Res/Extn	Yes
	Namibia	Sorghum/pearl millet	RM, FM	Res/Extn/CCN	Yes
	Zimbabwe	Sorghum/pearl millet	RM, FM	Res/Extn	
1993/94	Botswana	Sorghum	FM	Res/Extn	Yes
	Malawi	Sorghum/pearl millet	RM,FM	Res/Extn	Yes
	Namibia	Sorghum/pearl millet	RM, FM	Res/Extn/CCN	Yes
	Tanzania	Sorghum/pearl millet	FM	Res/Extn	Yes
	Zimbabwe	Sorghum/pearl millet	RM, FM, MDN	Res/Extn	Yes
	Swaziland	Sorghum	RM	Res/Extn	Yes
1994/95	Botswana	Pearl millet	FM	Res/Extn	Yes
	Lesotho	Sorghum	RM, FM	Res/Extn	Proposed
	Malawi	Sorghum	RM, FM	Res/Extn/WVI/CSC	No
	Mozambique	Sorghum/pearl millet	FM	Res/Extn/WVI	Yes
	Namibia	Sorghum/pearl millet	RM,FM	Res/Extn	
	Swaziland	Sorghum	RM	Res/Extn	Yes
	Tanzania	Sorghum/pearl millet	FM	Res/Extn/Mvumi RTC	Proposed
	Zambia	Sorghum	FM	Res/Extn/GTZ Project/Fosud	Proposed
1995/96	Lesotho	Sorghum	RM,FM	Res/Extn	Proposed
	Mozambique	Sorghum/pearl millet	FM	Res/Extn/WVI	Yes
1996/97	Lesotho	Sorghum	RM,FM	Res/Extn	Proposed
	Tanzania	Sorghum	FM	Res/Extn/Mvumi/SG2000/CCT	Yes

1. RM = researcher managed; FM = farmer managed; MDN = nurseries.
2. Res = national research program; Extn = national extension service; CCN = Council of Churches, Namibia; CCT = Christian Council, Tanzania; CSC = Christian Service Committee; Fosud = Forum for sustainable development; SG2000 - Sasakawa Global 2000; Mvumi RTC= Mvumi Rural Training Centre; WVI = World Vision International; GTZ - Deutsche Gesellschaft fur Technische Zusammcnarbeit.
3. Yes = farmer evaluations of varieties were conducted; Proposed = systems for obtaining farmer evaluations of varieties were proposed; but SMIP does not have information on whether these were actually conducted.

implemented them according to their own needs and conditions. SMIP collaboration with specific national programs in on-farm trials implementation, the types of trials conducted, and implementing organizations are given by year in Table 1.

In most countries, the on-farm variety trials were of two types, Researcher Managed (RM) trials and Farmer Managed (FM) trials. In both cases, the trials were implemented by farmers and included farmers' local varieties as controls. The RM trials were designed to evaluate the *potential of* the new varieties on farmers' fields, and typically included more varieties than the FM trials (an average of 10 varieties versus an average of 5-6 for the FM trials), had two replications per location, and received higher levels of crop management (timely sowing, thinning, clean weeding). In some countries, they also received standard inorganic fertilizer applications. The FM trials were designed to evaluate the *actual* performance of the new varieties, and to obtain *farmer assessments* of the varieties (primarily preference or

Table 2. Sorghum and pearl millet cultivars released (and varieties pending review by Release Committees) in SADC following the collaborative on-farm variety trials program of SMIP Phase III.

Crop	Country	Year of release	Source of genetic material	Cultivar name
Sorghum	Malawi	1993	ICRISAT	Pilira 1
			ICRISAT	Pilira 2
	Botswana	1994	ICRISAT	Pofu
			ICRISAT	Mahube
			ICRISAT	Mmabaitse
			ICRISAT	BSHI
	Tanzania	1995	ICRISAT	Pato
	Zimbabwe	1996	ICRISAT	Maria[1]
			ICRISAT	SDS 2690-2[1]
		1998	NARS/ICR1SAT	SV-3
			NARS/ICRISAT	SV-4
	Namibia	1998	ICRISAT	Macia
Pearl millet	Tanzania	1994	ICRISAT	Okoa
			NARS/ICRISAT	Shibe
	Malawi	1996	ICRISAT	Tupatupa
			ICRISAT	Nyankhombo
	Zimbabwe	1996	ICRISAT	SDMV 93032[1]
		1998	ICRISAT	PMV-3
	Namibia	1998	ICRISAT	Kangara
			ICRISAT	Okashana 2
	Zambia	1998	NARS	Sepo
Pearl millet[2]	Botswana		ICRISAT	SDMV 89004
			ICRISAT	ICMV 88908
	Mozambique		ICRISAT	SDMV 89005
			ICRISAT	SDMV 90031
			ICRISAT	SDMV 91018

1. Varieties were 'released' by commercial seed companies, who made the decision to produce and sell seed after evaluating the material; however, the seed companies did not go through the formal National Release Committees
2. Varieties pending review by Release Committees.

palatability data). Farmers were expected to apply their normal levels of nonexperimental variables (time of sowing, frequency of weeding, normal fertility management practices, etc.). Hence the term ' farmer-managed'. These trials were composed of fewer varieties, were replicated across farms but not within farms, and typically had lower grain yields than RM trials.

In five out of nine participating countries (Botswana, Namibia, Malawi, Mozambique, and Tanzania), on-farm trials led directly to national recommendations for release of sorghum and/or pearl millet varieties (Table 2). Of the remaining four countries, three (Swaziland, Zambia, and Zimbabwe) had previously released improved, early-maturing varieties, and the trials served to verify performance and farmer acceptance of the new varieties. In these cases, the trials also served to increase farmers' awareness of the new varieties. In the fourth country (Lesotho) droughts and other difficulties with trials implementation prevented clear identification of varieties suitable for release.

Thus, in virtually all the original nine participating countries, the on-farm trials served to identify varieties that performed well on farmers' fields and were acceptable to farmers in terms of their plant and grain characteristics. These varieties were therefore clearly suitable for wide-scale dissemination and adoption. In five cases these were new varieties, and in three cases they were varieties that had been previously released but not extensively tested on-farm. In general, farmer evaluations of the new varieties (both sorghum and/or pearl millet) indicated that the selected varieties were popular due to early maturity and preferred panicle and grain quality

Table 3. Sorghum and pearl millet cultivar releases in SADC prior to the collaborative on-farm variety trials program of SMIP Phase III.

Crop	Country	Year of release	Source of genetic material	Cultivar name
Sorghum	Swaziland	1992	ICRISAT	MRS 12
		1989	ICRISAT	MRS 13
		1989	ICRISAT	MRS94
	Tanzania	1988	NARS/ICRISAT	Tegemeo
	Mozambique[1]	1993	ICRISAT	Chokwe
		1989	NARS	Mamonhe
		1989	ICRISAT	Macia
	Zimbabwe	1992	NARS	ZWSH1
		1987	ICRISAT	SV-1
		1987	ICRISAT	SV-2
	Zambia	1995	NARS	ZSV 12
		1990	NARS	MMSH 375
		1990	NARS/ICRISAT	MMSH 413
		1989	NARS/ICRISAT	Sima
		1989	NARS	Kuyuma
		1987	ICRISAT	WSH 287
Pearl millet	Namibia[1]	1989/90	ICRISAT	Okashana 1
	Zambia	1991	NARS/ICRISAT	Lubasi
		1989	ICRISAT	Kaufela
		1987	ICRISAT	WC-C75(ZPM-871)
	Zimbabwe	1992	ICRISAT	PMV-2
		1987	NARS	PMV-1

1. At the time of 'release' there were no formal release procedures in these countries. The varieties mentioned were simply recommended for use by farmers by the NARS.

characteristics. Good grain yield was also sometimes mentioned as a contributing factor, but this was usually a lower priority.

The increase in on-farm trials in the region represented a significant increase in linkage development between research, extension, NGOs, and farmers at the national level. The benefits of the linkage development are likely to persist well beyond SMIP. Once people and organizations have developed successful methods for working together, it is relatively easy to continue these relationships. For example in Zimbabwe, though SMIP ceased supporting on-farm variety trials in 1994, research and extension personnel continued to conduct collaborative on-farm variety trials.

The on-farm trials had a significant effect on variety releases as well. In many countries, breeding programs had never previously taken improved sorghum and/or pearl millet varieties on-farm for testing, so there was naturally some concern over what farmers' reactions might be. However, in the vast majority of cases, the trials did contain some were varieties that proved very popular with farmers. Farmers then began requesting extension personnel and the researchers involved with the trials to provide them with seed of these varieties.

While trials should never be confused with demonstrations, the trials program nonetheless created a demand for specific improved varieties at the farm level. This demand had two very positive effects. First, it generated confidence and enthusiasm within the breeding programs and helped strengthen interaction between research, extension and farmers. With good data from the field as well as strong support from both farmers and extension, breeders could be confident that national release committees would approve release proposals. At the same time, the demand-pull from the farmers exerted pressure to formally release the materials. These two factors together have greatly increased the rate at which new varieties were moved through the system.

Interaction with farmers has led to a greater acceptance of the importance of, and potential benefits from, greater farmer participation in the technology development process. Today, most sorghum and millet research programs in SADC accept that farmers are the ultimate clients and that they should be partners in technology development.

Variety release

The decision of whether to release new cultivars, and which cultivars to release, is solely the responsibility of NARS. Most countries in the region have legally constituted bodies responsible for formal release of new cultivars, though there is a trend toward relaxing these restrictions.

ICRISAT and SMIP have assisted NARS scientists move new varieties through the fonnal release process, for example by generating data (such as grain quality data obtained in the Food Technology Laboratory at Matopos), assisting with data analysis, and contributing to the final editing of papers. However, these inputs have only been made at the request of, and in response to initiatives by, NARS scientists.

Variety development, testing, and release is a lengthy process, and could take 6-10 years. Given that there have been more than 40 releases in eight SADC countries during the 15 years of SMIP (Tables 2 and 3), this represents a tremendous amount of successful work by national program breeders and collaborating SMIP scientists.

As evidenced in Tables 2 and 3, and Figure 1, the successful process of variety release that was initiated in Phases I and II was continued and enhanced during Phase III. It is interesting to note that at the beginning of Phase III variety release procedures were perceived as a potential constraint to the dissemination of improved varieties (ICRISAT 1993, pp. 17-18). In the event, they were not a major constraint. It is likely that the process of on-farm testing, and the fact that NARS scientists took responsibility for promoting the new varieties, contributed considerably to mitigating this potential constraint.

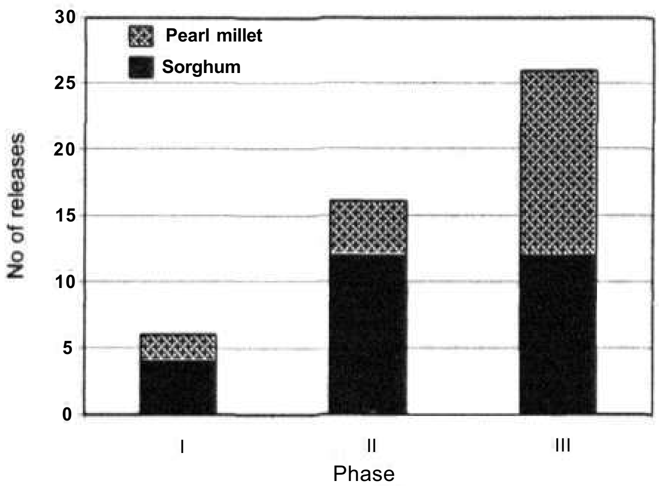

Figure 1. Sorghum and pearl millet releases (and pending releases) by NARES in Phases I, II and III.

Seed production and dissemination

Seed availability is a prerequisite for the adoption of new, improved varieties. In the planning for Phase III of SMIP, there was only one milestone related to seed production per se: "Development of NARS capacities to produce breeder seed (three countries by 1995, seven countries by 1998)" (ICRISAT 1993, p. 30). The issue of breeder seed production has been addressed elsewhere (see papers by Obilana and Monyo, this issue). However, SMIP and NARES activities in regard to seed production have gone well beyond this level during Phase III of the program. This has happened for several reasons given below.

- **Successful variety development and release.** Midway through Phase III it became clear that the process of variety development and release was going to be extremely successful. Therefore, SMIP and NARS scientists agreed that activities aimed at further variety development should be de-emphasized in favor of efforts to facilitate adoption of the new varieties.
- **Constraint to adoption.** Seed availability has been a constraint to the adoption of new varieties in the majority of countries participating in SMIP. Overcoming this constraint was seen as vital to the adoption and widespread use of the new varieties.
- **The concept of 'stewardship'.** From the outset of Phase III, SMIP and some NARS promoted the idea that scientists need to take responsibility not only for technology development, but also for facilitating the movement of that technology onto farmers' fields. This concept became widely accepted, and hence there has been strong support among NARS for enhancing seed availability.

Some of the collaborative activities that have been undertaken to further the process of seed production and distribution include the following:

- **Linkage development.** At the beginning of Phase III, SMIP supported national level meetings in all countries to bring together a wide range of stakeholders involved with sorghum and pearl millet production. These included research, extension, NGO, and private sector representatives. Partnerships and collaboration among stakeholders were seen as vital, both to identifying appropriate varieties and to deliver these to farmers. Initially, partnerships were developed for on-farm variety testing. Later, some of the same partnerships were extended to address the issue of seed systems.
- **Technical assistance and training in seed production.** SMIP breeders provided short-term and in-service training in seed production techniques to research, extension, and/or NGO staff in five countries (Botswana, Malawi, Mozambique, Namibia, and Zimbabwe). The program also provided financial support for national efforts in Tanzania, Zambia, and Lesotho.
- **National seed production/dissemination strategy meetings.** SMIP supported NARS-led meetings to develop national strategies for sorghum and pearl millet seed production and dissemination in Tanzania and Zimbabwe. In both countries, partners in the public and private sectors are now beginning to implement strategies for farmer-based seed production systems and commercial sale of seed.
- **Interaction with private seed companies.** SMIP plant breeders have maintained linkages with private-sector seed companies (with the knowledge and approval of relevant NARES), and have provided breeder seed to them. Private sector seed companies, particularly in Zimbabwe, have been producing seed of improved sorghum and pearl millet varieties, primarily for NGOs involved in humanitarian relief and/or resettlement projects. In addition, commercial seed companies in Zimbabwe have identified (from regional trials data and their own tests) two varieties of sorghum and one variety of pearl millet that they are now producing on their own (they have signed agreements with ICRISAT that the varieties are still available for production by other stakeholders).
- **Dissemination of successful seed production/dissemination models.** Because of the widespread and increasing interest in farmer-based seed production and dissemination systems in the region, SMIP promoted sharing of information on successful models. In 1998, SMIP facilitated a regional workshop to showcase the successful farmer-based pearl millet seed system developed by the Namibian NARES. There were 31 participants from 11 SADC countries.

Seed production and availability in SADC. Through the efforts of both public and private sectors, seed production of improved varieties of sorghum and pearl millet in SADC has steadily grown. At the end of the 1995/96 season, rough estimates indicated that there were about

Table 4, Seed stocks of improved varieties of sorghum and pearl millet that include ICRISAT genetic material, anticipated by producers in selected SADC countries, at harvest in 1998. Estimates collected in Feb 1998.

Country	Sorghum (t of seed)	Pearl millet (t of seed)
Angola	—	—
Botswana	234	—
Lesotho	—	—
Mozambique	183	8
Malawi	23	1
Namibia	—	388
Swaziland	—	—
Tanzania	[1]	[1]
Zambia	146[2]	5[2]
Zimbabwe[4]	3842	563
Region	4428	965

1. Farmer-based seed production efforts undertaken. Data not yet available.
2. Varieties developed by NARS.
3. Note: Zimbabwe data includes 720 tons of sorghum variety Macia produced by the private sector but not captured in the above Seed Stocks Inventory (AB Obilana, personal communication).

Source: Rusike and Rohrbach 1998.

2500 t of seed of improved sorghum varieties, and about 125 t of seed of improved pearl millet varieties available for sale in the region (this did not include seed retained by farmers). By 1998, these figures had increased considerably (Table 4.) While much of the increase was accounted for by the private sector (presumably servicing relief and rehabilitation programs), it nonetheless indicates an increasing demand for the varieties, and an increasing potential for developing sustainable, demand-driven seed systems.

Through strong efforts by national programs, with support from SMIP, significant levels of adoption (>20% of area sown) are now occurring in several countries (Botswana, Namibia, Swaziland, Zambia, and Zimbabwe). Further details on the adoption and impact of the new varieties in SADC are given elsewhere in this issue.

Seed availability remains the primary constraint to adoption of improved varieties in many SADC countries, including such major sorghum and millet producers as Tanzania and Mozambique, Continuing efforts to improve seed systems in SADC will be required to ensure that farmers have access to new varieties and that the potential benefits of regional crop improvement efforts are fully realized.

In addition to continuing efforts to improve seed systems, for the future it will also be important to increase user input in the variety development process. Incorporating user needs and interests in developing the next generation of improved varieties will increase the probability that these in turn will be adopted and utilized. One approach is through the application of farmer-participatory breeding techniques, and through consultations with the milling and livestock feed industries.

Technology exchange activities in crop management

There were two milestones related to crop management in Phase III of SMIP: (1) Extension recommendations for sorghum and pearl millet reviewed in all SADC countries (except Angola)—1995; and (2) Extension recommendations revised in at least four SADC countries—1998.

Review of extension recommendations

The workshop to review national extension recommendations and production systems for sorghum and pearl millet in SADC countries was held 19-23 Feb 1996 in Harare. It was sponsored by SADC/ICRISAT SMIP, the FAO/Swedish International Development Agency (SIDA) Farming Systems Programme, SACCAR, and the Southern African Association for Farming Systems Research and Extension (SAAFSRE). The workshop was attended by a multidisciplinary group of 34 participants from 10 SADC countries.

At the workshop, most of the national research programs in SADC presented papers that reviewed their formal crop management recommendations for sorghum and millet. In addition, these papers reviewed available information on farmers' production systems, levels of adoption of recommended practices, and constraints to adoption of recommended practices at the national level. Following the presentations, significant time was allocated to discussion of these reports and issues arising.

It was clear from the presentations and discussions that adoption levels for crop management recommendations, such as for tillage and soil fertility maintenance, are very low across the region. There was general agreement that the lack of farmer input into technology design and development had resulted in recommendations that were either inappropriate or impractical hence the low adoption rates. Further, there was general agreement that research does not have a good understanding of farmers' production systems and constraints, and that it is important for research to generate such an understanding as soon as possible.

Surveys had been conducted in most countries, and there was at least limited information available on farmer-identified production constraints. However, national reports indicated that in general there were no recommendations available to address these constraints. For example, while the constraint most commonly mentioned by farmers across the region was shortage of labor, there were no recommendations on labor-saving management options. Of eight countries reporting, six did not have recommendations to address the primary production constraints identified by fanners, one did not have information on farmer-identified constraints, and one did not discuss the issue.

Thus, scientists and extension personnel from across the region clearly identified the need to redirect research to focus more directly on farmers' production constraints as the highest priority for crop management research on sorghum and pearl millet in SADC. This included developing a thorough understanding of farmers' production systems and constraints, and the consensus that more farmer involvement in technology design and development is vital to ensuring that research products are relevant and practical.

To address the issue of increasing fanner participation in the development of practical and appropriate crop management strategies and technology, SADC national programs requested SMIP to conduct a regional workshop to enhance understanding of Farmer-Participatory Research (FPR) approaches. This workshop was held 7-11 Jul 1997, in Harare. Since this workshop, SMIP has assisted in promoting the use of FPR approaches in both crop management and crop improvement research.

Revision of extension recommendations

SMIP has collaborated in the revision of existing sorghum and/or pearl millet extension recommendations in Namibia, Swaziland, and Zimbabwe. Collaborative work with the national research program and the NGO World Vision International has also been undertaken in Mozambique. These efforts have focused primarily on refining plant density and fertilizer recommendations, although in Namibia and Mozambique, where recommendations for smallholder farmers did not previously exist, the work has addressed a broader range of crop management topics as well.

Given the very low rates of adoption of standard extension recommendations in countries across the region, and the concensus from the Recommendations Review Workshop (above) that the standard recommendations do not address farmers' primary constraints, efforts in this area have not, however, received a high priority. Rather, activity has focused on addressing the issue of greater fanner involvement in technology development (through FPR approaches) and in developing new strategies for crop management research as a whole. This process has been initiated in collaboration with the national program in Zimbabwe. Focusing on soil fertility, a new approach involves the use of FPR in understanding farmers' current systems and constraints, and in developing practical options for farmers. It also employs crop growth modeling to assess the sustainability and risk associated with different options. A significant change in crop management research strategy is required if real production increases are to occur at the farm level. Considerable expansion of this work is being proposed for the next phase of SMIP.

Discussion and conclusions

Approaches to technology exchange

While recognizing that technology development and adoption can only be achieved through strong national-level efforts, SMIP has been successful in developing collaboration between national and regional programs to assist and facilitate this process. In addition, the regional program has ensured that national programs have had access to the global knowledge base and germplasm resources, and this has been very important in the development of improved varieties. Within the SADC7 ICRISAT SMIP, the interaction among participating NARES has also led to the development of a strong defacto network of scientists that greatly facilitates the sharing of knowledge and technology across the region. The technology exchange process has been enhanced at both the regional and national levels.

Development and dissemination of improved varieties

Collaboration between the national programs and SMIP has been extremely successful in terms of the development, testing, and release of improved varieties of sorghum and pearl millet. With over 40 national-level variety releases in the last 15 years, the availability of improved varieties is no longer a major constraint.

SMIP has collaborated with the private sector, NARES, and others in the region in the development of seed systems to ensure that seed of the improved varieties is available to farmers. Significant levels of seed production are now occurring, leading to significant adoption. However, the availability of seed of the new varieties is still a major constraint to broader adoption in many countries of the region, and continued efforts to develop sustainable seed systems are required.

Revision of extension recommendations

Research in SMIP indicates that the adoption of a new variety alone may provide farmers with a 10-50% yield increase. Adopting the new variety together with improved crop management practices can provide a 100-300% yield increase. Thus, improved crop management is required both to capitalize on the yield potential of the new varieties, and to achieve the primary goal of increasing incomes and improving food security for smallholder farmers in the semi-arid areas of SADC.

Across the region, there is now consensus among scientists in sorghum and pearl millet research programs that it will not be sufficient to simply refine existing production recommendations. Rather, there is a need to address the issue with entirely new strategies. These new strategies include the need for an improved understanding of farmers' systems and constraints, and more farmer involvement in the development of practical options to address farmers' real constraints and needs.

The future

It is recognized that improved varieties and improved crop management technology alone will not be sufficient to achieve major increases in productivity at the farm level. Input supply systems (for seeds, fertilizers, etc.) will need to be improved, and output markets will need to be enhanced to provide the incentives and rewards for increasing farm production.

Thus, in Phase IV of SMIP it is proposed to continue collaborative research with NARES and other advanced research institutions on the important issues described above. But it is also expected that the existing partnerships will be significantly expanded to include other actors who can simultaneously assist in addressing the issues of input supply and product marketing and utilization. New partners in this process would include NGOs, the private sector, and an expanded range of public sector participants. A strong and effective network for communications, joint planning, and the sharing of information will be required for the effective coordination of activities by such a broad range of partners.

Collaboration among partners tends to increase in difficulty as the number of partners expands. Nonetheless, collaboration and cooperation are key to the process of technology exchange and are vital in effecting change at the farm level. In the next and last phase of SMIP, the objective will be to build on the strong regional partnerships developed to date, and expand these into an effective and sustainable system for the development and delivery of technology for the full range of end users.

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Sorghum Research Reports

Genetics and Plant Breeding

Genetic Diversity Among South African Sorghum Breeding Lines and Varieties

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The level of genetic diversity of South African sorghum (*Sorghum bicolor* (L.) Moench) breeding lines is mostly unknown. This information may improve the effectiveness of breeding programs with regard to placement in heterotic groups. Therefore, in this study 24 sorghum breeding lines and varieties commonly used in South African sorghum breeding were characterized using RAPD-PCR.

RAPD-PCR was carried out according to Ordon et al. (1997). Out of 60 RAPD-primers (Operon Technologies) tested, 12 primers showing distinct and polymorphic bands, i.e., OP-L03, OP-L05, OP-L08, OP-L15, OP-L18, OP-L19, OP-L20, OP-K7, OP-K13, OP-K17, OP-K19, and OP-K20, were used for the assessment of genetic diversity. RAPD-pattems were scored using the software package RFLPscan 2.0, and genetic similarity was estimated according to Nei and Li (1979). On the basis of these data UPGMA-clustering was carried out using the software package NYSYS-pc 1.7 (Rohlf 1992).

Data known about the origin and pedigrees of the lines tested are listed in Table 1.

Based on the analysis of 12 RAPD-primers corresponding to 246 different fragments ranging from 2587 bp to 378 bp, the genetic similarity (Nei and Li 1979) has been found to range between 0.740 (H2364 vs. H3761) and 0.933 (H3874 vs H4159). Association between the 24 genotypes calculated on these data by UPGMA-clustering are presented in Figure 1. In general, three groups of genotypes can be distinguished. The first group consists mainly of B-lines (maintainer lines) whereas the large cluster of R-lines (restorer lines) is subdivided into two clusters. With the exception of H3986, H1444, and H2364, all the lines and varieties were grouped according to their ability to restore or maintain male sterility. Furthermore, it is of interest to note that H2364, a restorer line that was obtained from Hungary, is more closely related to South African maintainer lines than the other restorer lines. The close relationship between some of the accessions indicates that these may have

Table 1. Origin and pedigree of South African sorghum lines analyzed for genetic similarity.

Accession	Pedigree/Origin	Accession	Pedigree/Origin
H1206 (R*)[1]	Tophand (S4)/USA	H1444(B**)	BTx2802/+
H1215(R)	RTx430/+	H2362 (R)	Framida/South Africa
H1987(R)	PN3/Malawi	H3761(R)	Local collection/Zambia
H3986(-***)	Tenant White/Lesotho	H498 (R)	Local collection/South Africa
H2520 (R)	IS 18479/++	H2541 (R)	ZSV-3/++
H677 (R)	Purdue 199012/USA	H1276(B)	BTx378/+
H1222 (R)	RTx432/+	H1436(B)	BTx2790/+
H3699 (R)	MSU Sel. 549/Lesotho	H1282(B)	BTx398/+
H1485 (R)	SCO 599-IIE/USA	H3102(B)	Tx2536YE/+
H2551 (R)	SDS 2690/++	H4000 (B)	Local collection/South Africa
H3874 (-***)	Zululand 3/South Africa	H1636(B)	BOK 8/USA
H4159 (R)	SPV 473/++	H2364 (R)	Early Kal/Hungary

1. * restorer;** maintainor;*** unknown; + Texas A&M University; ++ ICRISAT.

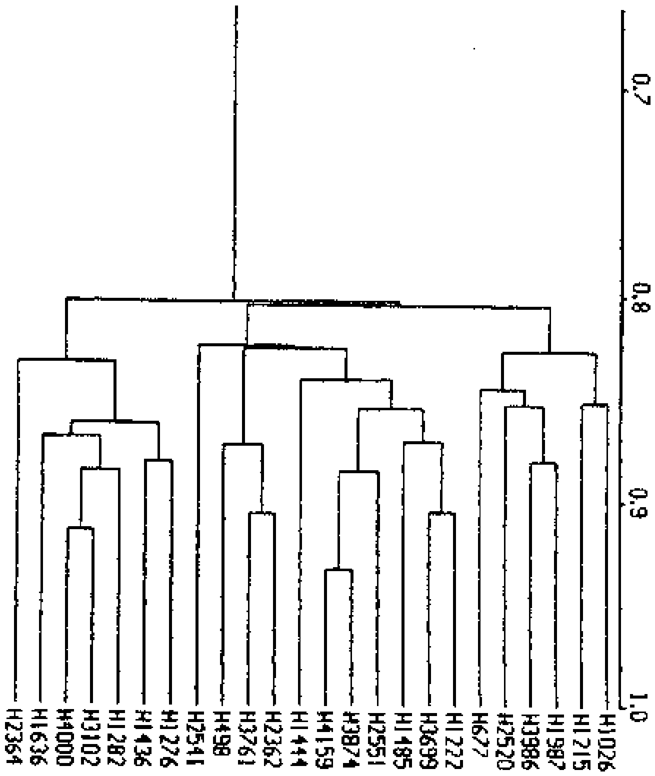

Figure 1. Association among sorghum breeding lines and varieties commonly used in South Africa revealed by cluster analysis performed on genetic similarity estimates (Nei and Li 1979) calculated from PCR data of 12 RAPD-primers corresponding to 246 bands.

similar origin or pedigree. These include PN3 from Malawi and Tenant White from Lesotho; Tophand (S4) and RTx430; RTx432 and MSU Sel. 549; Zululand-3 and SPV 475; Framida and the local collection from Zambia. Based on the results presented, RAPD-PCR, like RFLPs (Deu et al. 1994; Cui et al. 1995), can be considered an efficient tool for characterizing sorghum lines and germplasm at the DNA-level, enabling the establishment of heterotic groups in this important crop.

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Intensification of Tendency to Apomixis in Sorghum Autotetraploids

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A connection between polyploidy and apomixis is universally recognized but literature data are contradictory on artificial polyploidization influences upon manifestation of apomixis in cultivars. In sorghum (*Sorghum bicolor* (L.) Moench), polyembryonic seeds were found with an equal or lower frequency in autotetraploid analogues of three varieties compared with diploid analogues (Tsvetova and Ishin 1996). As polyembryony is a well-known marker of apomixis, these data suggests that in autotetraploid sorghums there is a tendency for apomixis to be lower than in diploids. An embryological study was undertaken to verify these findings.

Tetraploids of genotype k-3366/2 (*Sorghum nigricans* (Ruiz et Pavon) Snowd,) and a partially sterile line AS-1 (Elkonin et al. 1995) have been induced through treatment of shoot meristems with 0.2% aqueous colchicine for 24 h. In genotype Geltosernoye 10 (*S.* subglabrescens Schweinf. et Aschers.), tetraploids were induced by applications of nitrous oxide upon dividing zygotes (7 atms, 24 ins). Ovaries were fixed in an ethanol-acetic acid fixative (3:1) and stained with acetocarmine. The ovules were then dissected from the ovaries and embryo sacs (ESs) were obtained. For this investigation mature ESs were used.

Most of the tetraploid ESs had the same structure as found in diploid plants, but they were enlarged in comparison to those found in haploid plants. In some of the ES structures, anomalies typical for tetraploids were found: two nucleoli in egg cells, synergids or polar nuclei. In some cases, diploid ESs had one or three polar nuclei.

In the diploid and the tetraploid analogues of k-3366/2 some ovules contained additional ESs. The ESs from multiple ES arising from the same ovule had either approximately equal or different sizes. Sometimes one of the members of such a couple had symptoms of degeneration. In diploids, the percentage of such ovules was 4.3% and in tetraploids it was 3.0% (significant difference at 0.05% probability level).

In 1.24% of the tetraploid k-3366/2 ESs studied, synergids resembling egg-cells were found, whereas in diploid plants this anomaly was not found. In the tetraploid plants of Geltosernoye 10 about 5% of the ovules contained additional ESs versus 0.5% for the diploid plants. ESs of diploid plants were of equal size and situated near each other.

In five out of ten tetraploid Geltosernoye 10 plants, some ovules had considerably enlarged cells with one or two nuclei alongside the normal ES. These enlarged cells were located either near the antipodal region or near the micropolar end of the ES. They always maintained contact with the ES. The number and the size of such cells varied in different ovules.

Formation of additional structures was also observed in the ovules of almost all plants studied in the line AS-1 (Elkonin et al. 1995). Besides the additional ESs and enlarged cells with 1-2 nuclei, giant cells containing up to 10 nuclei (cenocytes) have been found in ovules of this line. In the material reported here, 3.4% of ovules in the diploid plants contained enlarged cells and 1.4% had cenocytic structures. In tetraploid plants, 7.5% of the ovules contained enlarged cells and 1.6% had cenocytic structures.

The additional enlarged cells or ESs associated with an individual meiotic ES may be interpreted as a manifestation of apospory, i.e., the development of ESs from somatic cells. In Geltosernoye 10 and AS-1, artificial polyploidization essentially strengthened a tendency to aposporous structure development.

In tetraploid analogues of k-3366/2, such structures have not been found. However, egg-cell-like synergids have been discovered that are connected with polyembryony and apomixis (Maheshwari 1950), and their increased frequency in ESs of the tetraploids also shows an intensification of tendency to apomixis.

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Nuclear Male-fertile Revertants Derived from a cms Sorghum Plant with Developmentally Regulated Levels of Male Fertility

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Male-fertile revertants are important for investigating structures and functions of the genetic systems controlling cytoplasmic male sterility (cms) in sorghum (*Sorghum bicolor* (L.) Moench).

Among the F_2 segregating population of the A_1 Saratovskoe-3/KVV-124 hybrid, we isolated a male-sterile plant The panicle on the main tiller of this plant was completely sterile. The immature panicle from one of its later tillers was used to obtain embryogenic callus cultures, while the donor plant itself was transferred from the field to the greenhouse. All 16 plants regenerated from callus cultures were also male sterile, thus confirming the male-sterile nature of the donor plant.

Table 1. Fertility level of different panicles and different parts of individual single panicles in the progeny of revertant fertile tillers obtained on male-sterile sorghum plant (combined data from two S_3, one S_4, and one S_5 families grown in 1996; in each family five plants were analyzed).

	Fertility level				
	Pollen fertility (% panicle part[1])		Seed set (no of panicles[2])		
Panicle	Middle	Base	S	PS	PF
N1 (main)	16.6a	35.1b	9	7	-
N2	30.6b	50.8cd	3	3	8
N3	40.5bc	58.4d	-	3	9
N4	44.4	62.4	-	2	4
N5	50.6	62.7	-	-	3
F panicle part		33.146*	T		0.185
F panicle number		15.045*	[X^2]		26.715*

1. Each value is a mean of 16 analyses for panicles N1 and N2,12 for N3.5 for N4, and 3 for N5. Means followed by different letters are significantly different (5% level) according to Duncan's Multiple Range Test. Data for panicles N4 and N5 were not included in the two-factorial variance analysis.
2. S = sterile. PS = partially sterile, F = fertile plants; T = Chuprov coefficient intended for determination of correlation between qualitative traits (Zaitsev 1984).

* Significant at $P < 0.05$.

After 6 months of growth in the greenhouse the donor plant began to produce fertile tillers. This plant continued to produce fertile tillers while growing in open air conditions during the following season. This fertility was inherited in the progeny of fertile tillers. Of three fertile panicles that were studied, approximately 50% of the offspring in the progenies consisted of partially-sterile plants (S_1 generation). In the S_2 generation of the progenies of these S_1 plants, fertile forms were observed, which points to the genetic nature of reversion to male fertility observed during growing the donor plant in the greenhouse. Testcrosses *of* partially-sterile plants from the S_1 and S_2 generations to the cms-line A, Saratovskoe-3 showed that induced fertility is transmitted through the pollen, and therefore is conditioned by mutation of nuclear gene(s).

The majority of plants in each generation (S_1-S_5) usually had sterile or partially-sterile main panicles, while the panicles on the next tillers had higher fertility rates. Careful analysis of pollen taken from different parts of the panicle showed that the base of the panicle has significantly more fertile (stainable) pollen than the middle part; in addition, the later the panicle was formed, the greater the amount of fertile pollen it had (Table 1). The highest fertility levels were found in later-developed panicles, and seed set data confirmed this observation.

These data show that male-sterile plants, which appear in segregating generations as a result of recombination of recessive nuclear gene(s) and sterile cytoplasm, may be genetically unstable under artificial prolongation of their ontogenesis in greenhouse conditions. The described mutation induces developmentally regulated reversion to male fertility. Perhaps mutated nuclear genes are sensitive to any environmental changes (e.g., temperature, photoperiod), and anthers in different panicles, which develop in different conditions, express various fertility levels. Examples of similar environmentally sensitive male-sterile mutants are well known in other plants (Murai and Tsunewaki 1993; Sun et al. 1993). Another supposition is that a mutated gene encodes a product that accumulates slowly during plant development, and gradually restores fertility of late-developed panicles. Research is currently underway to address these issues.

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Performance of Sorghum Hybrids under Rainfed Conditions in Andhra Pradesh, India

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Sorghum (*Sorghum bicolor* (L.) Moench) is second to rice (*Oryza sativa* L.) in Andhra Pradesh and is important both for its grain and fodder. In the 1996/97 rainy season it was grown in an area of 388 000 ha as a rainfed crop. Low productivity is one of the reasons for its steady decline in the state.

With the objective of releasing high yielding dual-purpose sorghum hybrids (for both grain and fodder), 56 hybrids were obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and tested under rainfed conditions along with 6 controls (3 hybrids and 3 varieties) at the Regional Agricultural Research Station, Palem, during the 1996 rainy season. The soil was black loam and the experimental design employed randomized block design with two replications. The rainfall received during the crop period was 704 mm.

The hybrids differed significantly (P = <0.01) both for grain and dry fodder yields. The hybrid ICSA 101 x ICSR 172 recorded the highest grain yield (4.97 t ha^{-1}) but the fodder yield was low (10.7 t ha^{-1}). On the other hand, the hybrid ICSA 101 x ICSR 165 registered the highest fodder yield of 23.1 t ha^{-1} but the grain yield was low (1.76 t ha^{-1}). Among the controls, CSH 6 recorded the highest grain yield and CSH 13 the highest fodder yield. Since the demand is for dual-purpose sorghum, the top 10 hybrids significantly superior to both controls for both grain (CSH 6) and fodder yields (CSH 13) are presented in Table 1. The first three hybrids listed are statistically on par with each other with respect to grain yields but they differ significantly for fodder yields. Hence ICSA 77 x ICSR 62 and ICSA 84 x ICSR 62 were chosen for futher evaluation during the 1997 rainy season due to their superior fodder yields over ICSA 102 x ICSR 91034.

Table 1. Sorghum hybrids significantly superior (P= 0.01) to the best check (CSH 6 for grain yield and CSH 13 for fodder yield) at the Regional Agricultural Research Station, Palem, India, during the 1996 rainy season.

Hybrid	Grain yield (t ha^{-1})	Percentage of the best check	Fodder yield (t ha^{-1})	Percentage of the best check
ICSA 102 xICSR 91034	4.12	168	19.4	173
ICSA 77 x ICSR 62	3.84	157	21.8	194
ICSA 84 x ICSR 62	3.71	152	23.6	210
ICSA 93 x ICSR 91034	3.65	149	18.1	161
ICSA 55 x ICSR 62	3.43	140	17.1	153
ICSA 89 x ICSR 155	3.36	137	16.0.	143
ICSA 93 x ICSR 172	3.06	125	15.5	138
ICSA 84 x ICSR 165	2.93	120	19,5.	174
ICSA 88006 x ICSR 194	2.89	118	14.9	133
Checks				
CSH 6	2.45	100	8.6	77
CSH 9	2.08	85	10.9	97
CSH 13	2.04	83	11.2	100

Review and Perspective on Sweet Sorghum Breeding in China

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Introduction

Sweet sorghum is a type of grain sorghum (*Sorghum bicolor* (L.) Moench) belonging to *Graminaceae,* It is taller than grain sorghum and the stem is full of sweet juice. The yield of the stem and leaf is high, reaching 52.5-75.0 t ha^{-1}, with grain yields of 4.5-7.5 t ha^{-1}. It is suitable for feeding to animals as forage, silage, and hay.

Sweet sorghum has a long history of cultivation, both in China and abroad. Large areas are cultivated in USA and the former USSR, Mexico, India, and Japan. The stalk is usually used for refining into syrup or as livestock feed. Despite the long history of cultivation in China, little attention has been paid to it because of its minor economic importance, and there has been little improvement made in the local varieties. Since the 1970s, some improved sweet sorghum varieties have been introduced from abroad, such as Rio, Roma, Ramada, and Wray, and some agricultural colleges and institutes have begun research into sweet sorghum breeding. The Sorghum Institute, Liaoning Academy of Agricultural Sciences began research in 1985, and successfully bred and released the new hybrids Liaosiza No. 1 in 1989 and Liaosiza No. 2 in 1995.

Review of sweet sorghum breeding

Along with social progress, economic development, and the elevation of science and technology, animal husbandry has become increasingly important in the rural and national economies. Our country is short of arable land, resulting in serious competition between forage and grain crops for land. The replacement of forage crops and degeneration of pasture has caused a feed deficit, limiting the development of animal husbandry. In 1985 we commenced research on sweet sorghum breeding in order to solve the feed shortage problem and promote the development of animal husbandry.

Cross breeding was first conducted with a number of germplasm resources collected from China and other countries. In 1985, adopting the conventional hybridization breeding method, a number of sterile lines and approximately 100 restorer lines were crossed. The combination ATx622 *x* 1022 produced excellent results in the identification nursery, and in December 1989 was released by the State Forage Variety Determining and Approving Committee and named 'Liaosiza No. 1'.

Through varietal comparisons, regional tests, production experiments, and demonstrations inside and outside the province, this hybrid was adopted because of its high yield, good quality, and wide adaptability. The yield of fresh stems and leaves is 52.5-65.0 t ha^{-1}, and grain yield is 4.5-6.0 t ha^{-1}. Compared to the popular silage maize (*Zea mays* L.) variety White Crane, the stem-leaf yield is 20-33% higher when grown on reclaimable pasture, the stem-leaf yield increased 6-8 times over the pasture yield, and grain yield was 3750-4500 kg ha^{-1}. When compared to maize silage of White Crane, silage of Liaosiza No. 1 had higher levels of nutrients: crude protein increased by 0.78%, crude lipid by 1.26%, N-less exudate by 5.06%, and sugar content (Brix degree) by 10%. In feeding trials for dairy cattle, milk yield increased by an average of 0.55 kg day^{-1} per cow and the fat content of milk increased by 0.12%. This variety can be grown on arable land, grassland, and light saline-alkali soils in Liaoning, Tianjin, Beijing, Hebei, Shandong, Hefei, Hangzhou, Liouzhou, Changchum, and Jiamusi districts.

From 1990 to 1991, more than 20 institutions, such as the Provincial Agri-Reclamation System Ensilage Task Cooperation Team and the Provincial Pasture System New Feed Exploitation Cooperation Team, collaborated on popularization of Liaosiza No. 1 over 3828 ha by 1991; the total economic benefit attained amounted to 5.526 million yuan. After popularizing this variety on reciaimable pasture (where it is impossible to grow maize) by the provincial pasture system team, the number of sheep fed with this forage increased from 4.35 to 21.45 ha^{-1}. Using the strong regeneration capacity of Liaosiza No. 1, dairy farms in Liouzhou, Hefei, and Hangzhou increased forage yields of sorghum silage by over 15.0 t ha^{-1} compared to maize silage. At the same time, Jinzhou Beishan Animal Farm used the juicey and sweet Liaosiza No. 1 mixed with maize straw to make silage for livestock feed, elevating the utility value of the dry and yellow maize straw. In 1993, Liaosiza No. 1 received the second prize for science and technology progress awarded by the Agriculture and Animal Husbandry Department, Liaoning Provincial Government.

Over the course of several years, the combining ability of the male-sterile lines LSIA, LS2A, LS3A, LS4A, LS5A, and such restorer lines as Rio, Roma, and 1022 was tested. Among the the male-sterile lines, LS3A performed better than others, and the combination LS3A x Rio was the best. From 1988 to 1994, through a series of tests, this combination (LS3A x Rio) attained the required quality criteria, with the following indices: LS3A x Rio are as follows: juice extracted = 65%, sugar content in stem = 15.5% (BX), protein in total dry weight = 2.5%, and hydrocyanic acid in stem and leaves <500 ppm (this data was obtained from the analysis center in Liaoning Academy of Agriculture Sciences). In addition, the silage yield of LS3A x Rio reached 52.5-75.0 t ha^{-1}. This variety is highly resistant to head smut (*Sphacelotheca reiliana*) (the disease has never been found in seven years of research inside and outside the province), shows low levels of leaf diseases, is resistant to lodging, and widely adaptable. In China, it can be grown in Liaoning, Hebei, Henan, Anhui, Shandong, Guangxi, and Jilin. In 1995, this variety was recommended by the State Forage Variety Determining and Approving Committee as an improved hybrid cultivar and named Liaosiza No. 2.

Liaosiza No. 1 and Liaosiza No. 2 have been widely sown throughout China, and some excellent new hybrid combinations have been made such as 24A x 1022. These combinations show promise for future production.

Looking back on more than 10 years of forage sorghum breeding, much has been achieved, but many problems remain to be overcome, such as lack of funding, shortage of materials, difficulty in popularization, and so on.

