SICNA

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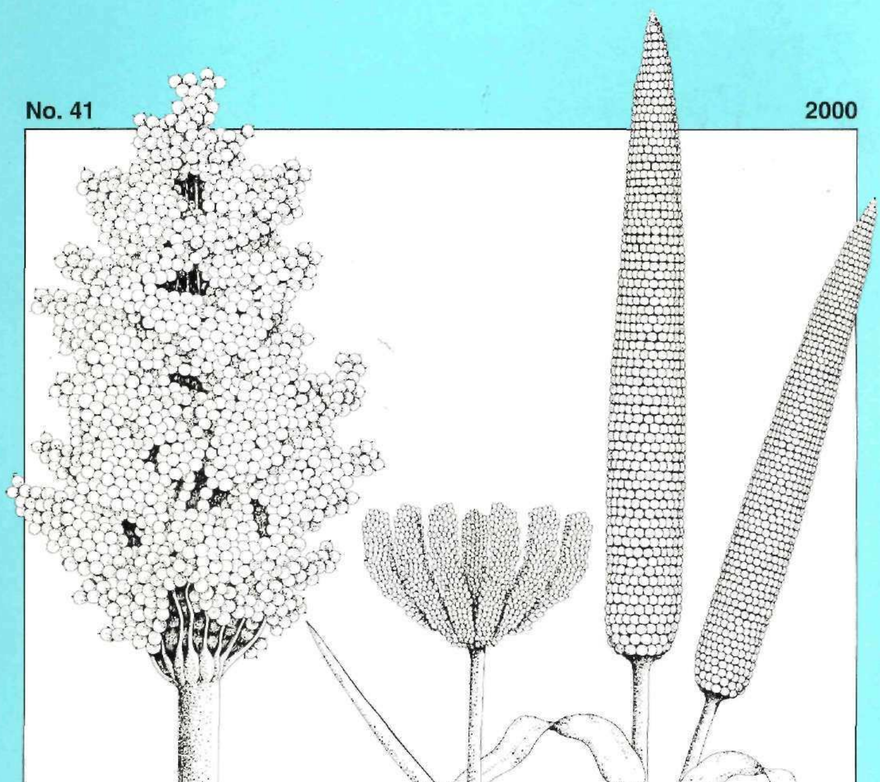

International Sorghum and Millets Newsletter

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 2000

J A Dahlberg **C T Hash**

Contents

SMINET News

Vol. 1, No. 1 (Dec 1999)

Vol. 2, No. 1 (Jul 2000)

Vol. 2, No. 2 (Dec 2000)

Sorghum Research Reports

Genetics and Plant Breeding

Agronomy

Pests and Diseases

SMINET News

Editorial

It is a great pleasure to feature in this issue of the International Sorghum and Millets Newsletter (ISMN) a number of news items and research notes that first saw the light of day in the first three issues of SMINET News. This new regional newsletter of the Sorghum and Millet Improvement Network (SMINET) is part of Phase IV of the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP). SMINET News is proposed to be published twice a year to carry information on new technologies (developed in pilot countries and elsewhere) so they can spread rapidly throughout the Southern African Development Community (SADC) region. Our intention here is to bring this information to the global sorghum and millet research community. In future issues of ISMN we plan to include relevant SMINET News news items and research notes among those received from other sources.

An informal network existed during the previous phases of SMIP, but involved mainly scientist-scientist interaction. It became necessary to broaden this participation in order to realize the common vision of improved productivity, food security, and sustainability. Not only scientists, but all stakeholder groups are now involved in SMIP— national and international research institutes, extension, NGOs, farmers' organizations, policymakers, donors, and the private sector (seed, food, and stockfeed industries).

With this broad participation, and pooled resources and expertise SMIP looks forward to a productive partnership. SMINET News will broadcast information as widely, quickly, and cost-effectively as possible and ISMN will share SMIP findings with its readers worldwide.

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Vol. 1, No. 1 (Dec 1999)

Sorghum and Pearl Millet Production in Southern Africa

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Sorghum and pearl millet are SADC's second and third most important cereal grains in terms of production area. Farmers in southern Africa annually sow over 1.9 million ha of sorghum and 0.9 million ha of pearl millet (Table 1). This compares with an aggregate production area of 12 million ha of maize. The area sown to sorghum and pearl millet in SADC has generally been increasing with the growth of smallholder farming populations.

Tanzania is the single most important sorghum producer, accounting for 35% of the total production area in the region. Mozambique, Zimbabwe, South Africa, and Botswana together account for about 48% of SADC's sorghum area. For pearl millet, Namibia and Tanzania each account for about 27% of the SADC acreage, Zimbabwe for almost 20%, and Mozambique for 7%.

Two countries are primarily dependent on sorghum and pearl millet based production systems. These are Botswana, where sorghum accounts for 84% of cereals area; and Namibia, where pearl millet provides a major source of livelihood and accounts for 81 % of cereals area. However, in other SADC countries these crops arc critically important in the drier and drought-prone regions.

Sorghum and pearl millet continue to be primarily grown as food security crops. More than 90% of the region's production is consumed as food in the areas where these crops are produced. The stability of production of these crops reduces the need to distribute food under drought relief programs.

Sorghum production is relatively commercialized only in South Africa and Zimbabwe. In South Africa, some 600 large-scale commercial farmers account for almost all of the commercial production. Roughly 60% of this harvest is used for food—sorghum meal, sorghum malt, and malt-based food products. Approximately 40% is used for animal feed. South Africa exports approximately 30,000 t of sorghum grain to the milling industry in Botswana.