Perspective on sweet sorghum breeding

With increased production and the elevation of living standards, the composition of the human diet in China has changed from mainly grain to meat, milk, and eggs, which places greater demand on the development of animal husbandry. In order to do this, sufficient feed is necessary, and sweet sorghum has bright prospects as a silage crop.

Compared with other crops, sweet sorghum has many advantages:

High-yield and good quality. Because of its height, robustness, juiciness, and stay-green nature, the silage yield of sweet sorghum reaches 52.5-75.0 t ha^{-1}, much higher than maize, In addition, the grain yields reach 4.5-7.5 t ha^{-1},with such nutrient levels as digestible crude protein, crude fat, and N-less exudates, similar to maize.

Strong resistance to biotic and abiotic factors Sweet sorghum is much more tolerant to drought, waterlogging, and saline-alkali soils than maize, and it is also highly resistant to leaf diseases and head smut.

Wide adaptability. Sweet sorghum has high tolerance to drought, waterlogging, and saline-alkali soil, so it can be sown on arable land, pasture, and light saline-alkali soil. Because of the advantageous climate in China, as long as the variety is appropriate, sweet sorghum can be grown throughout the country, from Hainan Island to Heilongjiang, and from Shandong to Xin jiang.

Ensilage of sweet sorghum mixed with maize stalks may elevate quality. Because of its juicy and sweet property, sweet sorghum can remedy the defects of maize. Mixed silage has excellent quality, is full of nutrients, easy to digest, and is particularly palatable to dairy cattle.

Rotation of grass and feed crops. Although China has a large population and limited arable land, 26 million ha of prairie and unreclaimed land can be used for growing sweet sorghum as a forage crop in rotation with pasture grasses. Thus the competition for land between forage crops and grain crops may be reduced.

The advantages of sweet sorghum should be enhanced in the course of breeding. Improved hybrids and varieties of different maturity periods (early, medium, and late) and different utility types (forage, silage, and forage-grain) should be bred as soon as possible to meet the needs of different districts. In addition, cultural practices such as sowing, density, and cultivation should be improved further, to enhance production and serve the development of agriculture and animal husbandry.

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A New Early-maturing Grain Sorghum cms Line A_2 KW-181 and F_1 Hybrid 'Volgar' for the Volga Region of Russia

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Sorghum (*Sorghum bicolor* (L.) Moench), a unique drought-tolerant crop, is very important for the extremely arid Volga Region of Russia. The geographical location (48-54°N) and climatic conditions of this region (a short period between spring and autumn frost of approximately 120 days) determine specific characters of sorghum cultivars and hybrids. They must have a short vegetative period (95-105 days) under long days (a 15.5-16.5 h light period during the photoperiod-sensitive stage of plant development), and should be able to grow with median day air temperatures of 19-20°C. To ensure stable grain yields in these restrictive environmental conditions, sorghum plants must be cold tolerant and extremely photoperiod insensitive in order to start flowering 45-50 days after seedling emergence.

A number of lines and cultivars adapted to these environmental conditions were developed during the past 30 years by A G Ishin, G I Kostina, and coworkers (Kostina 1992). However, development of heterotic hybrids was impeded because of the absence of early-maturing cytoplasmic-nuclear male-sterile (cms) lines. All developed early-maturing lines and cultivars are fertility restorers of the A_1 cytoplasm. However, use of alternative cms-inducing cytoplasms (A_2, A_3, A_4, and 9E) allowed us to create sterile analogous of several agronomically important lines (Elkonin et al. 1995).

The cms line A_2KVV-181 was created by repeated backcrossing of line KVV-181 to A_2Tx398, which was kindly donated to us by K Schertz of Texas A&M University, USA. Recurrent parent line KVV-181 was obtained by individual selection from the hybrid population Rosinka-2 x Feterita k-2812. Rosinka-2 was the donor of photoperiod insensitivity, while Feterita k-2812 was a donor of cold tolerance. A_2KVV-181 is an early-maturing line (46 days to anthesis), with a height of 100-120 cm; it has several productive tillers (2.8-2.9), leaves with white midrib, and an awnless panicle on a long peduncle (17-20 cm), with large white round kernels (27-35 g 1000^{-1}) with a starchy endosperm.

Pollination of A_2KVV-181 by another early-maturing line, Volzhskoe-4w, which is a fertility restorer of the A_2 cytoplasm and possesses waxy endosperm, produces an F_1 hybrid that combines early maturity with high grain yield. This hybrid, named 'Volgar', has plant height of 150-196 cm (depending on the season), 54-55 days to anthesis, 1.5-2.2 productive tillers, well exserted (10-15 cm) awnless panicles, with creamy-white grain color, grain mass of 22-25 g 1000^{-1}, semiwaxy endosperm, and grain yield of 5.0-6.3 t ha^{-1}. Two years' replicated

Table 1. Comparative trials of the F_1 hybrid Volgar (A_2KVV-181 x Volzhskoe-4w) and the cultivar Volzhskoe-4 registered for the Volga Region, Russia.

		Vegetative period		
	Year	Days to 50% anthesis	Days to complete maturation	Grain yield (t ha^{-1})
A_2KVV-181 x Volzhskoe-4w	1996	55	100	5.0
Volzhskoe-4		57	102	4.2
LSD (0.05)				0.3
A_2KVV-181 x Volzhskoe-4w	1997	54	99	6.3
Volzhskoe-4		56	101	4.0
LSD (0.05)				0.2

trials with Volgar exeeded the best previously registered cultivar, Volzhskoe-4, in grain yield by 20-60% while also being earlier by 2-3 days (Table 1).

Thus, use of the cms-inducing A_2 cytoplasm permitted us to create male-sterile analogs of photoperiod-insensitive early-maturing lines and a hybrid that are adapted for growing in the Volga Region of Russia, one of the harshest regions for growing sorghum.

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Bird-resistant Grain Sorghum A- and B-line Inbreds Released as Germplasm

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Eighteen grain sorghum (*Sorghum bicolor* (L.) Moench) cytoplasmic-genetic male-sterile A-line and maintainer (B-line) pairs of inbreds with bird-resistant characteristics have been released as germplasm by the Mississippi Agricultural and Forestry Experiment Station (MAFES). These lines, designated AMP 457 to AMP 474 and BMP 457 to BMP 474, were developed by L M Gourley with joint funding from MAFES and the International Sorghum and Millet (INTSORMIL) Collaborative Research Support Program (CRSP) at Mississippi State, Mississippi. The source of the bird resistance (tannins) was from the B-line, Combine Sagrain. The pedigree system of plant breeding was used to develop all of the maintainer line inbreds (B-lines). All of the A-lines are in A_1 cytoplasm.

All of the 18 lines have a pigmented testa (tannins) and will, when crossed with any R-line, produce bird-resistant hybrids. Although all of the inbreds are photoperiod insensitive, selections were made in the Colombian INTSORMIL project and the A-lines could be used as seed parents of hybrids in tropical countries where bird depredation of sorghum is severe. The tannins of grain from bird-resistant cultivars can be eliminated as antinutritional factors by traditional sorghum preparation techniques, such as treatment with lye or wood ashes, used in countries where these types of cultivars are consumed by humans.

These 18 bird-resistant inbreds represent selections from a cross between BTx623 and a high tannin source line, Combine Sagrain. The presence of a pigmented testa indicates that all of the inbreds contain tannins and are bird resistant.

Germplasm quantities (approximately 100 seeds per inbred) of the 18 A- and B-line pairs will be distributed, upon request, by Dr C Watson, Chairman, Plant Materials Release Committee, PO Box 9653, Mississippi State University, Mississippi State, MS 39762, USA. Those requesting seed must agree to supply, upon request, information about breeding behavior, desirability, and usefulness of the material and to cite it as the origia of useful derived lines and hybrids. A fee of US$ 100 for all 18 pairs of A- and B-lines will be charged to commercial seed companies requesting this released sorghum germplasm to help defray seed increase and handling expenses. Public institutions will be provided seed without charge.

Brown-midrib Grain Sorghum A- and B-line Inbreds Released as Germplasm

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Eleven brown-midrib (*bmr*) grain sorghum (*Sorghum bicolor* (L.) Moench) cytoplasmic-genetic male-sterile (A-line) and maintainer (B-line) pairs have been released as germplasm by the Mississippi Agricultural and Forestry Experiment Station (MAFES). These lines, designated AMP 446 to AMP 456 and BMP 446 to BMP 456, were developed by L M Gourley with joint funding from MAFES and the International Sorghum and Millet (INTSORMIL) Collaborative Research Support Program (CRSP) at Mississippi State, Mississippi. The source of the recessive *bmr* mutants in these lines was from the Purdue University Sorghum Improvement Program. The pedigree system of plant breeding was used to develop all of the maintainer line inbreds. All of the A-lines are in A_1 (milo) cytoplasm.

Brown-midrib plants produce less lignin than normal plants, making the forage from these plants more digestible by ruminants. All of the inbred pairs within this group are double *bmr* mutants except two (AMP/BMP 455 and AMP/BMP 456), which contain a single *bmr* gene. The double mutants represent sources of two nonallelic *bmr* genes (*bmr-6* and *bmr*-17, which are allelic, and *bmr-12* and bmr-18, which are allelic). The *bmr* genes in the double mutants were verified using crosses with A-lines having one *bmr* gene (AMP 11 to AMP 21). The single mutant inbreds contain only the *bmr-6* or *bmr-17* gene. Although not fully tested, some of these germplasm sources have shown lignin reductions of up to 40% according to Van Soest fiber analyses.

Several hundred *bmr* selections were backcrossed a minimum of five times into an A_1 source of cytoplasmic-genetic male-sterile cytoplasm. Each generation potential A-lines that produced any seed when self-pollinated were discarded. Brown-midrib forage hybrids can be produced using these A-lines and pollinator lines with a corresponding recessive *bmr* gene.

Germplasm quantities (approximately 100 seeds per inbred) of the 11 A- and B-line pairs will be distributed, upon request, by Dr C Watson, Chairman, Plant Materials Release Committee, PO Box 9653, Mississippi State University, Mississippi State, MS 39762, USA. Those requesting seed must agree to supply, upon request, information about breeding behavior, desirability, and usefulness of the material and to cite it as the origin of useful derived lines and hybrids. A fee of US$ 50 for all 11 pairs of A- and B-lines will be charged to commercial seed companies requesting this released sorghum germplasm to help defray seed increase and handling expenses. Public institutions will be provided seed without charge.

Distribution of Sorghum Germplasm Lines Tx5001 through Tx5030

W L Rooney and F R Miller (Department of Soil and Crop Science, Texas A&M University, College Station, TX 77843-2474, USA)

The Texas Agricultural Experiment Station, Department of Soil and Crop Sciences, Texas A&M University, College Station, Texas, made available 30 sorghum (*Sorghum bicolor* (L.) Moench) germplasms in April 1998. These germplasm lines were selected for distribution based on their agronomic desirability and unique combinations of disease resistances, grain quality, and plant-based traits of importance to sorghum breeders.

The pedigrees for the 30 lines are diverse (Table 1). All lines were developed from intentional crosses using standard pedigree selection. All lines were selected from F_2 populations grown in College Station, Texas, from 1979 to 1989, and selections in the F_3 generation and beyond were made in several locations. The exact location of selection of each generation can be determined from the letter abbreviations present in the pedigree of each line (Table 1). The locations that these lines were selected in include but are not limited to Weslaco (W), Texas; Corpus Christi or Beeville (B), Texas; College Station (C), Texas; Lubbock (L), Texas; Halfway (H), Texas; and Isabela (T), Puerto Rico. In most cases, the lines were selected in several environments in different years. Final selections were made in Corpus Christi, College Station, or Halfway. The generation of final selection in this material ranges from the F_5 to the F_{15}. Since the final selection, seed has been maintained in College Station.

Most of the parents involved in the cross have publicly released materials in their pedigree with the following exceptions: [EBA1 = Argentinian-derived germplasm (zera-zera)]; [B8201-3 = breeding line: good leaves, bright grain]; [B8203 = breeding line: good leaves, combining ability]; [SC326-6 = IS3758 (caudatum): excellent general disease resistance]; [QL3-India = reselection in QL-3 with resistance to all races of downy mildew *Peronosclerospora sorghi* (Weston & Uppal) C.G Shaw tested in Texas]; [TP21RB02 = breeding line selected for grain quality]; and [R6956 = breeding line: disease resistance, green leaf retention].

Agronomic desirability ratings for each of the lines were made in either Corpus Christi or College Station in 1996 and 1997 (Table 2). Of the 30 germplasms, 12 are B-lines, 17 are R-lines, and Tx5003 has not been tested

Table 1. Official designations, evaluation designations, pedigrees, and fertility reaction (R = restorer, B = maintainer) in A_1 cytoplasm of sorghum germplasm lines Tx5001 through Tx5030.

Designation	Source	Pedigree	Fertility reaction
Tx5001	97BE401-BK	(Tx2895 × (Tx430 × Tx2816)-1-1-5-3-1-C1-CBK × EBA1)-F1-B3-B1-B1	R
Tx5002	97CA576-BK	((BTx378 × SC110)-2-3-4-2-3-7-3-2-2-2-1 × BTx623)-C2-B8-B1-B1-B1-B1-T1-B2-B2-B1-B1-B1-B3	B
Tx5003	97CA718-BK	((BTx3197 × SC170) × SC748-5)-2-1-1-2-3-B1-B1-B1-B1-B1-B2-B2-B1-B1-B1-B1	-
Tx5004	97CA1115-BK	(Tx2894 × Tx433)-F2-B13-B1-B1-B3-B1-B1-B2-B2-B1-B1-B2-B1	R
Tx5005	97CA1176-BK	(BTx623 × B8201-3)-F2-B11-B1-B1-B2-B2-B2-B3-B1-B1-B1-B1	B
Tx5006	97CA1253-BK	((B2Tx632 × Tx430)-4-1-2-1 × SC414-12E)-F2-B4-B1-B1-B1-B3-B1-B1-B3-B2-B1-B4-B2	R
Tx5007	97CA1405-BK	(BTx631 × BTx623)-CF2-B7-B1-B2-B3-B2-B1-B3-B2-B2-B3-B3	B
Tx5008	97CA1504-BK	(BTx399 × BTx626)-CF2-B7-B4-B2-B2-B3-B4-B3	B
Tx5009	97CA1994-BK	(IS9530 × B8203)-F2-B7-B1-B2-B2-B1-B1-B2-B2-B2-B1-B1	B
Tx5010	97CA2082-BK	(B2Tx637 × Tx435)-CF2-B11-B2-B3-B1-B1-B2-B1	R
Tx5011	97CA2127-BK	(B2Tx637 × Tx435)-CF2-B6-B1-B2-B1-B1-B2-B2	R
Tx5012	97CA2226-BK	(((SC120-6 × Tx7000) × Tx7000)-10-4-6-2-2-1 × EBA1)-CF2-B6-B1-B5-B1-B1-B1-B2	R
Tx5013	97CA2822-BK	(Tx436 × Tx435)-CF2-B6-B1-B1-B2-B3	R
Tx5014	97CS4779-BK	(B8201-3 × QL3-India)-F2-B8-B1-B1-B1-B1-T1-C3-C7-C2-C3-C1	B
Tx5015	97CS4802-BK	(Tx432 × Tx2858)-F1-C5-C3-C2	R
Tx5016	97CS4858-BK	((B2Tx632 × SC103-12E)-C1-B4-B1-B4-B1 × B2Tx637)-F1-C9-C1-C1	R
Tx5017	97CS5078-BK	((Tx430 × SC326-6)-1-1-2-6 × Tx435)-GF1-CF20-CBK	R
Tx5018	97CS5116-BK	(BTx631 × BTx629)-CF2-B6-B1-B2-T2-L1-C2-C1	B
Tx5019	97CS5308-BK	(BTxARG-1 × BTx631)-F1-C4-C1-L2	B
Tx5020	97CS5317-BK	TP21RB02-106-3-1-2-2-H2-C3-C2-C1-C2-C1-C1-C1-C1	R
Tx5021	97CS5448-BK	((Tx430 × Tx2816)-1-1-5-3 × Tx435)-10-2-C1	R
Tx5022	97CS4953-BK	(SC599-11E × R6959)-F2-B1-B3-B1-B1-B1-T1-CBK	R
Tx5023	97CS5551-BK	(BTx630 × BTx631)-CF2-B6-B3-B2-B5-B1-B1-L1	B
Tx5024	97CS5600-BK	((BTx631 × B-Combine Sagrain)-CF2-B2-B1-B1 × BTxARG-1)-F1-B3-B1-B2-L1	B
Tx5025	97CS5611-BK	(BTx631 × BTxARG-1)-F1-B3-B1-B2-L2	B
Tx5026	97CS5625-BK	((BTx631 × BTx626)-CF2-B11-B2 × BTxARG-1)-F1-B2-B2-B1-L1	B
Tx5027	97LB136-BK	(((SC120-6 × Tx7000) × Tx430)-4-1-1-2-OP-2 × Tx435)-5-4-L7-B1-B2-B3-B2-B1-LBK	R
Tx5028	97LB194-BK	((Tx2817 × EBA1)-CF2-B10-B1-B1 × Dorado)-F1-B1-B4-B1-L1	R
Tx5029	97BKBR20	((Tx434 × SC414-12E)-F2-B9-B2-C1-C1 × Tx430)-CF2-B4-B3	R
Tx5030	97BKBR24	((Tx430 × Tx2536)-1-1-3-2 × Tx435)-CF2-B11-B2-B1-B2-B3-B1-B2-B1-B2-B1	R

Table 2. Plant, grain, and agronomic characteristics of sorghum germplasm lines Tx5001 through Tx5030.

Designation	Plant color[2]	Epicarp color[3]	Mesocarp thickness[4]	Endosperm type[5]	Maturity[6]	Plant height (cm) Corpus Christi	Plant height (cm) College Station	Desirability rating[1] Corpus Christi 1996	Desirability rating[1] Corpus Christi 1997	Desirability rating[1] College Station 1996	Desirability rating[1] College Station 1997
Tx5001	T	Wh	-	N	M	102	—	—	1.33	—	—
Tx5002	P	R	+	N	E	94	—	1.30	1.40	—	—
Tx5003	P	LY	-	N	M	86	—	1.50	1.37	—	—
Tx5004	T	R	+	N	ME	94	—	1.60	1.30	—	—
Tx5005	P	R	+	N	M	97	—	1.47	1.33	—	—
Tx5006	P	Wh	-	N	M	86	—	1.40	1.23	—	—
Tx5007	T	Wh	-	Y	M	102	—	1.50	1.37	—	—
Tx5008	P	R	+	N	ME	99	—	1.40	1.37	—	—
Tx5009	P	R	+	N	M	97	—	1.53	1.33	—	—
Tx5010	T	R	+	Y	M	84	—	1.30	1.33	—	—
Tx5011	P	R	-	N	M	99	—	1.23	1.30	—	—
Tx5012	T	Wh	-	Y	ML	84	—	1.20	1.33	—	—
Tx5013	T	Wh	-	N	ML	86	—	1.40	1.30	—	—
Tx5014	P	R	-	N	M	—	109	—	—	1.37	1.33
Tx5015	P	Wh	+	N	M	—	97	—	—	1.47	1.30
Tx5016	T	R	+	N	M	—	111	—	—	1.30	1.30
Tx5017	T	Wh	-	Y	ML	—	107	—	—	1.43	1.33
Tx5018	T	Wh	+	N	M	—	120	—	—	1.50	1.40
Tx5019	T	Wh	-	N	M	—	112	—	—	1.47	1.33
Tx5020	T	Wh	-	N	M	—	109	—	—	1.33	1.30
Tx5021	T	Wh	-	Y	M	—	112	—	—	1.47	1.33
Tx5022	T	Wh	-	N	M	—	112	—	—	1.47	1.37
Tx5023	T	Wh	-	N	M	—	112	—	—	1.30	1.33
Tx5024	T	Wh	-	W	ML	—	99	—	—	1.50	1.40
Tx5025	T	Wh	+	W	M	—	120	—	—	1.50	1.40
Tx5026	T	R	+	W	E	—	97	—	—	1.30	1.37
Tx5027	T	R	+	N	ML	—	102	—	—	1.47	1.27
Tx5028	T	Wh	-	N	M	—	102	—	—	1.47	1.33
Tx5029	P	R	-	N	ML	91	117	—	1.33	1.30	1.30
Tx5030	T	Wh	+	N	M	97	107	—	1.33	1.40	1.30
Tx430 (control)	T	Wh	-	Y	M	95	110	1.60	1.53	1.50	1.47
Tx631 (control)	T	Wh	+	N	ML	110	122	1.53	1.60	1.50	1.53

1. Desirability rating: 1.0 = best; 5.0 = worst.
2. Plant color: P = purple; T = tan.
3. Epicarp color: R = red; Wh = white; LY = lemon yellow.
4. Mesocarp thickness: + = present; - = absent.
5. Endosperm type: N = normal; Y = yellow; W = waxy.
6. Maturity: E = early; ME = medium early; M = medium; ML = medium late.

in the A_1 cytoplasmic-genetic male-sterility system (Table 1). These lines are variable for several important agronomic characteristics (Table 2). Nineteen lines have tan plant color and 16 have a white epicarp. None of the lines has a pigmented testa. In general, this material has good green leaf retention, agronomic desirability, and resistance to insecticide phytotoxicity. While none of the lines has been tested in hybrid combinations they are suitable for evaluation in hybrid combination or for use as parents in sorghum breeding programs.

These materials possess varying levels of resistance to anthracnose caused by *Collatorichum graminicola* (Cesati) Wilson for pathotypes in Texas. They also possess varying levels of resistance to head blight caused by *Fusahum* spp, rust caused by *Puceinia purpurea* Cooke, leaf blight caused by *Exserohilum turcicum* Leo and Sug., downy mildew caused by *P. sorghi* except pathotype-3, and show tolerance to head smut caused by *Sphacelotheca reiliana* (Kuhn) Clinton. Several of the lines have improve tolerance to grain mold caused by *Curvularia* spp and *Fusarium* spp.

Research leading to the development of Tx5001 through Tx5030 was supported by grants from the Texas Grain Sorghum Producers Board. Initial research and development were supported by INTSORMIL. The authors would like to acknowledge the efforts of the Texas A&M sorghum improvement program staff in the development of this germplasm. Breeder seed will be maintained at the Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843-2474, USA. Seed orders can be made by contacting the Sorghum Breeding Program, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843-2474, USA. Telephone: (409) 845-2151; fax: (409) 862-1931.

Food Grain Quality Grain Sorghum A- and B-line Inbreds Released as Germplasm

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Twenty-three grain sorghum (*Sorghum bicolor* (L.) Moench) cytoplasmic-genetic male-sterile (A-line) and maintainer (B-line) pairs of inbreds with food grain quality characteristics have been released as germplasm by the Mississippi Agricultural and Forestry Experiment Station (MAFES). These lines, designated AMP 475 to AMP 497 and BMP 475 to BMP 497, were developed by L M Gourley with joint funding from MAFES and the International Sorghum and Millet (INTSORMIL) Collaborative Research Support Program (CRSP) at Mississippi State, Mississippi. The sources of food grain quality were from U.S. public releases or germplasm from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The pedigree system of plant breeding was used to develop all of the maintainer line inbreds. All of the A-lines are in A_1 (milo) cytoplasm.

Food grain quality is a relative term and depends upon how the sorghum grain is processed into food products. As used to describe these inbreds, the seed generally have a white or translucent pericarp, absence of a testa, and a relatively high proportion of corneous-to-floury endosperm. The plants will generally have a tan plant color to avoid pigments that might discolor the grain.

These 23 photoperiod-insensitive, food-grain quality lines were developed to be used as cultivars or as seed-parent lines of hybrids. Developed in the INTSORMIL project in Colombia, these germplasm selections are from crosses of ICRISAT by elite U.S. B-line sources, except for AMP and BMP 493 to 497, which are selections from the cross BTx623 x Combine Sagrain. All of the inbreds have grain with a white epicarp, no testa, and have a tan plant color except for AMP and BMP 493 to 497, which have purple plant color.

Germplasm quantities (approximately 100 seeds per inbred) of the 23 A- and B-line pairs will be distributed, upon request, by Dr C Watson, Chairman, Plant Materials Release Committee, PO Box 9653, Mississippi State University, Mississippi State, MS 39762, USA. Those requesting seed must agree to supply, upon request, information about breeding behavior, desirability, and usefulness of the material and to cite it as the origin of useful derived lines and hybrids. A fee of US$ 125 for all 23 A- and B-lines will be charged commercial seed companies requesting this released sorghum germplasm to help defray seed increase and handling expenses. Public institutions will be provided seed without charge.

Grain Sorghum A- and B-line Inbreds Tolerant to Tropical Acid Soils Released as Germplasm

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Twenty-eight grain sorghum (*Sorghum bicolor* (L.) Moench) cytoplasmic-genetic male-sterile A- and B-line pairs of inbreds with tolerance to aluminium saturation levels of tropical acid soils have been released as germplasm by the Mississippi Agricultural and Forestry Experiment Station (MAFES). These lines, designated AMP 418 to AMP 445 and BMP 418 to BMP 445, were developed by L M Gourley with joint funding from MAFES and the International Sorghum and Millet (INTSORMIL) Collaborative Research Support Program (CRSP) at Mississippi State, Mississippi. The source of the acid-soil tolerance was IS 7I73C (SC 283) from the Texas A&M/United States Department of Agriculture (USDA) Sorghum Conversion Program. The pedigree system of plant breeding was used to develop all of the maintainer line inbreds (B-lines). All of the A-lines are in A_1 (milo) cytoplasm.

Acid-soil tolerance was determined by evaluating the inbreds in the Colombian INTSORMIL project. Those genotypes that produced near-normal plants when grown in Colombia on soils with a pH <4.5 and an aluminium saturation level of *65%* or more were rated as acid-soil tolerant. Acid-soil sensitive sorghum genotypes were killed by these extremely toxic conditions.

These 28 A/B pairs, AMP and BMP 418 to AMP and BMP 445, represent selections from crosses between the most acid-soil tolerant B-line, IS 7173C; an experimental yellow endosperm line from Mississippi, B-Yellow PI; and a Wheatland derivative. The lines were evaluated for acid-soil tolerance in Colombia and are tolerant up to at least 65% Al^{+++} saturation. More than 400 acid-soil selections were backcrossed a minimum of five times into an A_1 source of cytoplasmic-genetic male-sterile cytoplasm. Each generation, potential A-lines that produced any seed when self-pollinated were discarded. Experimental hybrids with good acid-soil tolerance were produced using these A-lines crossed with susceptible R-lines, indicating that the tolerance was dominant.

Germplasm quantities (approximately 100 seeds per inbred) of the 28 A- and B-line pairs will be distributed, upon request, by Dr C Watson, Chairman, Plant Materials Release Committee, PO Box 9653, Mississippi State University, Mississippi State, MS 39762, USA. Those requesting seed must agree to supply, upon request, information about breeding behavior, desirability, and usefulness of the material, and to cite it as the origin of useful derived lines and hybrids. A fee of US$ 150 for all pairs of 28 A- and B-lines will be charged to commercial seed companies requesting this released sorghum germplasm to help defray seed increase and handling expenses. Public institutions will be provided seed without charge.

Release of Early Sorghum Seed Parents N250A, N251A, and N252A and their Respective Maintainer Lines

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The sorghum breeding program, Department of Agronomy, Institute for Agriculture and Natural Resources, University of Nebraska-Lincoln, on 23 Apr 1998 released three early maturing sorghum *(Sorghum bicolor* (L.) Moench) seed parents, N250A, N251A, and N252A, which are male sterile in the A, cytoplasmic-genetic male-sterility (cms) system (milo cytoplasm), and their respective maintainer B-lines. These lines provide new genetic diversity for very early maturing grain sorghum hybrids.

N250A and N250B (144-2A and 144-2B) were developed by pedigree selection from an early-maturing progeny, No. 1207, from Bill Ross's population NP2/6B. In 1983 the testcross of 84H1207 (precursor to 144-2) to line MA3 (A_1 cms—milo cytoplasm) was male sterile and the first backcross was made in developing the A-line. Eight backcrosses were made, first in the Mead program, then from 1990 in the Panhandle program at the High Plains Agricultural Lab (HPAL), Sidney, Nebraska. Testcrosses started in 1990 indicated good hybrid potential. Hybrids with N250A in trials at various locations in the Panhandle and South Dakota from 1994 to 1997 have performed competitively, with yields from 1.10-8.18 t ha^{-1}.

N251A and N251B (38084-2A and 38084-2B) were obtained by pedigree selection from a 1984 cross between early-maturing red-seeded A_1 maintainer line H1160 from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)/Centro Internacional de Mejoramiento de Mafz y Trigo (CIMMYT) cold-tolerant random-mating population and a late-maturing tan plant tropically adapted B-line from 1CRISAT called MB5 (a zera-zera cross derivative). The F_2 population was grown at Mead in 1985, followed by F_3 to F_6 at Mead. The F_7 and subsequent selections were made at HPAL, Sidney. A testcross to $KS22A_1$ was male sterile in 1988. Eight backcrosses have been made to generate the A-line including two in winter nurseries. Hybrids with N251A have been tested at several locations in the Panhandle since 1995 and have performed competitively, yielding between 2.34 and 6.80 t ha^{-1}.

N252A and N252B (38153A and 38153B) resulted from a cross between early-maturing red-seeded A, maintainer line H1160 and tropically-adapted tan plant late-maturing line Diallel 346-8 from 1CR1SAT, India. Pedigree selection was conducted in the F_2 to F_4 generations at Mead, then transferred to HPAL, Sidney. A testcross made on an F_5 selection to $N123A_1$ was male sterile, and nine backcrosses have been made including three in winter nurseries. Hybrids tested in several locations in western Nebraska and South Dakota have performed competitively with yields between 1.16 and 6.2 t ha^{-1}.

N250B (144-2) is a dwarf, averaging 83 cm, tan plant with medium-sized (30 g 1000^{-1}) hard white grain. It flowers 3-5 days later than N123B, a standard control for the very early maturing class in the Panhandle.

N251B (38084-2B) is a dwarf, averaging 87 cm, normal color (purple) plant with medium-sized (29 g 1000^{-1}) hard pale red seed. The peduncle is long. It flowers 2-8 days later than N123B. N252B (38153B) is a dwarf, averaging 84 cm, tan glume tan plant with medium-small (25 g 1000^{-1}) hard pale cream seed with a translucent pericarp. It flowers 2-9 days later than N123B. Pest and disease reactions of these lines have not been determined.

All three seed parents, because of their earliness, parentage, and hybrid performance provide new genetic diversity for producing early-maturing hybrids. Both N250A (144-2A) and N252A (38153A), if used in conjunction with tan plant white grain restorers, will produce early food-quality hybrids.

This research was supported by grants from the Nebraska Grain Sorghum Board and INTSORMIL through grant number LAG-G-00-96-90009-00 from the United States Agency for InternationalDevelopment (USAID). Ten grams of each A- and B-line pairs are available at a preparation and handling cost of US$ 100 for each pair from D J Andrews, Department of Agronomy, University of Nebraska-Lincoln, PO Box 830915, Lincoln, NE 68583-0915, USA (fax 402-472-7904, email agro253@unlvm.unl.edu). Seed will be supplied without charge to public institutions. Additional seed in germplasm amounts will be available in the fall of 1998. Larger quantities of seed can be obtained by prior arrangement with the Nebraska Foundation Seed Division.

Release of Grain Sorghum Male Parents N248R and N249R

D J Andrews[1], J F Rajewski[1], D D Baltensperger[2], and P T Nordquisr[3] (1. Department of Agronomy, University of Nebraska, PO Box 830915, Lincoln, NE 68583-0915, USA; 2. Panhandle Research and Extension Center, Scottsbluff, NE 69361-4939, USA; and 3. West Central Research and Extension Center, North Platte, NE 69101, USA)

The sorghum breeding program, Department of Agronomy, Institute for Agriculture and Natural Resources, University of Nebraska-Lincoln (UNL), on 23 Apr 1998 released two very early maturing white-grained sorghum (*Sorghum bicolor* (L.) Moench) male parents, N248R and N249R, that restore male fertility on the A_1 cytoplasmic-genetic male-sterility (cms) system (milo cytoplasm). These lines provide new genetic diversity for very early maturing sorghum grain hybrids.

N248R (681R) is an F_{12} line developed by pedigree selection from a cross made in 1984 between SD106B and MR748. SD106B is a very early maturing A_1 cms system maintainer line of a mostly hegari background with an open panicle and brown grain with a testa containing tannin. MR748 is a semitall late-maturing tropically-adapted A_1 cms system restorer line from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India, breeding program with a zera-zera background and pale yellow food quality grain (no testa). The F_2 of the cross was grown at High Plains Agricultural Lab, Sidney, Nebraska, in 1985 and only dwarf early plants with white grain and no testa were retained. Pedigree selection continued principally at Sidney. Testcrosses in 1993 indicated that the 681R progenitor fully restored male sterility on the A_1 cms system and gave acceptable dwarf hybrids. Hybrid tests at Sidney, Scottsbluff, and North Platte, Nebraska, and Hamill, South Dakota, from 1993 to 1997 indicated 681R gave white grain hybrids with competitive yields in the range of 1.1-6.6 t ha^{-1}.

N249R (1017R) is an early-maturing open-panicled tan plant F_{10} line with large pale yellow grain, derived from a cross made in 1987 between an introduced tan plant large grain landrace IS7333 and SD106B. IS7333, from Nigeria, is a late-maturing member of the subgroup *Sorghum membranaceum* Chiov., which have exceptionally long glumes and are almost cieistogamous. SD106B is a very early maturing B-line (maintainer) with an open-panicle type, evidently with hegari in its background. It has light brown grain with a strong testa. The F_2 of this cross was grown in Sidney in 1989. Only three selections were found that were early and dwarf enough and without testa. Pedigree selection was made annually thereafter, including three generations in winter nurseries. F_3s were grown again at Sidney and the F_4s grown both at Mead and Sidney, and individual plants were testcrossed to SJ7A_1 in the 1992 F_5 nursery at Mead. The testcross hybrid evaluation at Sidney in 1993 showed selection 1017 was a restorer of A_1 (milo) cytoplasm and produced acceptable hybrids. Hybrids tests in western Nebraska and South Dakota during 1994-97 indicated that 1017R produced hybrids with good yields ranging from 1.16-6.601 ha^{-1} with several seed parents.

Both lines are dwarf and very early in maturity. N248R (681R) is a normal (purple) plant color with white seeds that are large (32 g 1000^{-1}) for its maturity class. It flowers 1 or 2 days earlier than N123B, a standard control for very early maturity in the Nebraska Panhandle. It is short, 68 cm, and tends to produce short-statured high-tillering hybrids. N249R (1017R) has tan plant, tan glume color with large (30 g 1000^{-1}) pale yellow endosperm seeds with a translucent (thin) pericarp. It flowers as early as N123B and is some 4 cm taller. Pest and disease reactions of these lines have not been determined.

N248R and N249R, because of their earliness, white large grain type, performance in hybrids, and parentage, provide new genetic diversity in male parents for white-grained hybrids. N249R, if used in combination with white-grain tan plant seed parents, will produce food-quality hybrids. This research was supported by grants from the Nebraska Grain Sorghum Board and INTSORMIL through grant number LAG-G-00-96-90009-00 from the United States Agency for International Development (USAID).

Twenty grams of seed of each line is available at a preparation and handling cost of US$ 100 for each line from D J Andrews, Department of Agronomy, University of Nebraska-Lincoln, PO Box 830915, Lincoln, NE 68583-0915, USA (fax 402-472-7904; email agro253@unlvm.unl.edu). Seed will be supplied without charge to public institutions. Germplasm quantities of seed will be maintained by the Department of Agronomy, UNL, but larger quantities of seed can be obtained by prior arrangement with the Nebraska Foundation Seed Division.

Release of 26 Grain Sorghum Seed Parents (A-lines) N253-N278 and their Respective Maintainers (B-lines)

D J Andrews, J F Rajewski, and A J Heng (Department of Agronomy, University of Nebraska, PO Box 830915, Lincoln, NE 68583-0915, USA)

The sorghum breeding program, Department of Agronomy, Institute for Agriculture and Natural Resources, University of Nebraska-Lincoln (UNL), on 23 Apr 1998 released 26 grain sorghum (*Sorghum bicolor* (L.) Mocnch) seed parents in the medium to full season maturity class for Southeast Nebraska and similar environments, which are male sterile in the A_1 cytoplasmic-genetic male-sterility (cms) system (milo cytoplasm). These provide new genetic diversity for making full season sorghum grain hybrids.

All seed parents, except N253, N254, and N278, were developed from the program to introgress tropically-adapted food-quality sorghum germplasm into existing Midwest sorghum seed parents. All lines resulted from emasculation crosses made in 1984 between the parents indicated in Table 1. Pedigree selection was continued from F_2 to F_{12} at the Agricultural Research and Development Center (ARDC), Mead, with two to three generation advances in winter nurseries. Testcrosses were made at F_4 and F_5 to cms CK60A_1 (milo cytoplasm). Where the testcross reaction included completely male-sterile plants, six to eight generations of plant-to-plant backcrosses were made while selecting in the B-line, until complete uniformity was obtained between the male sterile A-line and the maintainer B-line. Special attention was given to selecting complete male sterility. Where one or more lines in Table 1 have the same parentage, these show distinct phenotypic differences and originate from separate F_4 or F_5 selections.

Table 1. Sorghum seed parent germplasms N253-N278.

Name	A-/B-line no.	Derivation	Plant height[1] (cm)	Bloom[1] (days)	Color[2]	
					Plant	Grain
N253	076	NE POP 2B/6B	93	69	P	R
N254	217	NE POP 2B/6B	98	67	P	W
N255	234	NE POP x 348	102	68	P	W
N256	276	BTx623 x PPI-140	100	71	T	PY
N257	309	BTx623 x PPI-140	102	72	T	W
N258	311	BTx623 x MB9	87	76	T	PY
N259	315	BTx623 x MB9	93	75	T	PY
N260	317	BTx623 x MB9	98	77	T	PY
N261	323	BTx623 x MB9	93	72	T	PY
N262	585	BTx623 x IS89-2B	95	70	P	PY
N263	589	BTx623 x IS89-2B	93	74	T	PY
N264	599	BTx623 x IS89-2B	102	74	T	PY
N265	901	BTx623 x IS546-IB	88	77	T	W
N266	351	BTx623 x MB12	98	71	T	W
N267	371	BTx623 x MB12	112	74	T	W
N268	604	H1160 x MB5	100	72	P	R
N269	618	H1160 x MB5	105	71	T	R
N270	622	H1160 x MB5	117	76	P	W
N27I	717	CK60B x MB5	88	71	T	W
N272	721	CK60B x MB5	97	73	T	PY
N273	857	CK60B x MB5	90	70	T	W
N274	863	CK60B x MB5	107	68	T	W
N275	919	CK60B x Segaolane	97	70	P	PY
N276	94P529	455B x SYN 422B	95	72	P	W
N277	768	CK60B x IS89-2B	88	70	P	W
N278	9044	WTLDB x Redlan	114	70	P	R
_	N122A	(Control seed parent)	100	72	P	W

1. Three year means.
2. Plant color: P = purple (normal); T = tan. Grain color: R = pale red; W = white, chalky pericarp; PY = pale yellow/cream, translucent pericarp (none have pigmented testa).

While the lines have value as lines *per se* because of the new genetic variability in them, and in some, white or pale yellow grain on tan colored plants, they also need to make good yielding hybrids. One hundred fifteen seed parents were developed from the introgression program. Each was crossed to two contrasting common testers (Tx7000 and Tx2737). These hybrids were divided into five trials (keeping hybrids with sister lines, and the two testcrosses for each line together) and sown in three locations in 1994, 1995, and 1996. The same three control hybrids (DK48, Pioneer 8500, and N122A x RTx430) were included in each trial. Five locations gave usable results (two in 1994, one in 1995, and two in 1996). The 25 seed parents listed in Table 1 were those where the average yield of both testcrosses with that seed parent over five locations was not significantly different from the mean of the three hybrid controls.

The height of each seed parent, days to bloom, plant and grain color is shown in Table 1. All A-lines have consistently shown good male sterility over years. In general, these seed parents are average to short in height and medium early to medium late in maturity. All but 4 have white or pale yellow grain and 16 have tan plant color. Pest and disease reactions of these lines have not been determined.

These seed parents, because of their parentage and ability to make good hybrids, offer new genetic diversity for the development of new hybrids. White or pale yellow grain lines will permit the development of white-grain hybrids. Where the lines are also tan plant, food-quality hybrids can be made with tan plant white-grain restorer lines. This research was supported by grants from the Nebraska Grain Sorghum Board and INTSORMIL through grant number LAG-G-00-96-90009-00 from the United States Agency for International Development (USAID).

Ten grams of seed of individual A-/B-line pairs are available at a cost of USS 100 per pair from D J Andrews, Department of Agronomy, University of Nebraska-Lincoln, PO Box 830915, Lincoln, NE 68583-0915, USA (fax 402-472-7904; email agro253@unlvm.unl.edu). Seed will be supplied on request without charge to public institutions. Germplasm quantities of seed will be maintained by the Department of Agronomy, UNL, but larger amounts can be obtained by prior arrangement with the Nebraska Foundation Seed Division,

Release of 30 Partially Converted Sorghum Lines

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The Agricultural Research Service, U.S. Department of Agriculture, and the Texas Agricultural Experiment Station of the Texas A & M University System announce the one-time release of 30 partially converted bulks (BC_1) (original cross plus one backcross) from the Sorghum Conversion Program, conducted cooperatively by the U.S. Department of Agriculture, Agricultural Research Service, at Mayaguez, Puerto Rico, and the Texas Agricultural Experiment Station. The program is designed to convert photoperiod-sensitive, tall exotic sorghums (*Sorghum bicolor* (L.) Mocnch) to early-maturing, combine-height sorghums, providing diverse germplasm in a usable form to sorghum programs.

Conversion is accomplished by a crossing and back-crossing program using favorable short-day photoperiods during the winter in Puerto Rico, with selection for early, short genotypes within segregating populations under long-day, summer conditions at Chillicothe, Texas, Normally, four backcrosses are used to obtain a fully converted line, which is then released as a converted version of the original exotic. The nonrecurrent parents used were BTx406 (an early-maturing, 4-dwarf Martin B-iine), and TAM 428, both of U.S. origin.

During conversion, some 'excess panicles' from early-maturing plants, and generally short in height, were selected from segregating populations grown at Chillicothe, Texas. Private seed companies have expressed an interest in obtaining seed of partially converted bulks of unreleased converted lines in order to utilize the germplasm at an early stage. To develop these bulks, equal quantities of seed from each available excess panicle (generally 8-15 panicles per exotic) were sown in Puerto Rico and selfed panicles from each population were bulked for distribution.

The partially converted bulks are nonsensitive to photoperiod, and should mature normally in the United States. Most will be segregating for maturity and height and other grain and plant traits. They represent new sources of germplasm from the World Sorghum Collection. These materials contain bulks from eight Maicillos Criollos from Central America, six lines from the Sudan Collection, and six lines with possible midge resistance, and should be useful to breeders and other sorghum researchers as germplasm sources in developing improved sorghum lines and hybrids. Designations of the partially converted bulks and information on the original exotic varieties are shown in Table 1.

Recognition of the origin of this germplasm should be indicated whenever it is used for research or breeding purposes. Seed will be 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, TX 79401-9757, USA. It will be available in quantities of 25-50 grams, depending on supply. The U.S. Department of Agriculture has no seed for distribution. These bulks will be released as an entire set in a one-time, as-is release and will not be maintained or placed in long-term storage. Those receiving seed are asked to agree to supply, upon

Table 1. List of 30 partially converted (BC_1) bulks released from the cooperative USDA-ARS—TAMU-TAES Sorghum Conversion Program, 1998, and information on original exotic cultivars.