In Zimbabwe, approximately 20,000 t of sorghum are annually used in the opaque beer brewing industry, and smaller quantities in the animal feed and milling industries. However, rising maize prices have encouraged strong interest in expanded utilization.

Commercial utilization of pearl millet is negligible in both countries. Millers in Namibia have attempted to commercialize the production of pearl millet meal, though quantities remain small. Approximately 300 t of pearl millet is used in the brewing industry in Zimbabwe.

The contributions of sorghum and pearl millet to household food security, and the commercial prospects for these grains, depend on improvements in yield. Sorghum yields across the SADC region averaged only 0.8 t ha^{-1} during the 1995-97 period, compared to 2.1 t ha^{-1} in the more commercialized South African production system. Pearl millet yields average even less than those of sorghum: only 0.6 t ha^{-1} over the 1995-97 period, across the region as a whole.

Despite the release of more than 26 new varieties of sorghum and 15 new varieties of pearl millet over the past 12 years, improvements in average grain yields are negligible. This is partly because the new varieties derived from national breeding programs have not been widely distributed to farmers. Adoption rates (SADC, excluding South Africa) average about 18%. In addition, most small-scale farmers still apply traditional management practices. The use of inorganic fertilizer on sorghum and pearl millet remains rare, except on large-scale farms. Only a minority of small-scale farmers use organic manure. Yet soil quality is declining as farmers mine a shrinking land base.

In order to more directly stimulate productivity gains, the fourth phase of the SMIP project (1999-2003) concentrates greater attention on promoting the adoption of new seed and crop management technologies. The project is encouraging experimentation with alternative seed supply strategies. In addition, attention has been directed toward diagnosing constraints to the commercialization of these crops, and working with industry to resolve these constraints. Higher industrial demand for sorghum and pearl millet will improve incentives both to expand production area and invest in improved crop management.

Sorghum and pearl millet will remain essential food security crops in southern Africa for decades to come. These grains will continue to ensure that few households face starvation, even in years of serious drought. However, the prospects for technological change will largely depend on the competitiveness of these crops in commercial food and feed systems.

Table 1. Sorghum and pearl millet production area in SADC, 1995-97 average

	Sorghum			Pearl millet		
	Area ('000 ha)	Yield (t ha^{-1})	Production ('000 t)	Area ('000 ha)	Yield (t ha^{-1})	Production ('000 t)
Angola	82.6	na	37.5	66.1	0.5	30.0
Botswana	150.0	0.2	36.7	9.3	0.3	2.7
Dem. Republic of Congo	80.0	0.6	50.0	42 0	0.6	25.8
Lesotho	17.7	1.0	16.8	0.0	-	0.0
Malawi	74.7	0.7	53.2	13.8	0.6	7.8
Mauritius	0.0	-	0.0	0.0	-	0.0
Mozambique	439.8	0.5	235.5	69.9	0.4	30.4
Namibia	34.6	0.2	7.3	269.8	0.2	66.9
South Africa	172.5	2.1	356.9	21.0	0.6	13.0
Swaziland	2.0	0.7	1.5	0.0	-	0.0
Tanzania	683.2	0.9	648.6	263.3	1.0	255.7
Zambia	44.4	0.5	31.0	30.8	0.3	22.7
Zimbabwe	174.9	0.5	80.7	186.7	0.6	59.4
SADC total	1956.5	0.8	1555.6	906.7	0.6	514.5

na = not available.

Source: FAO Production Yearbook.

Successful commercialization will depend both on the availability of relevant production technology as well as efforts to encourage investment in applying these technologies to increase grain deliveries targeting particular end uses. There is ample evidence that sorghum and pearl millet can compete successfully with maize in the global coarse grains economy. The development of stronger links between technology supply and market development remains the main challenge for commercialization of these crops in southern Africa.

Sorghum and Millets in Zimbabwe—Production, Constraints, and Current Research

L T Mpofu (Sorghum and Millets Programme, Department of Research and Specialist Services, Matopos Research Station, Private Bag K 5137, Bulawayo, Zimbabwe)

Sorghum, pearl millet, and finger millet are generally grown in semi-arid environments because of their drought tolerance. In Zimbabwe, these crops are staple foods for most rural households in the low-rainfall (450 to 650 mm) agroecological regions III, IV, and V. These regions, which constitute over 70% of Zimbabwe, are drought-prone and characterised by high temperatures and poor soils. Yet smallholder farmers in these regions prefer to grow and eat maize despite its frequent failure due to drought Consequently, frequent food shortages occur, with farmers having to rely on drought relief food.

Yields of sorghum and millets on smallholder farms in Zimbabwe are generally low, barely reaching 500 kg ha^{-1}. This is largely because smallholder farmers continue to grow local landrace varieties characterised by low grain yields, tall plants, lodging, disease susceptibility, and late maturity. Apart from low production and productivity, lack of appropriate storage and processing technologies are additional constraints. Previous agricultural policies encouraged production of maize for export. Crop improvement programs, development of trading and grain processing infrastructure, were all built around maize. This encouraged reliance on maize as a source of food and cash. But if similar efforts had been invested on sorghum and millets, these crops would have remained staples today, ensuring household food security in Zimbabwe's semi-arid areas.

Currently there are four sorghum, three pearl millet, and two finger millet improved open-pollinated varieties available in Zimbabwe (Table 1). The sorghum varieties were all selected and released by the national Sorghum and Millets Research Program of the Department of Research and Specialist Services (DR&SS). The SADC/ICRISAT Sorghum and Millet Improvement Program provided exotic germplasm to the national program, assisting in the development and release of some of these varieties.

Improved varieties can outyield traditional varieties in semi-arid environments, by virtue of being short-statured and early maturing. These varieties are also resistant to major diseases: head blast in finger millet; leaf blight, head smut, and downy mildew in sorghum; and ergot in both sorghum and pearl millet. In Zimbabwe, pearl and finger millets are not affected by pests as much as sorghum is. Major pests include stemborers, armyworm, shootfly, armored cricket, and nematodes. Witchweed *(Striga asiatica)* is also of significant importance in sorghum and finger millet

At the moment, adoption of these improved varieties is poor. There are several reasons for this, including inadequate seed production and delivery systems for small grains, an unpredictable grain market, and lack of appropriate processing technologies like threshers and milling machines. The national program, in partnership with other research organizations, is currently engaged in activities to resolve these problems.

Table 1. Improved varieties released in Zimbabwe

	Variety	Year of release	Characteristics
Sorghum	SV 1	1987	Medium maturity, high yield
	SV 2	1987	Good milling quality, high yield
	SV 3	1998	Medium maturity, tolerant of *Striga*
	SV 4	1998	Late maturity, high yield potential
Pearl millet	FMV 1	1987	Dwarf, high tillering, early maturity
	PMV 2	1992	Intermediate height, dark gray seed, early maturity
	PMV 3	1998	Creamy white bold grain, good for composite flour
Finger millet	FMV 1	1992	Early maturity, high yield
	FMV 2	1992	Late maturity, high yield

Sorghum Hybrids from Varieties

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Introduction

Resource-limited farmers in South Africa and elsewhere do not grow sorghum hybrids largely due to high seed costs and unfamiliarity with hybrids. Hybrids have two advantages. They produce a higher yield than the parents and are usually more tolerant of biotic and abiotic-stresses. When commercial farmers changed from open-pollinated varieties to hybrids during the 1970s, the average yield increased from 1 to 2 t ha^{-1} (Abstract Agricultural Statistics 1997). A similar increase in yield can be predicted under low-input farming, e.g., by smallholder farmers. The present study was conducted in order to investigate the usefulness of hybrids developed from known varieties.

Material and methods

In order to produce hybrid seed, varieties were used to pollinate ears of four A-lines, SA 896, SA 1275, SA 1559, and SA 2436. The varieties were obtained from different sources: some had been evaluated for the Sorghum and Millet Improvement Program (SMIP), others developed at the ARC-Grain Crops Institute, and some obtained from the GCI-National University of Lesotho collaborative program. The hybrids and the parental varieties were sown in separate trials using randomized block designs with three replications. Plots were 4.5 m long and spaced 1.2 m apart. Weeds and pests were controlled with registered herbicides (Ramrod, Sorgomil, Basagran) and insecticides (Decis, Thiodan, Metasystox) when needed. The trials were fertilized at a rate of 150 kg ha^{-1} with 3:2:1 containing 12.5% N, 8.3% P, 4.2% K, and 0.5% Zn. In order to eliminate bird damage effects, 10 ears per plot were bagged. These ears were harvested and the mean ear yield calculated. Plot yield was estimated by multiplying mean ear yield by total number of ears per plot. Heterosis was determined as $(X_h/X_v)-1$, where X_h and X_v were the mean yields of hybrids and varieties. Forty-eight hybrids and varieties were evaluated during the 1996/97 season and 27 different hybrids and varieties during the 1997/98 season. The commercial hybrid SNK 3640 was used as a control.

Results and discussions

Varieties and hybrids were chosen that outyieldcd the control and exhibited heterosis = 1, i.e., varieties whose hybrids yielded twice as much as the parent variety (Tables 1 and 2). A total of 17 and 13 different varieties were selected in the two seasons for their own superior yield, the high yield of their hybrids, and their combining ability. Three varieties, SA 3744, SDSL 89566, and SDSR

Tablel. Varieties selected during 1996/97 for superior grain yield (>3.3 t ha^{-1}) and heterosis

Variety yield	Hybrid yield	Heterosis
P 898012	IS 12447	IS 12447
ICSV 219	SDS 3472	SA 3875
SA 3744	PFRCIE 69391	Macia
SA 3984	SA 3744	Larsvyt 58-85
SA 4089	SA 3875	R 8602
SDSL 89566	Larsvyt 58-85	
SDSL 87046	SDSL 89566	
SDSL 89426	SDSL 89426	
SDSR 9105	SDSL 91050	
SDSR 91052		
R 8602		

Table 2. Varieties selected during 1997/98 for superior grain yield (>5 t ha^{-1} for hybrids, >4 t ha^{-1} for varieties) and heterosis

Variety yield	Hybrid yield	Heterosis
E 102-B	ZSV 3	Early Kalo (Hungary)
SA 2254	WSU 387	ZSV 3
ZSV 3	MSU 549	91 MK-7014
WSU 387	91 MK-7014	SA 3761
SA 3761	SA 3761	SA 3981
SA 3977	MF 652	
Larsvyt 19	91 MW-7013	
	SA 3977	
	SA 3981	

91052, exhibited superiority in each characteristic during the 1996/97 season and four, ZSV 3, WSU 387, SA 3761, and SA 3977, during the 1997/98 season (Tables 1 and 2). The superior combining ability of these varieties may have resulted from their possible distant relationship to the commercial A-lines involved. Some of the varieties exhibited a superior yield on their own. Varieties IS 12447, SDS 3472, SA 3477, SDSL 89426, SDSR 91052, and Macia have a tan plant color, a high degree of grain mold resistance, and superior milling quality. These varieties were tested in one season only and should be evaluated again at different locations and seasons.