Designation[1]	IS no[2]	PI, NSL, or GRIF no[3]	Local name, no, or description[4]	Origin[5] City/province	Origin[5] Country	Classification[6] R	Classification[6] WG	Reason for conversion[7]
SC616-5BK	IS 1596	291238	K. I Irungu Cholam	Coimbatore	India	B	12: Dochna	Mod nur
SC1224-5BK	IS 7422	NSL 50598	BE 28, Ahumaka		Nigeria	G	3: Consp	Midge resistant
SC1233-5BK	IS 7467		K B 2, Oka Baba, ISan/A		Nigeria	G-C	30(2): Nigr-G	Midge resistant
SC1279-5BK			Pandora Wani		India	D	41: D	Sugary endosperm
SC1370-5BK[8]			Billy-203	Lijero Blanco, Marcovia	Honduras	D	40: C-D	MC/div/CA
SC1373-5BK[8]		NSL 355015	MC-40 (dwarf)	Choluteca	Honduras	C	33: C	MC/div/CA
SC1376-5BK[8]		NSL 355017	Liberal-94	Los Prados	Honduras	C-K	38: C-K	MC/div/CA
SC1379-5BK[8]			Pompom-170	Inst. DARNDR	Haiti	D	40: C-D	MC/div/CA
SC1383-5BK[8]			Cola de Caballo-159	Concepción de Maria, Cholutecu	Honduras	G	4: G	MC/div/CA
SC1385-5BK[8]			Pina-61	El Buen Paso, Oroquina	Honduras	C-K	38: C-K	MC/div/CA
SC1404-5BK			Manzano-177	La Coyota, Alianza, Valle	Honduras	D-K	46: D-K	MC/div/CA
SC1405-5BK			Rincon-188	La Paz, Comayagua	Honduras	D-K	46: D-K	MC/div/CA
SC1452-5BK		453217			Ethiopia	D	41: D	Acid soil tol (TS)
SC1461-5BK		NSL 365798	Fuor Ahmer	UnGalena, No. Kordofan	Sudan	C	33: C	Sandy/div
SC1496-5BK	IS 26845	570389	SU 2251, MBKB 24, Nolodaka	Mura-ikotos	Sudan	C	39: C-Nigr	Elite
SC1511-5BK		196048	MN 3052	Batie	Ethiopia	D	41: D	Long panicle
SC1514-5BK		257596	MN 4483; No 2 Gambela		Ethiopia	C	39(1): ZZ	Unique
SC1518-5BK	IS 12953	200758	No 3391	Ahuachapán	El Salvador	D	41: D	Excellent durra
SC1519-5BK	IS 12965/21861	208770	No 302	Isle of Pines	Cuba	G	4: G	White seed, tan plant
SC1525-5BK		255963			Ethiopia	C	39(1): ZZ	Elite
SC1528-5BK		GRIF 813	ETS02910		Ethiopia	D	41: D	DM resistant
SC1531-5BK		GRIF 809	82HNYT-2#24		Ethiopia	D	20: Dochna-D	DM res., agronomics
SC1534-5BK		524450			Sudan	G-C	35: C-G	Fall armyworm
SC1536-5BK		524467			Sudan	G	35: C-G	Fall armyworm
SC1539-5BK		526607			Zimbabwe	G	4: G	Acid soil tolerance
SC1545-5BK	IS 9805	571208	SU 650, Dari	Gezira Research Station	Sudan	G-C	35: C-G	Possible midge res.
SC1548-5BK	IS 9886	571274	SU 725, A132	Gezira Research Station	Sudan	C	38: C-K	Elite, yield, adaptation
SC1549-5BK	IS 19474	569412	SU 1270, Var-lope	Gezira Equatoria	Sudan	GC	30(2): Nigr-G	AF28 like
SC1554-5BK	IS 22551	569994	SU 1856, A-367-A	AbuNaama	Sudan	G-C	39: C-Nigr	AF28 type
SC1555-5BK	IS 22806	570028	SU1890, S-7		Sudan	G-C	30(2): Nigr-G	AF28 type

1. Designation = designation is assigned by adding 'BK' to the end of the Sorghum Conversion Number and the 'dash' number used to denote generation (-5 = BC_1).
2. IS = the original IS (International Sorghum/ICRISAT) number.
3. PI, NSL, or GRIF # = the PI No. assigned by the National Plant Germplasm System (NPGS), the NSL No. assigned by the National Seed Storage Laboratory (NSSL), or GRIF No. assigned by S-9 Plant Introduction Station, Griffin, GA.
4. The local name, number, code, or description of the exotic variety. The SU No. were those used in the 1993 St. Croix Sudan Sorghum Collection quarantined growout.
5. Origin indicates the location of the collection if known and country of origin of each exotic line insofar as records indicate.
6. Classification of exotic line. R = race is based on Harlan and DeWet (1972) where B = bicolor, G = guinea, C = caudatum, K = kafir, and D = durra. WG = Working Group number and name is based on Modified Snowden's Classification by Murty and Govil (1967).
7. General reason for conversion. MC = Maicillo Criollo; CA = Central America; TS = twin seeded; Div = diversity.
8. TAM 428 used as nonrecurrent parent.

request, information about breeding behavior, desirability, and usefulness of the material and to cite it as the origin of useful derived lines.

References

Harlan, J.R., and de Wet, J.M.J. 1972. A simplified classification of cultivated sorghum. Crop Science 12:172-176.

Murty, B.R., and Govil, J.N. 1967. Description of 70 groups in genus sorghum based on a modified Snowden's classification. Indian Journal of Genetics and Plant Breeding 27:75-91.

Release of 33 Grain Sorghum Seed Parent Germplasms (A-lines) N279-N311 and their Respective Maintainers (B-lines)

D J Andrews, J F Rajewski, and A J Heag (Department of Agronomy, University of Nebraska, PO Box 830915, Lincoln, NE 68583-0915, USA)

The sorghum breeding program, Department of Agronomy, Institute for Agriculture and Natural Resources, University of Nebraska-Lincoln (UNL), on 23 Apr 1998 released 33 sorghum (*Sorghum bicolor* (L.) Mocnch) seed parent germplasms that are male sterile on the A_1 cytoplasmic-genetic male-sterility (cms) system (milo cytoplasm) in the medium to full season maturity class for southeastern Nebraska and similar environments. These germplasms provide new genetic diversity for making full season sorghum grain hybrids.

All seed parent germplasms were developed from the program to introgress tropically-adapted food-quality sorghum germplasm into existing U.S. sorghum seed parents. All germplasms resulted from emasculation crosses made in 1984 between the parents indicated in Table 1. Pedigree selection was continued from F_2 to F_{12} at the Agricultural Research and Development Center (ARDC), Mead, with two to three generation advances in winter nurseries. Testcrosses were made at F_4 and F_5 to cms CK60A_1 (milo cytoplasm). Where the testcross included completely male-sterile plants, six to eight generations of plant-to-plant backcrosses were made while selecting in the B-line, until complete uniformity was obtained between the male-sterile A-line and the maintainer B-line. Special attention was given to selecting complete male sterility. Where one or more germplasms in Table 1 have the same parentage, these differ phenotypically and originate from separate F_4 or F_5 selections.

While the germplasms have value as lines *per se* because of the new genetic variability in them, and in some, white or pale yellow grain on tan colored plants, their capacity to make good yielding hybrids was also tested. One hundred fifteen seed parents were developed from the introgression program. Each was crossed to two contrasting common testers (Tx7000 and Tx2737). These hybrids were divided into five trials (keeping hybrids with sister lines, and the two testcrosses for each line together) and sown in three locations each in 1994, 1995, and 1996. The same three control hybrids (DK48, Pioneer 8500, and N122A x RTx430) were included in each trial. Five locations gave usable results (two in 1994, one in 1995, and two in 1996). The 33 seed parent gennplasms listed in Table 1 were those where the average yield of the testcrosses with Tx2737 over five locations was not significantly less than the mean of the two commercial control hybrids (DK48 and Pioneer 8500). (Note that this is a different and less demanding determination of hybrid potential than that used in the accompanying release of 26 sorghum seed *parents,* N253 to N278. These 33 gennplasms are all different from the 26 seed parents, but many originate from the same crosses.)

The height of each seed parent germplasm, days to bloom, and plant and grain color is shown in Table 1. All A-lines have consistently shown good male sterility over years. In general, these seed parents are average to short in height and medium early to medium late in maturity. All but one have white or pale yellow grain and 23 have tan plant color. Pest and disease reactions of these germplasms have not been determined. This research was supported by grants from the Nebraska Grain Sorghum Board and INTSORMIL through grant number LAG-G-00-96-90009-00 from the United States Agency for International Development (USAID).

These seed parent germplasms, because of their parentage and ability to make good hybrids, offer new genetic diversity for the development of new hybrids. White or pale yellow grain lines will permit the development of white-grain hybrids. Where the A-lines are also tan plant, food-quality hybrids can be made with tan plant white-grain restorer lines.

Ten grams of seed of individual A/B germplasm pairs are available at a cost of US$ 10 per pair from D J Andrews, Department of Agronomy, University of Nebraska-Lincoln, PO Box 830915, Lincoln,

Table 1. Sorghum seed parent germ plasms N279-N311.

Name	A-/B-line no	Derivation	Plant height[1] (cm)	Bloom[1] (days)	Color[2] Plant	Grain
N279	92M035	M B 3/5 x 348	95	68	T	PY
N280	142	NE POP x 2B/6B	100	61	P	W
N281	070	HI160 x MR748	95	63	P	W
N282	313	BTx623 x MB9	100	70	T	PY
N283	92M003	BTx623 x US/R-378	120	66	P	W
N284	334	BTx623xMB12	110	68	T	W
N285	340	BTx623 x MB 12	110	67	T	W
N286	342	BTx623 x MB12	115	69	T	W
N287	344	BTx623 x MB12	115	71	T	PY
N288	369	BTx623 x IS89-2B	100	74	T	W
N289	373	BTx623 x 1S89-2B	110	67	T	W
N290	385	BTx623 x IS89-2B	115	70	T	W
N291	493	H1160 x IS546-IB	125	65	P	W
N292	507	HI 160 x Segaolane	100	67	P	W
N293	608	H1160xMB5	110	77	T	R
N294	622	H1160xMB5	130	70	P	W
N295	516	HI 160 x Dial. 346	105	65	T	PY
N296	93M054	HI 160 x Dial. 346	85	68	T	PY
N297	528	HI 160 x Dial. 346	90	67	T	PY
N298	530	HI 160 x Dial. 346	120	67	T	PY
N299	532	HI 160 x Dial. 346	125	68	T	PY
N300	536	HI 160 x Dial. 346	120	68	T	PY
N301	538	HI 160 x Dial. 346	115	69	T	PY
N302	555	HI 160 x Dial. 346	115	69	P	PY
N303	92M050	HI 160 x Dial. 346	85	74	P	W
N304	92M053	HI 160 x Dial. 346	100	67	T	W
N305	724	CK60B x MB5	105	73	T	w
N306	92M5070	BTx623 x PPI-140	105	70	T	PY
N307	657	CK60B x Dial. 346	100	65	T	W
N308	939	CK60B x Segaolane	115	68	P	PY
N309	92M006	SPL81 x KS82B	115	76	P	W
N310	92M026	DP7-863 x 348	110	66	T	W
N311	91M134	BY398 x 348	105	69	T	PY

1. Three year means.
2. Plant color: P = purple (normal); T = tan. Grain color: R = pale red; W = white, chalky pericarp; PY = pale yellow/cream, translucent pericarp (none have pigmented testa).

NE 68583-0915, USA (fax 402-472.7904; e-mail agro253@unlvm.unl.edu). Seed will be supplied on request without charge to public institutions. Germplasm quantities of seed will be maintained by the Department of Agronomy, UML, but larger amounts can be obtained by prior arrangement with the Nebraska Foundation Seed Division,

Sorghum Midge-tolerant Grain Sorghum A- and B-line Inbreds Released as Germplasm

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Seventeen grain sorghum (*Sorghum bicolor* (L.) Moench) cytoplasmic-genetic male-sterile A- and B-line pairs of inbreds with a moderate level of tolerance to the sorghum midge (*Stenodiplosis sorghicola* (Coquillett)) have been released as germplasm by the Mississippi Agricultural and Forestry Experiment Station (MAFES). These lines, designated AMP 498 to AMP 514 and BMP 498 to BMP 514, were developed by L M Gourley with joint funding from MAFES and the International Sorghum and Millet (INTSORMIL) Collaborative Research Support Program (CRSP) at Mississippi State, Mississippi. Sources with tolerance to the sorghum midge were selected from converted lines in a regional sorghum midge evaluation trial. The pedigree system of plant breeding was used to develop all of the inbreds. All of the A-lines are in A_1 (milo) cytoplasm.

All 17 lines have a moderate level of tolerance (horizontal resistance) to the sorghum midge. This nonpreference type of resistance can be overpowered if the sorghum midge population is large during flowering. Developed in Mississippi, the inbreds were selected from crosses between the best tolerant lines grown in a regional midge evaluation trial and experimental B-lines from the Mississippi Sorghum Improvement Program.

These 17 inbreds represent germplasm sources of sorghum midge-tolerant genotypes. AH of the inbreds have a purple plant color and grain with red epicarp color except for AMP and BMP 507, which have a white epicarp.

Germplasm quantities (approximately 100 seeds per inbred) of the 17 A- and B-line pairs will be distributed, upon request, by Dr C Watson, Chairman, Plant Materials Release Committee, PO Box 9653, Mississippi State University, Mississippi State, MS 39762, USA. Those requesting seed must agree to supply, upon request, information about breeding behavior, desirability, and usefulness of the material and to cite it as the origin of useful derived lines and hybrids. A fee of US$ 75 for all 17 A- and B-lines will be charged commercial seed companies requesting this released sorghum germplasm to help defray seed increase and handling expenses. Public institutions will be provided seed without charge.

Agronomy

Growth and Yield of Post rainy-season Sorghum as Influenced by Preceding Rainy-season Legumes and Fertilizer Management under Dryland Conditions

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Introduction

Double cropping of rainy-season legumes followed by postrainy-season sorghum (*Sorghum bicolor* (L.) Moench) is more profitable than sole cropping. Hence, double cropping was recommended in Maharashtra, particularly in the Marathwada region in areas of assured and moderate high rainfall (Anonymous 1988). Soybean (*Glycine max* (L.) Merr.) was recently introduced to the Marathwada region. Its performance as a preceding crop under double cropping in comparison to such traditional legumes as green gram *(Vigna radiata* (L.) Wilczck) and black gram (*Vigna mungo* (L.) Hcpper) has not yet been evaluated. With this objective, a trial was conducted on deep Vertisol during the 1996/97 cropping season.

Materials and methods

The experiment was conducted in randomized block design with three replications on deep Vertisol during 1996/97 at the Sorghum Research Station, Marathwada Agricultural University, Parbhani. The treatment comprised three rainy-season legumes—green gram (BM 4), black gram (TAU 1), and early soybean (MAUS 56)—grown under recommended practices as preceding legumes. The succeeding postrainy-season sorghum (SPV 655) was grown with three fertilizer management practices—no fertilizer, 50% recommended dose of fertilizer (RDF; 20:10:0 kg NPK ha^{-1}), and full RDF (40:20:0 kg NPK ha^{-1}). The rainy-season legumes were sown on 3 Jul 1996 and the postrainy-season sorghum on 9 Oct 1996, The gross plot size was 3.6 m x 6.0 m and the net plot size was 3.0 m x 5.4 m. Plant protection measures were taken for the control of pests and diseases according to the recommended schedule and during rainy and postrainy seasons the optimum plant populations of legumes and sorghum were maintained. The data on grain yield of rainy-season legumes was recorded. Similarly, the data on grain and fodder yield of postrainy-season sorghum was recorded. The data were subjected to statistical analysis for their significant differences.

Results and discussion

The data on grain and fodder yield of the postrainy-season sorghum grain equivalent are presented in Table 1.

Rainy-season legumes. Among the rainy-season legumes, the highest sorghum grain yield equivalent of 1967 kg ha^{-1} was obtained for soybean, followed by 1503 kg ha^{-1} for black gram, and 935 kg ha^{-1} for green gram.

Sorghum grain yield. Data presented in Table 1 revealed that grain yield of postrainy-season sorghum differed significantly due to various treatments under study. Preceding rainy-season legumes significantly influenced grain yield of postrainy-season sorghum. The grain yield of postrainy-season sorghum grown after green gram was 1629 kg ha^{-1}, for black gram, 1572 kg ha^{-1}, and for soybean, 1499 kg ha^{-1}. The highest grain yield of postrainy-season sorghum was obtained in the treatment that was preceded by green gram and it was at par with black gram and significantly superior to soybean as a preceding rainy-season legume (Badnanur 1976). There was a significant effect of fertilizer management on the grain yield of postrainy-season sorghum. Grain yield increased with every increase in the fertilizer dose. The grain yield increased by 26.6% for the 50% RDF treatment and 44.8% for the full RDF treatment over no fertilizer treatment. Similarly, the full RDF treatment recorded an increase of 14.3% in the yield over 50% RDF (Pawar and Khuspe 1980; Rao and Rao 1988).

Fodder yield. Among the three preceding rainy-season legumes, green gram was significantly superior to that of black gram and soybean in recording the fodder yield of postrainy-season sorghum (Mahadkar and Saraf 1988). Fodder yield also increased significantly with every increase in fertilizer dose. The first half of the RDF gave a greater response than did the second half.

Table 1. Grain and fodder yield and grain equivalent of postrainy-season sorghum influenced by preceding rainy-season legumes and fertilizer management, Sorghum Research Station, Marathwada Agricultural University, Parbhani, Maharashtra, India, 1996/97.

Treatments	Yield (kg ha^{-1}) Grain	Yield (kg ha^{-1}) Fodder	Grain equivalent (kg ha^{-1})
Preceding rainy-season legumes			
Green gram/postrainy-season sorghum	1629	3927	3796
Black gram/postrainy-season sorghum	1572	3800	4759
Soybean/postrainy-season sorghum	1499	3629	4822
SE	±23.32	±33.77	±54.93
LSD (0.05%)	69.82	101.11	164.23
Fertilizer management to postrainy-season sorghum			
No fertilizer	1265	3301	4080
50% RDF[1]	1602	3944	4537
Full RDF	1832	4110	4760
SE	±23.32	±33.77	±54.93
LSD (0.05%)	69.82	101.11	164.24
Interaction			
SE	±40.40	±58.50	±95.06
LSD (0.05%)	NS	NS	NS
General mean	1567	3785	4459

1. RDF=recommended dose offertilizer to postrainy-season sorghum.

Grain equivalent (kg ha^{-1}). The preceding soybean treatment gave a significantly higher sorghum grain equivalent than the preceding green gram and black gram treatments. The grain equivalents of black gram/postrainy-season sorghum and soybean/postrainy-season sorghum sequences were at par. Application of full RDF gave a significantly higher grain equivalent compared to no fertilizer and 50% RDF.

Monetary return (Rs. ha^{-1}). The soybean/postrainy-season sorghum sequence gave a significantly higher monetary return than the green gram/postrainy-season sorghum sequence and was at par with black gram/ postrainy-season sorghum sequence cropping. The blackgram/postrainy-season sorghum treatment was also significantly superior to the green gram/postrainy-season sorghum sequence. In fertilizer management of postrainy-season sorghum the treatment of full RDF gave significantly higher momentary returns over the 50% RDF and no fertilizer treatments. Similarly, the 50% RDF treatment also recorded significantly higher monetary returns than the no fertilizer application treatment.

Conclusions

From this investigation, it can be concluded that under dryland conditions the grain and fodder yield of postrainy-season sorghum was higher on preceding green gram compared to black gram and soybean. However, the monetary returns of the system as a whole were higher in the soybean/postrainy-season sorghum sequence than the green gram/postrainy-season sorghum and black gram/postrainy-season sorghum sequences. The full RDF to postrainy-season sorghum gave higher grain and fodder yield than the 50% RDF and control treatments. Furthermore, it can be concluded that considering the higher monetary returns due to preceding soybean, an early type of soybean (e.g., MAUS 56) would be the best substitute for green gram and black gram as a sequence crop under the double cropping system in areas of assured rainfall under dryland conditions.

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Biotechnology

Effect of Plant Growth Regulators on Embryogenic Callus Formation and Growth In vitro of Grain Sorghum

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In the literature, reports on the effect of the plant growth regulators (PGRs) for embryogenic sorghum *(Sorghum bicolor* (L.) Mocnch) callus formation and development in vitro are variable. Apart from the requisite of 2,4-dichlorophenoxyacetic acid (2,4-D), cytokinins had been said either to have positive influences (Kaeppler and Pedersen 1996; Lusardi and Lupotto 1990; Elkonin et al. 1986) or negative influences (Mastellar and Holden 1970) on the initiation and growth of embryogenic callus from different explants, and plant regeneration. In order to obtain a reliable embryogenic callus culture system for genetic engineering of sorghum, an alternative auxin (NAA—ot-naphthaleneacetic acid) and cytokinins (kinetin, BAP—6-benzylaminopurine, and zeatin) have been tested extensively in our tissue culture procedure.

This report briefly presents the effects of cytokinins in embryogenic callus initiation and development of four grain sorghum genotypes (SA281, M35-1, TAM422, and QL41). Immature zygotic embryos were cultured on MS basal medium with B5 vitamins containing 2 mg L^{-1} 2,4-D, 3% sucrose, 0.8% agar, and 0.2% casein hydrolysate as the control medium and six others supplemented with kinetin, BAP, or zeatin at 0.05 mg L^{-1} and 0.5 mg L^{-1}.

The effects of cytokinins were determined via callus initiation frequency (CIF—%) and the callus growth rate (CGR—mg fresh weight) after 4 weeks on induction medium.

All genotypes responded negatively to the presence of cytokinins. Cytokinins reduced the capacity of all genotypes for initiating embryogenic callus, especially the high concentration of 0.5 mg L^{-1}kinetin with SA281 and QL41 and 0.5 mg L^{-1} zeatin with M35-1 and TAM422 (Fig. 1). They inhibited callus formation from scutella by promoting the germination of young zygotic embryos. In addition, very soft nonembryogenic calli formed from the root or leaf bases of young shoots rather than from scutella of many germinated embryos.

Cytokinins also had a deleterious effect on the growth rate of calli. The control medium with only 2,4-D gave the highest growth rate with all genotypes (Fig. 2) except M35-1, where the medium with 2 mg kinetin L^{-1} gave the highest growth rate.

In short, with all genotypes, 2 mg L^{-1} 2,4-D is the preferred PGR for callus formation and development from immature embryos of sorghum. Therefore, this is the medium we use for initiation of callus cultures for microprojectile bombardment. The effects of auxins,

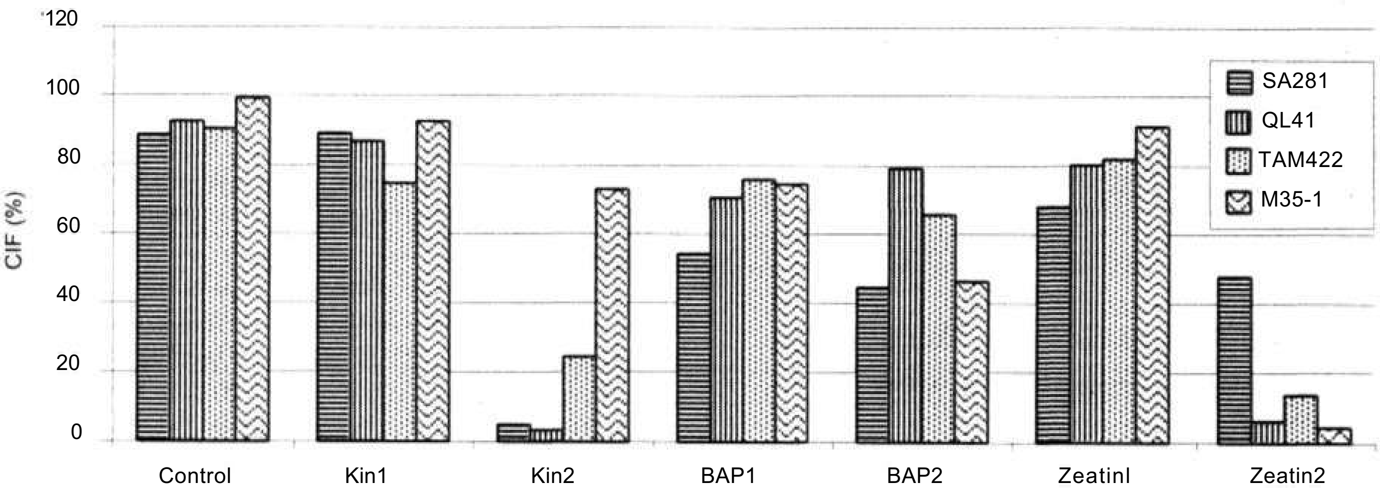

Figure 1. Effect of cytokinins on callus induction frequency (OF) in four sorghum genotypes (Kinl, BAP1, and Zeatin1 = 2 mg L^{-1} 2,4D + 0.05 mg L^{-1}; Kin2, BAP2, and Zeatin2 = 2mg L^{-1} 2,4D + 0.5 mg L^{-1}).

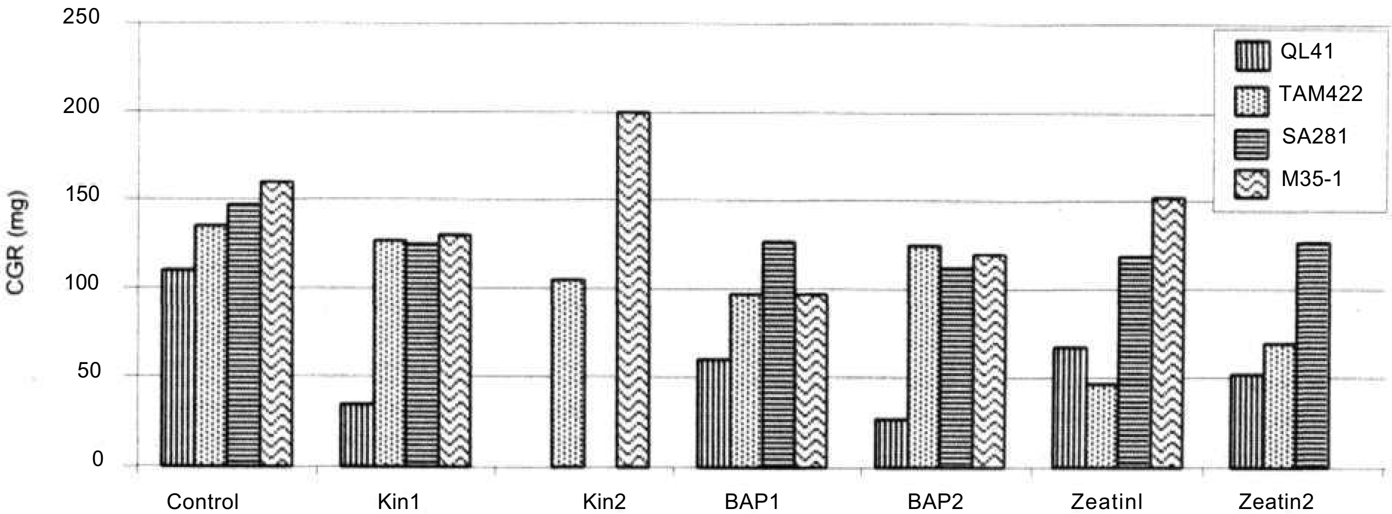

Figure 2. Effect of cytokinins on callus growth rate (CGR)in four sorghum genotypes (Kinl, BAP1, and Zeatinl = 2 mg L^{-1} 2,4D + 0.05 mg L^{-1} ; Kin2, BAP2, and Zea tin2 = 2 mg L^{-1} 2,4D + 0.5 mg L^{-1}).

cytokinins, and their combinations in maturation and regeneration stages of the culture procedure are currently being examined in detail.

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$N0_3^-$:NH_4^+ Ratio Governs Morphotype of Embryogenic Sorghum Callus

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Embryogenic cultures in a number of cereal species, including sorghum (*Sorghum bicolor* (L.) Moench), contain morphotypes of embryogenic callus differing by morphology, texture, growth rate, extent of embryo differentiation, and other characteristics. These morphotypes are compact embryogenic (type I) and friable embryogenic (type II) calli (Elkonin et al. 1995; Kaeppler and Pedersen 1996). Friable embryogenic callus has a higher growth rate, has greater uniformity, and gives rise to embryogenic cell suspensions more easily than does compact embryogenic callus. Therefore, it has more value for gene and cell engineering and mutant selection. However, formation of this type (II) of callus is observed in a limited number of genotypes. Factors controlling its formation have been poorly studied.

Previously, we have established that formation of type II callus in sorghum takes place on N6 medium supplemented with high concentrations of L-asparagine and L-proline, while addition of the same amino acids to the MS medium results in enhanced production of compact embryogenic callus (Elkonin et al. 1995). In this paper we report on the specific influence of $N0_3$- levels and its ratio to NH_4' levels on formation of friable embryogenic callus in sorghum.

To study the influence of medium mineral composition on morphotypes of embryogenic callus and to elucidate the reasons for the specific effect of N6 medium on type II callus formation we have developed modified media with different ratios of NO_3^-;NH_4^+ (Table 1).

Results indicate that transfer of previously established type II callus lines, which were subcultured for 4-5 passages on the N6 medium, to the MS medium induced significant changes in callus morphology: from friable embryogenic callus into compact embryogenic callus. However, increasing NO; concentration in the MS medium up to the NO_3^-:NH_4^+ ratio 4:1 (M14 medium), which is characteristic of the N6 medium, removed the negative effects of MS medium on compaction of friable embryogenic callus while maintaining its high growth rate. As a result, cultures grown on the M14 medium were characterized by intensive growth of type II callus that was significantly higher than on the N6 medium (Table 1).

Strong stimulation of type II callus proliferation was also observed on the M18 medium that contained the same high NO; levels as the M14 medium, but with double the concentration of NH_4^+ (Table 1). However, in cultures grown on this medium both friable embryogenic and compact embryogenic tissues were observed.

A similar stimulation of type II callus proliferation was also observed on the modified N6 medium with increased levels of $N0_3^-$ (M20 medium). In a number of genotypes, the mass of type II callus on the M20 medium was higher than on N6 (Table 1). However, after several subcultures on this medium, a strong differentiation of somatic embryos was observed. To prevent this phenomenon, the calli from the M20 were transferred to the N6 or M19 medium (39.9 mM of NO_3^-).

These data demonstrate that NO_3^- concentration and the ratio of NO_3^- and NH_4^+ concentrations are the main factors determining growth of type II callus in sorghum on media supplemented with asparagine and proline. Under relatively low concentrations of NO_3^- (28.0-39.9 mM), type II callus is formed only under low levels of NH_4^+, characteristic of the N6 medium (7.0 mM) (a NO^-: NH_4^+ ratio of 4:1). Under higher levels of NH_4^+ (20.6 mM) and the same relatively low NO; concentration, characteristic of the MS medium, a compact embryogenic callus is formed. However, when NO; levels in the MS medium are increased (up to 79.5-82.4 mM) type II callus could also develop on this medium. Moreover,

Table 1. Influence of NO_3^- and NH_4^+ level on the growth and morphotype of embryogenic sorghum callus.

Genotype/medium'	Concentration (mM) NO_3^-	NH_4^+	$NO_3^-:NH_4^+$ ratio	Callus morphotype[2]	Type II callus mass (mg)
KVV-301					
MS	39.9	20.6	1.9:1	I	—
M14	82.4	20.6	4:1	II	900 ±71**
M18	79.5	41.2	1.9:1	I; II	1174 ± 44**
M20	63.0	7.0	9:1	II	966± 19**
N6	28.0	7.0	4:1	II	510 ±44
Rosinka-2					
MS	39.9	20.6	1.9:1	I	—
M20	63.0	7.0	9:1	II	1170 ±14**
N6	28.0	7.0	4:1	II	57.0 ± 4
Milo-10					
MS	39.9	20.6	1.9:1	I	—
M14	82.4	20.6	4:1	II	+++
N6	28.0	7.0	4:1	II	+++

1. All media contained sucrose, 30 g L^{-1}; 2,4-D, 1.0 mg L^{-1}; and L-asparagine, 1.0 g L^{-1}; L-proline. 2.0 g L^{-1} . M14 and MI 8 media are modified MS media with addition of KNO_3 , 42.5 mM (M14), or KNO,, 19,6 mM, and NH_4NO_3, 20.6 mM (M18). M20 is modified N6 medium with addition of KM), 35 mM. 10-15 pieces of previously established type II callus lines subcultured for 4-5 passages on the N6 medium, were transferred to each media.
2. 1 - compact (type I); II = friable (type 11) embryogenic callus.

** Significant at $P < 0.0I$, in comparison with N6 medium.

under these high levels of NO_3^-, type II callus could develop with a higher NH_4^+ level (41.2 mM, as in the M18 medium) and the $NO_3^-:NH_4^+$ ratio of the MS medium (1.9:1). Such high concentrations of NO_3^- stimulate significantly more intensive growth of type II callus than the N6 medium.

Since the media with increased NO_3^- levels were superior to N6 for type II callus growth of genotypes Rosinka-2 and KVV-301, and no differences were observed in Milo-10 (Table 1), one would suppose that different genotypes possess different requirements concerning the level of NO_3^- necessary for growth of these callus morphotypes. Therefore, to obtain type II callus in some sorghum genotypes, one should use media with increased NO_3^- levels. These experiments demonstrate that manipulation of the nitrogen composition of the medium allows one to stimulate morphogenesis in sorghum tissue culture and to obtain either morphotype of embryogenic callus.

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Optimization of Nebulization Conditions for Shearing Sorghum Genomic DNA

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We are isolating, characterizing, and mapping sorghum (*Sorghum bicolor* (L.) Moench) microsatellites (also called simple sequence repeats, SSRs). These are di, tri, and tetranucleotide repeats that are present at high frequency in many organisms. Because they are highly polymorphic even in closely related individuals and are amenable to analysis using PCR techniques, they have emerged as an important class of genetic markers.

Utilization of this marker system requires the design and synthesis of oligonucleotide primers for the conserved regions flanking the SSRs. Only a small amount of sorghum DNA information is present in public databases, so construction of genomic DNA libraries, screening of the libraries with radiolabeled probes, and sequencing of SSR-containing clones is a necessary prerequisite to the design and production of sorghum SSR primers. Genomic libraries enriched for SSRs are commonly used for this purpose. The standard procedure involves digesting genomic DNA with a combination of six- and four-base-cutter restriction enzymes, annealing the DNA fragments that are produced to biotinylated repeat primers, and hybridization to streptavidin-containing magnetic particles (Prochazka 1996). After washing, the eluted SSR-enriched DNA is cloned and sequenced. Utilizing this procedure with sorghum DNA, we have found that as many as 40% of the positive clones are not usable because one of the cloning sites is

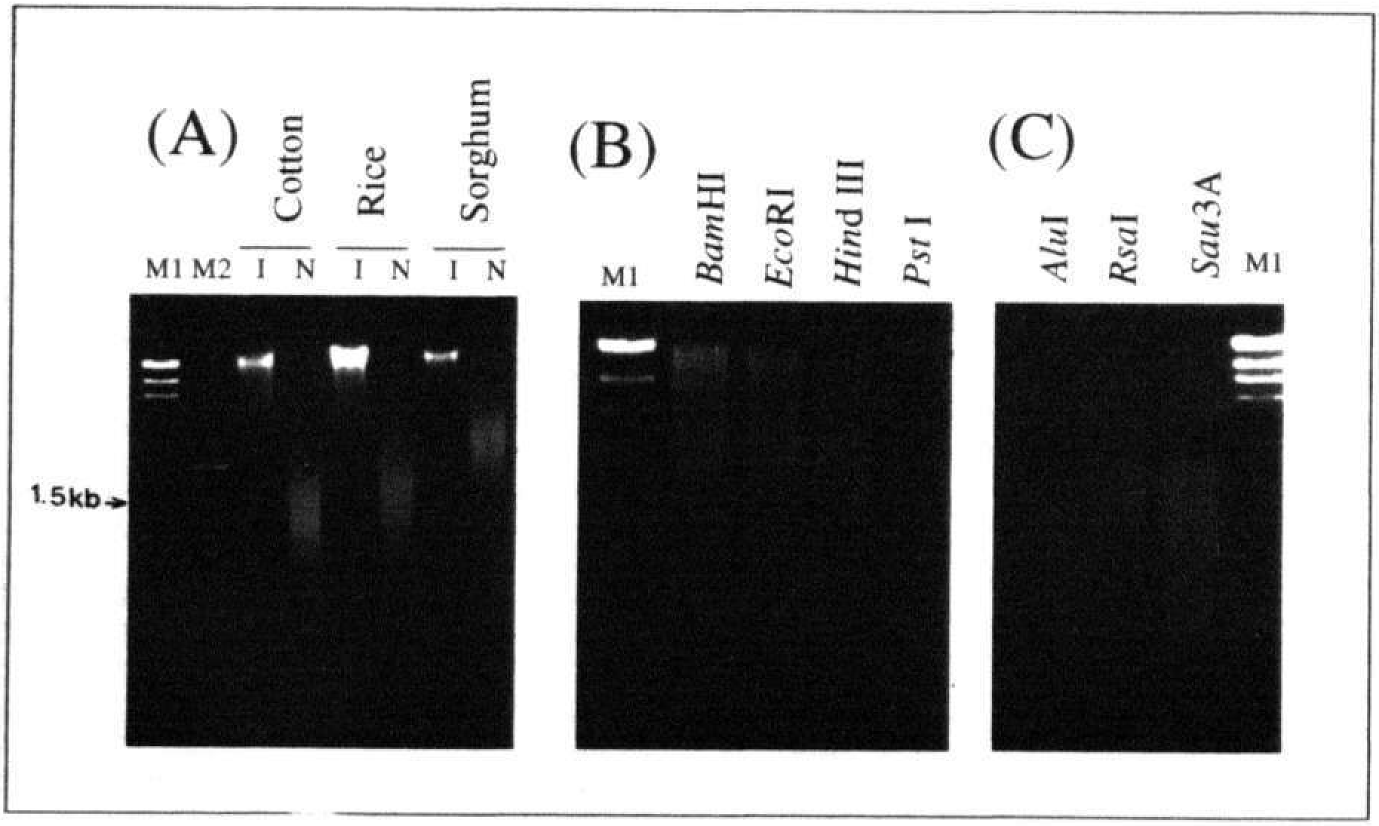

Figure 1. Effects of standard nebulization conditions on shearing of cotton, rice, and sorghum DNA. Nebulization was performed on 15 µg samples of purified DNA for 2 min at 28 psi in TM buffer containing 30% glycerol; aliquots of the samples were electrophoresed in 0.8% agarose gels and were stained in ethidium bromide. Ml, λ DNA cut with Hind111; M2, 100-bp ladder. (A) Agarose gel containing 1 µg of intact genomic DNA (I) and 2 µg of nebulized genomic DNA (N) of cotton, rice, and sorghum. (B) Agarose gel containing 1 µg of sorghum genomic DNA digested with four six-base-cutter restriction enzymes. (C) Agarose gel containing 1 µg of sorghum genomic DNA digested with three four-base-cutter restriction enzymes.

immediately adjacent to the SSR, making it impossible to design and produce one of the needed flanking primers.

To avoid this problem, we decided to shear the sorghum DNA by nebulization rather than digest it with restriction enzymes. Nebulization is a procedure for shearing DNA randomly under controlled pressure. It was developed by Steve Surzycki of Indiana University and modified subsequently by Roe and coworkers (1996). They suggested that it is necessary to optimize the nebulization conditions for each species, depending on the desired size of the fragments required. For our research, the desired fragment size is from 0.3 kb to 1.5 kb. Here we report the details of experiments conducted to produce sorghum DNA fragments of the desired size by nebulization.

DNA suspended in TM buffer (0.5 M Tris—HCl pH 8.0,0.15 M $MgCl_2$) with an appropriate amount of glycerol was placed in a nebulizer cup (IPI Medical Products Inc., Chicago, IL, USA), which was in turn placed in a ice-cold water bath and subjected to pressurized nitrogen gas essentially as described by Roe et al. (1996). Nebulization conditions that are optimum for the other tested crops were found to be unsatisfactory for sorghum. Cotton (*Gossypium* sp) and rice (*Oryza sativa*) DNA nebulized for 2 min at 28 pounds per square inch (psi) with 30% glycerol produced DNA fragment less than 1.5 kb in size (Fig. 1A) and fragments of the same size were produced when maize (*Zea mays*) and onion (*Allium cepa*) DNAs were subjected to these conditions (data not shown). All of the DNAs were extracted using a CTAB method (Saghai-Maroof et al. 1984) and the unnebulized DNA was found to be intact (Fig. 1A). Furthermore, digesting sorghum DNA with seven six-base and four-base cutting restriction enzymes demonstrated that there was no problem with the DNA quality *per se* (Fig. IB and 1C).

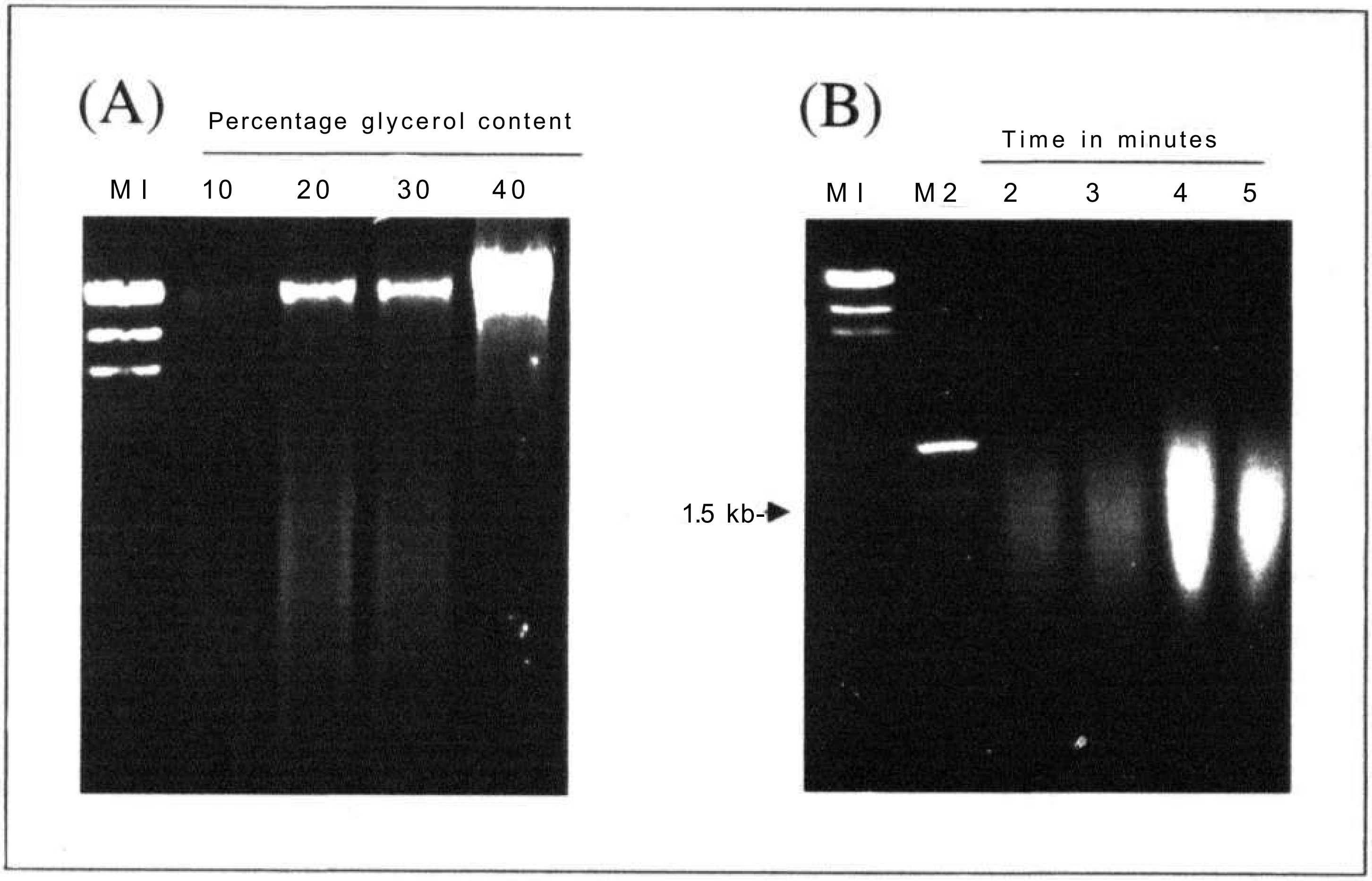

Figure 2. Effects of glycerol concentration and duration of nebulization on shearing of sorghum DNA. Electrophoresis and staining were performed as described in the Figure I legend. (A) Agarose gel containing 2 µg aliquots of 15 µg samples of sorghum DNA that were nebulized for 2 min at 28 psi in TM buffer containing 10, 20, 30, and 40% glycerol. (B) Agarose gel containing 2 µg aliquots of 15 µg samples of sorghum DNA that were nebulized 2, 3, 4, and 5 min at 32 psi in TM buffer containing 20% glycerol.