Improvement of the Protein Quality of Sorghum and its Introduction into Staple Food Products for Southern and Eastern Africa

J R N Taylor (Head, Dept of Food Science, University of Pretoria, Pretoria 0002, South Africa)

Sorghum is a drought-tolerant indigenous crop of Africa and as such plays a significant role in the food security of the rural populations of southern and eastern Africa. Unfortunately, sorghum proteins are thought to be less digestible than those of other cereals. Certainly on cooking there is a well documented fall in in vitro protein digestibility of sorghum which does not happen in maize, which in all other respects is a very similar grain to sorghum.

The aims of this 3-year project (1996-99) were:

- To quantify and attempt to identify the factors adversely affecting the digestibility of sorghum proteins.
- To quantify and identify how the simple traditional technologies of malting and fermentation affect the protein digestibility of sorghum.
- To attempt to improve the protein quality of sorghum by the use of these simple technologies.
- To incorporate the improved material into composite breads and instant weaning foods.
- By dissemination of the results of the project, attempt to improve the nutritional and economic status of people in sub-Saharan Africa.

The European Union funded project (EU INCO-DR contract IC 12-CT96-0051) brought together six partners, two from Europe and four from Africa, with widely differing areas of expertise. The coordinator was Prof P.S. Belton, Institute of Food Research, Norwich, UK, expert in protein functionality and NMR. The other partners were Dr J. Dewer, CSIR, Pretoria, South Africa (malting), Mr L.A.M. Pelembe (legume/cereal composites), and Ms L.F. Hugo, Eduardo Mondlane University, Mozambique (composite breads), Mr S.M. Wambugu, Kenya Industrial Research and Development Institute (KIRDI), Kenya (weaning foods), Dr 1. Delgadillo, University of Aveiro, Portugal (protein separation, FTIR), and Prof J.R.N. Taylor, University of Pretoria, South Africa (fermentation, protein bodies, sensory evaluation). All the African partners were based in Pretoria for the major part of the project, sharing equipment and expertise of both the University of Pretoria and the CSIR. Annual project meetings, training sessions, and frequent e-mails allowed the European partners to make their contributions known to all.

The goals of the project have largely been achieved. Some insight has been gained into changes in the sorghum protein structure on cooking and how this may effect the in vitro digestibility of the sorghum proteins. Conditions of malting and fermentation have been optimized to maximize the improvement in in vitro protein digestibility brought about by these simple technologies. Wheat/sorghum composite breads using 30% inclusion of either fermented material or malt have been successfully produced and have higher in vitro protein digestibility than composite bread made with untreated sorghum. Instant weaning foods containing sorghum malt, fermented sorghum, or a mixture of the two, have been produced by extrusion; and the fermented and mixture have higher in vitro protein digestibility than weaning foods made from untreated sorghum. Sensory evaluation of these products has been carried out, initially in South Africa and then in Mozambique for composite breads and Kenya for instant weaning foods. Handbooks have been produced, describing the production of sorghum malt and fermented sorghum in simple terms and how to use these products as ingredients for the preparation of composite breads and instant weaning foods. The handbooks are available in English and Portuguese and intended for use by community leaders, entrepreneurs, business and other interested parties. The end of the project was marked by two successful dissemination workshops in Jun/Jul 1999, held in order to make public the findings of the project. The workshops were held at the CSIR, South Africa, and KIRDI, Kenya.

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How Much Trouble Would a Farmer Take to Preserve Seed?

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Pearl millet is the major cereal crop in Namibia,, accounting for approximately 51% of total cereal production and 25% of calorie consumption. High-yielding large-seeded varieties have been released, but farmers have commented that the new varieties are also more susceptible to storage pests. Therefore we attempted to obtain information from farmers as to how they handle storage pests. The following information on indigenous methods of preserving pearl millet and sorghum seed was collected from Namibian farmers during a workshop on Farmer Participation in Pearl Millet Breeding and Farmer-based Seed Production Systems (Heinrich 1998).

Ash method. The seed is placed in a handling basket and ash is poured over the seed. The seed is then thoroughly mixed with the ash until it is coated with gray. The storage container (small granary or clay pot) is then selected, some amount of ash is poured into the container, the seed is poured in, and finally an even layer of ash is spread over the seed. The container is sealed with clay soil and placed in sunlight, from where it is removed only when rain is expected. The container is also placed over stones or wooden sticks—not on the ground—to protect it against soil moisture.

Mopane/bitter bush leaf method. Fresh leaves of the mopane tree or bitter bush are placed in the storage container. When the leaves are completely dry, one half is removed and seed is poured into the container. The remaining half of leaves is then spread over the seed and the container is sealed and placed in the sun as in the first method. Farmers explained that the heat of the sun causes the leaves to release a chemical with a bitter smell, thus preventing or reducing invasion by storage pests.

***Omuhongo* chopped piece method.** *Omuhongo* is a hardwood tree; the wood has a particular smell which is unpleasant to storage pests. This method works in the same way as the mopane leaf method, only that here the dry wood is chopped into small pieces, which are then mixed with the seed.

Fire smoke method. This method is used for cowpea seed only. Selected dry cowpea pods are tied in bunches and hung in a 'fire hut' such that they are continuously exposed to smoke. After some days, the pod becomes coated with dust from the smoke, which prevents beetles and other storage pests from entering the pods. Pods are removed from the fire hut and shelled only at sowing time.

Recently developed methods. Two other methods were also reported by farmers, and are believed to be used in some areas:

Hot chilly powder method (for legume seed). Hot chillies are ground into powder and the powder is thoroughly mixed with clean legume seed. The seed is put into a bottle or tin, which is then closed and vigorously shaken to ensure proper mixing. This bottle or tin can be stored under the roof eaves of the house.

Industrially manufactured fencing poles. Treated fencing poles from the industry are chopped into small pieces, which are then used to preserve seed (see *Omuhongo* method).

At sowing, the selected and preserved seed is the first to be sown. The most fertile parts of the land or field are sown first, followed by the poorer parts. If the selected seed is insufficient to cover the whole field, the remaining portion of the field is sown with unselected, "untreated" seed.

Who says farmers do not know the value of seed?

Reference

Heinrich, G. M. 1998. Proceedings of the workshop on farmer participation in pearl millet breeding and farmer-based seed production systems in Namibia, 23-27 Mar 1998, Oshakati. Namibia. PO Box 776, Bulawayo. Zimbabwe: SADC/ICRISAT Sorghum and Millet Improvement Program.

Vol. 2, No. 1 (Jul 2000)

Sorghum Variety Macia Released in Tanzania

The improved sorghum variety Macia (SDS 3220) was released on 14 Dec 1999 by the Tanzania National Variety Release Committee. Macia is a high-yielding, early-maturing, white-grained variety developed jointly by ICRISAT and national scientists in southern Africa. It has so far been released in five SADC countries—Mozambique, Botswana (under the name Phofu), Zimbabwe, Namibia, and now Tanzania. It is suitable for areas with a growing season of 3-4 months.

Macia was developed by mass selection in the F_4 generation from material originally developed at ICRISAT-Patancheru (India). The new line, indexed as SDS 3220, was selected by breeders at the SADC/ ICRISAT Sorghum and Millet Improvement Program (SMIP) in 1984/85. A series of preliminary and advanced trials at SMIP demonstrated its potential, after which SDS 3220 was evaluated in collaborative trials at multiple locations across the region between 1988/89 and 1990/91. It then underwent multilocational testing in Tanzania for three seasons—1991/92 (7 sites), 92/93 (5 sites), and 93/94 (2 sites). Grain yields of Macia in these trials were 15% higher than those of two released, improved varieties, Pato and Tegemeo. In on-farm trials conducted in northern Tanzania, Macia gave yields comparable to or better than Pato and Tegemeo.

The new variety has several other advantages. It has large heads and a high degree of uniformity. It matures earlier than other improved varieties, and is thus less susceptible to terminal drought. Plants are short, making bird scaring easier. It is also a multipurpose variety, suitable for food, fodder, and other uses.

A smallholder farmer in Tanzania, one of the early adopters of Macia

Macia has white, medium-sized grains, a thin pericarp, and a white pearly endosperm. It produces white flour, which is universally preferred throughout the region. Farmer-participatory assessments have confirmed the grain quality characteristics of the variety and its potential for widespread adoption. Macia also has the potential for improving fodder supplies—it has broad leaves that stay green even after maturity, a key advantage in mixed crop-livestock systems. Analytical laboratory tests by SMIP have shown that Macia has a high SDU value (Sorghum Diastatic Unit), indicating its suitability for malting. Current efforts in the five countries where it has been released are geared towards sustainable production and distribution of seed to farmers.

Sorghum Ergot—a Sticky Disease Problem in Southern Africa

D E Frederickson (INTSORMIL Pathologist, SADC/ICRISAT Sorghum and Millet Improvement Program, PO Box 776, Bulawayo, Zimbabwe)

Ergot disease of sorghum is not new to Africa - the causal pathogen, *Claviceps africana* Frederickson, Mantle, and de Milliano was first recorded in Kenya as far back as 1923. However, ergot disease only began to gain recognition as a potential problem in sorghum production in the 1960s, when all the A-lines in Nigeria's national breeding program became infected, to the near complete exclusion of seed production (Futrell and Webster 1965).

The pathogen has now been recorded in every sorghum-growing country on the continent. By 1997, when it had reached the Americas, Australia, and the USA, ergot disease had gained notoriety as the major biotic constraint to sorghum production globally (Bandyopadhyay et al. 1998). Ergot causes annual losses of 12-25% and 60% in hybrid seed production in Zimbabwe and South Africa respectively.

The pathogen, *Claviceps africana,* is a fungus that specifically targets the sorghum ovary. The spores, or conidia, germinate on the stigma and the germ tubes track down the ovary wall to the distal nutrient supply. Once the fungus has access to this sugar-rich nutrient source there is enormous proliferation of hyphae and almost complete destruction of the ovary to form the soft, white, globose body or sphacelium. The sphacelium produces millions more conidia in a sticky exudate called honeydew. Conidia represent the asexual form of the fungus, enabling rapid clonal propagation during the sorghum growing season. Honeydew droplets may collect on the tips of infected florets or may drip to smear the whole panicle or drip onto the leaves or soil.

Under conditions of high relative humidity, the honeydew turns from clear or brown throughout to superficially white. Here the first-formed primary or macroconidia germinate to form secondary conidia which, unlike macroconidia, are windborne. Secondary conidia are crucial to the pathogen for rapid disease increase to epidemic proportions, and for spread over moderate distances of tens to hundreds of kilometers (Frederickson et al. 1989, 1993).

Towards the end of the sorghum growing season, the ergot pathogen ceases spore production and may form a more resilient type of tissue adjacent to the sphacelium. For *Claviceps* species in general, this sclerotial tissue enables pathogen survival and perennation from one season to the next.

In Africa, where an alternate host with a role in perennation has yet to be found, *C. africana* sclerotia may possibly assume this role by germination to produce the sexual stage. However, conidia in crop residues contaminated with sphacelia/sclerotia may also assume that function. Thus inoculum may possibly be seedborne by one or both routes.