To improve the efficiency of nebulization of sorghum DNA, several nebulization parameters were varied, including glycerol content, duration of nebulization, and pressure, while the amount of sorghum DNA (15 µg) was kept constant. In the range of 10% to 40% glycerol a negative correlation with the amount of DNA sheared was detected, with 10% glycerol causing excessive shearing and 40% glycerol producing inadequate shearing (Fig. 2A). Increasing the pressure to 32 psi had a favorable effect on fragmenting DNA (data not shown). Based on several combinations of nitrogen gas pressure, glycerol content in the buffer, and duration of nebulization, we concluded that applying 32 psi to sorghum DNA suspended in 20% glycerol caused most fragments to be of the desired 0.3 to 1.5 kb size and that under these conditions, the duration of nebulization in the range of 2-5 min has no significant effect (Fig. 2B).

In summary, we have defined optimal conditions for the nebulization of sorghum DNA and we conclude that the viscosity of the medium and the pressure applied are the two most important parameters to be considered when optimizing nebulization conditions for plant DNA.

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QTLs for Photoperiod Response in Sorghum

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Introduction

The short day plant photoperiod response of cultivated grain sorghums (*Sorghum bicolor* (L.) Moench) has largely been eliminated in elite breeding lines in order to produce varieties with a wide range of adaptability and extend the crop area to temperate environments. Nevertheless, the photoperiod sensitivity in African landraces remains important for local farmers. It is a key feature adjusting flowering time to the length of the rainy season and securing the level and the quality of harvests. Thus sorghum improvement in tropical areas requires a better understanding of genetic factors implicated in photoperiod response.

Photoperiod response analysis can be done using different sowing dates for evaluation. The varietal photoperiod sensitivity can be directly estimated through the measurement of vegetative phase variations expressed in calendar or thermal time. It can also be modeled as described by Alagarswamy and Ritchie (1991) for sorghum, using the basic concepts introduced for many species by Major (1980). This author identified three genetic components to describe the photoperiod response: (1) BVP (Base Vegetative Phase) defined as the shortest possible time for floral initiation; (2) MOP (Minimum Optimal Photoperiod) defined as the photoperiod threshold beyond which the vegetative period is influenced by changes in day length; and (3) PSS (Photoperiod Sensitivity Slope) that expresses the varietal linear increase in flowering time as daylength increases.

Four major gene loci controlling flowering time have been identified in sorghum, designated Ma_1, Ma_2, Ma_3, and Ma_4. Now, molecular markers, genetic mapping, and quantitative trait locus (QTL) analysis allow new investigations for understanding genetic control of this complex trait. Using restriction fragment length polymorphism (RFLP) markers, Lin ec al. (1995) identified one QTL located on the Pereira's linkage group B and assigned it to the Ma_1 maturity gene. Recently, Childs et al. (1997) mapped the Ma_3 gene on the Pereira's linkage group C. The genotypes involved in these two studies were day-neutral and quantitative short day sorghum able to flower in the USA. To identify genomic regions controlling flowering time of more photoperiod-sensitive sorghums, we used a specific RIL population developed in a tropical environment by CIRAD (Centre en cooperation internationale en recherche agronomique pour le developpement) and INERA (Institut de l'environnement et des recherches agricoles from Burkina Faso). The present report presents preliminary results.

Materials and methods

The CIRAD RIL population named RIL249 consisted of 87 homogeneous inbred lines derived from a cross between IS 7680, a highly photoperiod-sensitive guinea landrace from Burkina Faso, and IS 2807, a poorly photoperiod-sensitive caudatum variety from Zimbabwe. Response to photoperiod of each line was established using plots of one 5.1 m row sown at six dates in the

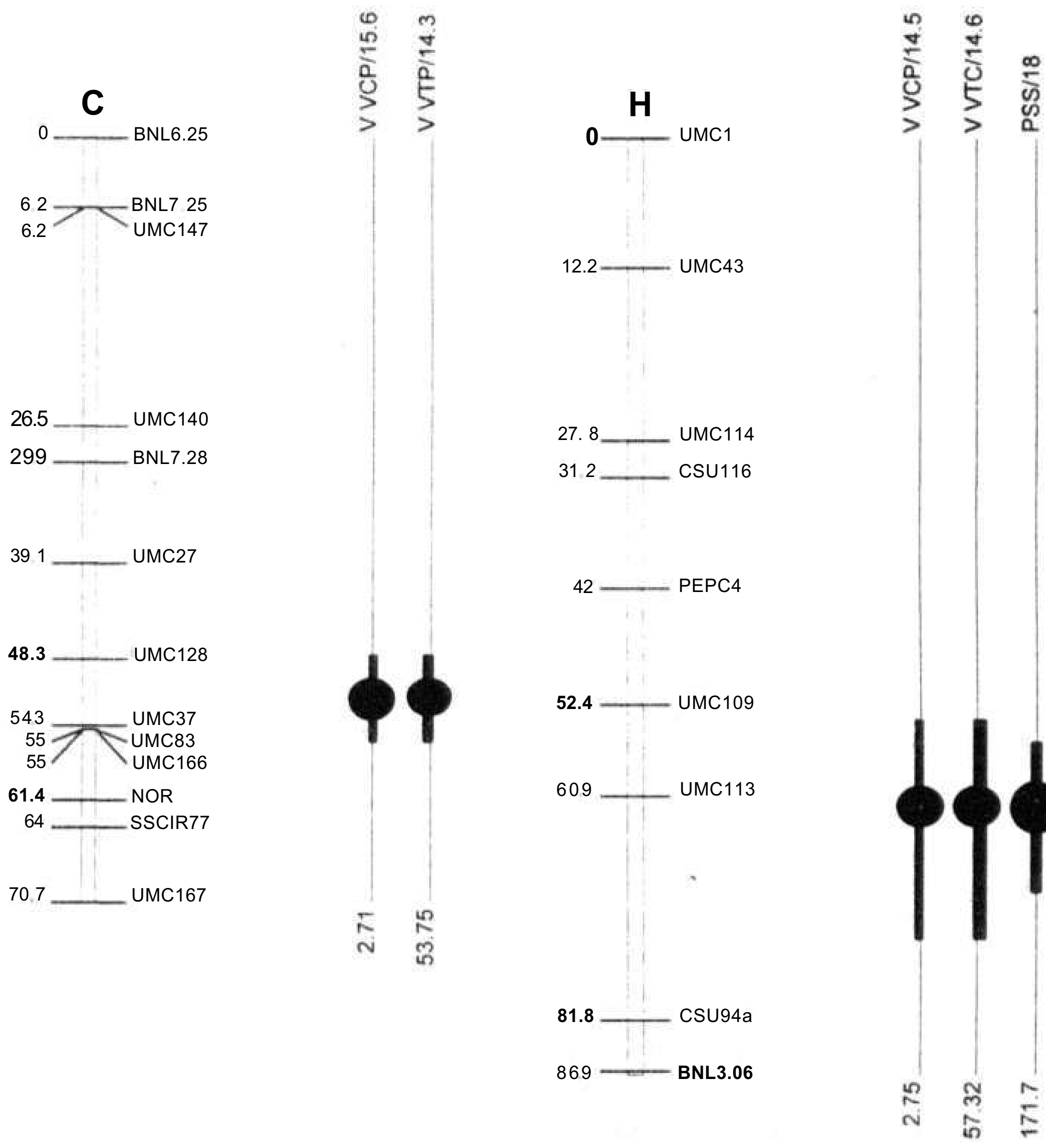

Figure 1. Genetic map and QTLs for photoperiod response in sorghum population RIL249. Each QTL is represented by a circle located on the LOD peak and by a box representing the confidence interval. The upper number is the percentage of phenotypic variance explained by the QTL and the lower number its additive effect expressed in day(s) (VVCP), °Celcius (VVTP), and °Celcius days hour^{-1} (PSS). Linkage groups presented correspond to C and H of days (Pereira et al. 1994).

rainy seasons of 1995-97 (10 and 21 Jun, 5 and 21 Jul, 4 and 22 Sep) at the Saria station in Burkina Faso. On each plot, the date of flag leaf emergence and the number of leaves were observed on the main stem of five random plants. The photoperiod response of each genotype was modeled according to the Ceres procedure applied to sorghum by Alagarswamy and Ritchie (1991) with Major's concepts. To implement this procedure, we assumed that the date of panicle initiation was situated at 60% of the Ceres thermal time from sowing to flag leaf emergence. Each line was characterized by its BVP, MOP, and PSS.

QTL analysis was conducted using the RFLP linkage map established by Dufour et al. (1997) for this population. Linkage groups were named on the basis of their homology with the linkage groups defined by Pereira et al. (1994). QTL analysis was performed by using composite interval mapping (CIM) with the Plabqtl software package as described by Rami et al. (1998). The additive effect of a putative QTL was estimated by half the difference between the two homozygous classes. It was assumed that the positive effect was carried by the guinea allele.

Results and discussion

Results obtained with the CIM method for QTLs detection are presented in Figure 1. Concerning Majors photoperiod sensitivity slope (PSS), one QTL with major effect was detected on linkage group H. This QTL explained a significant part of phenotypic variance (18.0%). In the same region, one QTL was also detected for two direct measurements of photoperiod response: the variation of vegetative phase between the 10 Jun and 21 Jul sowings expressed in calendar (VVCP) and thermal (VVTP) times. These QTLs accounted for 14.5% of phenotypic variance for VVCP and 14.6% of phenotypic variance for VVTP. Another QTL was detected on linkage group C explaining 15.6% of phenotypic variance for VVCP and 14.3% of phenotypic variance for VVTP, but none of that for PSS. For each QTL, the positive additive effect was carried by the guinea allele. The number of detected QTL agrees with other studies showing that PSS in sorghum is mainly due to a few major genes. No QTL was detected for MOP and BVP. In this case, numerous genetic factors with low effects are probably implied that cannot be detected in the RIL249 population owing to its small size.

Using another RIL population bred from two tropical cuitivars, Dufour (1996) already detected one QTL for flowering date in sorghum on linkage group H close to the loci UMC113 and CSU94a. This region may correspond with the gene Ma_1 for several reasons: (1) this gene is the most important in photoperiod sensitivity compared to Ma_2, Ma_3 and Ma_4 genes; (2) Pereira and Lee (1995) have located the dwarf gene Dw_2 on linkage group H; and (3) the Dw_2 and Ma_1 genes are known to be linked. Nevertheless, this conclusion is not in accordance with that of Lin et al. (1995) who located the Ma_1 gene on linkage group B. If these authors are right, the QTL on linkage group H may be due to one of the additional maturity genes Ma_5 and Ma_6 that W L Rooney (personal communication) has recently assumed to explain strongly inhibited floral initiation of some tropical genotypes in the U.S. There is less discrepancy concerning the QTL identified on linkage group C. It is associated with the locus UMC37 found by Dufour (1996) close to the genomic sequence of phytochrome B that Childs et al. (1997) similarly located on linkage group C and assumed to be encoded by the Ma_3 gene. This preliminary survey will be followed by a more detailed study in the next months.

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Spontaneous Ploidy Level Changes in an Offspring of Autotetraploid Sorghum Induced by Colchicine

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Introduction

In the practice of doubling plant chromosome complements, colchicine is the most widely applied agent. Infrequently, however, colchicine induces genie and cytoplasmic mutations, chromosomal aberrations, somatic crossing over, and somatic reduction. Offspring stability is extremely important to genetic or breeding programs and that is why one must not ignore the possibility of receiving genetically unstable material following colchicine treatment. This work reports a case of spontaneous changes of ploidy level in the offspring of a colchicine-induced sorghum autotetraploid.

Materials and methods

Tetraploids of the sorghum variety k-3366/2 (*Sorghum nigricans* (Ruiz et Pavon) Snowd.) were induced by treating shoot meristems with 0.2% aqueous colchicine for 24 h. In inbred tetraploid generation C5, the polyhaploid plant NT-12 was chosen. Plants with changed ploidy were selected on the basis of their morphological peculiarities. Subsequently, ploidy of these plants was confirmed by chromosome counts in root meristems.

Results and discussion

One hundred forty-seven offspring from plant NT-12 were studied in the field. Among them eight tetraploids were found along with two plants in which tillers differed for ploidy. In plant NST-41, ploidy differed not only for tillers, but panicles of second order differed from tillers of first order as well.

Pollen [a mixture of pollen grains (PGs) from the flowering parts of the panicle] from these plants was also studied. Earlier it was shown that diameters of sorghum PGs in the Saratov region environment ranged from 41.7 to 54.3 μm. PGs much larger than this were seldom found. There is no clear boundary between the size of sorghum haploid and diploid PGs, and their diameters coincide within the limits of 50.1-54.2 μm.

In the material studied, in the pollen of phenotypically diploid panicles (except that of panicle no. 8-3), the majority of PGs ranged from 37.6 to 45.9 μm. The percentage of PGs with diameter equal to or greater than 50.1 μm did not exceeded 8.0%, whereas for the phenotypically tetraploid panicles (except those of no. 8-2 and no. 8-7) 50.1 μm defined the lower boundary for the diameter of PGs.

In some cases (phenotypically diploid panicle no. 8-3 and phenotypically tetraploid panicles no. 8-2 and no. 8-7) pollen represented a mixture of 'normal' and giant PGs (Table 1). This may be explained by mixoploidy of the inflorescences.

Cytological analysis of the mixoploid plant progenies showed that phenotypically diploid panicles of plant no. 8 had diploid offspring and phenotypically tetraploid panicles of the same plant had tetraploid offpsring.

As for plant NST-41, the progenies of five panicles segregated for ploidy and contained both tetraploids and diploids with that ratio of 2n:4n—4:1, 6:1, 1:8, 72:2, and 76:1. In the next generation, no cases of segregation for ploidy were found.

Polyhaploid plant NT-12 arose, most probably, from parthenogenetic development of a reduced egg cell of an autotetraploid plant. As for tetraploids and mixoploid plants in its offspring, morphology of tillers and heads suggests that polyploidization took place before generative tissues formed.

Chimaerous plants of such kind were reported in rye and pearl millet (Muntzing and Prakken 1941; Rao and Nirmala 1986).

Table 1. Frequency distribution of pollen grain diameter for individual panicles of some plants from a *S. nigricans* polyhaploid progeny.

Plant and panicle no	Ploidy phenotype	Diameter of pollen grain (μm) 7.6	41.7	45.9	50.1	54.2	58.3	62.6	66.8
2-7	2n	4	36	50	6	2		2	
8-1	2n	6	40	48	4	2			
8-3	2n		1	6	31	26	33	2	1
9-2	2n	10	62	24	4				
10-4	2n	12	60	20	8				
11-4	2n	8	40	44	8				
13-3	2n	8	66	22	4				
1-4	4n				28	18	42	8	4
8-2	4n		18	12	34	28	8		
8-4	4n				13.9	23.3	46.5	11.6	4 6
8-7	4n			20	40	26	14		
8-8	4n				24	30	44	2	
8-9	4n				2	30	54	12	4

Apparently, the action of colchicine resulted in a mutation provoking mitotic disturbances in generations distant from the treated plant progeny.

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Transformation of Sorghum Using the Particle Inflow Gun (PIG)

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Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) has been successfully transformed in our laboratory using a modified biolistics device based on helium—the Particle Inflow Gun (PIG). To determine the most suitable parameters for PIG-mediated delivery of foreign deoxyribonucleic acid (DNA) into sorghum, experiments have been conducted evaluating several critical factors. The effects of using different tissue types and a number of variables related to the device have been investigated. These included the shelf distance from the DNA expulsion point to the target tissue, the pressure used to deliver the DNA, and the aperture of the helium inlet.

Initially, optimization was conducted using leaf segments because sorghum callus is difficult and time consuming to initiate in large quantities. Following optimization with leaf material, experiments using callus were performed establishing a strong similarity between the two tissue types. Both ß-glucuronidase (GUS) and Green Fluorescent Protein (GFP) were used as reporter genes.

Materials and methods

Leaf and callus from sorghum (M35-1, an Indian cultivar; SA281, a Hegari-type; QL41, an Australian inbred line; and P898012, an American inbred line) were used. The PIG procedure was used to insert foreign DNA (Rathus et al. 1996; Able et al. 1998). Transient expression for the reporter gene GUS was examined histochemically (Jefferson et al. 1987) by adding 5-bromo-4-chloro-3-indoyl-ß-D-glucuronide (X-Gluc) 24 h post-bombardment,

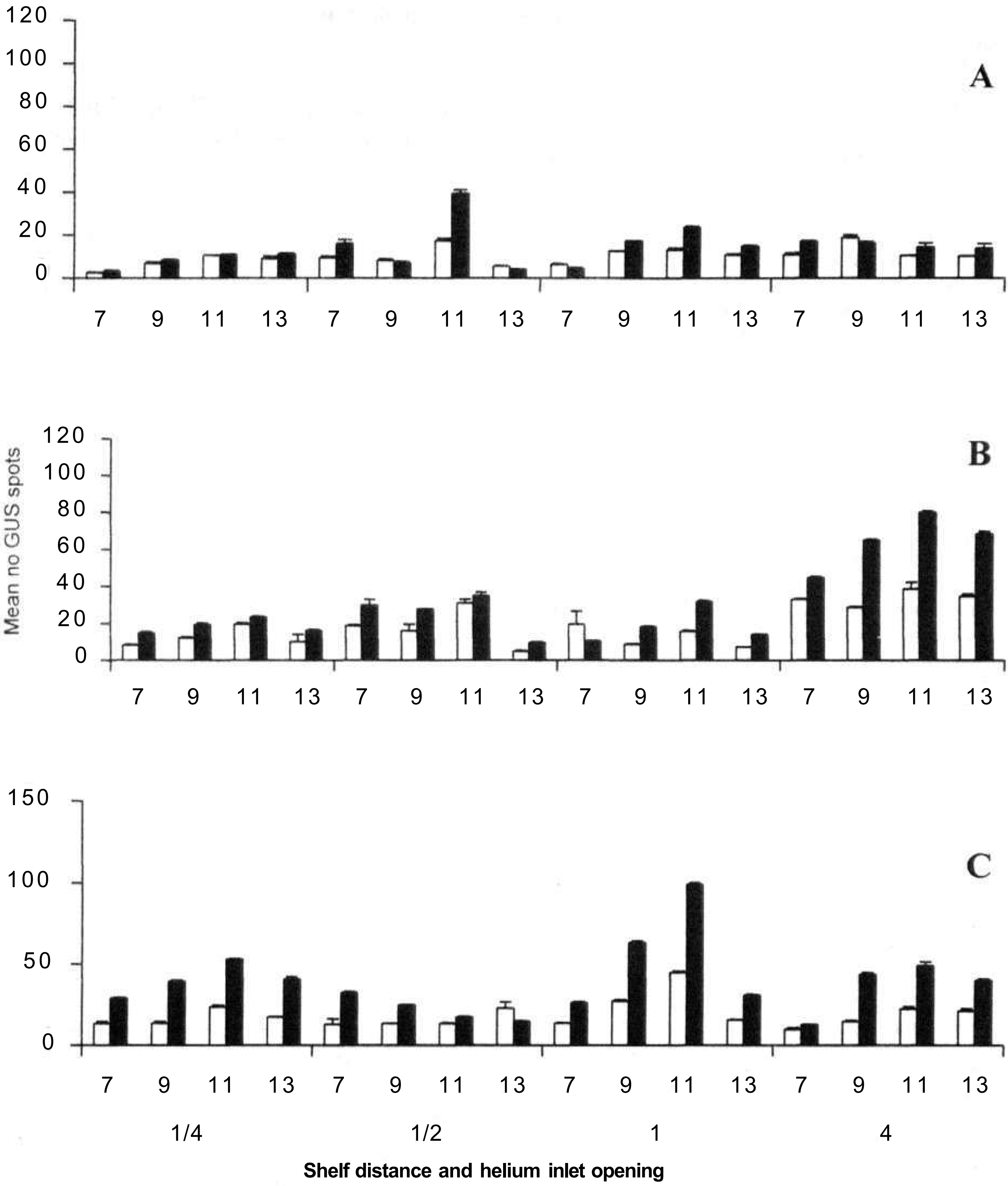

Figure 1. Mean number of GUS spots per leaf or callus piece for pressures of (A) 1400 KPA, (B) 1800 kPA, and (C) 2200 kPA; helium inlet openings of ¼,½, 1, or 4; and shelf distance from target tissue of 7, 9, 11, or 13. All leaf treatments were replicated twice, as were callus treatments up to 1800 kPa, 0.5 helium inlet opening and a shelf distance of 13. All other callus treatments were replicated three times. Clear bars represent leaf material while black bars represent callus material.

incubation overnight at 37°C, and counting of GUS spots.

Results and discussion

The mean number of GUS spots in leaf and callus material was similar (Fig. 1) (r = 0.83). For those plant species where difficulties generating large quantities of callus are encountered, optimization of gene transfer protocols can be achieved using leaf tissue. The mean number of GUS spots per leaf or callus piece was significantly greater when using pressures of either 1800 kPa or 2200 kPa compared to 1400 kPa. Although three high counts of GUS spots per leaf or callus piece were obtained with 1800 kPa (helium inlet fully opened, and a shelf distance of 9, 11, or 13), the mean number of GUS spots obtained at 2200 kPa (helium inlet valve opened one full turn, and a shelf distance of 11) was consistently greater over three replicated experiments. These conditions (2200 kPa, helium inlet valve opened one full turn, and a shelf distance of 11 from the target tissue) were selected as optimal.

More recently callus material has been shot with both the herbicide resistance gene (BAR) and the GFP gene to observe stable expression. Stable sectors have been observed with the reporter gene GFP using a fluorescence microscope, while stable BAR sectors grow on selection medium containing 2 mg L^{-1} bialophos.

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Abiotic Factors

Changes in Fatty Acid Composition of Sorghum Leaf Polar Lipids under Chilling Stress

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Introduction

High-altitude sorghum (*Sorghum bicolor* (L.) Moench) is distributed in the highlands of eastern Africa, Mexico, and the Yemen Arab Republic (Peacock 1982). Occasional frost and low night temperatures during the growth and reproductive period cause loss yield (Van Arkel 1979). Membrane lipids and fatty acid composition of plant organelles have important roles in the modulation of the effects of temperature stress. In higher plants, correlations between fatty acid unsaturation and chilling tolerance have been variable (Lyons 1973). The objective of this study was to determine the changes in fatty acid composition of leaf polar lipids of tropical highland and temperate sorghum in response to chilling temperatures.

Materials and methods

Three sorghum genotypes, N-17, a tropical highland genotype, and two temperate genotypes, Bmr989 and RTx430, were grown in the greenhouse at Mississippi State, Mississippi in 1995 in 3-L pots (one plant pot^{-1}). Temperatures were maintained at 30/24°C (day/night) under natural light. Twenty-one days after emergence, four plants $genotype^{-1}$ were transferred into two walk-in growth chambers, one set maintained at a constant day/night temperature of 24°C and 85% relative humidity, and the other maintained at 10°C day/night temperature and 85% relative humidity. Fluorescent and soft white bulbs (200mE m^2 s^{-1}) were placed 1.5 m above the canopy to provide illumination. The experiment was maintained for 7 d after which leaf samples from the second and third leaf from the top were harvested for extraction of lipids. The 5-g samples were placed in a mortar and homogenized in liquid nitrogen. After drying, the fine powder was transferred into 16 x 100 mm pyrex culture tubes, sealed under nitrogen, and stored at -15°C. Isolation and purification of leaf lipids was performed according to the method of Whitaker (1986). Nonlipid contaminants were removed as outlined by Folch et al. (1957). Total lipids were separated by adsorption column chromatography using silicic acid (Bio-Sil A), 100-200 mesh Bio-Sil A (Bio-Rad Laboratories, Richmond, CA, USA). Lipids were separated into neutral, glycolipid, and phospholipid fractions by sequential addition of solvents. Glycolipid and phospholipid fractions were further separated by thin-layer chromatography. Individual lipids were identified by co-chromatography with authentic standards. Quantitative analysis of fatty acid methyl esters was performed after transesterification using gas liquid chromatography on a Varian 3400 gas chromatograph (GC) equipped with a flame ionization detector and utilizing a supelcowax 10 fuse-silica wide-bore capillary column, 30 m length x 0.53 mm inner diameter and 1.0 ml film thickness. One-uL samples were manually introduced using a 5-μL micro-injector. Injector and detector temperatures were 250 and 300°C, respectively. Helium was used as a carrier gas at the flow rate of 6 ml min^{-1} and N_2 was used at the flow rate 24 ml min^{-1}. Initial column temperature was 185°C. After 7 min initial holding time, the column oven temperature was raised 3°C min^{-1} to a final temperature of 220°C, which was maintained for 15 min. The GC was connected to a Varian 4290 integrator. Fatty acid content of leaf extracts was evaluated by comparison of chromatographic output to that of authentic standards.

Results and discussion

Chlorosis and wilting symptoms associated with chilling injury were more evident in Bmr989 and RTx430 than in N-17. Decreased temperature significantly increased the level of unsaturated fatty acids in polar lipids of sorghum leaves. Leaf composition of oleic acid (18:1), linoleic acid (18:2), and linolenic acid (18:3) was higher at 10°C than at 24°C. At 10°C, the greatest increase occurred in 18:2, followed by 18:3. N-17 tended to have lower concentrations of palmitic (16:0) and arachidonic acid (20:0) and higher levels of unsaturated fatty acids, especially 18:2 and 18:3, than did Bmr989 and RTx430; however, differences among genotypes were not significant (P <0.05) and no genotype x temperature interactions were observed. Palmitic acid (16:0), linoleic acid (18:2), and linolenic acid (18:3) were the most abundant fatty acids in all three genotypes.

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Comparison of the Protein Profiles of Four Genotypes of "glossy" Sorghum Subjected to Salinity at the Seedling Stage

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Introduction

Different abiotic and biotic factors reduce sorghum (*Sorghum bicolor* (L.) Moench) productivity in the semi-arid regions of the world. Salinity is one of the most important factors affecting productivity in many parts of the world (Maiti 1996). This causes a reduction in germination (Malibari et al. 1993; Igartua et al. 1994), growth (Maiti et al. 1994), and modifies the physiological

Table 1. Results of the SDS-PAGE profiles of the four genotypes of "glossy" sorghum under salinity.

	Protein A 46 kDa		Protein B 29 kDa		Protein C 27kDa		Protein D 22kDa		Protein E 16kDa	
	Ctrl.[1]	Treat.	Ctrl.	Treat.	Ctrl .	Treat.	Ctrl.	Treat.	Ctrl.	Treat.
IS 8311	*[2]	*	*	*	*	*	*	*	*	*
IS 4405	*	*	*	*	*	*	-	-	*	*
IS 4776	*	*	*	*	*	*	-	-	*	*
IS 4576	*	*	*	*	*	*	-	-	*	*

1. Ctrl. = control; Treat. = treatment.
2. * = protein present; - = protein absent.

and biochemical processes of the plant (He et al. 1993; De la Rosa-Ibarra 1996; Dubey 1994). An increase in salinity affects the synthesis of proteins (Levitt 1972; Hamada 1994; De la Rosa-Ibarra 1996). However, the synthesis of polypeptides induced by salinity, called stress proteins, has been reported by various authors in various crops (Hurkman and Tanaka 1987; Ramagopal 1986; Singh et al. 1987; Dubey 1994; De la Rosa-Ibarra 1996).

The objective of the present study was to locate differences in protein characteristics of glossy sorghum lines subjected to salinity at the seedling stage.

Materials and methods

Genetic materials of sorghum were provided by the Agronomy School, Universidad Autonma de Nuevo Leon These materials were selected by De la Rosa-Ibarra (1996) for their tolerance/susceptibility to salinity at the seedling stage. Eight seeds of four sorghum genotypes (one tolerant, IS 8311, and three susceptible, IS 4405, IS 4776, and IS 4576) were sown in perlite in 300 mi polyethylene plastic pots in a growth chamber maintained at 12 h photoperiod and 28°C. The two treatments included in the experiment were application of distilled water alone, and addition of 200 mM L^{-1} of NaCl to the distilled water at day 10. The experiment was replicated three times. At 15 days after emergence leaf samples from each genotype were collected and SDS-PAGE was conducted for protein profile as described by Hames (1981). Four conjugates of hemoglobin (16, 32,48, and 64 kDa) (Sigma) were utilized as molecular weight markers. For nondissociating PAGE, the previous procedure was used except that SDS, B-ME, and DTT were not used, nor were samples heated; in addition, electrophoresis was conducted at 5°C and 20°C.

Results and discussion

The SDS-PAGE profiles of the four genotypes of sorghum revealed detectable protein bands of varying molecular weight of which A, B, C, D, and E were the most important (Table 1). Three genotypes showed the presence of polypeptides bands called A (46 kDa), B (29 kDa), C (27 kDa), and E (16 kDa), but in salinity-tolerant genotype IS 8311 the presence of polypeptide band D was also detected, which has an apparent molecular weight of 22 kDa. This protein is absent or present in insignificant amount in susceptible lines. These results coincide with Hurkman and Tanaka (1987) in barley (*Hordeum vulgare*). Singh et al, (1985, 1987) reported the presence of a protein of low molecular weight in tobacco (*Nicotiona tabacum*) tolerant to salinity. Therefore, this protein might be related to the salinity tolerance mechanism functioning in IS 8311.

In conclusion, sorghum genotypes subjected to salinity showed variations in protein profile. The genotype tolerant to salinity showed the presence of a specific protein of 22 kDa molecular weight, which is absent or negligible in the rest of the genotypes susceptible to salinity at the seedling stage, Therefore, this specific protein might be related to salinity tolerance.

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Bird Resistance

Isolation, Purification, and Quantification of Dhurrin from Tannin-free Bird-resistant Grain Sorghum

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Introduction

The presence of tannin in the grain of conventional bird-resistant grain sorghum (*Sorghum bicolor* (L.) Moench) confers resistance to grain-eating birds. However, biological assays have shown reduction in the grain nutritional quality with increasing tannin content. Recently, three bird-resistant sorghum lines, CMSXS 180 R, CMSXS 181 R, and CMSXS 182 R, have been developed by Embrapa Maize and Sorghum in which the grain is tannin-free (Schaffert et ai. 1994). An additional bird resistant sorghum genotype from Arkansas (ARK 3048) has also been identified by Or Butler's group at Purdue University as being tannin-free.

Bird resistance in tannin-free sorghum has been attributed to the presence of dhurrin, a cyanogenic glycoside in the grain (L Butler, personal communication, 1995), Dhurrin has previously been isolated from sorghum leaves (Swenson et al. 1989), but this is the first report of the presence of dhurrin in sorghum grain. Preliminary feeding trials conducted at Purdue with rats and chicks indicate that this tannin-free sorghum with dhurrin contributes to bird tolerance, but does not reduce weight gain or feeding efficiency (L Butler, personal communication, 1995). In the present work an independent method was developed at Embrapa Maize and Sorghum and used to extract and to purify dhurrin from sorghum seedlings, which allowed its spectroscopic characterization and the establishment of an analytical procedure for its quantification by HPLC in sorghum grain.

3. In memoriam of Dr L Butler, deceased in February 1997.

Material and methods

Dhurrin was isolated from seedlings of the sorghum variety ARK 3048 and quantified in grain of the R-lines CMSXS 180 R, CMSXS 181 R, and CMSXS 182 R, and of the B-lines CMSX 102 B, CMSXS 101 B, CMSXS 156 B, and CMSXS 112 B.

Seedlings were cut close to the roots and ground in the presence of MeOH. Extraction was carried out in MeOH at 65°C on a magnetic rod stirrer. Isolation and purification from the crude extract was obtained on a silica gel column, eluted with mixtures of $MeOH/CHCl_3$ increasingly concentrated up to 10% MeOH. The presence of dhurrin was confirmed by thin layer chromatography compared with a standard sample. Dhurrin derived from seedlings (ARK 3048) and grain (B- and R-lines) was identified by UV, IR, ^{13}CNMR, and ^{1}HNMR Spectroscopy. ^{13}CNMR and ^{1}HNMR parameters were consistent with reports in the literature (Nahrstedt et al. 1993). ^{1}HNMR (400 MHz, $(CD_3)_2CO$) spectrum showed: AA'BB' pattern for aromatic hydrogen in *para* substitution at d 7.41 and 6.90 (dd), a methinic hydrogen at 5.94 (s), anomeric hydrogen at 4.70 (d), and a multiplet due to carbohydrate hydrogens and hydroxyls from d 4.00 to 2.98. The newly established conditions for HPLC quantification are: reverse phase, C-18 column, mobile phase $CH_3CN:H_2O:CH_3COOH$ 5:94:1, flow rate = 1 mL min^{-1}, λ = 280 nm (UV detector).

Results and discussion

The HPLC method was adequate for quantification of dhurrin in grain of sorghum. Analysis of sorghum bird-tolerant R-lines showed dhurrin concentrations of 0.035-0.073% during milk stage and 0.018-0.034% at dough stage. On the other hand, B-lines presented concentrations in the range 0.008-0.023% during the same growth stages (Fig. 1). Hybrids (12 combinations) are being evaluated. Dhurrin levels obtained in milk stage grains of the three R-lines were 75-265% higher than in ARK 3048 (0.02% dhurrin in the grain).

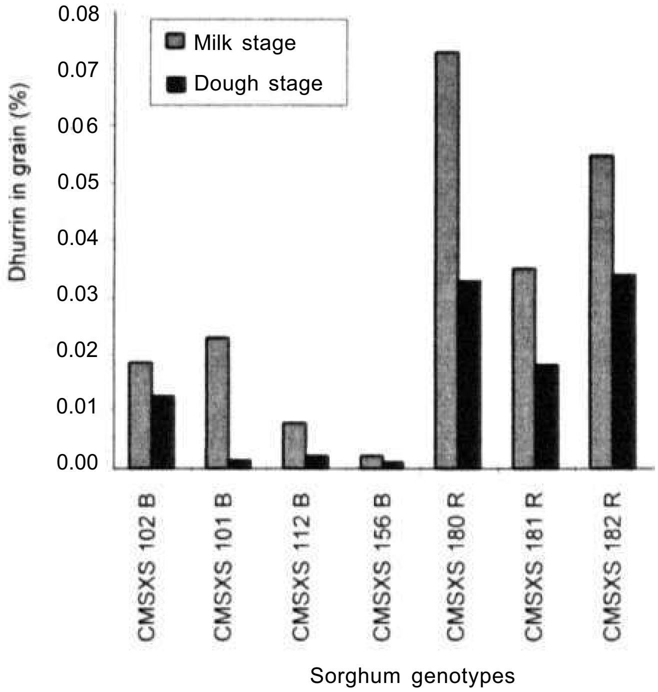

Figure 1. Percentage of dhurrin in the grain of sorghum R- and B-lines during milk and dough growth stages.

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Pathology

Chemical Control of Sorghum Ergot (*Claviceps afrkana*) in the Field

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Introduction

In 1996, most of the hybrid sorghum (*Sorghum bicolor* (L.) Moench.) seed production in Venezuela was lost due to an outbreak of sorghum ergot caused by *Claviceps africana* (Malaguti and Pons, in press). Fungicides have been used in other countries to control ergot (Nagarajan and Saraswathi 1971; Chauhan et al. 1978a, b; Ajrekar 1979; McLaren 1994) but little work had been done to evaluate products of common use in our country. An experiment was conducted to evaluate efficacy of common fungicides in controlling sorghum ergot in Venezuela.

Material and methods

The trial was sown at Maracay on 5 Nov 1997 at the central experimental field of CENIAP (latitude 10°11 'N and longitude 67°30'W). A 'Combine Sagrain' male-sterile line was used as experimental material. A randomized block design with three replications was used and the plots were of four rows 6-m long. The treatments were: Tl = Tilt® (propiconazole, systemic triazole 250 g ai L^{-1}); T2 = Propizole® (propiconazole, systemic triazole 200 g ai L^{-1}); T3 = Anvil 25 SC® (hexaconazole, systemic triazole 220.7 g ai L^{-1}); T4 = Plantvax 75% P.M.® (oxicarboxin, systemic carboxanilide 750 g ai kg^{-1}); T5 = Benlate® (benomyl, systemic benzimidazole 500 g ai kg^{-1}); and T6 = Tester (control—no fungicide). An adherent carrier was used for liquid fungicides. The total doses were 1 L ha^{-1} of the commercial product for the liquid fungicides, or 1 kg ha^{-1} for the granulated fungicides. The fungicide doses were divided into three subdoses of 0.25 L or kg applied at panicle emergence, 0.5 L or kg applied at 50% flowering, and 0.25 L or kg applied postflowering. The fungicides were applied in 300 L of water using a backpack sprayer. A solution using water-soaked infected panicles was used as a source of inoculum that was applied prior to the first fungicide application. The observations taken on the trial were: (1) percentage of infected panicles $plot^{-1}$ (incidence), (2) percentage of infected florets per infected panicle $plot^{-1}$ (severity), and (3) total infection per plot calculated by multiplying incidence x severity. The temperatures during the growing season ranged from 17.6°C to 34.2°C, with a mean average temperature of 25.6°C.

Results and discussion

Results for incidence are presented in Table 1. Tilt®had a mean of infection of 42% and Propizole® had a mean of

Table 1 . Infection and effectiveness of fungicides on control of sorghum ergot (*Claviceps africana*) on the Combine Sagrain male-sterile line evaluated in Mara cay, Venezuela, in 1997.

	Incidence (%)		Severity (%)		Total infection (%)[1]	
Treatment	Infection	Efficacy	Infection	Efficacy	Infection	Efficacy
Tester®	92.25c[2]	-	96.25c	-	88.20c	-
Tilt®	41.66a	58.33a	3.03a	96.96a	1.28a	98.72a
Propizole®	46,60a	53.39a	3.44a	96.55a	1.62a	98.38a
Anvil®	72.38b	26.61b	9.57b	90.43b	7.07b	92.93b
Plantvax®	78.62b	21.38b	11.53b	88.47b	9.46b	90.54b
Benlate®	77.90b	22.09b	12.75b	87.25b	10.74b	89.25b
CV(%)	11.60		17.18		15.24	

1. Total infection = infection x severity.
2. Means followed by the same letter within a column are not significantly different at P = 0.05.

47%;although they were stattstically similar, Tilt® showed better disease control. In the second group of fungicides, Anvil® had a mean of 72%, Benlate® was 78%, and Plantvax® was 79%; they were not significantly different in their incidence ratings. Visual observations indicated that Anvil® had very poor efficacy in control of ergot despite it being a systemic triazole fungicide.

Both Tilt® and Propizole® gave significantly greater control of the severity of the disease than did Benlate®, Plantvax®, and Anvil® (Table 1), Both Tilt® and Propizole® were significantly more effective in controlling total infection than the other three fungicides. Differences in effectiveness may have been due to differences in concentrations of the active ingredients. Because of the use of an A-line, infection rates were expected to be high and this is probably not the same as would be expected under normal commercial production. These results indicated that of materials tested Tilt® and Propizole® fungicides provide the best control of sorghum ergot/However, both Plantvax® and Benlate®, which provide adequate control, could be used under low inoculum pressure in a rotation scheme to prevent resistant sources of ergot from appearing.

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Effect of Delayed Harvesting on Grain Mold Development in Sorghum

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Introduction

In Maharashtra, rainy-season sorghum *(Sorghum bicolor* (L.) Mocnch) is generally affected by grain molds due to rainfall in September and October. Grain mold is caused by a complex of many fungi, and the severity of development increases when a prolonged wet period delays harvesting (Garud et al. 1994). Infected grains suffer breakdown of grain structure, loss of viability, increased chalkiness of endosperm, and contamination with mycotoxins; these reduce grain quality and lower its nutritional value. Grain mold also reduces the yield and market value of the grain. Hence, studies were undertaken to determine the effects of delayed harvesting on mold development on different sorghum genotypes.

Materials and methods

Two field experiments were conducted during the rainy seasons of 1996/97 and 1997/98 using cultivars CSH 9, CSH 14, CSV 15, 296 B, and GMRP 12. A randomized block design was used. The crop was sown in the month of June, and recommended agronomical practices were adopted for cultivation. The crop was harvested at three different stages in 1996/97 and at four stages in 1997/98, where harvest 1 = at physiological maturity, harvest 2 = at maturity, harvest 3 = 1 week after maturity, and harvest 4 = 2 weeks after maturity. At each harvest grain mold observations such as field grade, threshed grade, number of grains affected, percentage germination, and fungi associated with the seed were recorded.

The grain mold data was recorded on a scale of 1-5 where 1 = mold free and 5 = fully molded, and statistically analyzed in a factorial randomized design.

Results and discussion

In general, field and threshed grain mold ratings increased significantly and progressively as harvesting was delayed in all the genotypes under testing (Table 1). The results were similar in both years, Due to infection of grain mold, the seed germination percentage was

Table 1. Effect of delayed harvesting (harvest dates H_1–H_4) in five sorghum genotypes (V) on grain mold development in sorghum.[1]

	1996/97								1997/98									
	Threshed grain mold ratings				Germination (%)				Threshed grain mold ratings					Germination (%)				
Treatment	H_1	H_2	H_3	Mean	H_1	H_2	H_3	Mean	H_1	H_2	H_3	H_4	Mean	H_1	H_2	H_3	H_4	Mean
CSH 9	2.33	4.16	4.33	3.61	67.33	59.00	64.00	63.44	3.25	2.58	3.25	3.08	3.04	87.00	85.33	76.00	70.33	79.66
CSH 14	1.00	1.83	4.33	2.38	66.33	62.00	67.66	65.33	2.33	3.16	3.33	3.75	3.14	83.66	66.66	71.33	75.66	74.33
CSV 15	1.00	1.00	2.00	1.33	89.33	77.00	77.33	80.22	2.66	3.16	3.25	3.83	3.22	76.66	70.74	33.22	72.00	73.41
296 B	4.16	4.33	4.16	4.22	46.00	39.66	36.33	40.66	3.25	3.58	3.58	4.00	3.60	37.66	43.34	66.66	36.33	38.08
GMRP 12	2.33	4.16	4.33	3.61	67.33	59.00	64.00	63.44	–	–	–	–	–	–	–	–	–	–
Mean	1.90	2.60	3.36	–	72.46	62.86	64.60	–	2.87	3.12	3.35	3.66	–	71.25	66.58	64.08	63.58	–
	H	V	H×V		H	V	H×V		H	V	H×V				H	V	H×V	
SE±	0.10	0.08	0.15		2.21	1.97	3.42		0.042	0.072	0.14				1.40	1.26	2.58	
CD at 5%	0.30	0.25	0.44		8.76	5.73	9.92		0.12	0.21	0.42				4.10	2.58	7.37	

1. H_1 = physiological maturity; H_2 = maturity; H_3 = 1 week after maturity; H_4 = 2 weeks after maturity; H × V = harvest × variety interaction.

affected in all the genotypes and for both the years. Germination in CSH 9 at the first harvest date (physiological maturity) in 1996/97 was 67% and it was reduced to 64% at the third harvest date. In 1997/98, the germination level in CSH 9 was 87% at the first harvest date, whereas it was 71% at the fourth harvest date. Similar reductions in seed germination were found in all the genotypes. Furthermore, association of the grain mold fungi *Fusarium monoliforme* and *Curvularia lunata* were also found to increase under delayed harvesting. These results indicate that minimum deterioration due to grain mold both for mold infection and seed germination was found at physiological maturity. Hence, it is suggested to harvest the crop at physiological maturity to avoid reduced grain quality due to grain molds. This would require farmer access to facilities for artificially drying grains in years of wet harvest seasons. Similar observations to reduce grain mold infection were made in a review of sorghum grain molds by Williams and Rao (1981).

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Effect of Sowing Dates on the Incidence of Long Smut (*Tolyposporium ehrenbergii*) on Sorghum

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Introduction

Long smut caused by *Tolyposporium ehrenbergii* (Kuhn) Patovillard is an important disease of sorghum (*Sorghum bicoior* (*L.*) Moench) in Niger and several other African countries (Hilu 1986). *T. ehrenbergii* survives the long dry season as teliospores. Sorghum plants are susceptible only at the boot stage when the panicle is still enclosed in the boot sheath (Manzo 1976). In Niger, long smut is more prevalent in areas with low rainfall. In the southern areas of the country that receive an annual average rainfall greater than 700 mm, long smut is a minor disease despite the fact that all local landraces are highly susceptible to *T. ehrenbergii.* However, it has been observed that in years with a delay in the onset of the cropping season or with a substantial rainfall deficit, long smut can be severe even in those areas.

Data collected from our screening program indicate that early-maturing sorghum genotypes escape infection whereas the tall and late-maturing landraces are highly susceptible to *T. ehrenbergii.* Regression analysis has shown a significant positive correlation (r^2 = 0.55) between the number of smut sori per head and the days to 50% flowering (Issoufou Kollo, unpublished results).

Field observations suggest that sowing date has an effect on the incidence of long smut, but there was no data to substantiate this hypothesis. The objective of this experiment was to determine the effects of sowing dates on long smut of sorghum.