There are no ergot-resistant sorghum genotypes anywhere in the world. Pollen and pathogen take the identical route into the ovary and any biochemical or mechanical stigmatic or gynoecial exclusion mechanism probably has mutual consequences: no ergot but no seed! Fertilization of the ovary precludes infection, so varieties with good fertility tend to "escape" ergot most of the time; and in evolutionary terms, no other "resistance" mechanism has probably ever been necessary.

It is obvious, therefore, that male-sterile A-lines in hybrid seed production are at greatest risk. All ovaries of all sorghums are potentially susceptible, however, depending upon environment. Cold nights (temperatures below 12°C) at pollen microsporogenesis, inducing pollen sterility, lead ubiquitously to reduced fertility and increased ergot severity (McLaren and Wehner 1992). Selecting varieties, hybrids, and their parents with cold-tolerance has had some success in minimizing ergot severity. However, rainfall or high RH at anthesis will have an overriding influence, because these factors disrupt pollen-shed, deposition and germination, and simultaneously induce secondary conidiation, splash dispersal, and favor germination of pathogen spores.

Screening for cold-tolerance in sorghum is clearly one good strategy to reduce ergot. Few other methods are currently available. Early planting, which in Zimbabwe means before the end of December, reduces the risk of ergot, in part by avoiding flowering around the time of lowered night temperatures.

The protection of valuable germplasm by the application of triazole fungicides at heading may occasionally be warranted in seed production but severely reduces the already slim profit margins.

The reason for the lack of alternative control strategies is that there are wide gaps in our knowledge of the life-cycle and biology of the pathogen. The INTSORMIL (International Sorghum/Millet Collaborative Research Support Program) project, networking with other scientists in the region and globally, focuses primarily on the very important question of inoculum mentioned earlier. The key question is:

What is the source of initial inoculum each season (e.g. honeydew, conidia, sphacelia, sclerotia)? To answer this question requires research in the following areas:

- The effect of environment on the survival of macroconidia in honeydew, in sphacelia/sclerotia, and on the survival of secondary conidia
- Formation, survival, and germination of sclerotia to produce ascospores (sexual reproduction)
- How frequently does sexual reproduction occur in nature; how much variability does the pathogen exhibit in Zimbabwe and regionally[1] ?

Answers to these questions will help us target the critical stages of the life-cycle of C. *africana,* enabling us to formulate new strategies and integrate multiple strategies for better control of ergot on all sorghum genotypes.

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Dr Frederickson is very keen to network with anyone in the region with an interest in sorghum ergot, or who would be able to provide samples from their country.

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Progress in SMIP Intermediate Result 1.2, Increasing Productivity

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Introduction

Research in Phase IV of the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP) is structured under four broad objectives, or Intermediate Results (IRs) —development and dissemination of improved varieties; improvements in crop management and productivity; partnership building and networking; and development of market systems for commercialization of sorghum and pearl millet. The second IR in this list (IR 1.2) relates to: "Farmers in targeted areas using a wider range of crop management options, leading to improved productivity."

This work focuses primarily on the adoption of improved soil fertility and soil water management technology by smallholder farmers. Progress will be evaluated in terms of the level of adoption of improved production technologies by farmers in specified target areas in Zimbabwe and Tanzania.

The work in IR 1.2 is linked to the other SMIP work on seed systems, marketing and commercialization, and regional networking. Improved markets provide incentives for farmers to adopt both improved varieties and improved crop management practices. Combining improved varieties with improved management practices ensures that farmers are able to capitalize on the increased production potential of the new varieties, and provide a consistent supply to developing markets. SMIP scientists and partners work together to ensure that activities under the different IRs are implemented in the same geographical areas, and experiences gained are shared through the regional network. SMINET.

This article provides an update on progress on IR 1.2, as outlined in the SMIP Project Document (pages 24-29).

Activities and progress

Following the SMIP Phase IV Document, IR 1.2 activities were planned for Tanzania and Zimbabwe. Three main activities were scheduled for the first year—literature reviews, baseline surveys, and identification of at least five promising technology options for participatory on-farm evaluation in target areas.

Literature reviews covering past research on soil fertility and soil water management, as well as current extension recommendations and adoption levels, were conducted by partners in both Tanzania and Zimbabwe.

In Tanzania, the review was led by Dr George Ley, based at the national soil research institute, Mlingano. In Zimbabwe, the work was led by scientists at the University of Zimbabwe: P. Mapfumo, E. Chuma, and K. Giller. The FAO Regional Office for Southern Africa contributed both financially and technically to the review in Zimbabwe. The literature reviews for both countries have been completed and will be published in the next few months.

Baseline surveys were necessary both to assess farmers' current practices and constraints and to provide a baseline against which future adoption of innovations could be measured.

In Tanzania, a baseline survey was conducted in Same district in the Northern Zone, in Aug and Sep 1999. Due to a series of unforeseen constraints, data analysis has been delayed. However, data entry and verification has now been finalized, and the analysis should be completed fairly soon. Also, since the scientists who implemented the survey were directly involved in setting up the subsequent on-farm research program, much of the information gained has been utilized. Since the implementation of this first survey, an additional target area in Dodoma district has been identified. It is likely that a second baseline survey for Dodoma will be required.

In Zimbabwe, baseline surveys were conducted in the first quarter of 1999. This work was led by Dr David Rohrbach of ICRISAT. The surveys were conducted in two districts, Tsholotsho and Gwanda South. Tsholotsho district lies in a 400-600 mm rainfall zone, while Gwanda South normally receives around 400 mm or less. Data from these surveys have been analyzed. An initial report has been drafted, and will be published before the next cropping season.

Identification of promising technologies for on-farm participatory evaluation was based on the outputs from the literature reviews, baseline surveys, and discussions with scientists, extension workers, and farmers. In **Tanzania,** technologies identified included: sorghum/ pigeonpea inter-cropping, legume rotations (pigeonpea, groundnut, and *Dolichos lablab*) to improve soil fertility, and the use of farmyard manure (FYM). In future, work on the management of FYM (to increase both quantity and quality) and combinations of organic and inorganic fertilizers may be added to the program.

Pigeonpea has a ready market, and a high market value, in Tanzania. It can contribute significantly to maintaining and improving soil fertility, as well as improving household nutrition and income. However, medium-duration varieties adapted to the semi-arid areas have not yet been clearly identified and released, and sorghum/pigeonpea intercropping systems have received little attention. Current work focuses on identifying appropriate varieties and cropping systems.

On-farm participatory research was initiated in the 1999/2000 cropping season. It is being implemented by scientists from the Department of Research and Development, in collaboration with extension staff. Due to a late start to the rainy season, and limited planting opportunities, the program got off to a somewhat shaky start. Nonetheless, the trials have been implemented, and work is under way.

In **Zimbabwe,** technologies selected for on-farm research included: manage-ment and utilization of FYM, combina-tions of FYM and inorganic nitrogen, legume rotations (cowpea, groundnut, bambaranut), and the use of modified tied ridges for water conservation. The use of dead-level contours and infiltration pits may be added as additional water management options.

The work was initiated, in a limited way, in the 1998/99 season and considerably expanded in 1999/2000. It is being implemented by SMIP and ICRISAT, in collaboration with several partners—the Department of Research and Specialist Services (DR&SS), AGRITEX (extension), TSBF (Tropical Soil Biology and Fertility), DFID (Department for International Development, UK), and the Intermediate Technology Development Group (ITDG). Due to unusually high rainfall in western Zimbabwe, the trials have been very productive this year. The response from farmers involved in the technology evaluation has been very positive.

Conclusions

The activities planned for IR 1.2 have been largely implemented on schedule, and work is progressing well. Publication of some of the outputs has been unfortunately delayed, but these should become available in due course.

The future

In Tanzania, there appears to be considerable potential for improving soil fertility and farm incomes by including appropriate pigeonpea varieties in semi-arid production systems. Both farmers and institutional partners are very enthusiastic about the possibilities. Since market-acceptable medium-duration varieties are available for on-farm testing, it is hoped this work can progress rapidly.

In Zimbabwe, farmers have responded positively to technologies for the management and use of FYM. In the higher-rainfall areas, the combination of organic and inorganic fertilizer is also popular. Tests have shown that improved water management systems are practical under smallholder conditions. Plans are currently being made with DR&SS and AGRITEX to test methods of stimulating broad adoption of the most popular technology options in the coming season.

Performance of the Sorghum Variety Macia in Multiple Environments in Tanzania

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Introduction

Sorghum is grown in six out of seven zones in Tanzania. It is produced mainly for home consumption and is a key factor in household food security, particularly in marginal areas with low rainfall and poor soil fertility. Collaboration between the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP) and the National Sorghum and Millet Improvement Program (NSMIP) was initiated in the early 1980s and has been instrumental in the development, selection, and release of improved varieties. This article summarizes information about the development and testing of the recently released sorghum variety Macia (SDS 3220), including comparisons with two released varieties, Pato (SDS 2293-6) and Tegemeo (2KX 17/B/I); and an improved, Zimbabwe release SV 1.

On-station and on-farm trials

SDS 3220 was developed at SMIP's Matopos Research Station in Zimbabwe through mass selection in the F_4 generation from M91057 (pedigree [GPR 148 x E35-1] x CS 3541) introduced from ICRISAT-Patancheru, India.

SDS 3220 was found promising, and then tested in preliminary and advanced SMIP trials, which further confirmed its potential. It was then evaluated in regional collaborative trials between 1988/89 and 1990/91, and subsequently in on-station multi-locational national variety trials for three seasons: 1991/92 (7 sites), 92/93 (5 sites), and 93/94 (2 sites). The test sites covered almost all the important sorghum-producing regions in Tanzania.

This was followed by on-farm, farmer-managed trials conducted for three seasons in two drought-prone districts in northern Tanzania—Same district in 1994/95 and 95/96, and Mwanga district in 97/98. Several improved sorghum lines were evaluated for agronomic as well as grain characteristics.

Results from on-station and on-farm trials

All data obtained from randomized and replicated variety trials in which SDS 3220 (Macia) was included as a test entry, were analyzed for location and year/season effects using the ANOVA method.

Data from on-station trials were pooled across locations (Table 1). Significant differences were observed among entries in the 1991/92 season, with SV 1 giving the highest yield of 3.6 t ha^{-1}. Grain yields of Macia were not significantly different from those of SV 1 and Pato. The entries did not differ significantly in 92/93 and 93/94. The latter season was very good, with high mean yields (Table 1). Generally, Macia was shorter in stature and flowered earlier than the other entries. Farmers prefer short-statured varieties as this makes bird-scaring easier. The earliness allows the variety to escape terminal drought.