Materials and methods

The experiment was conducted at the Kollo Research Center during the 1990/91 growing season. Four sorghum genotypes, Tchilori, A4D4, Sepon 82, and El Mota, were used. Tchilori is a highly susceptible, late-maturing, photoperiod-sensitive landrace from southwestern Niger. A4D4 is an experimental line that is also highly susceptible to *T. ehrenbergii.* Sepon 82, developed by ICRISAT and adopted by a number of farmers, is moderately resistant to *T. ehrenbergii.* El Mota, an early-maturing landrace extensively grown by farmers, is moderately resistant to long smut. Three sowing dates, 1, 8 and 15 Jul, were used in this experiment.

The experimental design was a split plot arranged in four blocks. The sorghum genotypes constituted the main plots and the dates of sowing the subplots. Plots consisted of two rows 6 m in length. The distance between rows was 0.8 m and the distance between hills was 0.3 m. Plots were weeded twice and hills were thinned to three plants after the second weeding. At the soft dough stage, the average number of smut sori per head was estimated by randomly choosing 10 plants from each plot. Before analysis, the data was normalized by a logarithmic transformation. The analysis of variance was performed by using the SAS statistical package.

Results and discussion

The analysis of variance (Table 1) shows a strong interaction between sowing dates and sorghum genotypes (P = 0.02). For each cultivar the relationship between sowing date and the level of infection is shown in Figure 1. With the susceptible cultivars Tchilori and A4D4 the maximum level of infection occurs at the second date of sowing and the minimum level at the first date. The number of infected florets decreased with the third sowing date. This decrease can be explained by the lack of rain or free moisture inside the boot. With cultivar Sepon 82, sowing date did not significantly affect the number of infected florets. With cultivar El Mota, infection increased slightly with the third date of sowing.

Table 1. Analysis of variance[1] for the number of smut sori per panicle (log (x + 1)) for four sorghum genotypes, Kollo Research Center, Niger, 1990/91.

Source	df	Mean square	F	Probability
Replication	3	0.243	0.63	0.61
Genotype	3	27.242	70.82	0.0001**
Error	9	0385		
Date	2	6.262	15.09	0.0001**
Date x genotype	6	1.246	3.00	0.0247*
Error	24	0.415		

1. CV = 25.43%.
* Significant at P=0.05:**Significant at P =0.01 level.

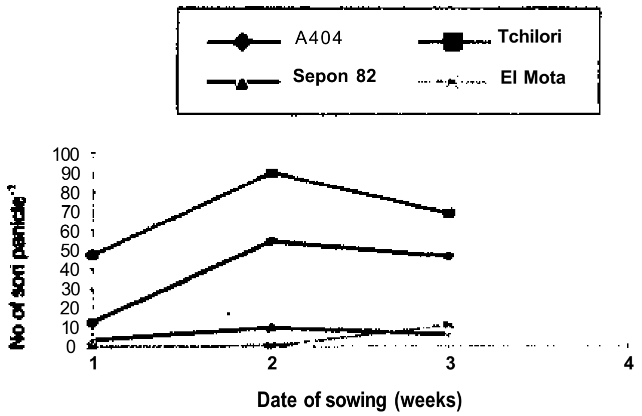

Figure 1. Effect of sowing date on the incidence of long smut on four sorghum genotypes, Kollo Research Center, Niger, 1990/91. Sowing dates were separated by 1 week. incidence is the average number of sori per panicle.

Early sowing significantly reduced the level of infection, independently of sorghum genotype With early-maturing cultivars late sowing should be avoided. Freshly produced teliospores of long smut readily germinate (Eissa 1989). Therefore a secondary cycle may occur if rains are available and this may explain the increase in disease incidence with the delay of sowing. In West Africa, sorghum seedling mortality is so important that farmers have to resow several times. Improved agricultural practices that significantly enhance seedling vigor and survival rate may be necessary for the management of long smut because they can eliminate the need for resowing.

Acknowledgment

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Electrical Conductivity of Seed Leachates in Sorghum

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Sorghum (*Sorghum bicolor* (L.) Moench) seeds infected with *Curvularia lunata* (Wakker) Boedijn, *Fusarium moniliforme* var *subglutinans* Wr. & Reink., and *Phoma sorghina* (Sacc) Boerma, Dorenbosch & van Kestern were more prone to breaking than healthy seeds. The 100-seed weight was reduced by 67% for *C. lunata,* 43% for *P. sorghina,* and 40% for *F. moniliforme* (Singh and Agarwal 1989). It was also noticed that *F. moniliforme* infection resulted in maximum loss of electrolytes in seed leachates and inhibited germination.

Seeds of 15 genotypes including hybrids, varieties, B-lines, and germplasrn accessions, were studied for electrical conductivity of leachates. Electrical conductivity of the leachates was measured using the method of Hendricks and Taylorson (1976) with some modifications. Three g seed samples of the genotype under study were washed twice with distilled water and placed in test tubes with 12 ml distilled water. After 4 h of soaking at 25°C the electrical conductivity of the supernatants was measured. 'Elico' conductivity bridge, model no. M-82 T was used. The instrument was warmed up for 30 min before taking readings. The blank reading noted was 1.76. The observed conductivity at 0.1 k was 1.76 x 100/10 = 17.6 M ohms. The specific conductivity was calculated as: observed conductivity x cell constant, where cell constant was 1.03. The test was run in duplicate.

Table 1. Electrical conductivity of sorghum seed leachates.

Genotypes	Observed conductivity (M ohms)	Specific conductivity (M ohms)
CSH 1	238,4	242.3
CSH 5	228.4	234.6
CSH 9	215.4	221.9
CSH 11	166.3	171.4
CSH 14	136.4	140.5
CS 3541	196.4	202.3
SPV 462	132.4	126.4
CSV 10	28.4	29.3
CSV 11	115.4	118.9
CK 60B	188.4	194.3
296 B	202.4	208.5
IS 84	215.4	221.9
IS 2825	107.6	110.6
IS 14332	93.4	96.2
IS 14388	94.4	97.2
Mean	157.27	161.75
CD (5%)	7.48	5.81
GV(%)	2.22	1.67

Table 1 shows that minimum seed leachates were noticed in CSV 10, followed by IS 14332 and IS 14388, and the maximum was in CSH 1 followed by CSH 5, CSH 9, 296 B, and IS 84. On the basis of electrical conductivity, entries were arbitrarily grouped as follows;

Group 1 (EC<100 M ohms): CSV 10, IS 14332, and IS 14388

Group 2 (EC 100-150 M ohms): SPV 462, CSV 11, CSH 14, and IS 2825

Group 3 (EC 151.-200 M ohms): CS 3541, CSH 11, and CK 60B

Group 4 (EC>201 M ohms): CSH 1, CSH 5, CSH 9, IS 84, and 296 B.

Glueck et al. (1977) suggested that rate of water absorption and conductivity of seed leachates were possible mechanisms for resistance to grain molds.

Waniska et al. (1992) reported that thicker mesocarp and soft endosperm increased water absorption and gave richer leachates. For white grain sorghum this statement generally holds true. Electrical conductivity of seed leachets was greater in cultivars susceptible to grain molds and in red grain types and was less in resistant genotypes.

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Structure of *Sporisorium reilianum* Populations from Mexico, USA, and Niger

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Introduction

Sporisorium reilianum (Kuhn) Langdom & Fullerton, the causal agent of sorghum head smut (SHS), is a variable pathogen that affects sorghum (*Sorghum bicolor* (L.) Moench) crops worldwide. Over the past several decades, variation in populations of *S. reilianum* has resulted in losses of deployed resistance. Current sorghum breeding requires extensive field evaluation for resistance to at least three different pathotypes. A program for characterization of SHS populations requires the evaluation of uniform disease nurseries grown in areas with known high levels of smut infestation (Frederiksen 1986). However, most of the field evaluation techniques are unreliable because of escapes (Craig and Frederiksen 1992).

We have developed nuclear DNA restriction fragment length polymorphisms (RFLPs) as genetic markers that are being used to characterize the genetic structure of nine field populations of *S. reilianum.* Three populations from Mexico, four from USA, and two from Niger were studied with the anonymous probes developed. Seven RFLP loci were used to measure the gene and genotypic diversity of these populations.

Materials and methods

Origin of samples. Ten SHS isolates originating from USA, Mexico, China, Mali, and Uganda were employed to screen two genomic libraries. Nine SHS populations were studied. Three populations were collected from the northern region of Tamaulipas, [Matamoros (MtMx), Rio Bravo (RBMx), and San Fernando (SFMx)], Mexico; four from Texas [Corpus Christi (CoCr), Beeville (Beev), Danevang (Dane), and Taylor (Tayl)]; and two from Niger [Tillabery (Tbry) and Konni (Koni)]. About 50 isolates from each population were collected in a hierarchical grid of 10 x 10 m.

DNA extraction. Single spore cultures of *S. reilianum* were grown for 3-5 days in 100 ml of potato dextrose broth on arotary shaker at 150 rpm. Total cellular DNA was extracted using the CTAB method (McDonald and Martinez 1990b).

Development of probes. Two genomic libraries containing random *S. reilianum* DNA fragments were constructed for use as probes. The total genome of one isolate of SHS was digested with the *Pstl* enzyme and the fragments ligated into pUC18. Recombinant piasmids were used for transformation of *E. coli* strain DH5aMCR. Two-hundred and ninety clones obtained from the libraries were used as potential probes for RFLP analysis.

Southern blotting and hybridization. A screen of the probes was performed with the 10 SHS isolates from different regions of the world. Each isolate was digested with the restriction enzymes *Bam*III, *Eco*RI, *Hind*III, *Pstl,* and *Xho*I. Five mg of DNA from each isolate was digested independently with each enzyme. The fragments were separated on 0.8% agarose gels and then transfered to Zeta-probe membranes (BioRad, Hercules, CA). Probes were labeled with ^{32}P using nick translation and then hybridized overnight with the membranes before placing on x-ray film.

Data analysis. RFLP analysis was conducted by treating each probe as a separate locus and each fragment or combination of fragments as an allele at that locus. The alleles were numbered according to their frequency in the sample; i.e., the allele appearing most frequently on the autoradiograms was called allele 1. The alleles present at each locus were combined to make a multilocus genotype (MLGT) for each isolate.

Nei's measure of gene diversity (Nei 1973) was calculated for each locus and then averaged over all loci for each population. Stoddart and Taylor's measure (1988) was used to calculate genotypic diversity $\hat{G}$:

$$\hat{G} = \frac{1}{\sum_{x=0}^{n} \{(f_x)\cdot(x/n)^2\}}$$

where n is the sample size and f_x is the number of distinct multilocus genotypes, based on MLGT pattern, observed *x* times in the sample. The highest number possible, which occurs when each isolate has a different genotype, is *n.* To compare between different samples, $\hat{G}$ is divided by *n* to get the percentage of the maximum genotypic diversity observed.

Results and discussion

Probe screening. A low level of variation was detected when 173 anonymous probes from the two genomic libraries were screened with the 10 international isolates. Only 8% of 505 probe-enzyme combinations were polymorphic. The enzymes *Hindill* and *Pstl* gave more polymorphisms than the other three enzymes tested with the first 42 probes screened, and were selected to continue the screening of the remaining probes. Most of the polymorphic probes hybridized to single or low copy sequences. Seven of these probe-enzyme combinations (Table 1) and a fingerprint (data not shown) were selected to study the genetic structure of the nine populations.

Table 1. Multilocus genotypes of 10 *Sporisorium reilianum* isolates from sorghum. Each number represents an allele present at a nuclear RFLP locus defined by a particular probe-enzyme combination.

	RFLP locus						
Isolate	pSR126 PstI	pSR130 *Hind*III	pSR143 PstI	pSR210 *Hind*III	pSR239 *Hind*ill	pSR250 PstI	pSR250 *Hind*ill
SFMx 46	2	1	2	2	1	1	1
RBMx 3	1	1	1	2	1	1	1
CoCr 3-13	2	1	2	2	1	1	1
Uganda 2-93	2	1	1	1	2	3	2
Tayl 4-18	1	1	1	1	1	1	1
Mali 3-91	1	1	1	1	2	2	3
China 101	2	2	1	2	1	3	2
Dane 3-3	1	1	1	2	1	1	1
Vict 101-4	1	1	1	1	1	4	1
MtMx 50	1	1	2	2	1	1	1

The low variability detected in *S. reilianum* was similar to that found in the oak wilt pathogen *Cetatocystis fagacearum* (Kurdylaet al. 1995), where only 8% of 437 probe-enzyme combinations detected RFLPs among nine isolates, A higher degree of polymorphisms has been detected in other fungi: in M*yccsphaerella graminicola* 74% of 196 probe-enzyme combinations detected RFLPs (McDonald and Martinez 1990a), and in *Colletotrichum graminicola* 81% of 299 probe-enzyme combinations were polymorphic (Rosewich 1996).

RFLP data. Low levels of genetic diversity were detected in the nine populations studied. The seven populations from the Western Hemisphere shared the majority of frequent alleles at a number of loci (Table 2). Other alleles were present in the African populations.

Table 2. Allele frequencies for nine *Sporisorium reilianum* populations (three from Mexico: RBMx, MtMx, and SFMx; four from Texas: CoCr, Beev, Dane, and Tayl; and two from Niger: Koni and Tbry) at seven RFLP loci defined by particular probe-enzyme comlunations.

RFLP locus	Allele	RBMx n=66	MtMx n-56	SFMx n=53	CoCr n=46	Beev n=57	Dane n=60	Tayl n=50	Koni n=39	Tbry n=36
pSR210	1	0.17	0.02	0.13	0.47	0.51	0.67	0.47	0.92	1.0
*Hind*III	2	0.79	0.98	0.87	0.47	0.47	0.33	0.53	0.08	0.0
	3	0.05	0.0	0.0	0.05	0.02	0.0	0.0	0.0	0.0
pSR126	1	0.58	0.29	0.45	0.55	0.78	0.98	0.76	0.97	0.97
Pstl	2	0.41	0.71	0.55	0.39	0.22	0.02	0.21	0.03	0.03
	3	0.01	0.0	0.0	0.05	0.0	0.0	0.03	0.0	0.0
pSR130	1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
*Hind*III	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pSR143	1	0.51	0.50	0.49	0.42	0.52	0.83	0.55	0.13	0.14
Pstl	2	0.17	0.36	0.35	0.33	0.23	0.06	0.32	0.51	0.08
	3	0.32	0.14	0.16	0.25	0.25	0.11	0.13	0.15	0.03
	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.64
	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.0
	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.08	0.06
	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.06
pSR239	1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.64	0.86
Hindil	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.36	0.14
pSR250	1	0.89	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0
Pstl	2	0.11	0.0	0.0	0.0	0.0	0.0	0.0	0.13	0.0
	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.51	0.97
	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.15	0.03
	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.21	0.0
pSR250	1	0.89	1.0.	0.98	0.98	1.0	1.0	1.0	0.0	0.0
Hindm	2	0.09	0.0	0.0	0.0	0.0	0.0	0.0	0.97	1.0
	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	4	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.0
	5	0.0	0.0	0.02	0.02	0.0	0.0	0.0	0.0	0.0

On average, 12.5 different MLGTs were present per population studied. Danevang in Central Texas had only 6 different MLGTs while Konni in Niger was the population with the highest number of different MLGTs with 23. Genotypic diversity was moderately high with a value of 6.16. In total, 53 MLGTs were identified. The two African populations had 30 MLGTs that were not present in the Mexican and US populations. Africa is most likely the center of origin of *S. reilianum,* which is consistent with the greater number of MLGTs we found in these populations, but the gene and genotypic diversity observed were still unexpectedly low for this sexually reproducing organism.

The low number of polymorphic probes detected and the low gene diversity found in the populations studied suggest that, in nature, the sister sporidia intermate during the sexual cycle leading to high levels of inbreeding. Similar inbreeding has also been reported in other smut fungi such as *Tilletia* species (Holton et al. 1968). Alternatively, high diversity of the 'b' mating type locus in the common corn smut pathogen *Ustilago maydis* suggests that *U. maydis* populations are largely outbreeding (Zambino et al. 1997).

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Winter Survival of *Claviceps africana* Spores in the Central Plains of the USA

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Introduction

Claviceps africana Frederickson, Mantle & Dc Milliano has been well known in Africa, India, and other tropical areas of the world for several years. In 1995 it was discovered in Brazil. From there it spread rapidly northward across South America and Central America and entered the USA in Texas in March of 1997 (Bandyopadhyay et al. 1998). The disease was observed spreading northward as the sorghum (*Sorghum bicolor* (L.) Moench) crop came into bloom. In October of 1997 infected florets were found on sorghum in southeastern Nebraska. It is apparent that the pathogen can spread northward with prevailing winds but there were no reports or evidence that the pathogen can survive the winter in this northern environment when exposed to repeated rain and snow and the extremes of freezing and thawing temperatures. This report documents the survival and infectivity of *C. africana* spores through the winter of 1997/98 in Nebraska.

Materials and methods

In mid-November 1997, 200 ergot-infected panicles of sorghum that had been collected from a heavily infected field near Wichita, Kansas, were placed in a wire screen cage about 1 m wide, 1.5 m long, and 0.5 m deep. The cage, which prevented damage by birds or rodents but allowed full exposure to the environment, was placed on the ground in a field near Virginia, Nebraska, where ergot had been observed. The winter of 1997/98 was only slightly milder than normal. The average daily temperatures for January, the month with the lowest temperatures, were a low of -8°C and a high of 2°C. The extreme low temperature for the winter was -26°C. The panicles were exposed to rain, snow, sun, and repeated freezing and thawing. At intervals ranging from 2 to 4 weeks, samples of 8 to 12 panicles were brought into the laboratory and spores washed from the panicles were used to inoculate potted sorghum plants in the greenhouse. During several collections the panicles in the cage were found to be partially covered with ice and snow. The March sampling was missed because the cage was under a 1 m deep drift of snow. With the first samplings 10-15 florets with signs of ergot were removed from the panicles and after soaking in 15 ml of water for 1 h the spore suspension was filtered through cheesecloth and used to inoculate three to five panicles of a male-sterile forage sorghum, var Sweet Leaf 11, that had just begun bloom. With the later samplings, weathering had so damaged the appearance of the panicles that the infected florets could not be identified. For those collections, 8-10 whole panicles were soaked for 1 h in 300 ml of water in a graduated cylinder. After agitation the spore suspension was filtered and centrifuged to concentrate the spores. For all samplings an attempt was made to have a spore suspension of at least 10^6 spores per ml. Nearly all of the spores from the early sampling were microspores, while the later samplings had a large number of all types of fungal spores, and identification and counting was difficult. Inoculation was accomplished by enclosing the panicle in a 4-L plastic bag and, after cutting a small hole to admit the nozzle of an atomizer, the spore suspension was sprayed over the florets. After 24 h the bags were removed and the plants maintained with supplemental light in a humidified greenhouse held at 23°C. At each sampling date a positive control, using macrospores from fresh honeydew at approximately the same concentration as the field sample, was included in the trial to test the effectivness of the inoculation method.

Results and discussion

At each trial date the control panicles inoculated with the fresh macrospore suspension developed good levels of ergot infection as evidenced by 5-20 infected florets per panicle. Survival of viable spores in the field was demonstrated by five or more infections per panicle from the samples tested in December and early January but the late January sample had only three infected florets on five panicles. The February, April, and May samplings were obtained by washing whole panicles and concentrating the spores by centrifugation. This led to a more concentrated inoculum and all of these samplings resulted in numerous infections indicating that the spores were still virulent until the end of testing on 20 May 1998.

These results only indicate that viable infectious spores did survive the winter of 1997/98 in Nebraska after full exposure to the elements of the weather. We have not proven that natural infection will occur from overwintering spores under field conditions, but we have demonstrated that it is possible. These trials will be repeated

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Entomology

Association of Grain Size and Levels of Resistance to the Sorghum Midge

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There has been a commonly held concern that increased levels of resistance to the sorghum midge (*Stenodiplosis sorghicola* Coquillett) have resulted in decreased grain size. This assertion was examined in three separate situations.

1. Farmer deliveries

Screenings (this is a measure of grain size being the percent volume of grain passing through a 2 mm slotted sieve) and hybrid name data were collected on 3123 fanner deliveries of sorghum (*Sorghumbicolor*(*L.*) Moench) to four depots in Central Queensland in 1996. Percent screenings is routinely assessed for farmer deliveries. Samples with screenings above 11% are docked; so grain size is a significant farmer issue.

The level of resistance for each of the hybrids had been measured in a standardized test developed by the seed industry and the Queensland Department of Primary Industries (QDPI). The level of resistance varied from a Midge Tested Rating of 1 (i.e., susceptible) to 7 (i.e., an economic injury level seven times that of a susceptible hybrid).

The correlation between the level of midge resistance and percent screenings varied amongst the four depots, being 0.29, -0.16, -0.40, and -0.55. The reasons for this variation are unknown. The negative correlations (i.e., where the resistant hybrids had larger grains) may be due to the fact that the hybrids with the higher levels of resistance also had higher levels of stay-green. Dr Andrew Borrell (personal communication) has data from a set of recombinant inbred lines suggesting stay-green results in larger grain under terminal water stress conditions.

2. Tests involving experimental hybrids

Percent screenings was measured on a set of 200 experimental hybrids from the QDPI sorghum breeding program grown at four test sites in 1997. The midge resistance of these hybrids was measured in another two tests designed for the purpose. The results (Table 1) clearly show there is no correlation between percent screenings and midge resistance.

3. Tests involving recombinant lines

The level of midge resistance of a set of 160 random recombinant inbred lines from the cross QL41 x QL39 was tested as part of the molecular marker project. Grain size for these same lines was measured in Dr Andrew Borrell's "Physiology of Stay-green" project and as part of the molecular marker project.

This data indicated no relationship (r = 0.03) between midge resistance and grain size. Correlations calculated from data on random recombinant lines are more likely to indicate the relationship between the midge resistance and grain size genes. This is because possible 'background' genes affecting grain size will be distributed more at random across the midge resistance genes than they would be amongst genotypes in which there may have been some selection for grain size and midge resistance.

Table 1. Correlations between midge resistance and percent screenings of a set of 200 experimental sorghum hybrids in Australia, 1997.

Test site	Correlation
Bauhinia	0.17
Biloela	0.06
Dalby	-0.07
Bongeen	0.11

Conclusions

There is clearly no relationship between the level of midge resistance and grain size in these test conditions and with the genetic backgrounds involved. The perception that there may have been, may be due to the fact that a number of the sources of midge resistance had small grain. It follows that it is possible to develop sorghums with high levels of midge resistance and large grain size.

Association of Sorghum Seedling Characters with Resistance to Shoot Fly, *Atherigona soccata* (*Rondani*)

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The sorghum shoot fly, *Atherigona soccata* (Rondani) (Muscidae: Diptera) is an important pest of sorghum (*Sorghum bicolor* (L.) Moench) causing substantial reduction in crop yield. Plant resistance to insect pests is an important component of integrated pest management. The relationship of various plant characters with shoot fly resistance has been studied earlier by many workers (Khurana and Verma 1985; Singh 1986; Patel and Sukhani 1990). The present investigations were undertaken to identify the stage and physical characters of sorghum seedlings that are associated with shoot fly resistantance.

Materials and methods

Field trials were conducted at the Forage Research Area, CCS Haryana Agricultural University, Hisar, Haryana, India, in a randomized complete block design having three replications with a plot size of 9.0 m^2. Ten sorghum genotypes were sown during the 1996 and 1997 rainy seasons to study the relationship between different plant characters and shoot fly resistance. Shoot fly eggs were recorded 7 and 14 days after germination (DAG) on 10 randomly selected plants in each plot, while deadhearts and total number of plants in the two middle rows per plot were recorded 15 and 30 DAG. Observations were recorded for various plant characters from 10 randomly selected plants from each plot. Seedling mass, shoot length, number of leaves per plant, leaf length, and leaf width (fourth leaf from base) were recorded 10 and 20 DAG.

The pooled mean values over seasons for plant characters were taken as independent variables (X) and shoot fly oviposition and deadhearts as dependent variables (Y) to compute simple correlations.

Results and discussion

The mass of sorghum seedlings at 20 DAG, number of leaves per plant at 10 and 20 DAG, and leaf width 10 DAG were positively correlated with oviposition and deadhearts formation (Table 1). However, seedling mass at 10 DAG, and shoot length at 10 and 20 DAG were negatively associated with both oviposition and deadheart formation.

The positive association of seedling mass at 20 DAG, number of leaves per plant at 10 and 20 DAG, and leaf width at 10 DAG with shoot fly susceptibility suggests that healthy and stout seedlings bearing more and broader leaves are most preferred for egg laying by shoot fly females, consequently leading to greater deadheart formation. Singh (1986) and Patel and Sukhani (1990) observed similar relationships between seedling characteristics and resistance/susceptibility to sorghum shoot fly.

The negative correlation of seedling mass at 10 DAG, shoot length of 10 and 20 DAG, and leaf length at 10 and 20 DAG with susceptibility to shoot fly suggests that shoot fly resistant genotypes grow faster and escape deadheart formation. Blum (1972) and Mate et al. (1979) also reported that most resistant genotypes were taller and had higher initial growth rates than the susceptible ones. These studies have indicated that genotypes with fast seedling growth and long and thin leaves during the seedling stage are generally less susceptible to shoot fly. These parameters should be taken into consideration while selecting sorghum genotypes for resistance to shoot fly.

Table 1. Correlations[1] of seedling characters with shoot fly oviposition and deadheart formation in sorghum at Hisar, Haryana, 1996 and 1997 rainy seasons.

Seedling characters	No of eggs $plant^{-1}$	Deadhearts (%)
Seedling mass 10 DAG	-0.683*	-0.525*
Seedling mass 20 DAG	0.539[2]	0.615
Shoot length 10 DAG	- 0.721*	-0.542*
Shoot length 20 DAG	- 0.645*	-0.587*
Number of leaves 10 DAG	0.592*	0.621*
Number of leaves 20 DAG	0.682*	0.341
Fourth leaf length 10 DAG	-0.516*	-0.592*
Fourth leaf length 20 DAG	-0.584*	- 0.283
Fourth leaf width 10 DAG	0.638*	0.569*
Fourth leaf width 20 DAG	0.412	0.214

1. DAG = days after germination.
* Significant at $P<0.05$.

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Failure of Sorghum in Rotation with Corn to Manage Mexican Corn Rootworm

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Introduction

Mexican com rootworm, *Diabrotica virgifera zeae* Krysan & Smith, adults lay eggs in the soil of com (*Zea mays* L.) fields during the summer. Eggs overwinter in the soil and hatch in the spring. Larvae then feed on the roots of com plants, causing plant lodging and yield loss. Together with northern corn rootworm, *D. barberi* Smith & Lawrence, and western corn rootworm, *D. virgifera virgifera* LeConte, these pests have been estimated to cost US$ 1 billion annually in corn yield losses and control costs. Sorghum, *Sorghum bicolor* (L.) Moench, has played an important role in the management of Mexican corn rootworm in Texas. Because larvae can survive only on the roots of corn and a few grass species, annual rotation of corn with sorghum terminates the life cycle of corn rootworm. Corn sown in the season following sorghum should be free of damage by corn rootworm larvae. Recent reports, however, have linked Mexican corn rootworm to damage to corn sown the season following sorghum. Similar reports have surfaced in the midwestem USA where soybeans, *Glycine max* (L.) Merr., were rotated with corn to manage northern corn rootworm and, most recently, western corn rootworm. Without crop rotation, these pests must be managed using soil insecticides. Soil insecticide application typically reduces by about 50% the number of larvae surviving to adulthood. This level of suppression, however, is not sufficient to prevent the need for soil insecticide the following season. Experiments were conducted in Bell County, Texas, during 1996 and 1997 to determine the factors contributing to failure of crop rotation using sorghum to prevent damage by Mexican corn rootworm to corn.

Factors that could reduce the effectiveness of crop rotation include prolonged diapause of corn rootworm eggs, development by larvae of an ability to survive on roots of sorghum, and oviposition by adults in sorghum fields, in some areas of the midwestem USA, as much as 51% of northern corn rootworm eggs sampled remained in diapause for two years. A two-year egg diapause allows eggs to remain dormant while a nonhost crop is growing. These eggs hatch when corn is resown. Mexican corn rootworm eggs sampled from Bell County, Texas, during 1996 did not exhibit prolonged egg diapause. Eggs began hatching 269 days after oviposition, and 90% had hatched 280 days after oviposition.

Materials and methods

In 1996 and 1997, traps to capture Mexican corn rootworm adults emerging from the soil were placed over corn and sorghum plants. Capture of adults in these traps indicates the level of survival by larvae on the roots of each of the plant species.

Results and discussion

Survival by Mexican corn rootworm larvae on sorghum was 3.0-11.2% of that from corn. This suggests that survival by larvae on the roots of sorghum was not a significant factor in the failure of crop rotation to prevent damage by Mexican corn rootworm to corn. In 1997, larval survival measured on cotton, *Gossypium hirsutum* L., was 2.0% of that on sorghum, soybeans was 1.6%, and Texas panicum, *Panicum texanum* Buckley, was 0.5%.

Oviposition by Mexican corn rootworm adults in corn and sorghum fields was measured in 1996. Mexican corn rootworm oviposition in sorghum did not differ significantly from that in corn. An average of 1 egg per liter of soil was found in sorghum compared to 1.7 eggs per liter of soil in com. In 1997, oviposition was measured in corn, sorghum, cotton, soybeans, and Texas panicum. Again, there was no significant difference between oviposition in sorghum and that in corn. However, oviposition in cotton, soybeans, and Texas panicum was significantly lower than that in corn. Average numbers of eggs per 0.5 liter of soil in corn was 6.8, sorghum was 3.9, cotton was 1.2, soybeans was 1.6, and Texas panicum was 0.5. Adult abundance and crop phenology also were monitored in these crops during 1997. Adults were most attracted to crops during the flowering stage of growth.

In summary, neither prolonged egg diapause or survival by larvae on roots of sorghum played a significant role in the failure of crop rotation using sorghum to prevent damage by Mexican corn rootworm to corn. Oviposition in sorghum did not differ significantly from that in corn, suggesting adult migration from corn to sorghum for oviposition. Because adults were most attracted to flowering crops, manipulation of sorghum flowering time may allow sorghum to escape oviposition by Mexican corn rootworm. For example, sowing sorghum so it flowers before corn or selecting cultivars with shorter flowering periods are two potential solutions.

Yield of Sorghum Midge-resistant Sorghum Hybrids

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Resistance to sorghum midge, *Stenodiplosis sorghicola* (Coquillett), of 52 sorghum (*Sorghum bieolor* (L.) Moench) hybrids (43 resistant x resistant experimental hybrids, 3 resistant x resistant controls, 1 resistant x susceptible control, and 5 susceptible controls) was evaluated at the Texas A&M University Agricultural Research and Extension Center at Corpus Christi and the Texas A&M University Agricultural Experiment Station Research Farm near College Station in 1997. Susceptible sorghum sown 3 weeks early adjacent to the experimental area provided a source of sorghum midge to infest the experimental sorghums. At Corpus Christi, seeds of the experimental sorghums were sown on 8 Apr in 6-m-long plots, with 98 cm between rows. Sorghum was sown at College Station on 8 May, with 76 cm between rows. Damage caused by sorghum midge and grain yield (kg ha^{-1}) were compared between experimental hybrids and controls. Sorghum at physiological maturity was rated by plot for sorghum midge damage (based on a scale of 1 = 1-10%, 2 = 11-20%... 9 = 81-100% of kernels that failed to develop). Sorghum panicles from 0.0025 ha per plot were hand harvested. Threshed grain mass (g) was converted to kg ha^{-1} to obtain grain yield. ANOVA was used for data analysis and and $LSD_{0.05}$ for mean separation.

Although differences were not always significant between experimental hybrids and resistant x resistant controls, most experimental hybrids were significantly less damaged by sorghum midge and produced significantly more grain within and over locations than susceptible x susceptible controls. Sorghum at Corpus Christi was damaged significantly more by sorghum midge (5.2 vs 3.0 rating) and yielded less grain (1492 vs 5563 kg ha^{-1}) than at College Station. Hybrids that performed well under high sorghum midge abundance (Corpus Christi) also performed well under moderate abundance (College Station). Female parental lines designated ATx639, ATx640, and ATx641 have consistently performed well for the past five years and were released recently to private industry. Hybrids from these female parents had 1.9 and 4.1 damage rating scores and yielded 7035 kg ha^{-1} at College Station and 2195 kg ha^{-1} at Corpus Christi. Hybrids with female parent A94 are being evaluated for commercial release. Hybrids produced from lines designated A94-6, A94-7, or A94-15 were rated 1.7 and yielded 6397 kg ha^{-1} at College Station and rated 3.4 and yielded 2157 kg ha^{-1} at Corpus Christi. By comparison, susceptible x susceptible controls at College Station were rated 6.5 and yielded only 2183 kg ha^{-1} and these controls at Corpus Christi were rated 9.0 and yielded only 186 kg ha^{-1}. Data indicated that when sown late, many sorghum midge-resistant hybrids yield significantly more grain without the use of insecticide than do susceptible hybrids.

Striga

Preliminary Results on Evaluation of Trap Crops for *Striga hermonthica* (Del.) Benth. Control in Sorghum

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Introduction

Striga hermonthica belongs to the family Scrophulariaceae. It is an obligate root parasitic weed on cereal crops, especially on sorghum (*Sorghum bieolor* (L.) Moench), pearl millet (*Pennisetum glaucum* (L.) R. Br.), maize (*Zea mays* L.) and rice (*Oryza sativa* L.) in tropical Africa (Parker and Riches 1993). The effect of this parasite has been so devastating that crop yield losses of 10-100% have been recorded, leading to complete crop failure and abandonment of land (Gworgwor 1997).

The annual loss of revenue from sorghum, pearl millet, and maize due to *S. hermonthica* infestation could amount to US$ 2.9 billion in Africa (Sauerbom 1991). Because of its economic importance, various measures have been attempted to control *S. hermonthica,* but no stable and satisfactory results have been achieved due to the complicated nature of the parasite's seed ecology, host specificity, and mode of parasitism. Control measures include cultural, agronomic, chemical, and biological methods. No single method has proved entirely effective and therefore, a combination of more than one method of control (integration) is required, given the diversity of farming systems and the resource constraints of small-scale farmers.

The use of appropriate trap crops, such as soybean (*Glycine max* (L.) Merrill), cotton (*Gossypium hirsutum* L.), and bambara groundnut (*Vigna subterranean* (L.) Verdcount), in combination with resistant/tolerant cereal crop varieties may reduce the number of *S. hermonthica* seeds in the soil (Parkinson et al. 1988). The objective of this research was to evaluate the performance of available trap crops in suppressing *S. hermonthica* in traditional cropping systems in a semi-arid zone when intercropped with resistant and susceptible sorghum varieties under controlled conditions.

Materials and methods

A pot experiment was conducted at the Research and Teaching Farm of the Faculty of Agriculture, University of Maiduguri, Nigeria, during the months of Apr-Jul 1997. Four sorghum varieties were used for the experiment (ICSV 1002, ICSV 1007, BES (KSV4), and Ware-warenbashi). ICSV 1002 and ICSV 1007 were reported to be resistant to *S. hermonthica* and were developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)-Mali. BES is a sorghum variety also reported to be resistant and was obtained from Lake Chad Research Institute (LCRI), Maiduguri, and Ware-warenbashi is a susceptible local variety obtained from Borno State, Nigeria. These sorghums were intercropped with six trap crops: soybean, cotton, bambara groundnut, sunflower (*Helianthus annuus* L.), okra (*Hibiscus esculentus* L.), and sesame (*Sesamum indicum* L.). These were sown in perforated plastic pots of 22 cm diameter in a sandy loam soil. The top 6 cm was mixed thoroughly with 200 grams of one-year-old *S. hermonthica* seed. Each plastic pot received basal fertilizer of 15:15:15 NPK at 0.5 g pot^{-1}, which was ground and mixed with the top soil before sowing sorghum and trap crops. Three seeds of each sorghum variety were sown per pot at about 2-4 cm depth for sorghum and 2-5 cm for the trap crop. Plants were thinned 2 weeks after sowing (WAS) leaving two sorghum plants and two trap crop plants per pot. The two-factor experiment was laid out in a split-plot design with sorghum varieties as main plots and the trap crops as subplots, replicated four times. Weeds were controlled manually. Data were statistically analyzed using analysis of variance according to Gomez and Gomez (1984).

Results and discussion

Striga counts were significantly affected by sorghum varieties and trap crop treatments at 12 WAS (Table 1). ICSV 1007 supported significantly lower numbers of *Striga* than the other varieties, while Ware-warenbashi had significantly higher levels of *Striga.* Sesame and bambara groundnut trap crops had significantly lower numbers of *Striga* plants than either the control sorghum sowings or any other of the trap crop treatments (Table 1). Significant *Striga* count interaction between sorghum varieties and trap crop treatments were observed at 12 WAS (Table 1). ICSV 1002 x sesame, BES x sesame, and ICSV 1002 x bambara groundnut interactions resulted in significantly lower numbers of *Striga* plants per pot, while Ware-warenbashi x sorghum interactions supported significantly higher numbers of *Striga* per pot compared to the interaction between Ware-warenbashi and each of the other trap crops. BES x okra also supported significantly higher numbers of *Striga* per pot (Table 1). These results indicate that sorghum varieties supported significantly lower numbers of *Striga* plants when intercropped with trap crops than when sown as sole crops.

Ware-warenbashi supported significantly higher numbers of *Striga* plants than the resistant sorghum varieties, while ICSV 1007 supported significantly fewer *Striga* plants than either ICSV 1002 or BES. Based on crop vigor and the number of emerged *Striga* plants per pot, the best trap crops were as follows: sesame, bambara groundnut, cotton, soybean, sunflower, and okra. The significant interaction for *Striga* counts between variety and trap crop treatment indicates the need for an integrated approach for *Striga* control to increase sorghum yields by using resistant sorghum varieties and trap crops.

The effect of sorghum varieties and trap crops on crop vigor had significant effects at 12 WAS. ICSV 1002,1007, and BES had similar crop vigor when compared to Ware-warenbashi. Among the trap crop treatments, sorghum sown with soybean, bambara groundnut,

Table 1. Effect of sorghum varieties and trap crops on *Striga* counts, Maiduguri, Nigeria, 1997.[1]

	Striga count pot^{-1} at 12 WAS[2]				
	Sorghum varieties				
Trap crops	ICSV 1002	ICSV 1007	BES	Ware-warenbashi	Mean
Sorghum	20.0ef[3]	15.0ghij	30.0c	64.0a	32.3a
Soybean	12.2ijkl	8.0lmn	13.0hijk	37.0b	17.6b
Cotton	10.0klm	11.0jklm	16.0fghi	20.0ef	14.3b
Bambara groundnut	0.1p	0.3p	6.0mn	17.0fgh	5.9c
Sunflower	11.0jklm	13.0hijk	13.0hijk	24.0de	15.3b
Okra	12.8ijkl	12.0ijkl	26.0cd	23.0de	18.5b
Sesame	3.0np	0.2p	0.1p	18.0fg	5.3c
Variety mean	9.9c	8.5d	14.9b	29.0a	

1 S.E: variety (V) =±0.52, trap crop (TC) =±2.10, V x TC = ±2.30.
2. WAS=weeks after sowing.
3. Means followed by the same letter are not significantly different at $P = 0.05$ according to Duncan's Multiple Range Test.

Table 2. Effect of sorghum varieties and trap crops on *Striga* growth, Maiduguri, Nigeria, 1997.

	Sorghum			*Striga*		
Treatments	Crop vigor[1] (0-10 scale) 12 WAS[2]	No of tillers plant[1] 12 WAS	Plant height (cm) 14 WAS	Days to emergence	Plant height (cm) 14 WAS	Dry matter yield (g pot[1]) 15 WAS
Varieties (V)						
ICSV 1002	6.1a[3]	2.4a	56.3d	50.0b	14.5b	63.2b
ICSV 1007	6.2a	1.6b	61.1c	60.0a	7.3b	49.1b
BES	5.9ab	3.2a	70.7b	55.0ab	27.6a	97.5a
Ware-warenbashi	5.6b	3.1a	89.2a	51.4b	36.9a	106.0a
S.E.	±0.20	±0.50	±1.30	±3.10	±5.90	±13.00
Trap crops (TC)						
Sorghum	5.2c	3.1	55.5e	51.2	40.6a	185.5a
Soybean	6.0b	2.9	67. lcd	52.3	25.4b	119.0b
Cotton	5.9b	2.5	66.5d	52.8	14.5bc	45.1c
Bambara groundnut	6.8a	2.5	76.1b	49.5	16.9b	12.9d
Sunflower	6.0b	2.4	70.6c	53.3	21.8b	67.0c
Okra	5.0c	2.3	69.4c	56.5	25.1b	122.1b
Sesame	6.9a	2.4	87.5a	62.3	6.7c	1.0d
SE	±0.31	±0.80	±1.40	±2.10	±8.10	±16.30
V x TC	NS[4]	NS	NS	NS	NS	NS

1. 0-10 scale, where 0 = total crop failure, and 10 = excellent crop vigor.
2. WAS = weeks after sowing.
3. Means followed by the same letter are not significantly different at P * 0.05 according to Duncan's Multiple Range Test.
4 . M = not significant.

sunflower, or sesame was significantly more vigorous than sorghum alone (Table 2). The difference in crop vigor among the varieties could be attributed to the infestation levels of *Striga* and the differences in effectiveness of various trap crops. Growing sorghum alone resulted in low crop vigor, thus indicating the need to intercrop sorghum with other trap crops to control *Striga.* Statistical analysis indicated that there was no significant interaction between sorghum varieties and trap crops on crop vigor at 12 WAS (Table 2).

The number of tillers produced per plant was significantly affected by the variety at 12 WAS (Table 2). The susceptible local variety, Ware-warenbashi, had more tillers than BES and both had significantly higher tiller numbers per plant than the resistant varieties, ICSV 1007 produced significantly lower numbers of tillers than all other entries (Table 2). Trap crop treatments had no significant effects on tiller numbers produced per plant. Similarly, there was no significant interaction between sorghum variety and trap crop treatments on tiller number per plant (Table 2).

Sorghum variety and trap crop treatments had a significant effect on plant height of sorghum at 14 WAS. ICSV 1002 was significantly shorter than ICSV 1007 and BES. The treatments without trap crops were significantly shorter than treatments with trap crops. Sorghum intercropped with sesame produced significantly taller plants than all other treatments. There was no significant interaction between sorghum variety and trap crop treatment on plant height at 14 WAS (Table 2).

Days to *Striga* emergence was significantly delayed in ICSV 1007 compared with BES and Ware-warenbashi. However, intercropping with trap crops had no significant effect on days to *Striga* emergence. No significant interaction between varieties and trap crops were observed for this (Table 2). Emerged *Striga* plants associated with ICSV 1007 were significantly shorter than those with Ware-warenbashi and BES. All trap crop treatments produced significantly shorter *Striga* plants than the sorghum sole crop controls. Trap crops of cotton, bambara groundnut, and sesame were significantly shorter, and had comparably shorter *Striga* plants than trap crops of soybean, sunflower, and okra (Table 2). Statistical analysis indicated that there was no significant interaction between sorghum varieties and trap crops on *Striga* plant height at 14 WAS (Table 2). Control sowings of sorghum produced significantly higher *Striga* dry matter than sorghum sown with trap crops. Sesame and bambara groundnut had significantly lower *Striga* dry matter yields than all other treatments; however, interactions between variety and trap crop treatments for this were not significant (Table 2).

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Millet Research Reports

Genetics and Plant Breeding

Agronomic Potential of *Pennisetum glaucum* subsp *monodii* Germplasm for Forage Production

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Introduction

The wild grassy subspecies *Pennisetum glaucum* (L.) R. Br. subsp *monodii* has been an important source of genes for improving pearl millet. Genes for resistance to rust (*Puccinia substriata* Ellis & Barth. var *indica* Ramachar & Cummin) and pyricularia leafspot (*Pyricularia grisea* (Cooke) Sacc.) have been identified in this subspecies and incorporated into commercial forage [Tifleaf 2 and Tifleaf 3 (Hanna et al. 1997)] and grain (HGM-100) hybrids. A new stable cytoplasm, A_4, was identified in an accession from Senegal and incorporated into improved germplasm for use in producing commercial forage and grain pearl millet hybrids.

Bramel-Cox et al. (1987) studied cultivated x *monodii* crosses and found that "no strong association of traits was found that would hinder recombination of parental types to select agronomically desirable segregates with high grain yield or growth rate." Hanna (1997) reported up to a 17% increase in dry matter production in pearl millet hybrids due to cytoplasmic or cytoplasmic-nuclear effects. The objective of this research was to determine whether the *monodii* germplasm in our collection had genes that could increase forage dry matter yields in pearl millet.

Materials and methods

One-hundred fifty-six *monodii* accessions from Niger, Mali, and Senegal were crossed as pollen parents with Tift $85D_2A_1$, a commercial cytoplasmic-nuclear male-sterile line with good general combining ability. These hybrids, along with commercial hybrids Tifleaf 2 and Gahi 3, were evaluated for forage yields for one year in two 9 x 9 lattice square design tests at Tifton, Georgia, USA. Test 1 included 79 *monodii* hybrids and Test 2 included 77 *monodii* hybrids in addition to the two commercial checks. Test 2 also included two unrelated hybrids. Entries were sown in single rows 4.8 m long and 1.8 m between centers to facilitate mechanical harvesting. Plots were harvested in July, August, and October.

Results and discussion

Five *monodii* hybrids in Test 1 yielded significantly (P = 0.05) more dry matter than either of the commercial checks. The highest yielding cross produced 20% more dry matter than Tifleaf 2, the highest yielding commercial check (Table 1). All five *monodii* accessions originated from Senegal. It is interesting to note that most of the disease resistance genes (Hanna et al. 1993) and cytoplasms that gave increased dry matter yields (Hanna 1997) were derived from Senegal accessions. in contrast, seven hybrids yielded significantly less dry matter than Tifleaf 2, with the lowest yielding hybrid producing 23% less dry matter than Tifleaf 2.

No *monodii* hybrids yielded more dry matter than the commercial checks in Test 2. However 16 hybrids yielded significantly less dry matter than Tifleaf 2. The lowest yielding hybrid produced 57% less dry matter than Tifleaf 2.

This study indicates that genes are present in the *monodii* germplasm for increasing dry matter yields in pearl millet. Dry matter yields can probably be significantly increased by utilizing germplasm from both the 'cultivated gene pool' and the *monodii* subspecies.

Table 1. Dry matter yields of Tift $85D_2A_1$ x *Pennisetum glaucum* subsp *monodii* crosses.

	Dry matter yield (t ha^{-1})	
Cultivar or cross	Test 1	Test 2
Tift $85D_2A_1$ crosses		
Range	10.1-15.8	5.8-15.5
Tifleaf 2	13.2	13.3
Gahi 3	13.1	14.3
LSD (P = 0.05)	1.7	3.0

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Development of Apomictic Pearl Millet

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Although cultivated pearl millet, *Pennisetum glaucum* (L.) R. Br., is a sexual diploid (2n=2x=14) species, many aposporous apomictic polyploid wild species exist in this genus. One of the polyploid apomictic species is *P. squamulatum* Fresen. (2n=6x=54). This species was used as the source of the gene(s) controlling apomixis for transfer by backcrossing (BC) to pearl millet, Tetraploid (2n=4x=28) pearl millet was used in the crosses to maintain partial male and female fertility in the BC program. The BC program has progressed to the BC_7 generation with the maintenance of partial male and female fertility. Beginning in the BC_3 generation, we observed partial ovule abortion (resulting in 5-15% seed-set) at about 1 week after anthesis, partially due to problems with endosperm development (Morgan et al, 1998). Ovule abortion may be due to inbreeding, resulting from the BC process. We do know that apomictic genotypes of wild species are usually highly heterozygous.

In an effort to increase the heterozygosity of the apomictic BC plants, we made the last series of BCs to a new genetically diverse induced tetraploid in 1997. During the winter of 1997/98, we used a molecular marker (ugt 197) linked to apomixis (Ozias-Akins et al. 1998) to screen for apomictic reproduction in a population of over 12 000 BC plants. Over 300 apomictic plants were identified. Seed-set on apomictic plants in the greenhouse in 1998 was significantly higher than on previous BC plants due to less ovule abortion after anthesis. Information on seed-set and levels of apomictic reproduction for these new BC plants will be determined in the field in the summer of 1998.

Many of the BC_4 to BC_7 apomictic plants closely resemble cultivated pearl millet in inflorescence and plant characteristics. Plants usually have 2n=28 or 29 chromosomes. Plants with 28 chromosomes more closely resemble cultivated pearl millet. Some advanced BC generation apomictic plants produce up to 95% maternal progenies.

Development of apomictic pearl millet cultivars and/ or populations with agronomic potential appears possible based on our research to date. Apomictic pearl millet could have a major impact on improving the forage and grain yields of this species wherever it is grown on over 30 million ha around the world.

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Potential of A_4 and A_5 Cytoplasmic-nuclear Male-sterility Systems in Pearl Millet

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The A_1 cytoplasmic-nuclear male sterility (cms) system, discovered by G W Burton in 1956, has been used very successfully in breeding both grain and forage hybrids of pearl millet (*Pennisetum glaucum* (L.) R. Br.). However, research at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and University of Nebraska comparing this cytoplasm with two of the several alternative sources, designated as A_4 (Hanna 1989) and A, (Rai 1995), shows that the A, system has a number of relative disadvantages, which are significant constraints in the breeding of acceptable parental lines and the production of hybrids.

Male-sterile line $81A_1$ is one of the most stable A_1-system A-lines, but a two-season study of isonuclear A-lines showed that the A_1 version had up to 0.6% pollen shedders and up to 0.4% of the nonshedding plants had 6-20% seedset under selfmg. There were no pollen shedders nor did any plants set seed under selfing in $81A_4$ and 81 A_5 (Table 1). Therefore, the use of A_4 and A_5 cms systems in breeding male-sterile lines could practically eliminate the problem of pollen shedders and consequent excessive roguing requirements often encountered in seed production of A_1-system A-lines and their hybrids.

A significantly higher proportion of breeding lines from diverse genetic backgrounds are maintainers (B-lines) of the A_4 system than of the A, system (Rai et al. 1996), and the frequent reversion to partial fertility observed in backcross progenies during conversion of B-lines into A-lines with the A_1 cytoplasm does not occur with the A_4 cytoplasm (Andrews and Rajewski 1994). Also, a large proportion of progenies from B x B crosses of the A_1 cms system produces partial maintainers While current experience with the A_4 system is not as extensive, there are indications that a majority of the progenies from B x B crosses of the A_4 system are likely to be good maintainers. Thus, the use of A_4 cytoplasm can considerably enhance the effectiveness of breeding programs to diversify the genetic base of seed parents, Almost every breeding line is likely to be a maintainer of the A_5 cms system (Rai 1995). This, along with its most stable male sterility, is an indirect indication that sterility maintenance of the A_5 cytoplasm is least influenced by modifiers. Hence, A_5 cytoplasm provides the greatest opportunity for genetic diversification of seed parents.

The quality of male fertility restoration of A_1-system hybrids, in terms of both extent and stability, appears to be a mirror image of male sterility of the seed parents. Even in commercial A_1-system grain hybrids, a majority lack complete male-fertility restoration, which is highly influenced by environmental variation, especially temperature and moisture stress. Also, inbred lines that are good restorers on one A_1-system seed parent may be poor restorers on other A-lines with the same cytoplasm. Hybrids based on A_4-system seed parents have higher and more stable fertility restoration across environments, and restorers of the one A_4-system seed parent are equally good restorers on others with this cytoplasm (Andrews and Rajewski 1994).

Table 1. Pollen shedders and selfed seed-set in pollen-sterile plants of three isonuclear A-lines of pearl millet, 1996 rainy season (R96) and 1997 dry season (D97), Patancheru, India.

				Selfed seedset				
		Pollen sterility			Plants in seed-set class (%)			
A-line	Season	No of plants	Shedders (%)	No of plants	0	1-5	6-20	>20
$81A_1$	R96	1618	0.6	599	97.8	2.2	0.0	0.0
	D97	1200	0.3	483	95.7	3.9	0.4	0.0
$8IA_4$	R96	1049	0.0	671	100.0	0.0	0.0	0.0
	D97	1200	0.0	414	100.0	0.0	0.0	0.0
$81A_5$	R96	835	0.0	586	100.0	0.0	0.0	0.0
	D97	1167	0.0	575	100.0	0.0	0.0	0.0

A majority of the A_1-system restorers will be maintainors of the A_4 system, and A_4-restorers would obviously be less frequent in the current breeding materials of most programs. This, however, is a transient constraint in the utilization of A_4 cytoplasm in breeding restorer parents. Experience shows that restorer gene(s) of A_4 cytoplasm can be transferred into elite inbred lines much more effectively than those of the A, cytoplasm, and the most efficient method for doing it would be to use fertile plants in F_1 and backcross progenies as female parents carrying the sterility-inducing cytoplasm. Development of an array of genetically diverse A_4-restorers is currently underway at the University of Nebraska and ICRISAT. Restorer stocks of the. A_5 cms system have now been developed that give 90-100% selfed seed-set in hybrids of $81A_5$. It is yet to be determined if transfer of A_5-restorer gene(s) into elite inbred lines will be as efficient as for the A_4 restorer gene(s).

While utilization of the A_4 cms system in breeding pearl millet seed parents and restorers at ICRISAT and University of Nebraska continues, a good foundation has been laid for utilization of the A_5 cms system. Research is underway to examine the effect of the A_4 cms system on grain yield and agronomic/adaptation traits. Isonuclear A-lines in diverse genetic backgrounds and elite restorers are being developed to undertake similar studies for the A_5 cms system.

In conclusion, the A_4 and A_5 cms systems provide access to more diverse germplasm and offer new opportunities for greater exploitation of heterosis in pearl millet hybrids. However, their main value appears to be in increasing the efficiency with which parental lines can be identified and produced. Hybrid seed production with these new cms systems will be easier, and greater male fertility levels of hybrids should lead to greater and more stable seed-set, and possibly better control of floral diseases through more rapid and effective pollination.

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Genotypic Variability for Quality Traits in Finger MiUet (*Eleusine coracana* (L.) Gaertn.)

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Finger millet (*Eleusine coracana* (L.) Gaertn.) is grown in the Aravali hill slopes and undulating marginal lands of Rajasthan for food and fodder during the rainy season. The crop is an important source of protein and energy for the tribal and poor communities. It is also a rich source of calcium and iron (Gopalan and Balasubramaniam 1981). As in other cereals, it is now well established that nutritional quality in small millets is affected by environment (Kaoutu et al. 1993; Marimuthu and Rajagopalan 1995). To assess the importance of this effect, 57 genotypes of finger millet were evaluated for such nutritional quality parameters as seed sugar, seed protein, seed calcium, and seed iron content over three years.

The material was sown during three rainy seasons of 1995, 1996, and 1997 at Rajasthan College of Agriculture, Udaipur, India. Each genotype was sown in a 3-m row at a spacing of 22.5 x 8 cm. The experiment was conducted in a randomized block design with three replications in each season. Following uniform and recommended agronomical practices in each season, 40 kg N and 20 kg P_2O_5 ha^{-1}.were applied. Nitrogen (N) content of the seed was estimated by standard micro-Kjeldahl method. Values of N obtained were converted to crude protein percentage by multiplying with a factor of 6.25. Seed sugar was biochemically analyzed according to the standard method suggested by Plummer (1971). Seed calcium was analyzed according to Cheng and Bray (1951) and seed iron contents according to Chapman and Pratt (1961). A number of variability parameters were computed following standard statistical methodology.

Analysis of variance showed that genotypes differed significantly. Superior genotypes were identified on the basis of their high per se performance and consistant performance over three years and over pooled basis (Table 1).

Table 1. Superior varieties of finger millet for quality traits based on evaluation of grains produced in Rajasthan, India, during rainy seasons of 1995,1996, and 1997.

Seed protein content	Seed sugar content	Seed calcium content	Seed iron content
Dholimarua-1, RAU 8, IGF 13, AKE 10-33, VR 696, TNAU 876	VR 292, TNAU 876, VR 704, PR 2679, SIMHADRI, AKP-2, Dholimarua-1, KM 229	PRN 3,VR 695, AKP-2, RR 14, VL 294, PR 202, VR 704	TNAU 876. TNAU 888, TNAU 910, VR 704, VR 520, Ratnagiri, UC 149, TNAU 887, Dholimarua-1, KM 232, AKE 1633, VZM 2, KM 225

Table 2. Variability parameters[1] for quality traits in finger millet for three years, on year-wise and pooled basis.

Characters		GM	SE	Range (%)	CV (%)	GCV (%)	PCV (%)	H (%)	GG
Seed protein (%)	Y_1[2]	8.83	±0.44	6.65-12.9	6.12	19.9	20.8	91.4	39.2
	Y_2	9.17	±0.58	6.58-13.3	7.74	19.7	21.2	86.6	37.8
	Y_3	8.62	±0.46	5.83-12.8	6.52	20.6	2.1.6	90.9	40.5
	P	8.87	±0.29	6.37-13.0	6.86	20.0	21.2	89.4	39.1
Seed sugar	Y_1	67.0	±0.92	63.6-74.6	1.68	4.85	5.1	89.3	9.45
	Y_2	67.8	±1.43	64.1-76.0	2.59	4.79	5.4	77.4	8.68
	Y_3	66.5	±1.08	62.4-73.9	1.98	4.79	5.2	85.4	9.12
	P	67.1	±0.67	63.6-74.7	2.12	4.77	5.3	82.4	8.93
Seed calcium	Y_1	355	±26.7	293-507	9.21	13.7	16.5	69.0	23.5
	Y_2	367	±15.5	273-516	5.19	15.4	16.3	90.0	30.1
	Y_3	351	±27.2	285-500	9.48	13.3	16.4	66.5	22.4
	P	358	±13.7	286-507	8.14	14.1	16.4	74.0	25,0
Seed iron	Y_1	3.99	±0.27	3.10-5.10	8.41	13.4	15.8	71.8	23.4
	Y_2	4.33	±0.33	3.30-5.57	9.46	12.6	15.7	63.8	20.7
	Y_1	3.72	±0.32	2.70-4.90	10.6	13.5	17.1	61.7	21.8
	P	4.01	±0.18	3.12-5.10	9.50	13.1	16.2	65.2	21.8

1. Variability parameters, where GM =trial mean; GCV = genotypic coefficient of variation; PCV = phenotypic coefficient of variation; H = broad sense heritibility; and GG = genetic gain.
2. Y_1 =1995 rainy season; Y_2 = 1996 rainy season; Y_3 = 1997 rainy season; and P = pooled.

While assessing overall position in three years independently and across year on a pooled basis, the present study revealed high potential genetic gain along with high estimates of genotypic coefficient variation (*GCV*) and broad sense heritability for quality traits like seed protein, seed iron, and seed calcium content (Table 2). Therefore it appeared that these quality traits are largely governed by additive genetic effects that in turn could be improved by selection.

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Germplasm

Pearl Millet Parental Lines 842A and 842B

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Pearl millet (*Pennisetum glaucum* (L.) R. Br.) parental line 842B is the inbred maintainor of cytoplasmic-nuclear male-sterile line 842A. Original seed stocks of these two lines, initially developed and designated as BKM 2221 and AKM 2221 by W D Stegmeier at the Fort Hays Branch Experiment Station, Kansas State University, USA, were introduced to SAT-Patancheru in 1980 by D J Andrews. Their reselected versions, named at 1CRISAT as 1CMB 3 and ICMA 3, have been widely disseminated by ICR1SAT since 1984 as 842B and 842A, respectively.

BKM 2221 was developed by eight generations of pedigree selection in a population derived from the second backcross of Tift $23D_2B_1$ to P1 185642- Tift $23D_2B_1$ is the maintainer line of Tift $23D_2A_1$, developed at the Coastal Plain Experiment Station, Georgia, USA (Burton 1969). PI 185642, collected in 1949 from a market in Kumasi, Ghana, was supplied by the Soumern Region, Plant Introduction Experiment Station, Georgia, in 1971. The BC_2-derived line was crossed onto Tift $23D_2A_1$, and during the course of developing BKM 2221 four successive generations of it were concurrently back-crossed into the sterile cytoplasm of Tift $23D_2A_1$ to develop AKM 2221. At this stage, AKM 2221 and BKM 2221 were introduced to India by ICRISAT-Patancheru. When grown in a pearl millet downy mildew [caused by *Sclerospora graminicola* (Sacc.) J. Schror.] disease nursery at Patancheru, seed stocks of these lines displayed variability for reaction to this most devastating disease of pearl millet in India. Two generations of pedigree selection for downy mildew resistance in BKM 2221 and concurrent plant x plant backcrossing onto disease-free plants of AKM 2221 produced 842A and 842B, which had only 3% downy mildew incidence compared to 31% in the originally introduced stocks of AKM 2221 and BKM 2221 (and 55% in the susceptible control NHB 3). While 842A and 842B had improved levels of resistance to downy mildew, their phenotypic characteristics remained similar to those of AKM 2221 and BKM 2221.

Male-sterile line 842A has stable male sterility across seasons and sites, but is otherwise phenotypically similar to its maintainer line 842B. Both lines have excellent seedset under open pollination. However, 842B has poor seedset under selfing (generally <10%), apparently due to some combination of long protogyny and short stigma receptivity periods, although it is a prolific pollen producer. Both lines are genetically d_2 dwarf of medium height and medium early maturity, averaging plant heights of 115 cm and 47 days to reach 50% flowering across locations in India during the rainy season. They have erect growth habits, produce 15 cm long candle-shaped panicles, have excellent panicle exsertion, and stiff stalks that are moderately susceptible to breakage at the nodes. Plants of these lines generally produce 2-3 panicles $planr^{-1}$, large grains (10-11 g 1000^{-1}) of hexagonal-globular shape and light grey color, and have dark green foliage until maturity. Further, these lines have dominantly inherited nonhairy leaf sheaths and leaf blades; dominantly inherited dark reddish plant base, node (when exposed to the sun), and glume tip pigmentation; and recessively inherited nonhairy leaf margins and nodes.

Male-sterile line 842A is the seed parent of public-sector hybrid HHB 68, developed by CCS Haryana Agricultural University and released in 1993 for cultivation in all pearl millet growing zones of India. This line is

2. In memoriam of Dr W D Stegmeter, deceased 25 July 1998,

also the seed parent of several private sector hybrids, including at least one dwarf hybrid, produced and marked by private seed companies in India. From 1993 to 1998, ICRISAT supplied 358 kg of 842A breeder seed and 135 kg of 842B breeder seed to public- and private-sector seed producing agencies in India. Seed stocks of 842A and 842B will continue to be maintained and distributed in germplasm amounts by ICRISAT, under the terms and conditions of the relevant ICRISAT Breeding Material Transfer Agreement.

Reference

Burton, G.W. 1969. Registration of pearl millet inbreds Tift $23B_1$, Tift $23A_1$, Tift $23DA_1$ and Tift $23DB_1$ (Reg. Nos. PL 1, PL 2, PL 3, and PL 4). Crop Science 9:397.

Pearl Millet Parental Lines 843A and 843B

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Pearl millet (*Pennisetum glaucum* (L.) R. Br,) parental line 843B is the inbred maintainer of cytoplasmic-nuclear male-sterile line 843A. Original seed stocks of these two lines, initially developed and designated as BKM 2068 and AKM 2068 by WD Stegmeier at the Fort Hays Branch Experiment Station, Kansas State University, USA, were introduced to ICRISAT-Patancheru in 1980 by D J Andrews. Their reselected versions, named at ICRISAT as ICMB 2 and ICMA 2, have been widely disseminated by ICRISAT since 1984 as 843 B and 843A, respectively.

BKM 2068 was developed by nine generations of pedigree selection in a population derived from the first backcross of Tift $23D_2B_1$ to PI 185642.Ttft-$23D_2B_1$ is a maintainer line of Tift $23D_2A_1$, developed at Coastal Plain Experiment Station, Georgia, USA (Burton 1969), PI 185642, collected in 1949 from a market in Kumasi, Ghana, was supplied by the Southern Region, Plant Introduction Experiment Station, Georgia, in 1971. The BC_1-derived line was crossed onto Tift $23D_2A_1$, and during the course of developing BKM 2068 seven successive generations were concurrently backcrossed into the sterile cytoplasm of Tift $23D_2A_1$ to develop AKM 2068. At this stage, AKM 2068 and BKM 2068 were introduced to India by ICRISAT-Patancheru. When grown in a pearl millet downy mildew [caused by *Sclerospora graminicoia* (Sacc.) J Schrot.] disease nursery at Patancheru, seed stocks of these lines displayed variability for reaction to this most devastating disease of pearl millet in India. Two generations of pedigree selection for downy mildew resistance in BKM 2068 and concurrent plant x plant backcrossing onto disease-free plants of AKM 2068 produced 843A and 843B, which had 2% disease incidence compared to 10% in AKM 2068 and BKM 2068 (and 55% in susceptible control NHB 3). While 843A and 843B had improved levels of pearl millet downy mildew resistance, their other phenotypic characteristics remained similar to those of AKM 2068 and BKM 2068.

Male-sterile line 843 A has stable male sterility across seasons and sites, and is otherwise phenotypically similar to 843B. Both lines have fairly good open-pollinated seedset, but this is seldom complete. Maintainer line 843B is a prolific pollen producer and has average-to-good seedset under selfing. Panicles of both 843A and 843B have small female-sterile sectors but this trait is not expressed in their hybrids. These short-statured d_2 dwarf lines are the earliest commercial seed parents of pearl millet hybrids produced so far anywhere in the world, averaging plant heights of 95 cm and 42 days to reach 50% flowering across locations in India during the rainy season. They have a semispreading growth habit, produce 12 cm long candle-shaped panicles with naked pinkish tips, and have excellent panicle exsertion. Plants generally produce 3-4 panicles $plant^{-1}$, with large grains (11-12 g 1000^{-1}) of globular shape and light grey color. Further, these lines have dominantly inherited nonhairy leaf sheaths and leaf blades; dominantly inherited light reddish plant base and node (when it is exposed to sunlight) pigmentation; and recessively inherited nonhairy leaf margins and nodes.

Male-sterile line 843 A is the seed parent of the earliest maturing (65-70 days to maturity) public-sector hybrid (HHB 67) released to date in India (Kapoor et al. 1989). HHB 67 was developed by CCS Haryana Agricultural University and released in 1990 for cultivation in all pearl millet growing zones of India. This hybrid is especially popular in the arid to semi-arid margins of the

2. In memoriam of Dr W D Stegmeier, deceased 25 July 1998.

pearl millet tract in northwestern India. 843A is also the seed parent of released hybrid RHB 30, developed by Rajasthan Agricultural University, and at least three additional hybrids produced and marketed by private seed companies in India. During 1991 to 1997, ICRISAT supplied 780 kg of breeder seed of 843 A and 396 kg of breeder seed of 843B to both public- and private-sector seed agencies in India, Since 1998, ICRISAT has turned over responsibility for breeder seed production and supply of 843A and 843B to the Andhra Pradesh State Seeds Development Corporation Ltd. (Registered Office: 5-10-193 2nd Floor, HACA Bhavan, Opp. Public Gardens, Hyderabad 500 004, Andhra Pradesh, India). Nucleus seed stocks of 843A and 843B continue be maintained and distributed by ICRISAT, in germplasm amounts, under the terms and conditions of the relevant ICRISAT Breeding Material Transfer Agreement.

Maintainor line 843B has been extensively used as a promising elite germplasm for seed parents breeding in India. For instance, of the 49 promising seed parents produced by ICRISAT-Patancheru during 1981 to 1998 and disseminated to pearl millet hybrid breeding programs in India, 37 involve 843B as one of the parents in their pedigrees.

Finally, because of its relatively photoperiod-insensitive early flowering, high tillering capacity, compact plant size, and prolific pollen production, 843B is the pearl millet genotype of choice for use in wheat dihaploid production (Inagaki and Hash 1998).

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Release of NM-1 and NM-2, Two Sets of Dwarf Grain Pearl Millet A, and A_4 Cytoplasm Seed Parents and their B-lines

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The pearl millet breeding program in the Department of Agronomy, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, in May 1998 released two sets, NM-$1A_1$/NM-$1A_4$/NM-IB and NM-$2A_1$/NM-$2A_4$/NM-2B, of pearl millet (*Pennisetum glaucum* (L.) R. Br.) cytoplasmic-nuclear male-sterile (cms) dwarf grain-type seed parents (A-lines) and their maintainer (B-line) counterparts.

NM-1B (90PV0293B) and NM-2B (92M59022B) were both derived from 1984 F_2 selections at the Department of Agronomy Farm at the University of Nebraska's Agricultural Research and Development Center (ARDC), Mead, from a cross between ICMB 1 - 81B (a downy mildew resistant dwarf B-line from ICRISAT) and KS 79-2068B (a dwarf B-line developed by W D Stegmeier, Kansas State University, Hays). Pedigree selection was continued to F_{15} for both lines. NM-1 B, when testcrossed as a F_6 selection with Tift $23DA_1E_1$ (an A, cytoplasm early dwarf A-line from USDA-ARS and University of Georgia, Tifton) in the 1988 winter nursery near Puerto Vallarta, Mexico, gave a male-sterile reaction. Backcrossing was continued to the BC_9 generation to obtain complete uniformity between the male-sterile A_1 cytoplasm A-line and the maintainer B-line. NM-2B was testcrossed as a F_7 selection with Tift $23DA_1E_1$ in the 1989 Puerto Vallarta winter nursery, and backcrossing to develop the A, cytoplasm A-line was continued to the BC_{10} generation. Both NM-1B and NM-2B were also crossed to Tift $23DA_4E_1$ in 1992 and backcrossed five generations to obtain an A_4 cytoplasm version of each line.

NM-1B is an early, dwarf, synchronous tillering inbred that averages 76-95 cm in height at maturity and flowers 56-64 days after early to mid-June sowings. NM-1B has ovate-shaped, dull gray seeds (11 g 1000^{-1}) and yellow anthers. NM-2B is an early, dwarf, synchronous tillering inbred that averages 66-78 cm in height at maturity and flowers 58-65 days after early to mid-June sowings. NM-2B has ovate-shaped, bright gray seeds (10 g 1000^{-1}) and yellow anthers. Pest and disease reactions of these lines have not been determined.

The main advantages of NM-1B and NM-2B are their earliness, short stature, and large seed size, which provide significant improvement over Tift $23D_2B_1E_1$ as seed parent maintainer lines for use in a Midwest grain hybrid production situation. Release of these lines in both the A, and A_4 cms systems will extend their use to hybrid combinations by permitting use of male parents of wider genetic diversity. Depending on the male parent, hybrids with these parents can have a maturity comparable to very early grain sorghum hybrids. Yield performance tests from 1994-97 in a limited number of hybrid combinations indicates NM-1A and NM-2A have good combining ability for grain yield and potential as seed parents of early maturing dwarf grain pearl millet hybrids for the midwestern U.S. Yields of individual hybrids in these tests ranged from 810 to 5280 kg ha^{-1}. The development of these seed parents was funded in part by USAID Grant no. LAG-G-00-96-90009-00 through the USAID Title XII International Sorghum/ Millet Collaborative Research Suppport Program (INTSORMIL).

These lines are available individually (in either A, or A_4 cytoplasm) through a Research and Development user fee based on hybrid seed production by arrangement with the University of Nebraska at Lincoln. Interested seed companies should contact the Department of Agronomy, PO Box 830915, Lincoln, NE 68583-0915, USA; tel. (402) 472-2811; fax (402) 472-7904.

Release of NM-3, NM-4, and NM-5, Three Sets of Dwarf Grain Pearl Millet A_1 and A_4 Cytoplasm Seed Parents and their B-lines

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The pearl millet breeding program in the Department of Agronomy, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, in May 1998 released three sets, NM-$3A_1$/NM-$3A_4$/NM-3B, NM-$4A_1$/NM-$4A_4$/NM-4B, and NM-$5A_1$/NM-$5A_4$/NM-5B, of pearl millet (*Pennisetum glaucum* (L.) R. Br.) cytoplasmic-nuclear male-sterile (cms) dwarf grain-type seed parents (A-lines) and their maintainer lines (B-lines).

NM-3B (90PV0378-2B), NM-4B (90PV0413B), and NM-5B (91M59052B) were selected at the Department of Agronomy Farm at the University of Nebraska's Agricultural Research and Development Center (ARDC), Mead. NM-3B (90PV0378-2B) was derived from an F_2 selection of a cross between KS 79-2068B (a B-line developed by W D Stegmeier, Kansas State University, Hays) and 5141B (a B-line from the Indian Agricultural Research Institute, New Delhi, India). NM-4B (90PV0413B) was derived from a F_2 selection of a cross between 26B (a reselection of Kansas State University B-line 79-2226 made at iCRISAT, India) and 67B (a line selected from a Uganda population at ICRISAT). NM-5B (91M59052B) was derived from a F_2 selection of a cross between KS 79-2068B and (Tift23DB x Tift $23DB_1E_1$); an F_1 of two near-isogenic B-lines from USDA-ARS, and the University of Georgia, Tifton). Pedigree selection was continued to F_{15} for all three lines. NM-3B was testcrossed as a F_5 selection with 79-$2068A_1$ (the A_1 cytoplasm A-line counterpart of 79-2068B) in the 1987 winter nursery near Puerto Vallarta, Mexico, and gave a male-sterile reaction. Backcrossing was continued to the BC_{11} generation to obtain complete uniformity between the male-sterile A, line and the maintainer B-line. NM-4B was testcrossed as a F_4 selection with 79-$2068A_1$ in the 1987 ARDC Agronomy Farm nursery and backcrossing was continued to the BC_{10} generation. NM-5B was testcrossed as a F_6 selection with Tift $23DA_1E_1$ in the 1988 Puerto Vallarta winter nursery and backcrossing was continued to BC_{11} generation. NM-3B, NM-4B, and NM-5B were also crossed to Tift $23DA_4E_1$ in 1992 and NM-3B was backcrossed eight generations, NM-4B was backcrossed five generations, and NM-5B was backcrossed three generations to obtain an A_4 cytoplasm version of each line.

NM-3B is a medium-maturity, leafy, dwarf, synchronous tillering inbred with semierect leaves that averages 82-108 cm in height at maturity and flowers 69-76 days after early to mid-June sowings. NM-3B has ovate-shaped, gray seeds (6.3 g 1000^{-1}) and yellow anthers. Grain hybrids with NM-3B have a tendency to root lodge in heavy clay soils in the fall after heavy rainfall and wind. NM-4B is a medium-maturity, dwarf, synchronous tillering inbred that averages 66-80 cm in height at maturity. It flowers 68-75 days after early to mid-June sowings and has a very stiff stalk. NM-4B has ovate shaped, gray seeds (8.2 g 1000^{-1}) and yellow anthers. NM-5B is a medium-maturity, dwarf, leafy, synchronous-tillering inbred with semierect leaves that averages 72-88 cm in height at maturity. It flowers 69-78 days after early to mid-June sowings and has a very stiff stalk. NM-5B has ovate-shaped, gray seeds (9.0 g 1000^{-1}) and purple anthers. Pest and disease reactions of these lines have not been determined.

The main advantages of NM-3B, NM-4B, and NM-5B are their medium maturity, short stature, and large seed size, which provide significant improvement over Tift $23D_1BE_1$ as seed parents for use in a Midwest grain hybrid production situation. Yield performance tests from 1993 to 1997 in a limited number of hybrid combinations indicate NM-3A, NM-4A, and NM-5A have good combining ability for grain yield, Grain yields of individual hybrids at different locations in these tests ranged from 970 to 5620 kg hr^{-1}. The stiff stalk nature of NM-4B and NM-5B is a heritable trait that could be useful in future hybrid combinations. NM-3A, NM-4A, and NM-5A are also useful as seed parents for making high yielding forage hybrids with the previously released forage male parent NFPM-1 (FS#1). With the use of the A_4 cms cytoplasm, reliably sterile F_1 seed parents can be used to increase seed yields in forage hybrid production. Release of these lines in both A, and A_4 cms systems will also extend their use in hybrid combinations by permitting use of male parents of wider genetic diversity. The development of these seed parents was funded in part by USAID Grant no. LAG-G-00-96-90009-00 through the USAID Title XII International Sorghum/Millet Collaborative Research Support Program (INTSORMIL).

These lines are available individually (in either A, or A_4 cytoplasm) through a Research and Development user fee based on hybrid seed production by arrangement with the University of Nebraska at Lincoln. Interested seed companies should contact the Department of Agronomy, PO Box 830915, Lincoln, NE 68583-0915, USA; tel. (402) 472-2811; fax (402) 472-7904.

Release of NM-6R_1, a Dwarf Grain Pearl Millet Inbred Restorer Line

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The pearl millet breeding program in the Department of Agronomy, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, in May 1998 released NM-6R_1, a dwarf inbred grain-type line that restores male fertility on pearl millet (*Pennisetum glaucum* (L.) R. Br.) A_1 cytoplasm cytoplasmic-nuclear male-sterile (cms) seed parent lines.

NM-6R_1 (90PV0086R) was selected at the Department of Agronomy Farm at the University of Nebraska's Agricultural Research and Development Center (ARDC), Mead, in 1984 out of row 84105-1222-1 of segregating germplasm obtained in the late 1970s from Dr A J Casady, Kansas State University. The germplasm had undergone random mating and selection for at least three cycles prior to 1984. The 1984 selection was sown in the 1986 ARDC nursery and a selection was testcrossed to KS 79-2068A, (a cms A-line from W D Stegmeier, Kansas State University, Hays). The 1986 selection showed restoration of male fertility in the testcross and selfed plant selection was continued for three more years to identify an inbred selection, 90PV0086R, in the 1990 Puerto Vallarta, Mexico winter nursery, which gave complete restoration in testcrosses and complete seed set when selfed. Pedigree selection for shorter plant height and testerossing was continued to the S_{10} generation. Testcrosses to cms Tift23DA_4E_1 in 1992 showed NM-6 to be a maintainer of A_4 cytoplasmic male sterility.

NM-6R_1 is a medium early, dwarf, near-synchronous tillering inbred that averages 78-92 cm in height at maturity and flowers 57-63 days after early to mid-June sowings. NM-6R_1 has yellow anthers, sheds pollen profusely, and has elongate-shaped, light gray seeds (8.0 g 1000^{-1}). NM-6R_1 has thin compact pencil-shaped panicles (20-22 cm in length) and panicle exsertion of 10-15 cm with a stiff peduncle and stalk, NM-6R_1 produces 1-2 tillers per plant, which are upright in habit at both high and low sowing densities. Pest and disease reactions of this line have not been determined.

The main advantages of NM-6R_1 as a pollen parent are its medium-early maturity, dwarf stature, profuse pollen production, and its complete restoration of male fertility in the A_1 cytoplasm, which are highly desirable for use in a Midwest hybrid seed production situation. Yield performance tests from 1995 to 1997 in a limited number of hybrid combinations indicate NM-6R_1 has good combining ability for grain yield with several early and medium maturity seed parents over a wide range of environments. Yields of individual hybrids with this pollinator in 1995-97 regional tests conducted in five to seven states ranged from 1330 to 6470 kg ha^{-1}. Lodging evaluation of NM-6R_1 hybrids indicate the stiff stalk trait reduces lodging in midwestem environments and could be useful in future hybrid combinations. The development of this parental line was funded in part by the United States Agency for International Development (USAID) Grant no. LAG-G-00-96-90009-00 through the USAID Title XII International Sorghum/Millet Gollaborative Research Support Program (INTSORMIL).

This line is available for use through a Research and Development user fee based on hybrid seed production by arrangement with the University of Nebraska at Lincoln. Interested seed companies should contact the Department of Agronomy, PO Box 830915, Lincoln, Nebraska 68583-0915, USA; tel. (402) 472-2811; fax (402) 472-7904.

Release of NM-7R_1, a Dwarf Grain Pearl Millet Inbred Restorer Line

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The pearl millet breeding program in the Department of Agronomy, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, in May 1998 released NM-7R_1, a dwarf inbred grain-type line that restores male fertility on pearl millet (*Pennisetum glaucum* (L.) R. Br.) A_1 cytoplasm cytoplasmic-nuclear male-sterile (cms) seed parent lines.

NM-7R_1 (94M58001R) was selected at the Department of Agronomy Farm at the University of Nebraska's Agricultural Research and Development Center (ARDC), Mead, in 1990 from a 1988 greenhouse selection derived from a cross between ICMB 1 = 81B (a downy mildew resistant dwarf B-line from ICRISAT) and F_1 parent (843B x PT732-9RF-MS) (843B is an ICRISAT reselection of KS 79-2068B from W D Stegmeier, Kansas State University, Hays, and PT732 is a line from Tamil Nadu Agricultural University, Coimbatore, India). Pedigree selection for stiff stalks was continued in the 1991 and 1992 nurseries. A selection was testcrossed with isonuclear cms lines Tift 23DA_1E_1 and Tift 23 DA_4E_1 (early dwarf lines in two separate cytoplasms from USDA-ARS and University of Georgia, Tifton) in 1992. Despite its parentage, the selection showed complete restoration of male fertility in the A_1 cytoplasm and maintenance of male sterility in the A_4 cytoplasm. Selection for good selfed seed set was continued to the F_8 generation.

NM-7R_1 is a medium late, dwarf, synchronous-tillering inbred that averages 72-98 cm in height at maturity and flowers 72-79 days after early to mid-June sowings. NM-7R_1 has yellow anthers that shed pollen profusely, and ovate-shaped, light gray seeds (7.3 g 1000^{-1}).

NM-7R_1 has compact candle-shaped panicles (20 cm length x 10 cm circumference at the base) and panicle exsertion of 2-3 cm with a very stiff peduncle and stalk. NM-7R_1 has semierect leaves and produces 2-3 tillers per plant, which are upright in habit at both high and low sowing densities. Pest and disease reactions of this line have not been determined.

The main advantages of NM-7R_1 as a pollen parent are its medium-late maturity, dwarf stature, stiff stalk, profuse pollen production, and its complete restoration of the A_1 cytoplasm, which are highly desirable traits for use in pearl millet hybrid grain production situations in the Midwest. Yield performance tests in 1996 and 1997 in a limited number of hybrid combinations indicate NM-7R_1 has good combining ability for grain yield with several medium maturity seed parents. Grain yields of individual hybrids at different locations ranged from 660 to 6540 kg ha^{-1}. Lodging evaluation of NM-7R_1 hybrids indicate the stiff stalk trait reduces lodging in the midwestern environments and could be very useful in future hybrid combinations with selected stiff stalk seed parents. The development of this parental line was funded in part by the United States Agency for International Development (USAID) Grant no. DAN-1254-9-00-0021-00 through USAID Title XII International Sorghum/Millet Collaborative Research Support Program (INTSORMIL).

This line is available through a Research and Development user fee based on hybrid seed production, by arrangement with the University of Nebraska at Lincoln. Interested seed companies should contact the Department of Agronomy, PO Box 830915, Lincoln, Nebraska 68583-0915, USA; tel. (402) 472-2811; fax (402) 472-7904.

New Cultivar *of Panic urn miliaceum,* 'Il'Inovskoe'

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A new cultivar of *Panicum miliaceum* (L.) 'Il'Inovskoe', has been registered in Russia. It was developed at the Institute of the Agriculture for South-East Region using the method of intraspecific hybridization. It belongs to the steppe ecological group and is a smut-resistant cultivar bearing a new effective gene *Sph2.* In results

Table 1. Grain and groat quality of proso millet cultivar Il'Inovskoe.

Cultivar	1000-grain mass (g)	Melanosis (%)	Yellowishness (Rel. scale[1])	Carotenoids (mg kg^{-1})	Protein content (%)	Porridge taste (Rel. scale[1])
Saratovskoe-6[2]	8.7	0.18	3.7	12.6	10.5	3.9
Saratovskoe-8	8.4	0.18	4.0	13.5	9.2	4.1
Il'Inovskoe	8.9	0.16	4.4	14.8	9.8	4.3
LSD (0.05)	0.2	0.08	0.3	0.4	0.2	0.1

1. On a scale where 1 = best, 9 = worst.
2. Control.

from state trials, Il'Inovskoe was resistant to a majority of known smut races, including the highly virulent race 2, which overcame resistance in early cultivars carrying the *Sph1* and *Sph5* genes. A combination of smut-resistance with a complex of agronomically valuable traits was grounds for its admission for cultivation in the Lower Volga Region. This region produces 50% of the total proso millet grain in Russia and the threat of smut epidemics here is real Later, this cultivar was admitted for production in the North-Caucasus and Ural Regions.

Il'Inovskoe is a medium-maturing cultivar. It belongs to the second class of cultivars that react positively to precipitation in the second period of vegetative growth. This fact differentiates irinovskoe from such other early-maturing cultivars as Saratovskoe-6. Four-year average grain yields were 2.33 t ha^{-1} versus 2.13 t ha^{-1} for our early-maturing standard. Yield of the most productive late-maturing, but smut-sensitive cultivar Saratovskoe-8 was higher by 0.091 ha^{-1}. However, higher yields of the late-maturing standard were observed only in years when sufficient moisture was present, which are atypical for the Volga Region. In drought years, the yield of Il'Inovskoe was equal to or higher than the yield of Saratovskoe-8. Results from production trials in the semidesert conditions of the Left Bank District of the Saratov Region (Malouzenskya Experimental Station) in 1996, which experienced more than 50 dry-wind days during vegetative growth and minimal soil moisture reserves, showed yields of 1.61 t ha^{-1} for Il'Inovskoe versus 0.83 t ha^{-1} for Saratovskoe-8. These data testify not only to the high levels of drought tolerance in Il'Inovskoe, but also to its high tolerance to heat stress. At the same time, in results from the State trials during 1994-96 Il'Inovskoe had the highest yield among the proso millet cultivars; in 1995 in the Belgorod Region (Central Russia) it yielded 6.71 t ha^{-1} and significantly exceeded other new cultivars.

Il'Inovskoe has both high quality grain and groats (Table 1), which shows for the first time that it is possible to reduce the negative correlations between grain size and melanosis, protein content, and carotenoid content. Il'Inovskoe is the first new cultivar to exhibit these improved quality trait associations, and significantly exceeds Saratovskoe-6, the existing proso millet quality control in Russia. Owing to its large, round grain, Il'Inovskoe is better adapted for groat processing. Because of its high grain quality, Il'Inovskoe was included in the State register as one of the more valuable cultivars for proso millet production. Because of its good processing qualities and wide adaptation to both biotic and abiotic stresses, Il'Inovskoe is an important new cultivar for the proso millet growing area of Russia.

Effect of Gypsum on Productivity of Pearl Millet Hybrids under Sodic Soil Conditions

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Introduction

In the arid and semi-arid region of northern India, indiscriminate use of sodic underground water for irrigation of winter crops results in sodification of soil. These fields either remain fallow in the rainy season or pearl millet (*Pennisetum glaucum* (L.) R. Br.) is raised with very poor yields. Application of gypsum can amendment the sodic soil condition (Yadav and Kumar 1994). Therefore, to evaluate the effect of gypsum on pearl millet hybrids under sodic soil conditions a study was carried out at Chaudhary Charan Singh Haryana Agricultural University, Regional Research Station, Bawal during the rainy seasons of 1994, 1996, and 1997.

Materials and methods

The soil was sodic loamy sand with pH ranging from 9.3 to 9.4 and electrical conductivity (1:2) ranging from 0.22 to 0.26 d Sm^{-1}. Three pearl millet hybrids (HHB 50, HHB 60, and HHB 67) were evaluated with two levels of gypsum [0% (control) and 50% gypsum requirement of soil] in a randomized block design with three replications under rainfed conditions. Plots were 6.75 m x 6.0 m with row spacing of 45 cm; recommended agronomic practices were followed. The gypsum requirement for 50% neutralization of the soil was calculated as 1.71 t ha^{-1} in 1994, 1.27 t ha^{-1} in 1996, and 1.71 t ha^{-1} in 1997. In 1994 the crop was sown on 20 Jul and received 623 mm rainfall; in 1996 it was sown on 5 Jul and received 1039 mm; and in 1997 it was sown on 8 Jul and and received 464 mm rainfall.

Results and discussion

The results in Table 1 indicate that gypsum application at 50% gypsum requirement of soil increased the grain yields of pearl millet by 51% and the straw yield by 49%, over no gypsum. A beneficial effect of gypsum application on pearl millet under sodic conditions has also been reported by Yadav et al. (1995). Pearl millet hybrids showed differential behavior to gypsum application.

Table 1. Effect of gypsum application on yield and net returns of pearl millet hybrids (pooled data of three years), Haryana, India.

	Grain yield (t ha^{-1})			Straw yield (t ha^{-1})			Net returns (Rs. ha^{-1})			Return per rupee invested on gypsum
Hybrids	Control[1]	Gyp[2]	Mean	Control	Gyp	Mean	Control	Gyp	Mean	
HHB 50	1.30	1.75	1.53	4.82	6.94	5.88	2845	5148	3997	1.80
HHB 60	1.19	1.90	1.55	4.44	6.86	5.65	2108	5555	3832	2.69
HHB67	1.53	2.44	1.98	4.26	6.40	5.33	3033	6850	4942	2.98
Mean	1.34	2.03	-	4.51	6.73	-	2662	5851	-	
CD (P = 0.05)										
Gypsum			0.20			0.39				
Hybrids			0.25			0.48				
Interaction			0.36			N.S				

1. Control = 0% application of gypsum.
2. Gyp = 50% application of soil requirement of gypsum.

HHB 67 yielded 0.69 t ha^{-1} higher grain yield than HHB 50, and 0.54 t ha^{-1} higher than HHB 60, when gypsum was added. In the absence of gypsum application the genotypic differences were not significant. Contrary to grain yield, the straw yield of HHB 50 was significantly higher than HHB 67 (0.54 t ha^{-1}), but was similar to HHB 60. Application of gypsum enhanced the net profit from pearl millet cultivation by Rs. 3189 ha^{-1} over no gypsum, HHB 67 gave Rs. 945 higher net profit than HHB 50 and and Rs. 1110 ha^{-1} higher net profit than HHB 60. The return per rupee (Rs. 40 = US$ 1) invested on gypsum was Rs. 1.80 for HHB 50, Rs. 2.69 for HHB 60, and Rs. 2.98 for HHB 67. We conclude that pearl millet can be successfully cultivated under sodic soil conditions by amending the soil with gypsum and adopting HHB 67 as the cultivar.

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Pearl Millet in Indian Agriculture

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In most parts of the world pearl millet (*Pemisetum glaucum* (L.) R. Br.) is grown as a subsistence crop, largely for its ability to produce grain under hot dry conditions on infertile soils of low water-holding capacity where other cereal crops generally fail completely. Worldwide, India accounts for 42% (10.1 million ha) of the area under pearl millet. Production figures at the national level (3.3% of total cereal production) underestimate the importance of this coarse cereal, which is often referred as "the poor man's crop." The demand for pearl millet is localized to areas of its production, and there pearl millet grain is used almost exclusively for human food. In these areas, it will remain a major source of calories and a vital component of local food security systems. Pearl millet straw is also highly regarded and valued in these production systems where livestock are as important as the crop component

Impressive gains in the productivity of irrigated rice (Oryza *sativa* L.) and wheat (*Triticum aestivum* L.) observed over the past 20 years have led to an area increase and a sustained upward trend in production. In comparison, the yield gains in dryland pearl millet have been considerably lower and) the production virtually stagnant (Table 1). The combination of poverty and severe environmental conditions make it difficult to improve the productivity of pearl millet. Unless other uses of pearl millet can be found, its importance will continue to decline. While studies have confirmed the high nutritional value of pearl millet grain, its future use as feed depends on the long-term price differential between pearl millet and maize.

Since 1966/67, more than 2 million ha have gone out of pearl millet cultivation. It has already lost its importance as a crop in Punjab (-93.4%) and Andhra Pradesh (-68.8%), while in the states of Tamil Nadu (-46.3%), Haryana (-41.3%), and Gujarat (-37.1%) its importance has declined considerably. There have also been dramatic decreases in area under pearl millet in Madhya Pradesh (-26.4%), Uttar Pradesh (-24.5%), and Karnataka (-26.3%). While a decrease in per capita consumption has resulted in declining real prices, in areas of traditional pearl millet consumption another trend is emerging. In Gujarat, 0.69 million t of pearl millet grain is produced on 1.0 million ha in the rainy season (dryland), while in the summer season 0.21 million t is produced on only 0.17 million irrigated ha. As the pearl millet needs of Gujarat are met from proportionately smaller areas, the land freed is being used to grow higher value crops.

Table 1. Area and production trends for pearl millet in India.

Years	Area (million ha)	Production (million t)	Productivity (kg ha^{-1})
1965-70	1231	4.51	366
1970-75	12.08	5.16	427
1975-80	11.08	5.17	467
1980-85	11.37	5.96	524
1985-90	10.70	5.17	483
1990-95	10.17	6.49	634
Compound growth rate(%)			
1971/72 and 1984/85	-0.8	+1.2	+2.1
1984/85 and 1994/95	-1.0	-0.4	+0.6
1971/72 and 1994/95	-0.9	+0.5	+1.4

Table 2. Performance of pearl millet in comparison to all food grains in India.[1]

Area	PM[2] area ('000 000 ha)	Percentage of food crops	PM production ('000 000 t)	Percentage offood crops	PM yield (kg ha^{-1})	Percentage of food crops	Area irrigated (%) PM	Food crops
Rajasthan	4.99	39	2.81	25	562	63	1.7	18
Maharashtra	1.91	14	1.78	13	933	92	3.3	11
Gujarat	1.27	30	1.65	30	1298	103	11.6	23
Uttar Pradesh	0.81	4	0.97	3	1189	67	4.6	56
Haryana	0.63	16	0.74	7	1166	45	15.4	70
Karnataka	0.37	5	0.24	3	631	53	8.2	19
All India	10.58	8	8.72	5	824	57	5.4	35

1. Statistics for 1992/93, one ofthe best seasons for pearl millet.
2. PM = pearl millet.
Source: Government of India 1994.

The picture is quite different in Rajasthan where most of the pearl millet is grown in the western region, in the very dry, formidable environment of the Thar Desert. Grain yields are low (304 kg ha^{-1}) and extremely variable (46% CV) in this obviously risky production environment. Nevertheless, the area decrease is minimal (-13.3%) because it is a traditional crop of this region, and not grown as a matter of choice. Preference for pearl millet as a major staple food and the high value attached to its straw in the crop-livestock production system could be other reasons. In Maharashtra the situation is similar except for the low value attached to pearl millet straw in this region where sorghum straw is readily available.

In India, pearl millet is mainly grown as a rainy-season crop, wholly dependent on erratic monsoon rains. When affected by downy mildew caused by *Sclerospora graminicola* (Sacc.) J. Schrot., the crop may fail completely. The pathogen's ability to rapidly overcome uniformly deployed genetic resistance to this disease is the major instability factor. Other field pests pose relatively little risk to pearl millet. Other diseases like smut (*Moesziomyces penicillariae*) and ergot (*Claviceps fusiformis* Loveless) are not as widespread, or damaging, as downy mildew.

Technical changes in pearl millet production systems have lagged behind other cereal crops. Neither the development of high yielding varieties nor the spread of improved technologies in pearl millet have kept pace with those of irrigated wheat and rice. These factors, combined with its low preference as food and limited opportunities for other uses, have pushed pearl millet to marginal environments in spite of its comparative advantage of adaptation to drier and less fertile conditions.

At present, pearl millet is the major food crop in Gujarat, contributing 30.5% of the total food production in the state. Maximum productivity (1298 kg ha^{-1}) of this crop in comparison to other food crops reveals its production efficiency in spite of its much lower share in irrigated area (Table 2). As the demand for pearl millet grain is localized to areas of its production, increased productivity leads to cultivation of pearl millet in smaller but well-adapted zones. Haryana and Uttar Pradesh are other high production states. However, due to its comparative disadvantage relatived to other food crops and the miniscule fraction of the population dependent on pearl millet grain as food, its cultivation is likely to be further reduced in these states.

Rajasthan has the maximum area under pearl millet; nearly one-quarter of the population is dependent on it as a food source. In all likelihood, pearl millet will continue to be grown as a subsistence crop except in areas with >400 mm annual rainfall. Although pearl millet contributes only 12.6% to the food production in Maharashtra it has a comparative advantage (92.3% productivity) in rainfed areas. Having identified demand as a limiting factor constraining growth in production, it seems the area under pearl millet will decrease with increased productivity.

An in-depth study led to identification of 36 districts that contributed around 80% of the area under pearl millet (Table 3). Out of these, 14 resource-poor districts account for 40% of pearl millet acreage in India. In these low rainfall areas, research focus should be on drought-tolerant, moderate yielding cultivars and crop management practices with low external input levels. The rest of the districts with higher productivity and lower coefficient of variation could be broadly classified in two groups. In some districts pearl millet is an

Table 3. Area and productivity of pearl millet in selected districts in India.

Districts	Area (million ha)		Deviation[1] (%)	Productivity (kg ha^{-1})		Deviation (%)
	1981-83-	1991-93		1981-83	1991-93	
Rajasthan						
Banner[2]	1.01	0.93	-7.7	138	87	-36.9
Jodhpur[2]	0.58	0.62	+6.3	139	231	+66.2
Nagaur	0.46	0.49	+6.7	357	431	+20.7
Churu[2]	0.45	0.41	-9.5	246	324	+31.7
Jalore[2]	0.35	0.30	-13.3	237	137	-42.2
Bikaner[2]	0.25	0.22	-15.8	134	120	-10.5
Sikar	0.24	0.27	+ 11.6	354	434	+22.6
Jhunjhunu	0.24	0.25	+0.3	488	561	+ 14.9
Jaipur	0.25	0.22	-11.6	533	555	+4.1
Jaisalmer[2]	0.16	0.13	-18.8	203	267	+21.5
Alwar	0.18	0.17	-6.5	813	767	-5.7
S. Modhopur	0.12	0.13	+1.7	631	645	+2.2
Madhya Pradesh						
Morena	0.07	0.06	-3.8	724	811	+12.0
Maharashtra						
Ahmednagar[2]	0.24	0.32	+32.3	350	611	+74.6
Nasik[2]	0.34	0.35	+1.8	385	431	+11.9
Pune	0.15	0.21	+43.8	428	508	+ 18.6
Aurangabad	0.16	0.19	+ 17.0	553	524	-5.2
Dhule	0.13	0.15	+ 15.9	660	658	-0.3
Satara[2]	0.11	0.10	-1.6	252	416	+65.1
Jalgaon	0.11	0.12	+2.1	601	700	+ 16.4
Sangali[2]	0.09	0.08	-7.2	236	336	+42.4
Gujarat						
Banaskantha[2]	0.30	0.22	-26.6	805	570	-29.8
Mehsana	0.17	0.11	-32.1	1270	998	-21.4
Bhavnagar	0.16	0.12	-28.9	1325	845	-36.2
Kheda	0.15	0.11	-26.8	1279	1347	+5.3
Surendranagar	0.09	0.11	+30.3	471	627	+33.1
Kuteh[2]	0.11	0.09	-18.9	727	609	-16.5
Rajkot	0.07	0.08	+8.4	846	560	-33.8
Haryana						
Bhiwani	0.23	0.17	-23.8	541	674	+24.6
Mahendragarh	0.15	0.09	-34.9	434	652	+50.2
Hisar	0.11	0.08	-25.2	824	1123	+36.3
Karnataka						
Bijapur[2]	0.18	0.14	-22.3	383	498	+23.1
Gulbarga[2]	0.11	0.09	-18.2	425	578	+24.5
Uttar Pradesh						
Badaun	0.08	0.07	-12.5	905	1134	+25.3
Aligarh	0.11	0.10	-9.1	990	1281	+29.4
Agra	0.13	0.12	-7.7	788	1067	+35.4
Total districts	794	742	-6.5	568	613	+7.9
Ail India total	11.45	10.07	-12.1	525	607	+15.6

1. Percent change(±) in 1991-93 compared to 1981-83.
2. Resource-poor districts.

important source of green and dry fodder and is competitive with other crops in sharing irrigated area. In other districts, pearl millet is competitive with other food and oil seed crops under rainfed farming conditions.

The development of cultivars and management practices for improved fodder productivity and quality attributes would be justified for these districts, subject to policy decisions by the government to keep it competitive with high value crops.

Environmental degradation, common to many crops, is particularly serious in pearl millet. Population growth has forced farmers to adopt shorter fallow periods and to expand millet cultivation on marginal lands, which in turn has resulted in declining soil fertility. The adoption of new technologies has been poor partly because of the inadequate spread of extension services in harsh areas and the increased risk of crop failure compared to favorable environments. Limited commercial demand for pearl millet grain has generally depressed incentives to use purchased inputs. Such factors require more imagination from scientists and extension workers in developing technologies suited for these difficult environments. I suggest that we focus on the following points:

- As the returns from investing in pearl millet production are much lower than the comparative gains in other farm and nonfarm enterprises, it remains a low-cost low-input crop requiring greater stress on stability than on productivity. Breeders need to carefully consider the trade-off that farmers calculate between yield and stability, grain and fodder input responsiveness, and productivity under low input conditions.

- Scarcity of resources implies that location-specific research should be given higher priority in a sequential manner: on crop establishment under suboptimum conditions, problems of crust formation, use of moisture conservation techniques, studies on root systems, drought management, organic recycling, and risk distribution systems.

- The assumptions that new technology is neutral to farm size, finance, inputs, and other operational constraints, and is insensitive to social and cultural factors do not stand the test of time. Social scientists could better judge who profits from the technology and in what manner, and find reasons for the reluctance of ordinary farmers to adopt a low-risk technology that appears sound in the high-input environment of research stations.

- Small and marginal farmers are often concerned with earning their daily bread. They do not have enough time to spare for information transfer at a fixed time and place. It is necessary to reach them where they are and deliver relevant technologies at their doorstep.

- The opportunity cost of women's time has encouraged the shift from millet to readily available food that is quick and more convenient to prepare. Value addition and product diversification are important to improve the image of the crop.

- The availability of rice and wheat in the public distribution system amongst populations that consume pearl millet at highly subsidized rates has prompted farmers (particularly in Andhra Pradesh and Tamil Nadu) to change their traditional food habits. Immediate policy intervention is essential to harvest the benefits of technology innovations in pearl millet production: price support and procurement; distribution of pearl millet instead of rice/wheat in pearl millet consumption areas under the public distribution system; payment in kind (pearl millet) in food for work, famine relief, afforestation, and other development works; and incentives for commercialization of pearl millet in bakery, confectionery, brewery, and fast food enterprises. These innovations could stop further decline in pearl millet acreage and provide incentives to farmers for increasing its productivity.

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Pathology

A Highly Virulent Pathotype *of Sclerospora graminicola* from Jodhpur, Rajasthan, India

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Introduction

Downy mildew of pearl millet (*Pennisetum glaucum* (L.) R. Br.), caused by *Sclerospora gramimcola* (Sacc.) J. Schrot., continues to be a serious problem in India. With the commercial cultivation of genetically uniform F_1 hybrids, emergence of several cultivar-specific virulences have been detected (Thakur and Rao 1997), and popular hybrids such as HB 3, BJ 104, MBH 110, and MLBH 104 have had their resistances overcome by downy mildew. So far four cultivar-specific pathotypes have been identified based on their high susceptibility in farmers' fields (Thakur et al. in press). During the 1997 rainy season, the pearl millet crop at the farms of the Central Arid Zone Research Institute (CAZRI) and the Agricultural Research Station, Mandor, both at Jodhpur, Rajasthau, recorded severe downy mildew incidence on released hybrid ICMH 451, many elite breeding lines, and several local landrace populations. A number of breeding lines from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the All India Coordinated Pearl Millet Improvement Project (AICPMIP) that were resistant to the known pathotypes of *S. gramimcola* showed extreme susceptibility at both locations. Several of the well-established male-sterile lines (863A, 81A, 843A, and 852A) that are being used extensively in hybrid breeding also recorded high downy mildew incidence (Table 1). The extreme susceptibility of some of the highly resistant lines was probably due to emergence of a new virulence in the pathogen population. Our objective in this investigation, therefore, was to determine the pathological identity of the population of *S. gramimcola* from Jodhpur.

Table 1. Downy mildew Incidence (%) on selected homogenous pearl millet genotypes at agricultural research stations of the Central Arid Zone Research Institute (CAZRI, Jodhpur) and the All-India Coordinated Pearl Millet Improvement Project Coordinating Unit (AICPMIP, Mandor) during the 1997 rainy season.

	CAZRI		
Host genotype	Field 1	Field 2	Mandor
863A	100	10	100
81A	100	58	88
841A	0	19	42
843 A	25	30	74
852 A	88	54	92
MBH 110	14	27	40
7042S	100	88	96

Source: Data provided by A S Rao, Genetic Resources and Enhancement Program, ICRISAT.

Materials and methods

We collected oosporic inoculum from infected plants of a local landrace cultivar, Nokha Local, that had been used as a control entry in several collaborative trials conducted at the Jodhpur research farm of CAZRI. This entry recorded 50-80% downy mildew incidence in the field. We assumed, perhaps incorrectly, that this local cultivar would not carry much in the way of resistance genes and hence would not have screened out specific virulences from the pathogen population. We produced asexual spores on the seedlings of Nokha Local (seeds courtesy of Eva Weltzein Rattunde) grown in oospore-infested pot soil in a greenhouse at ICRISAT-Pataneheru. This isolate (as a bulk population) was designated as Sg 139 and will be referred as such throughout this article. The isolate was then transferred as asexual spores to 7042S, a highly susceptible inbred line that supports better sporulation than Nokha Local. This asexual inoculum collected from 7042S was used for all subsequent greenhouse inoculation experiments. No change in virulence was expected with this change, because 7042S is universally susceptible to all previously tested pathogen populations. Data from Table 2 showed that the asexual spores of Sg 139 from Nokha Local produced 92% incidence on IP 18292 and 94% incidence on 7042S.

We conducted three greenhouse experiments involving Sg 139 and other known pathotype isolates, and also summarized relevant data from breeding material screening where this isolate was used. Path-1 through Path-5 are host-specific pathotypes multiplied on their

Table 2. Downy mildew incidence (%) on a set of pearl millet differential lines inoculated with known pathotypes and Sg 139 (Nokha Local) in a greenhouse experiment at ICRISAT-Patancheru.[1,2]

	Pearl millet line				
Pathotype (isolate)[3]	IP 5272-1	IP 18292	IP 18296	IP 18297	7042S
Path-1(Sg 008)	0	0	0	3	84
Path-2 (Sg 009)	0	0	0	1	83
Path-3(Sg 010)	0	0	0	2	90
Path-4(Sg 011)	0	0	48	2	93
Path-5(Sg 012)	0	0	37	0	96
Path-6(Sg 021)	0	1	0	5	67
Nokha Local (Sg 139)	74	92	10	6	94
SE isolate x line = ± 4.9					

1. Mean of three replications with at least 100 seedlings replication^{-1}
2. Experiment conducted by Kirti Pathak, Apprentice (MSc Botany candidate, University of Pune, Maharashtra, India).
3. Cultivar-spccific pathotypes Path-1 (NHB 3); Path-2 (BJ 104); Path-3(MBH 110); Path-4 (852B); Path-5 (700651); and Path-6(MLBH 104).

respective hosts. Path-6 was only multiplied on 7042S. Sg 139 was multiplied on Nokha Local for the experiment shown in Table 2, while for the rest of the experiments it was multiplied on 7042S.

Results and discussion

In the first experiment, isolates of six standard pathotypes (Thakur and Rao 1997), along with Sg 139, were inoculated on five pearl millet differential lines. Isolate Sg 139 induced very high disease incidence on IP 5272-1 (74%) and IP 18292 (92%), while these lines remained downy mildew-free following inoculation with all six other isolates (Table 2). In other experiments where isolates Sg 139 and Sg 008 (Path-1) were used, IP 18292 recorded over 80% incidence when inoculated with Sg 139, while it remained nearly disease-free (3% incidence) when inoculated with Sg 008 (Tables 3 and 4).

Table 3. Downy mildew incidence (%) on three pearl millet lines inoculated with two pathotypes of *Sclerospora graminicola* under greenhouse conditions at ICRISAT-Patancheru.

	Host genotype		
Pathotype (isolate)	IP 18292	IP 18293	7042S
Nokha Local (Sg 139)	87	35	97
Path-1 (Sg 008)	3	0	86

IP 18292 has previously been resistant to all downy mildew pathotypes against which it has been screened, Further, this resistance has been demonstrated to have a strong monogenic dominant component (Singh and Talukdar 1998). This line has been used as a resistance donor by several public and private sector breeders in India. With the identification of a virulence matching the resistance in IP 18292, it is likely that this resistance will not hold for long, even in other parts of India if it is deployed in isolation from other resistance genes. It is important, therefore/that the users of IP 18292 be aware of this information, They should diversify the sources of resistance being used in their breeding programs and should not expect the resistance from IP 18292 to hold up if it is deployed in a genetically uniform background that is otherwise susceptible to downy mildew. Results from molecular mapping of resistance genes from IP 18292 confirm the Mendelian inheritance studies and suggest that it would be dangerous to use this line as a sole source of resistance to downy mildew in India, or elsewhere (Hash et al. unpublished).

The disease symptoms induced by isolate Sg 139 on IP 18292 are leaf chlorosis, stunted plant growth, and very scanty sporangial sporulation, which are typical of those induced on hybrid BJ 104 and its parental line 5141 A. Symptoms induced on other host genotypes by this isolate include normal leaf chlorosis, no stunting of seedlings, and profuse asexual sporulation.

Several other resistance donor lines (P 7-4, P 310-17, 700651, 7042R, ICMP 85410, and IP 18293) recorded much higher incidence of downy mildew when inoculated

Table 4. Downy mildew incidence (%) in pearl millet lines induced by the Path-1 isolate and Nokha Local isolate in a greenhouse experiment at ICRISAT-Patancheru.

	Downy mildew isolate used	
Line	Path-1 (Sg 008)	Nokha Local (Sg 139)
P7-4	7	40
P310-17	6	17
700651	3	34
7042R = ICML 22	17	63
ICMP 85410	18	60
IP 18292	3	81
IP 18293	0	34
852B	9	70
MBH 110	1	20
J 104	84	56

Table 5. Downy mildew incidence (%) on three homogenous pearl millet genotypes induced by *Sclerospora graminicola* isolate Sg 139 from Nokha Local (pooled data from 20 screens of breeding lines from Rajastban) under greenhouse conditions at ICRISAT-Patancheru, during Mar-May 1998.

Host genotype	Mean disease incidence and range (%)
7042S	89 (86-100)
NHB3	9 (0-20)
ICMB 88004	3 (0-12)

with Sg 139 than in the case of Sg 008 (Table 4). This again suggests resistance from a single donor may not provide adequate protection against this pathotype.

From large scale screens of breeding lines (more than 3000 entries in 20 screens) from Rajasthan against Sg 139 under greenhouse conditions at ICRISAT-Patancheru we found that when used as susceptible checks, NHB 3 scored 9% (0-20% range) and 7042S scored 89% (86-100%) incidence (Table 5).

NHB 3, one of our standard susceptible checks, which has the pedigree 5071A x J 104, is moderately resistant to this new pathotype. Data from the above experiments and observations clearly suggest that Sg 139 is different from the previously described pathotypes of *S. graminkola.* It is the most virulent isolate reported to date from India. Based on these results, we tentatively designate the Nokha Local population of *S. gramimcola* from Jodhpur as a new virulence pathotype, Path-7, represented by isolate Sg 139. We will further confirm this virulence diversity using molecular marker techniques.

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Entomology

Field Evaluation of Fecundity, Longevity, and Oviposition Period of Millet Head Miner (Lepidoptera: Noctuidae) in Niger

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Introduction

Millet head miner, *Heliocheilus albipunctella* de Joannis, has been a major pest of pearl millet, *Pennisetum glaucum* (L.) R. Br., since its first recorded major outbreak in the Sahel during the drought years of 1972-74 (Vercambre 1978). Millet head miner often causes severe grain yield loss, as much as 81% in Niger, and reduces millet grain quality (Guevremont 1982).

In a review of millet head miner biology, its natural enemies, and a descriptive biological control research approach, Gilstrap et al. (1995) concluded that a cohesive management strategy was not available for millet insect pests. Therefore, the objective of this research was to determine factors regulating development and abundance to improve understanding of millet head miner biology as a part of a larger research effort to assess the impact of natural enemies on millet head miner abundance.

Materials and methods

Research was conducted at the the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center at Sadore, 45 km southeast of Niamey, Niger. Seed of 3/4 HK (an early maturing pearl millet variety) was sown in the field on 6 and 21 Jun and 7 Jul 1996, and 23 Jun and 4 and 16 Jul 1997. Sowing dates were varied so relationships between millet head miner development and growth of pearl millet could be observed throughout the growing season. Each plot of millet consisted of 35 rows, 25 m long and 0.75 m apart. Hills in each row were 1 m apart After emergence, plants were thinned to three per hill to assure uniform plant growth.

Exclusion cages were used to assess millet head miner adult fecundity, longevity, and oviposition period in the field. Cages were 70-90 cm long x 30 cm diameter and constructed from wire frames covered with fine cotton-mesh screen. Each cage was placed in the field over a panicle exserted 5-10 cm. Panicles were supported with strings attached to iron bars to prevent stalk breakage. A pair (1f:1m) of millet head miner adults from a laboratory colony was released into each cage at sundown to coincide with the time adults become active in the field. Daily, a dissecting microscope was used to examine cut panicles for eggs. The total number of eggs oviposited by each female during its life span was recorded. Longevity, fecundity, and length of oviposition in the cage were assessed by maintaining individuals until they died. Mean number of days for millet head miner pairs, longevity, female fecundity, and length of oviposition period were estimated on pearl millet panicles.

Table 1. Field longevity, fecundity, and oviposition period of millet head miner on enclosed panicles of pearl millet cultivation 3/4 HK, ICRISAT Sahelian Center, Sadore, Niger, 1996 and 1997.

Sowing date	No of pairs	Longevity (days)		Oviposition period (days)	Eggs laid $female^{-1}$	Eggs laid day^{-1}
		male	female			
6 Jun 96	5	3.8	4.0	2.4	29.6 (7-52)[1]	12.2
23 Jun 97	10	3.5	3.5	2.9	27.60 (7-50)	10.0
4 Jul 97	10	3.4	3.4	3.4	69.8 (13-106)	21.6
16 Jul 97	10	3.2	3.1	3.0	37.2 (4-88)	12.4
Mean	-	3.4	3.3	3.2	44.9	14.7

1. Numbers in parentheses represent the range of eggs oviposited during a female lifetime.

Results and discussion

Mean number of days millet head miner adult pairs lived and oviposition period are presented in Table 1. Also presented are the total number of eggs oviposited by each female during its life span in the exclusion cage, In 1996, mean numbers of days of adult longevity on the panicles were 3.8 for males and 4.0 for females. In 1997, mean numbers of days of adult longevity were 3.4 for males and 3.3 for females. For both years, millet head miners in exclusion cages survived between 2 and 6 days, This confirmed the conclusion reached by Ndoye (1992) that adults survived 5-6 days in nature or in closed cages. For both years, the female oviposition period was 1-4 days. Mean oviposition period for a female was 2.4 days in 1996 and 3.1 days in 1997. The longest oviposition period of 3.4 days per female was recorded on pearl millet sown on 4 Jul 1997, while the shortest oviposition period of 2.9 days was recorded on pearl millet sown on 23 Jun 1997. Mean number of eggs oviposited per female was 29.6. This mean is very low compared to the 400 eggs in batches of 20-50 reported by Gahukar (1984). In 1996, the total number of eggs oviposited by each female was between 7 and 52, while in 1997, the total number oviposited was between 4 and 106. In 1997, the number of eggs oviposited differed by sowing date. Ranges of 7-50, 13-106, and 4-88 eggs oviposited per female were recorded for the three sowing dates. Mean numbers of eggs oviposited per female were 29.6 in 1996 and 44.9 in 1997.

These data will be used to construct a stage-specific life table to gain an understanding of factors that regulate the biology and abundance of millet head miner. The life table can be used to develop an improved plan for managing millet head miner on pearl millet in West Africa.

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Impact of Natural Enemies on Abundance of Millet Head Miner (Lepidoptera: Noctuidae) in Niger

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Since its first major outbreak following the 1972 drought, millet head miner, *Heliocheilus albipunctella de* Joannis, has been the most serious insect pest of pearl millet, *Pennisetum glaucum* (L.) R. Br., in the Sahel (Vercambre 1978). Guevremont (1983) reported yield losses of 60%. Gilstrap et al. (1995) proposed that biological control might be effective but that indigenous natural enemies of millet head miner first needed to be assessed. The goal of this research was to use exclusion methodology to assess mortality, particularly impact and contributions of natural enemies, on abundance of millet head miner in the field.

Research was conducted in 0.5-ha plots at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center, Sadore, Niger, and in farmers' fields at Daybon and Dogalkeina, 3 and 7 km from the ICRISAT Sahelian Center. Each week from emergence to maturity, 10 millet panicles in each plot were selected randomly, labeled with a number correlated to the date of emergence from the boot, and cut. Millet head miner eggs and larvae were collected from the panicles and counted. Parasites and predators were collected on panicles in the field by using aspirators, nets, and shaking bags at early panicle emergence and during flowering.

Cylindrical exclusion cages of wire frames covered by fine-meshed cloth were placed over 120 newly emerged panicles to prevent natural infestation. Each panicle was infested with 25 eggs from female millet head miners collected in the field or reared in a laboratory. One group of panicles remained covered after infestation and until prepupae dropped to the base 6f the cage to prepare for the dry season, The other groups of panicles were uncovered at 3, 13, 23, and 36 days after infestation to allow access of natural enemies to millet head miner eggs, early-instar larvae, late-instar larvae, and prepupae. The groups of panicles were harvested at 3,10, 10, and 13 days after being uncovered and were taken to a laboratory, where emerging parasitoids were collected and identified.

In another experiment, 50 panicles at the boot stage were covered. Twenty-five eggs were placed 3, 6, or 9 cm from the distal end of each of 10 emerged panicles. Eggs were removed 48 h later, counted, and incubated in the laboratory. Partially destroyed eggs were assessed for predation. Another set of 10 panicles was examined 1 week later for parasitism of middle-instar larvae. The last set of 10 spikes was examined 1 week later for parasitism of full-grown larvae.

Natural enemies were abundant in farmers' fields. Ants of the genus *Cremastogaster* were most abundant, followed by the egg predator, *Orius* sp, and the egg and larval parasite, *Cardiochiles* sp. Also collected were *Bracon hebetor* in the field and *Copidosoma* sp in the field and from field-collected larvae reared in the laboratory. *Orius* sp and *Cardiochiles* sp were more abundant in September than in August or October

Many millet head miner eggs and larvae disappeared from panicles enclosed in exclusion cages. Natural enemies consumed more than 100 millet head miner eggs within 3 days after infestation. Large numbers of eggs were missing 14,24, and 37 days after infestation. Numbers of brown, wrinkled eggs, indicating predation by predators such as *Orius* sp, and total numbers of dead larvae were almost equal 4 and 37 days after infestation. Of 2400 millet head miner eggs placed on panicles in exclusion or open cages, 1016 (42.3%) were missing, 277 (11-5%) were nonhatched (attacked) brown eggs, and 40 (1.7%) hatched. Two-hundred-thirty (70%) live and 100 (30%) dead larvae developed from the 2400 eggs placed on panicles in exclusion cages,

Many eggs disappeared when exposed to natural enemies. In mid-September, fewer egg remains, indicating predation, were found than nonhatched brown eggs and more second than third or fourth instar larvae were dead. After 50 first instar larvae were exposed to natural enemies for 1 week, 3 (6%) were dead, 8 (16%) were missing, and 39 (78%) were alive,

Mortality of third, fourth, fifth, and sixth instar larvae was great between 8 and 30 September. Mortality throughout the growing season was greatest for fourth, fifth, and sixth instars. A total of 659 (33.5%) millet head miner larvae were live, 1307 (66.5%) dead, and 119 (9.1%) parasitized.

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Yield Loss Caused by *Coryna hermanniae* Fabritius (Coleoptera: Meloidae) on Pearl Millet in Nigeria

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Introduction

Numerous beetles of the family Meloidae have been observed feeding on pearl millet (*Pennisetum glaucum* (L.) R. Br.) panicles in Nigeria (Ajayi 1985). They include *Coryna hermanniae* Fab., *Cylindrothorax audouini* Hagg., C. *westermanni* Makt., *Decapotoma afinis* Olivier, *Mylabris holosericae* Klug., *M. fimbriatus* Mars., *M. partinax* Per., *Psalydolytta aegytiaca Makl., P. jaloffa* Cast., *P. leprievri* Makl., *P. lecophaea*Makl., and *P. vestita* Daf. Since they feed on flowers, it has been assumed that they reduce pollination and, thereby, grain yield. Severe infestations by meloid beetles reportedly caused considerable yield losses in certain parts of West Africa (Gahukar 1984; Doumbia and Bonzi 1985,1986; Gahukar et al. 1986). However, there is little experimental evidence of the level of yield reduction attributable to these insects (Ajayi 1987). Jago et al. (1993) had argued that blister beetles should not be considered as economic pests of pearl millet (*Pennisetum glaucum* (L.) R. Br.). Recently, however, Tanzubil and Yakubu (1997) reported that meloid beetles caused up to 69% yield loss in millet in Ghana when 20 adults were caged per millet panicle, under no-choice conditions, from the onset of flowering until harvest. In Nigeria, a survey of farmers' fields in 1996 revealed that infestation of millet by *C. hermanniae* was widespread, and up to 40 adults per panicle were recorded (Dike and Ajayi, unpublished). Field trials were conducted in 1997 to determine grain yield losses caused by this insect under free-choice and no-choice conditions.

Materials and methods

To measure yield loss attributable to *Coryna,* millet panicles were artificially infested with varying numbers of adult beetles collected from neighboring millet fields. Head cages, designed for artificially infesting sorghum panicles with head bugs (Sharma et al. 1992), were used to confine 5,10,15,20,25, or 30 adults per panicle for 3 weeks from the beginning of flowering. There were five replications per level of infestation, with one panicle representing one replicate. As a control, an equal number of panicles at the same stage of development were covered with head cages but were not infested. Beetles were removed after 3 weeks but the cages were left in place. At maturity, measurements were made on panicle weight and grain weight; each panicle was weighed separately. Similar measurements were made on an equal number of neighboring panicles which had not been caged but were naturally infested by *C. hermanniae.* Data were expressed per 25 cm panicle length, and subjected to analysis of variance and regression.

Results and discussion

Table 1 shows that panicle weight declined from 43 g (25 cm)$^{-1}$ in the control to 16 g (25 cm)$^{-1}$ with 30 beetles panicle^{-1}. Reduction in panicle weight ranged from 14.9% with 5 beetles panicle^{-1} to 63% with 30 beetles panicle^{-1}. Similarly, grain yield decreased from 30 g (25 cm)$^{-1}$ in the control to 7 g with 30 beetles panicle^{-1}; grain yield loss ranged from 18% with 5 beetles panicle^{-1} to 75% with 30 beetles.

Table 1. Componential grain yield loss in pearl millet artificially infested with different densities of the blister beetle, *Coryna hermanniae,* during the 1997 rainy season, Bagauda, Nigeria.

No of beetles panicle[1]	Panicle weight [g (25 cm)$^{-1}$]	Reduction (%)	Grain weight [g (25 cm)$^{-1}$]	Reduction (%)
0	43.1	-	29.6	-
5	36.7	14.9	24.6	17.5
10	29.1	32.6	19.0	35.8
15	28.6	33.8	17.0	42.5
20	16.7	61.2	8.3	71.9
25	16.6	61.5	9.2	69.0
30	15.6	62.9	7.4	75.0
Mean	26.7		16.4	
SE	±3.47		±2.63	
CV(%)	29		36	

The relationship between beetle population and grain yield is expressed by the equation y = 31.79-3.845x where y = grain yield and x = number of adult beetles per panicle (R^2 = 66.7%; df = 33; P = 0.001).

Yield loss on naturally infested panicles was calculated based on the yield of caged uninfested panicles. Naturally infested panicles weighed 38 g and yielded 24 g of grain. This represented a reduction of 12% for panicle weight and 19% for grain yield.

These results indicate that *Coryna* can cause severe yield losses, especially when high populations occur. However, such high numbers tend to occur sporadically and may be localized. This may explain why *Coryna hermanniae* is not usually reported as a serious pest of pearl millet (Ajayi 1987; Gahukar 1989; Jago 1993, Ndoye and Gahukar 1987; Nwanze 1992; Ratnadass and Ajayi 1995), and why Jago et.al (1993) did not consider *Coryna* spp as an economic pest. Nevertheless, the results presented here support the view expressed by Tanzubil and Yakubu (1997) that pollen beetles are potentially serious pests of pearl millet in West Africa. Further studies are needed to determine actual losses caused by these beetles in farmers' fields. Their bioecology needs to be studied with a view to understanding why they cause damage in some years and in some localities but not in others, so that an effective management strategy can be developed.

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Helicoverpa armigera Incidence in Finger Millet (*Eleusine coracana* Gaertn.) at Kiboko, Kenya

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Abstract

Finger millet is an important cereal crop in Africa and South Asia, and there is considerable variability in finger millet germplasm for susceptibility to cotton bollworm, *Helicoverpa armigera* (Hub.). *Helicoverpa* incidence varied from 8% in IE 46 to 37% in Nagaikuro. AICSMIP 6, AICSMIP 11, AICSMIP 10, IE 581, IE 97, IE 120, IE 17, IE 2154, IE 2323, IE 46, AICSMIP 8, and Ending had <15% panicles with *H. armigera* damage compared with 37% in Nagaikuro. Lines resistant to *H. armigera* can be used to develop finger millet cultivars with resistance to this insect.

Introduction

Finger millet, *Eleusine coracana* Gaertn., also known as ragi in India, is cultivated for human food in Africa and

South Asia. Among the millets, finger millet ranks fourth after pearl millet (*Pemisetum glaucum* (L.) R. Br.), foxtail millet (*Setaria italica* Beauv.), and pro so millet (*Pamcum miliaceum* L.) (Rachie and Peters 1977). It comprises nearly 8% of the total area, and accounts for 11% of the total millets production. Finger millet grain is more nutritious than the grains of other cereals grown in these regions, and the stalks are used as animal fodder. Finger millet is damaged by 57 insect species (Sharma and Davies 1988), of which shoot fly (*Atherigona miliaceae* Malloch), stem borer (*Sesamia inferem* Wlk.), flea beetle (*Chaetocnema* sp), red hairy caterpillar (*Amsacta albistriga* Walk.), Bihar hairy caterpillar (*Diacrisia obliqua* Walk.), Oriental armyworm (*Mythimna separata* Walk.), and head caterpillars [*Heiicoverpa armigera* (Hub.), *Cryptoblabes* sp, *Eublemma silicula* Walk., and *Sitotroga cerealella* Oliv.] are the most important.

Recently, efforts have been made to improve the productivity potential of this crop through national, regional, and international crop improvement programs. In this process, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) regional programs in eastern and southern Africa have undertaken the testing and evaluation of improved varieties of finger millet, and distribution of the high yielding lines to national programs. To achieve these objectives, 23 promising genotypes were evaluated for their yield potential at Kiboko, Kenya. There was a heavy incidence of *H. armigera* in this trial during the 1994 short rainy season. Since there was no earlier information on the plant resistance to *Helicoverpa* in finger millet, data were recorded on *Helicoverpa* incidence in different genotypes to gain an understanding of differences in genotypic susceptibility to this pest.

Table 1. Incidence (%) of *Helicoverpa armigera* in finger millet at Kiboko, Kenya (1994 short rainy season).

Genotypes	*Helk overpa* damaged panicles (%)
IE 97	8 (2.6)[1]
IE 46	8 (2.8)
IE 2323	9 (2.7)
IE 17	9 (2.9)
IE 2154	10 (2.8)
IE 120	12 (32)
AICSMIP 10	12 (3.3)
AICSMIP 11	12 (3.4)
AICSMIP 6	13 (3.1)
IE 581	13 (3.5)
AICSMIP 8	14 (3.6)
Ending	15 (3.7)
IE 2322	16 (3.6)
IE 234	20 (4.5)
IE 49	21 (4.2)
KNE 479	22 (4.2)
IE 2294	22 (4.5)
IE 2096	22 (4.6)
IE 694	27 (4.9)
IE 528	27 (4.9)
KAT/FM 1	30 (5.4)
IE 85	31 (5.4)
Nagaikuro (ex-Kishii)	37 (5.8)
Mean	18 (5.6)
SE	± (1.08)

1. Figures in parentheses are square-root transformed values.

Material and methods

Twenty-three genotypes selected as highly promising in the preliminary yield trials were sown in a replicated trial to determine their relative productivity potential at the Kenya Agricultural Research Station, Kiboko, Kenya, during the 1994 short rainy season. Each entry was sown in a 4-row plot, 4-m long. The entries were sown on ridges, 75 cm apart. The seedlings were thinned to a spacing of 5 cm within the row 15 days after germination. There were three replications, and the experiment was laid out in randomized complete block design. Normal agronomic practices were followed to raise the crop. No insecticide was applied on the crop. The crop was exposed to natural *Helicoverpa* infestation. At the milk stage, heavy *Helicoverpa* incidence was observed in this trial. Data were recorded on number of panicles damaged by *Helicoverpa* larvae (expressed as a percentage of the total number of panicles) in the central two rows of each plot. Data on percentage panicles with *Helicoverpa* damage were converted to square root values, and subjected to analysis of variance.

Results and discussion

There was considerable variability in finger millet germplasm for susceptibility to *H. armigera* (Table 1). *Helicoverpa* incidence varied from 8% in IE 46 to 37% in Nagaikuro. Genotypes AICSMIP 6, AICSMIP 11,

AICSMIP 10, IE 581, IE 97, IE 120, IE 17, IE 2154, IE 2323, IE 46, AIGSMIP 8, and Ending had <15% panicles with *H. armigera* damage compared with 37% in Nagaikuro, Time of flowering seemed to influence *Helkoverpa* incidence. Compact-panicled genotypes suffered greater damage than those having loose/separate fingers. There were considerable genotypic differences for susceptibility to *H. armigera* in finger millet, and this information can be used to develop Finger millet genotypes with resistance to this insect. Seeds of the less susceptible lines can obtained from ICRISAT, EARCAL, Nairobi, Kenya. Since this is one of the most difficult pests to control with insecticides, it is important that crop improvement programs focus on selecting genotypes that are less susceptible to this pest. Low to moderate levels of resistance can be combined with natural enemies to minimize the extent of losses due to this insect in finger millet.

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Striga

Striga hermonthica Infection of Wild *Pennisetum* Germplasm is Related to Time of Flowering and Downy Mildew Incidence

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Introduction

Infection by *Striga hermonthka* (Del.) Benth., on corn (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench) can be managed by sound cultural practices and, where available, use of resistant cultivars (Berner et al. 1995; Hess et al. 1992; Ramaiah and Parker 1982). Cultural practices that reduce *Striga* populations in other crops can be adapted to pearl millet (*Pennisetum glaucum* (L.) R. Br.) cultivation; however, little information is available concerning genetic resistance in pearl millet. The objective of this experiment was to evaluate a collection of wild *P. glaucum* ssp *monodii* and ssp *stenostachyum* accessions for resistance to *S. hermonthka.* 'Resistance' in this report is defined as supporting few emerged *Striga* plants.

Materials and methods

Two-hundred-seventy-five wild *P. glaucum* accessions were sown in Bamako, Mali on 11 Jul 1997. Accessions were sown in two-row plots spaced 50 cm apart. Within each row, four hills spaced at 60 cm were sown, and plots were infested with 3 g seed (approximately 230 000 viable seeds) of *S. hermonthka.* Stands were thinned to a single *Pennisetum* plant per hill Incidence of downy mildew (*Sclerosporagraminkola* (Sacc.) J. Schrot.) infection was assessed by counting the number of symptomatic plants in each plot. Metalaxyl (0 5 g L^{-1}) was sprayed on diseased tissue to runoff on 20 Aug and 3 Sep to halt the epidemic.

Numbers of emerged *Striga* plants within plots were counted on 25 Aug, 8 and 23 Sep, and 7 Oct. Due to erratic emergence of the *Pennisetums,* not all accessions were represented by eight hills so the mean number of *Striga* per hill for each plot was calculated and analyzed. Data were transformed to log (*Striga* + 0.05) prior to analysis of variance. Sums of squares for transformed *Striga* emergence at each evaluation date, and for maximum *Striga* were partitioned into replication and accession effects. Maximum *Striga* (strigamax) for each plot was determined as the emergence count of the four evaluation dates that had the greatest number of *Striga.* Correlation coefficients and simple linear and multiple linear regression equations were calculated for the relationships between mean values for log (strigamax + 0.05) with days to flowering and downy mildew incidence. Maximum *Striga* counts were used to determine relationships between days to flowering and downy mildew reactions since counts frequently declined on the last evaluation date, which is typical of *Striga* infection and independent of *Pennisetum* genotype.

Results and discussion

In the analyses of variance, *Pennisetum* accession was a significant source of variation (P <0.01) for *Striga* emergence on the last three dates of evaluation, and for maximum emergence. Transformed *Striga* data was correlated with days to flowering (r = 0.82, P <0.0001), and negatively correlated with downy mildew incidence (r = -0.65, P <0.0001). Linear regressions revealed that *Striga* emergence was lower on early flowering accessions and accessions with a high incidence of downy mildew infection. The multiple linear regression equation predicting log (strigamax + 0.05) (Y) considering both independent variables was calculated as $Y = 0.103 + (0.014X_1) - (0.008X_2)$ where X_1 = days to flowering and X_2= downy mildew incidence.

Selection of *Striga* resistance could be confounded by the relationships between *Striga* emergence with date of flowering and downy mildew incidence. If selection were based only on low *Striga* emergence, early flowering and/or downy mildew-susceptible accessions would tend to be selected. A relationship between *Striga* infection and date of maturity has been previously Observed in com (Ransom and Odhiambo 1995). While early maturity can be a useful selection criterion for reduced *Striga,* early maturity is not necessarily desirable in all cropping systems. Selection for low *Striga* emergence without considering downy mildew infection will tend to select accessions susceptible to *S. graminicola.*

An alternative means of selecting *Striga* resistance is to calculate the predicted log (strigamax + 0.05) from regression equations using data of days to flowering and downy mildew incidence. Entries with observed values at least a standard error less than the predicted values may be more likely to express resistance. Fifty-four entries were identified that had observed values lower than the (predicted - one standard error) values calculated by the linear regressions of transformed *Striga* on days to flowering and downy mildew incidence, and by the multiple linear regression considering both independent variables.

Acknowledgment

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Utilization

Biochemical Constituents Related to Odor Generation in Some ICRISAT Pearl Millet Materials

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Development of mousy odor in the meal shortly after grain milling is an important constraint to the wider acceptability and utilization of pearl millet (*Pennisetum glaucum* (L.) R. Br.). The hydrolytic breakdown of meal lipids (Kaced et al. 1984; Kadlag et al, 1995) and enzymatic degradation of meal phenolics, C-glycosylflavones (Reddy et al. 1986), have been speculated to cause odor generation in the stored meal. Recently, Bangar (1998) has shown that phenolics and peroxidase activity (POD), mainly from the germ fraction of the seed, are responsible for odor generation in pearl millet meal. To study genetic variation and identify low POD types, 29 pearl millet genotypes from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (including several parents of mapping populations) with green, brown, or white seed colors were analyzed for crude fat, fat acidity, total phenolics (AOAC 1990), polyphenol oxidase (PPO), and peroxidase (POD) activities (Kumar and Khan 1982).

The genotypes studied showed a wide variation in these constituents (Table 1). The total lipids ranged between 3.3 to 7.6%, the fat acidity (a measure of lipolytic fat degradation) in 30-day stored meal varied from 206 to 680 mg KOH (100 g meal)$^{-1}$, and the total phenolics from 228 to 486 mg (100 g)$^{-1}$. Seed color was not related with total lipids, fat acidity, or content of total phenolics except that IP 18293—which has a purple pericarp—had the highest total phenolics content and lowest POD activity. Among the enzymes, POD activity varied markedly (54-332 units g^{-1} min^{-1}) in different genotypes. The low POD activity genotypes identified are IP 18293, Banner Pop, 863B, and,ICMP 451-.P8. Since the POD activity is related to odor generation, the genotypes with low POD activities may be advantageous to develop new cultivars with improved meal shelf life. As three of the low POD activity lines identified in this study (IP 18293, 863B, and ICMP 451-P8) have been used as parents of pearl millet mapping populations (Hash and Witcombe 1994; Devos et al. 1995), it should be possible to rapidly map quantitative and quantitative trait loci associated with this trait at relatively low cost. Further, the substantial difference detected between near-isogenic lines ICMP 85410 (E_1E_1) and ICMR 94410 (e_1e_1) (Bidinger et al. in press) suggest that some of the genetic factors controlling this trait may be linked with alleles conferring early flowering.

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Table 1. Crude fat, fat acidity, total polyphenols, peroxidase (POD), and polyphenol oxidase (PPO) activity in whole-grain meal produced from some pearl millet genotypes with varying seed colors.

Cuitivar	Seed color	Crude fat (%)	Fat acidity[1]	Total polyphenols [mg (100 g)$^{-1}$]	POD[2]	PPO[3]
Raj 171	Green	6.12	451	282	136	66.4
ICMB 89111	Green	5.04	680	324	248	52.2
PT 732B	Green	3.30	343	330	240	67.4
CZ-IC 923	Green	6.26	603	312	160	80.0
GICV 93191	Green	5.62	451	396	200	77.1
PCB-IC 148	Green	5.62	343	360	168	83.8
CZ-IC416	Green	7.36	461	258	164	88.6
843B	Light green	4.30	559	390	112	69.6
ICMR 94410	Light green	4.02	304	288	184	88.6
1CMP 85410	Light green	6.01	284	270	332	69.6
LGD-1-B-10	Light green	6.14	412	282	192	91.2
Tlft 238D$_1$	Light green	3.54	372	288	112	66.4
863B	Light green	4.16	255	300	64	83.8
ICMV 91773	Light green	5.02	412	270	188	60.8
ICMB 88004	Dark green	5.02	647	246	148	52.0
AIMP 92901	Dark green	5.54	363	300	138	60.8
RCB-IC 911	Dark green	5.16	265	228	136	60.5
ICMS 7703	Brown	6.60	539	228	120	66.4
ICMB 90111	Brown	7.60	274	312	116	75.2
ICMR 356	Brown	6.54	285	396	128	94.4
ICMP 451-P8	Brown	5.04	412	366	108	90.4
IP 18292	Brown	5.78	490	390	—	—
PRLT2/89-33	Brown	6.32	461	396	216	100.8
CZ-IC 618	Brown	5.77	274	258	124	89.6
Nokha Local	Brown	5.51	421	234	120	110.4
Barmer Pop	Brown	5.60	401	228	92	100.8
Balu Local	Brown	5.91	578	246	-	—
IP 18293	Dark brown	4.32	343	486	54	66.4
ICMB 88006	Light brown	4.88	206	312	184	60.5
Ranges		3.3-7.6	206-680	228-486	54-332	60.5-110.4

1. Mg KOH (100 g meal)$^{-1}$.
2. Units g^{-1} min^{-1}.
3. Units g^{-1} h^{-1}.

Obituary

In Memoriam

Bill Stegmeier and 'Pearl'.

It was with great sadness that the international pearl millet research community noted the passing away of W D 'Bill' Stegmeier on Saturday, 25 Jul 1998.

As the originator of several early-maturing, bold-seeded, dwarf pearl millet seed parents that were later widely distributed by ICRISAT to public and private sector breeding programs—especially those within India—as 842A/842B, 843A/843B, and AKM 1163/BKM 11163, Bill must be considered one of the fathers of the private sector of the pearl millet hybrid seed industry in India and of pearl millet as a grain crop in the USA (see pages 128-129 of this volume). Although he was by no means a prolific author, the extensive commercial use of products of his breeding program in India over the past decade—and his interactions with the livestock industry in the USA to evaluate and demonstrate the potential of pearl millet as a feed grain—clearly show him to have been a man of vision. Results from his research—freely shared with others long before publication—have substantially changed the way the world will look at pearl millet and other 'orphan crops' in the future.

William D 'Bill' Stegmeier, was born on 4 Oct 1931, in Green Bay, Wisconsin, USA, to William and Marie Stegmeier. He married Jean Cromer on 2 Jan 1953 in Yuma, Arizona. She passed away on 25 Jun 1996. He received his Bachelors and Masters degrees from Colorado State University, in Fort Collins, Colorado, and completed his graduate studies at South Dakota State University in Brookings, South Dakota. He worked 40 years as an agronomist, becoming an internationally recognized crop breeder for the Kansas State University Agricultural Research Center at Hays, Kansas. He started in 1958 at the K-State Agricultural Experiment Station, Garden City, moved to Hays in 1971, and retired in May 1998.

In addition to his scientific contributions in pearl millet and sunflower improvement, he was an active member of the communities in which he and his family lived—serving as a member and President of the Prairie Acres Improvement District, member and President of the Ellis County Rural Fire District, and member of the Hays City Zoning Board of Appeals. He was also a US Marine Corps veteran and served during the Korean Conflict.

Most importantly, he is remembered by his surviving children—Jill Stegmeier Herreman, William Rand Stegmeier, and Richard Stegmeier—as a true humanitarian. He instilled in them his concern about feeding the people of the world efficiently and economically. They remember fondly how, after more than one of his trips, he told his family of the great scientists he was working with, his feelings of awe for the knowledge being developed by them, and the respect and friendship he shared with them. His children indicate they grew up feeling that their father either had all the answers or knew where to get them—although maybe not twenty years ago as rebellious youngsters when they knew that they had all the answers.

Bill was so dedicated to his research that he sowed pearl millet isolations in his own garden, miles from the experiment station, to prevent unwanted outcrossing. From his family's point of view, he 'lost' much vacation time each year to concentrate on research. Many of his Saturdays and Sundays were spent at the experiment station, making crosses, as that was when the plants were ready and pearl millet waits for no one. Bill and his wife, Jean, often kidded each other about the 'other woman' in his life, Pearl. When people who had not seen him for a period of time inquired with her about his activities, Jean would tell them that he was "still messing around with Pearl".

With Bill's passing, the global pearl millet research community has lost a quiet, productive man who will be sorely missed. The impact of Bill's pearl millet breeding program speaks for itself.

I thank Bill's colleagues and children for sharing with me their memories of this visionary, yet simple, man.

C Tom Hash
ICRISAT Pearl Millet Breeder
and
ICRISAT Technical Editor, ISMN

Notes and News

News Items

K N Rai Acknowledges Award

K N Rai, Senior, Scientist (Breeding), in the Genetic Resources and Enhancement Program of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) received the Consultative Group on International Agricultural Research (CGIAR) 1998 Outstanding Locally Recruited Scientist Award at International Centers Week 98 in Washington in October. We reproduce below Dr Rai's acknowledgement and response to the award:

Thank you Mr Chairman, Ladies and Gentlemen.

I am very happy to receive this award, especially because it is for research achievements on a crop considered as a poor man's crop, grown in marginal lands, where we have done pretty well; but also because pearl millet seems to be quite rich in winning awards. Pearl millet research team won the Mashler Award in 1994, then came the King Baudouin Award in 1996, and now here I am in 1998. Does this award pattern for pearl millet research follow a mathematical series? We in pearl millet shall remain optimistic, and continue with our good tradition of 'work and wait to win'.

Research achievements of high order in any agricultural discipline, especially so in Genetic Enhancement, do not come from the efforts of single individuals. There are a number of players who have made their own good contributions to my research achievements. These include my team of dedicated support staff down to the lowest level of Regular Work Force; and my scientist colleagues at ICRISAT, in Indian national programs and elsewhere. The list is too long to mention all the names, but 1 would like to mention a few most significant ones. These include Professor David Andrews who laid the foundation of the Pearl Millet Improvement Program at ICRISAT; Dr Anand Kumar who initiated Pearl Millet Seed Parents Research—the major area of my research activity for more than 15 years; Mr A S Rao who has been working as my Research Associate ever since I joined ICRISA T; and Dr T T Patil, Chief of the Seed Production Division in Maharashtra State Seeds Corporation, who played an important role in seed production and popularization of some of the most successful cultivars developed by us. I thank them all

Finally, I would like to thank Dr Shawki Barghouti who nominated me for this award; and the CGIAR Selection Panel and the Chairman who found me worthy of this recognition.

Thank you.

Opportunities for the Development of Village Seed Systems in the Semi-Arid Tropics of West and Central Africa

J Ndjeunga (Special Project Scientist—Economist, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), BP 12404, Niamey, Niger)

During the last two decades, more than US$ 100 million have been invested in state seed multiplication and distribution projects in the semi-arid tropics of West and Central Africa. At least 36 pearl millet and 31 sorghum varieties have been developed and released in the subregion by national and international agricultural research centers. These investments have largely failed because the large scale and scope of the projects made them unsustainable. Research centers were unable to provide the quantity of breeder seed required for further multiplication; insufficient numbers of quality control personnel didn't allow for proper field inspections and laboratory tests; and there were very few seed distribution points. Consequently, farmers, nongovernmental organizations, and rural development project managers have complained about the low germination rate of, and poor access to, seed of improved varieties. For example, during the last five years in Niger, state seed production units have been unable to adequately control quality due to lack of personnel and funding; less than 30% of seed produced was actually sold, and the average cost of producing 1 kg of pearl millet seed was estimated at 1300 CFA francs (550 CFA francs = US$ 1), i.e., about eight times the price of pearl millet grain and six times the improved seed safe price. Therefore, seed projects consistentiy operate at a loss and are not financially sustainable. Consequently, farmers continue to draw a large share of their seed for sowing from previous harvests.

In contrast, recent research highlights the efficiency of local village supply schemes at recycling traditional varieties and supplying high quality seed to farmers at low transaction costs. In Niger, for example, 30 out of 33 pearl millet varieties grown by farmers are local cultivars; more than 90% of rural households draw the largest share of their seed for sowing from their own harvests and less than 1% from the formal seed markets. Standard quality tests on farmers' pearl millet seed stocks indicate an average germination rate of 88% with 12% moisture content, and few physical impurities. Of those farmers who are efficient at farming, about 35% are seed suppliers. Farmer-to-farmer and farmer-to-grain trader exchanges remain the main seed distribution channels. Seed prices are equal to grain prices, as many farmers purchase high quality grain as seed from the local village markets. However, the local village supply systems have difficulties meeting the demand for seed security stocks.

A large share of donor investments should target the further development of local village seed supply systems by enhancing their capacity to produce and maintain seed security stocks and promoting the development of small-scale seed multiplication at the rural community level. Large and efficient farmers could be targeted and encouraged to become entrepreneurs tasked with the multiplication of new pearl millet varieties. Along with grain traders, they could be used as seed distributors. The role of formal seed systems should be limited to providing high quality breeder seed and training small entrepreneurs in seed production techniques.

A New Breakthrough in Developed Sorghum Hybrids in China

Yang Zhen (Sorghum Research Institute, Liaoning Academy of Agricultural Sciences, 84 Dong Ling Road, Shenyang, China)

Since the formal implementation of project UNDP-CPR/91/132 in 1992, the capacity of sorghum breeding and seed propagation in China has been greatly strengthened.

In sorghum breeding, implementation of an integrated key sorghum research project during the National Eighth Five-Year Plan resulted in five new sorghum hybrids. These new sorghum hybrids developed by the Sorghum Research Institute (SRI), LH No. 4, LH No. 5, LH No. 6, LH No. 7, and LH No. 10, are high yielding with good grain quality and multiple pest resistance. They will replace old hybrids and play an important role in increasing grain production in the arid and semi-arid areas of Liaoning province and throughout China.

A new hybrid, LH No. 10, considered the best, has far exceeded its control, Jin Za 93, in grain yield and pest resistance. This achievement has won a national patent (Patent no. 95-1-10228.1). In 1996 the sown area of LH No. 10 was 1000 ha at HuLudao. The average grain yield of LH No. 10 was 10.2 t ha^{-1}, 25% higher than that of the popular cultivar Jin Za 93 (8.1 t ha^{-1}). A new record for high yield in LH No. 10 (13.5 t ha^{-1}) was obtained in a 0.33-ha demonstration field in Nanpiao country. In Xingcheng county, the yield was 12.0 t ha^{-1} in a 2-ha field.

Implementation of the project prompted poverty alleviation through science and technology and benefited farmers directly. Distribution of elite hybrid seed has made farmers richer. It is estimated that by 1997, the area sown to LH No. 4 will reach 93 300 ha, LH No. 5 will reach 206 700 ha, LH No. 6 will reach 44 700 ha, and LH No. 10 will reach 26 700 ha. Total increase in grain yield will be 278 million kg, and the increase profit will be RMB 278 million Yuan.

It is planned that in the northern and northwestern sorghum-growing areas of Liaoning province, two-thirds of sorghum fields will be sown to new hybrids developed by SRI in the National Ninth Five-Year Plan.

Network News

Market-driven Opportunities for Sorghum

Lack of market has been identified as a major constraint for sorghum production in West and Central Africa. To remove this constraint, the West and Central Africa Sorghum Research Network (WCASRN) is conducting research on diversification of sorghum utilization. To this end, we have recently developed a partnership with GAM (General alimentaire du mali), a food processing industry based in Bamako, Mali. An agreement has been signed so that GAM produces and promotes sorghum-based biscuits and bread.

To achieve this, the Network, in collaboration with the national agricultural research system in Mali, has identified farmers who will produce and provide good quality grain of the sorghum variety Ntenemissa, a suitable variety currently in diffusion in Mali. We have also identified a partner who will produce a good quality sorghum flour.

The first batch of biscuits produced has been tested on the market and was well received.

Cereals and Legumes Asia Network (CLAN)

As reported in the previous issue of this Newsletter, the Asian Sorghum Scientists' Meeting was held during 18-21 Nov 1997 at Suphan Buri, Thailand. The participants at the meeting listed the potential research areas and discussed possible activities that could be developed for collaborative research (see ISMN 38:152-153).

The following activities were undertaken by the Cereals and Legumes Asia Network (CLAN), as a follow-up to the recommendations to the meeting.

- Requests were sent to China, Indonesia, Iran, Myanmar, Thailand, and Pakistan to send two or three released varieties that will be used in a marker-assisted backcrossing program to incorporate the stay-green trait. Material was received from all countries, except Iran. These materials have been sown in the Post-entry Quarantine at ICRJSAT-Patancheru and the crossing program will start next season.
- It is planned that these sorghum varieties will be exchanged among participating network member countries.
- The National Research Centre for Sorghum, Hyderabad, India, provided four released varieties (SPV 462, CSV 13, CSV 15, and RS 29) for exchange with other countries. These have been sent to China, Indonesia, Myanmar, Thailand, and Pakistan for evaluation.
- The exchange of germplasm and breeding material from ICRISAT to national programs continued. During the period of Oct 1997 to Sep 1998, germplasm scientists from ICRISAT's Genetic Resources and Enhancement Program supplied 3912 sorghum and 926 pearl millet seed samples to eight Asian countries. During the same period, plant breeders supplied 17 434 sorghum and 2947 pearl millet seed samples (early and advanced generation material, released varieties, breeder seed, etc.) to seven Asian countries.

Conferences

Mexican (XXVIth) and Latin American (Xth) Phytopathological Societies Joint Meeting

G Fuentes-Davila (Vice-President, Mexican Phytopathological Society, CIMMYT INT, Apdo Postal 140, Cd. Obregon, Sonora CP 85000, Mexico)

The Latin American Phytopathological Society cordially invites you to attend and participate in the international congress that will take place in Guadalajara, Jalisco, Mexico, from 27 Sep to 1 Oct 1999. The Mexican Phytopathological Society will host this event. Called "the pearl of the Occident" by poets, Guadalajara is Mexico's second largest city and one of its most beautiful. The climate is pleasant with an annual mean temperature of 21°C (70°F). Guadalajara combines the colonial architecture of mansions and churches from the 1500s with modern hotels, clubs, and residential areas, modern shopping malls with traditional handicraft centers, and discoteques with folkloric, regional dances, mariachi, and charreria. The museums, parks, theaters, and other tourism-oriented recreational centers within a short distance assure the visitor a complete and enjoyable stay; For the professional in agriculture, it is also an area of interest, since Guadalajara is located between the wheat-growing areas of Mexico and the subtropical and tropical agricultural zones, where fruits like mango are found growing between agave (from which the traditional liquor tequila is produced) and sugarcane. Guadalajara is easily accessed: the international airport is served by many airlines, and ground transportation is provided from nearly everywhere in Mexico.

The technical program will include oral and poster sessions, as well as symposia, conferences, precongress courses, and postcongress trips. Social, cultural, and tourist activities will form part of the meeting.

For more information, contact Lic Veronica Gonzalez (tel 52-3-641-8630, fax 52-3-642-7982); Dr Guillermo Fuentes-Davila (tel 64-141940,145799; fax 64-145898; e-mail: gfuentes@gatelink.net or gfuentes@cimmyt.mx); or Dr Juan Pablo Martinez-Soriano (tel 462-39637; fax 462-45996; e-mail: jpms@irapuato.ira.cinvestav.mx).

Summary Proceedings

Summary Proceedings of the Technology Exchange and Training Workshop on Advances in Sorghum Anthracnose Research, ICRISAT-Patancheru, 23-25 Sep 1998

R P Thakur (International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India)

Inaugural session

The Technology Exchange and Training Workshop on Advances in Sorghum Anthracnose was organized by the Genetic Resources and Enhancement Program (GREP) for collaborating scientists in Asia with the following objectives:

- improve understanding of pathogenic and genetic diversity in populations of the sorghum anthracnose pathogen, *Colletotrichum graminicola;*
- learn molecular and statistical techniques/methods for virulence analysis;
- learn more about epidemiology, resistance utilization, and disease management; and
- discuss opportunities for future collaborative research.

The workshop provided theoretical insight, practical observations, and hands-on experience in several areas of sorghum anthracnose research.

There were seven participants and resource persons from India and one participant from Thailand. In addition, there were five resource persons from ICRISAT-Patancheru. Resource persons representing breeding, pathology, molecular biology, and statistics were selected based on their interest, experience, and involvement in sorghum anthracnose research.

The workshop was inaugurated by C L L Gowda, Cereals and Legumes Asia Network (CLAN) Coordinator. He mentioned the heavy losses caused by anthracnose on both forage and grain sorghum, and the existence of variability in the pathogen *C. graminicola,* which makes breeding for durable resistance difficult. He emphasized the importance of current research collaboration on anthracnose variability through the International Sorghum Anthracnose Virulence Nursery (ISAVN) and appreciated the active partnership of national agricultural research systems (NARS) in this exercise. He also briefly introduced the current structure and function of CLAN for the benefit of participants.

B Diwakar, Senior Manager, ICRISAT Training and Fellowship Program (TAFP), highlighted the various training opportunities ICRISAT offers to NARS scientists, technical staff, and students, and requested participants to disseminate this information to their organizations and colleagues.

R P Thakur, the Workshop Coordinator, introduced the objectives of the workshop and emphasized the importance of collaboration based on true partnership. He highlighted the keywords of this workshop:

informal interactive, partnership, feedback, and research needs.

While highlighting the importance of studies on pathogenic variability in sorghum anthracnose, he informed participants of one Plenary Session theme in the recently held International Congress of Plant Pathology at Edinburgh, UK, 9-16 Aug 1998. This was "Plant Pathogens, Diversity and Conservation", which was proposed by D S Ingram, President British Society of Plant Pathology and the Congress President. Like crop plant biodiversity, plant pathogen biodiversity and conservation have been recognized as an important theme for research in the future. Pathogen biodiversity and their conservation are important because:

- they serve a role in revealing genetic diversity in potential breeding material and provide vital screens for the development of new cultivars;
- they are the raw material for much of the basic scientific research on life cycles and genetics that generate better understanding of pathogen variation, evolution, and population dynamics; and
- they constitute a potentially significant biotechnological resource of particular importance to molecular geneticists.

Unless plant pathogens are conserved along with their hosts, the selection pressure that influences the host will be lost and gradually the genes that confer resistance on the host will fall to extremely low frequencies and will exist in danger of being lost. He further highlighted the need and importance of understanding diversity in pathogen populations in natural ecosystems, the need for a proper system for preservation and curation of the isolates and their DNAs, and the need for an international policy on conservation of plant pathogens. He related these ideas with the collection, characterization, and maintenance of sorghum anthracnose isolates at ICRISAT-Patancheru. Currently we have 226 anthracnose sample collections from different sorghum cultivars from different states of India, of which about 20% have been purified and characterized for pathogenicity. However, only a few of these have been charcterized for both pathogenic and molecular-genetic diversity.

Each of the participants briefly described his/her research activities in relation to sorghum anthracnose and collaboration with ICRISAT in the ISAVN during the past 5-6 years. They also highlighted the importance of anthracnose in their respective states and areas in these states. At the moment, anthracnose is not a serious problem in Thailand, but it is recognized as a potential problem in forage sorghum. In India it is more serious in parts of Gujarat, Rajasthan, Madhya Pradesh, Karntaka, Haryana, Andhra Pradesh, and Tamil Nadu, mainly on local sorghums. It is less important on grain hybrids than on local cultivars and forage hybrids.

Field visit

A field visit was organized to see the ISAVN and interact on evaluation of plants for disease reaction and severity. This was quite useful, as participants clarified their doubts on scoring systems, allowing everybody to clearly understand how the disease scores should be taken.

Epidemiology

A discussion session on epidemiology of sorghum anthracnose was led by A H Rajasab. His comprehensive presentation covered a wide area, including disease distribution in different parts of the world; loss in grain yield and fodder yield and quality, and syrup quantity in the case of sweet stalk sorghums; the host range of the pathogen and its relevance to survival and inoculum spread; different forms of inoculum consisting of conidia, mycelia, chlamydospores and sclerotia; the seed-borne nature of the disease; types of anthracnose symptoms at different plant growth stages—seed rot, seedling blight, leaf spot, stalk rot, leaf sheath anthracnose, leaf blight, peduncle rot, spot and split, panicle blight, small seeds, and seed spot. The leaf blight phase (diffuse lesions) occurs in severe form at anthesis and postanthesis stages of crop growth and is reponsible for more than 50% loss in grain yield. The pollen grains deposited on leaf surfaces supply nutrients to the pathogen and aid in rapid infection and colonization.

The acervuli, consisting of conidia and setae, are embedded in a mucilaginous mass. The setae help conidial dispersal during rain. Conidia embedded in mucilage exhibit germination inhibition. Mucilage contains mycosporine-alantne and acetic acid, which can inhibit conidial germination. The mucilage also contains an enzyme—-laccase—a polyphenol oxidase that is involved in detoxification of plant phenols during infection.

Some of the phytoalexins produced due to host-pathogen interactions are apigeninidine, luteolinidin, chiteolinidin, and caffeic acid. Phytoalexin accumulation has been detected more in resistant than in susceptible plants. This information can be used for identification of host resistance.

He also emphasized various control measures and the need to develop an integrated disease management (IDM) system involving host plant resistance (HPR), chemical, and biocontrol agents.

The presentation was well received by the participants and initiated lively discussion.

Pathogen variability

K Mathur made a comprehensive presentation on pathogenic variability encompassing general theories of host-pathogen coevolution, sexual recombination, asexual-somatic recombination, spontaneous mutation, and genetic drift. The role of host genotype in evolution of new virulence was also highlighted. Dramatic breakdown of HPR occurs when a particular pathogen clone (virulent mutant or migrant whose genotype dominates a new population) becomes highly adapted to a popular host genotype. Deployment of HPR without an awareness of pathogenic variation within pathogen populations could result in costly failure. She highlighted the results of several studies on pathogenicity, fungicide resistance, vegetative compatibility, and DNA polymorphism that were done at ICRISAT during the past 2-3 years and also through the collaborative ISAVN at many locations overyears.

The presentation was followed by good discussion and raised several issues for future research.

Laboratory demonstration

Cultural and morphological variability

K Mathur and VP Rao organized a practical demonstration to show the tremendous variability that exists in *C. graminicola* isolates for cultural and morphological traits. These included growth characteristics on oatmeal agar plates, colony color, spore shape and size, presence and absence of setae, sclerotia, etc. Participants were able to examine the variability, both macro- and microscopically.

Identity of the sorghum anthracnose pathogen *C. graminicola* (Ces.) Wils. (= *Colletotrichum sublineolum* Henn. Rabat & Bub.) has been controversial, probably due to its high morphological and pathogenic variability, and wide host range among cereals and grasses. Sutton (1968) separated the species infecting maize as *C. graminicola,* and that infecting sorghum as *C. sublineolum* on the basis of their appressoria. Sherriff et al. (1995) confirmed the distinction between *C. graminicola* and *C. sublineolum* based on rDNA sequence analysis. Contrary to that, Rosewich (1996), through DNA analysis, concluded that there were no genetic differences between these two species. Nevertheless, specificity of maize isolates to maize, and induction of its perfect state in the lab indicate that pathogen infecting sorghum is different.

Isolates of *C. graminicola* show considerable variation in symptoms produced on sorghum, and in culture. Populations vary in the extent of heterogeneity. In some, all the single lesions yield similar cultures, while in others, different single lesions yield variable cultures, or individual lesions yield two to three segregating cultures.

Cultural variations were observed for:

Colony growth	varying from white, white-grey, grey-green, or black; mycelial growth may be aerial or submerged, felty or wooly; substrate color may be white, grey, or lilac
Sporulation	varies from dull to bright salmon pink or grey
Acervuti	may be indistinct with occasional setae, or well developed with 2 to >20 setae; setae may vary in length and color
Conidia	isolates vary in the rate of sporulation, and size of conidia
Appressoria	some isolates form appressoria in culture, which vary in shape, color, and size (single-lesion isolates from a single leaf vary in formation of appressoria)
Sclerotia	sclerotia are present in some cultures, which vary in size

Cultural and morphological variations may or may not be associated with pathogenic variability. In some cases, morphological variants segregating from single lesions were found to be different pathotypes. The cultures of *C. gloeosporioides* isolates from leaf lamina collected from yellow sorghum from Maharashtra and grain collected from yellow sorghum from Tamil Nadu were also exhibited.

The exercise generated a great deal of enthusiasm and discussion.

Screening techniques (greenhouse and field)

V P Rao and K Mathur organized a practical demonstration of the various steps involved in screening techniques, including inoculum preparation, spore concentration adjustment, spraying plants in the greenhouse, and subjecting them to high relative humidity in an incubation chamber. These techniques were later tried by each participant. The appearance of symptoms on earlier inoculated plants was also demonstrated and procedures for recording latent period were explained. Inoculation of plants in the field was also demonstrated by placing *C. graminicola* infected sorghum seeds into the whorls of 30-day-old seedlings, which was tried by each participant. Inoculation was followed by sprinkler irrigation of the plots.

Inoculation methods

Greenhouse

- Isolates were grown in 0.1% oatmeal broth in a rotary shaker (25°C, 125 rpm, with cool fluorescent light) for 10 days.
- Conidia were separated by filtering cultures through double-layered muslin cloth. Spore concentration of a 1×10^5 ml^{-1} was adjusted with the help of a haemocytometer.

- Two drops of Tween-20 were added to 100 ml of each inoculum, just before inoculation.
- Tweny-one-day-old, pot-grown plants were spray inoculated with a hand-held atomizer. inoculated plants were air-dried, and transferred to a humidity chamber (25°C, RH >95%) for 24 hours.
- Plants were transferred to the greenhouse (25°C, RH >90%) benches in a randomized block design, keeping isolates as blocks.
- Observations for latent period (time in days for appearance of first chlorotic/necrotic lesion) started on the third day; disease reaction and severity were recorded 14 days after inoculation.

Field

- Isolates were grown on autoclaved sorghum grains in flasks for 10 days [grains were soaked overnight in water, decanted, filled in flasks, autoclaved for one hour, cooled, and inoculated with specific isolate(s)].
- Grain culture was taken out in trays and air-dried for 30 minutes.
- Two to three grains were placed in each whorl of 21-day-old plants.
- Inoculations were done in the evening hours, and followed by light sprinkling with water or good irrigation to provide adequate moisture for infection.

Note; It is preferable to sow susceptible lines along with test lines to ensure development of adequate disease pressure in the field.

Breeding for resistance

In his presentation, B V S Reddy outlined the basic principles of breeding for disease resistance and highlighted his experience in breeding for anthracnose resistance in sorghum. Two sources of resistance, TRL 74/C-57 and A 2267-2, have been widely used in this breeding program. The former has been found to be a maintainor on all four available cytoplasm (A_1, A_2, A_3, and A_4) while the latter is a maintainer on cytoplasms A_3 and A_4 (Maldandi), These two resistance sources have been converted to A-lines and are being maintained in the above mentioned cytoplasmic backgrounds at ICRISAT-Pataneheru.

Male-sterile lines with high yield and reasonable levels of anthracnose resistance to the Patancheru pathotype have been bred following pedigree-backcross methods. At present 28 anthracnose-resistant sorghum male-sterile lines are available at ICRISAT Participants greatly appreciated this presentation and learned more about resistance breeding. Some participants requested seeds for evaluation at their locations.

Statistical data analysis

In his lecture, S Chandra highlighted the importance of several aspects before the data can be considered for actual statistical analysis. These included selection of a data entry format according to the computing software intended to be used for statistical analysis, validation of data for correctness, identification of structure and dimension of the experiment, the nature of data recorded on each variable, the nature of experimental and blocking factors, selection of appropriate univariate and/or multivariate analysis techniques, and building appropriate statistical model(s). These issues were explained in the context of ISAVN data obtained from 26 locations over the past six years and examples of the above points were demonstrated in relation to the objectives of the TSAVN. He suggested the adoption of a systems approach to derive biologically meaningful and statistically efficient results that, in view of the unbalanced nature of the data, could be obtained through the application of restricted maximum likelihood (REML) procedures. He suggested using weather variables for developing models to predict disease reaction and disease severity. Participants highly appreciated this lecture and a lively discussion took place to clarify several issues.

Integrated disease management

S Pande, with his vast experience of working on integrated pest management (IPM)/IDM and his earlier experience working on anthracnose and other sorghum diseases, provided a comprehensive outlook on IDM in general and anthracnose in particular. Because sorghum is a crop of subsistence agriculture in the semi-arid tropics and anthracnose is a serious problem on forage sorghum, HPR plays a central role in integrated disease management. HPR can be combined with seed dressing chemicals, cultural, or other control methods depending on the cropping system and fanner's interest. Management of both diseases and insects was emphasized as a holistic approach of crop health management. Participants took an active part in discussing several issues related to IPM/IDM.

Molecular studies on *C.graminicola*

S Sivaramakrishnan described several molecular methods that are being used to study genetic variability in pathogen populations, including isozymes, hybridization, and PCR-based DNA fingerprinting. In the hybridization method, restriction fragment length polymorphism (RFLP) and simple sequence repeats (SSR) are the important techniques for detection of pathogen variation. In the RFLP method, the genomic DNA is digested with sequence-specific restriction enzymes and the resulting fragments are separated by gel electrophoresis. RFLPs are detected by Southern hybridization with probes targeted to hyper variable regions of DNA, obtained from a genomic library of the fungus or from a closely related species. DNA fingerprinting with mini- and microsatellites, which are hyper variable DNA sequences dispersed in the form of long arrays of short tandem repeat units throughout the genome and usually referred to as SSR polymorphisms, are highly informative.

The PCR-based fingerprinting techniques include random amplified polymorphic DNAs (RAPDs), sequence characterized amplified regions (SCARs), DNA-amplified fingerprinting (DAF), arbitrarily primed-PCR (AP-PCR), and sequence tagged microsatellite sites (STMS).

Flor's gene-for-gene interaction model involving the resistance (R) genes in the host and avirulence (Avr) genes in the pathogen has been widely used. PCR has been employed to identify changes in gene expression associated with infection. Resistance genes are mostly dominant or codominant and exist as a family of genes with each member conferring resistance to specific strains of the pathogen. Considerable progress has been made in identification and cloning of resistance genes using map-based cloning and transposon tagging. Resistance genes have been classified into five groups based on their structural similarities: nucleotide banding domains (NBD), leucine-rich repeats (LRR), and a protein kinase motif in various combinations. Marker-aided selection has great potential in breeding for disease resistance—markers can substitute for disease screens in many cases.

Participants were invited to visit the molecular lab, observe equipment in use, and see the banding pattern on gels and autoradiograms of some of the anthracnose pathogen genetic diversity.

Host plant resistance

S D Singh described the need and importance of host plant resistance in disease management. He outlined the essential elements needed to develop effective field and greenhouse screening techniques, identify stable resistance through multilocational testing, develop collaborative nurseries, and manage disease nurseries.

He also outlined different kinds of host plant resistance available: recovery resistance, dilatory resistance, and adult plant resistance, with particular reference to pearl millet downy mildew (caused by *Sclerospora graminicola* (Sacc.) J. Schrot.) on pearl millet (*Pennisetum glaucum* (L.) R. Br.).

Sorghum disease nurseries

S Indira mentioned various diseases and their prevalence and severity in India. She described different nurseries being conducted with the All India Coordinated Sorghum Improvement Project (AICSIP), sources of resistance available to major diseases such as grain mold, charcoal rot, downy mildew, pokah bong, and leaf blight, as well as anthracnose. She also highlighted the need for considering other disease management practices such as chemical and biological control in combination with HPR.

General discussion

A highly interactive discussion took place and every participant expressed his/her ideas and thoughts. All participants appreciated the central role ICRISAT has been playing and were happy with the content and structure of this workshop, which allowed them to learn a great deal within a short period. The following research areas were identified for future investigations:

- role of weather parameters on disease development and prediction modeling;
- effect of anthracnose on fodder quality;
- role of phenols in host resistance;
- role of soil water stress on disease development;
- yield loss due to the leaf blight phase of anthracnose;
- vegetative compatibility among anthracnose isolates;
- identification of different R-genes and development of near-isogenic lines to be used as host differentials;
- characterization of isolates from grain, midrib, and leaf lamina;
- role ofsclerotia in pathogen survival;

- virulence and resistance monitoring through systematic field surveys; and
- development of an IDM system.

Concluding session

Participants expressed their responses to the workshop, which were all highly appreciative. C L L Gowda and B Diwakar thanked the participants and resource persons for successfully achieving the set objectives of the workshop. Certificates were distributed to the participants.

The workshop was supported financially by CLAN and GREP, and logistic supports were provided by TAFP. R P Thakur gratefully acknowledged the support provided by C L L Gowda, P J Bramel-Cox, and B Diwakar. He expressed his thanks and appreciation for the contributions and efforts by the resource persons and keen interest of the participants. Participants expressed their appreciation and complimented the efforts of ICRISAT in organizing this workshop.

R P Thakur also thanked Housing and Food Services, Transport Unit, Security, secretarial staff, and all others at ICRISAT-Patancheru who contributed in various ways to make this workshop a success.

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Secretarial resource persons: S M Ahmed and S V Prasada Rao

Workshop Coordinator: R P Thakur, Senior Scientist (Pathology)

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This bulletin explains what pheromones are, how they have been used in the management of pests, especially stem borers, the advances that have been made in the management of the millet stem borer (*Coniesta ignefusalis*), how to use the pheromone traps developed for this species, and the prospects for the integration of pheromone-based methods into management strategies of this key pest in the Sahel.

Youm, O., Russell, D., et Hall, D.R. 1998. Utilisation des pieges a pheromone pour la surveillance du foreur du mil (*Coniesta ignefusalis*) Bulletin d'information n°40. 20 pages. ISBN 92-9066-375-8. Code de commande IBF 040. LDC $10.50. HDC $28.50. India Rs 395.00.

Cet ouvrage a pour but d'expliquer ce que sont **les** pheromones, leur utilisation dans la lutte contre les insectes nuisibles, surtout les foreurs des tiges, les progres enregistres dans la maitrise du foreur du mil (*Coniesta ignefusalis*), la methode d'utilisation **des** pieges a pheromones mis au point pour la lutte contre cette espece ainsi que les perspectives d'integration des methodes a base de pheromones dans les strategies de lutte contre cet important ravageur au Sahel.

Chung, K.R. 1998. The contribution of ICRISAT's mandate crops to household food security: a case study of four rural villages in the Indian semi-arid tropics. Information Bulletin no. 52. 40 pages. ISBN 92-9066-390-1. Order code IBE 052. LDC $19.50. HDC $55.50. India Rs 775.00.

The conceptual linkage between increased food production and improved nutritional status appears straightforward; yet, devising research strategies that lead to real change has proved difficult. Although intrahousehold resource allocations are a strong determinant of individual nutritional status, this bulletin focuses on the possibilities for technical change to improve consumption at the household level. The reported study therefore seeks to update knowledge of the role that the International Crops Research Institute for the Semi Arid-Tropics (ICRISAT) mandate crops play in the diets of the rural poor. Specifically, it examines the state of undernutrition in the study area, the dependence of the rural poor on ICRISAT's mandate crops, the actions available for improving the diets of the rural poor, and the role agricultural research should play in the fight to reduce undernutrition. These topics are addressed through a household-level analysis of dietary patterns in four rural villages in the semi-arid tropics. The ultimate purpose is to discuss the menu of options available to researchers interested in strengthening the link between agricultural technology and nutritional well-being. The analysis focuses on identifying current dietary and expenditure patterns in two regions within the Indian SAT.

Gowda, C.L.L., and Stenhouse, J.W. 1998. Strengthening sorghum research collaboration in Asia: report of the Asian Sorghum Scientists' Meeting, Suphan Buri, Thailand, 18-21 Nov 1997. 72 pages. ISBN 92-9066-392-8. Order code CPE 117. LDC $10.50. HDC $28.50. India Rs 395.00.

The Asian Sorghum Scientists' Meeting was attended by 28 researchers from eight countries in the Cereals and Legumes Asia Network—Australia, China, India, Indonesia, Iran, Myanmar, Pakistan, and Thailand—and from ICRISAT. The meeting reviewed the current status of collaborative sorghum research in Asia, identified new research priorities, and laid out plans for new initiatives in specific areas. These include marker-assisted selection to improve the stay-green trait, development of alternative cytoplasmic male-sterility systems, development of improved forage sorghums, and the creation of a database on available cultivars as a means to promote technology spillovers across countries. This publication contains the presentations made at the meeting, and a summary of the recommendations. It thus provides an overview of the current status of sorghum research in Asia, future research priorities, and progress that may be expected.

Bantilan, M.C.S., and Joshi, P.K. 1998. Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, ICRISAT, Patancheru, India, 2-4 Dec 1996. 288 pages. ISBN 92-9066-396-0. Order code CPE 119. LDC $27.50. HDC $74.50. India Rs 1025.00.

Pursuit of a joint approach to the assessment of research impact is critical for the continuing viability of national and international research within the global agricultural R&D system. This workshop on "Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics" was organized to achieve three objectives: (1) to report results of case studies on adoption and impact undertaken jointly by teams from ICRISAT and the national programs; (2) to provide a forum for peer review; and (3) identify through working group sessions key issues and priority areas for the ICRISAT/NARS research agenda on impact assessment.

The workshop was attended by ICRISAT scientists from all disciplines, by representatives from private and public sector research institutions, the seed sector, and other international research organizations. These proceedings include the presentation of case studies featuring research impact in four areas—genetic enhancement research; resource management options; intermediate products of research; and impact of networks. That adoption is a condition of impact was noted. The efficiency dimension of impact served as a starting point in most analyses. Other dimensions of impact include food security, gender equity, sustainability, human nutrition, employment, and spillover effects. The integration of these dimensions in the research evaluation process was discussed. Peer review was an important feature of this workshop: it served as a basis for the discussions on priorities for the future research agenda on impact assessment.

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 who are interested in the research and development of sorghum (*Sorghum bicolor* (L.) Moench), pearl millet (*Pennisetum glaucum* (L.) R. Br.), and finger millet (*Eleusine coracana* (L.) Caertn.), 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 later in refereed journals. It is assumed that contributions in ISMN will not be cited unless no alternative reference is available.

ISMN welcomes short contributions (not exceeding 600 words) about matters of current interest to its readers.

What to contribute?

Send us the kind of information you would like to see in ISMN.

- **Contributions should be current, scholarly, and their inclusion well-justified on the grounds of new information.**
- Results of recently concluded experiments, newly released varieties, recent additions to germplasm collections, etc.
- Genome maps and information on probe-availability and sequences, and populations synthesized for specific traits being mapped. Glossy black and white prints of maps should be included, if possible. Partial maps can also be submitted.
- Short reports of workshops, conferences, symposia, field days, meetings, lours, 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 30 June

- Keep the items brief—remember, ISMN is a newsletter and not a primary journal. About 600 words is the upper limit (no more than two double-spaced pages).
- If necessary, include one or two small tables (and no more). Supply only the essential information; round off the data-values to just one place of decimal whenever appropriate; choose suitable units to keep the values small (e.g., use tons instead of kg). Every table should fit within the normal typewritten area of a standard upright page (not a 'landscape' page).
- Black-and-white photographs are welcome—photocopies, color photographs, and 35-mm slides are not. Please send disk-files (with all the data) whenever you submit line figures and maps.
- Keep the list of references short—not more than five references, all of which should have been seen in the original by the author. Provide all the details such as author/s, year, title of the article, full title of the journal, volume, issue, and page numbers (for journal articles), and place of publication and publishers (for books and conference proceedings) for every reference. Incomplete references will not be accepted.
- Express all quantities only in SI units. Spell out in full every acronym you use.
- Give the correct Latin name of every crop, pest, or pathogen at the first mention.
- Type the entire text in double spacing. Contributions should be sent on diskette. on a double-sided/high density IBM-compatible disk. MS Word files are preferred.
- Contact the Editors for detailed guidelines on how to format text.
- **Include the full address with telephone, fax, and e-mail numbers of all authors.**

ISMN will carefully consider all submitted contributions and will include in the Newsletter those that are of acceptable scientific standard and conform to 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 style of the reports in this issue. Contributions that deviate markedly from this style will be returned for revision. and could miss the publication date. If necessary, we will edit communications so as to preserve a uniform style throughout the Newsletter. This may shorten some contributions, but particular care will be taken to ensure that the editing will not change the meaning and scientific content of the article. Wherever we consider that substantial editing is required, we will send a draft copy of the edited version to the contributor for approval before printing.

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