Table 1. Performance of sorghum lines in on-station trials, Tanzania, 1991/92 to 1993/94. Data pooled across 14 locations

Entry	Days to 50% flowering	Plant height (cm)	Grain yield (t ha^{-1})		
			91/92	92/93	93/94
Macia	65	129.7	3.1	1.5	4.6
Pato	69	175.3	3.3	1.6	4.4
Tegemeo	67	119.5	1.9	1.2	4.2
SV 1	68	152.3	3.6	1.4	3.9
Trial mean [1]	67	147.4	3.0	1.4	3.7
LSD 0.01			0.6	ns	ns
CV (%)			25.1	na	na

1. Includes all entries tested in that year's trial, na = data not available, ns = not significantly different.

Similar observations on plant height and earliness were made from on-farm trials (Table 2). However, grain yield data from on-farm trials were not conclusive. In the 95/96 season, Pato yields were significantly higher than those of SV 1, but not different from Macia and Tegemeo. In 97/98, there were no significant yield differences between entries, but yields were generally high (>4.0 t ha^{-1}), indicating a good season and the high yield potentials of the improved varieties.

Table 2. Performance of sorghum lines in on-farm trials, Same and Mwanga districts, northern Tanzania [1].

Entry	Days to 50% flowering	Plant height (cm)	Grain yield (t ha^{-1})		
			94/95	95/96	97/98
Macia	64	131	na	1.50	4.16
SV 1	70	153	2.76	1.35	4.03
Pato	68	173	2.27	1.99	4.26
Tegemeo	67	na	2.03	1.92	na
Trial mean	68	152	2.38	1.69	4.15
LSD 0.01			ns	0.58	ns
CV (%)			11.6	22.3	10.0

na = data not available, ns = not significantly different
1. Same district in 1994/95 and 95/96, Mwanga district in 97/98.

Grain quality characteristics

Laboratory tests were carried out at the SMIP food technology facilities in Matopos to complement the field trials, and provide data on grain quality and thus on possible end uses of the varieties (e.g. in the food processing and malting industries). This information is valuable for the testing and selection program. Macia, Pato, and Tegemeo, which were then being tested on-farm in Tanzania, were analyzed for a total of 15 physical and physico-chemical traits (Tahle 3).

Macia has a thin pericarp (similar to Pato), whiter grains (75.3 Agtron reading versus 74.5 for Pato), and a white pearly endosperm. This indicates that Macia is a superior food type cultivar that is likely to meet farmers' preferences. Macia also has a higher SDU value (Sorghum Diastatic Units), indicating its suitability for malting.

Table 3. Grain quality evaluation of sorghum cultivars from Tanzania

Characteristic	Cultivars: Macia	Pato	Tegemeo
Grain color	White	Cream/ yellow white mottled	Creamy white
Pericarp	Thin	Thin	Thick
Testa	Absent	Absent	Absent
Endosperm color	White	White	White
Endosperm texture	Pearly	Inter- mediate	Pearly
Size fractions (%)			
Large	0.26	80.54	46.45
Medium	99.27	19.44	53.33
Small	0.38	0.00	0.17
100-kernel mass (g)	1.68	3.56	2. 18
Grain hardness (visual)	3.6	3.4	3.4
Milling yield (%)	81.60	87.00	83.60
Dehulling loss (%)	15.20	7.23	11.05
Floaters (%)	22	23	15
Water absorption (%)	14.30	4.0	8.2
Tannin content (= %CE)	0.00	0.00	0.00
Dry Agtron reading	75.3	74.5	76.0
Wet Agtron reading	56.1	53.2	56.5
SDU	42.60	28.76	20.12

Size fractions: Large = >2.6 mm, Medium = 1.7-2.6 mm, Small = <1.7 mm

Visual hardness rated on 1-5 scale: 1 = very soft, 5 = very hard.

Processing and utilization traits: farmer evaluation

In Oct 1997, Pato and Macia were evaluated for processing and utilization traits by 26 farmers (22 women, 4 men) from Kwakoa-Mwanga district in northern Tanzania. The farmers evaluated grain size and color, processing and cooking quality (Table 4).

The palatability, taste, and acceptability of food prepared from these two varieties was further evaluated by 81 women and 67 men who filled in a questionnaire after sampling the food. Macia was reported to have the acceptable white, large grains that produced white flour. The traditional foods like *makande.* porridge (*uji*), and stiff porridge (*ugali*) were of acceptable taste and appearance. Both sets of evaluations thus indicate that Macia, like Pato, will be readily accepted by farmers.

Table 4. Farmers' rating (26 farmers) of sorghum variety characteristics, 1997, Kwakoa-Mwanga district, northern Tanzania

	SV 1	Pato	Macia
Grain yield	3	4	5
Large grain size	3	5	4
Earliness	3	3	5
Disease resistance	2	2	2
Pest resistance	2	2	2
Stem strength	2	2	3
Large head size	2	3	5
Plant height (convenience for bird scaring)	2	3	5
Ease of dehulling	3	3	3
Flour color	3	3	3
Palatability/cooking quality	3	3	3
Storage pest resistance	2	2	2

Scored on a 1-5 scale, where 1= poor and 5 = excellent.

Conclusions

Macia is an early-maturing sorghum variety that was released in Tanzania in Dec 1999, targeted at semi-arid areas with a 3-4 month growing period. The variety has a number of useful characteristics—short plant height that is convenient for bird scaring, large head size, high yield, low dehulling losses, and good eating quality. Macia also has a staygreen characteristic and the residues are therefore suitable for feeding farm livestock. The recommended agronomic practices for Macia are similar to those for Tegemeo and Pato.

Variety Development and Seed Systems for Sorghum and Millets in Zimbabwe

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Introduction

The purpose of applied plant breeding is to develop better varieties. But the benefits of an improved variety cannot be realized until enough seed has been produced to allow the variety to be grown on a commercial scale over the entire area to which it is adapted. Zimbabwe (and many other countries) have therefore established procedures governing seed multiplication, quality control, and variety maintenance. These procedures cover three overlapping areas—breeding, certification, and commercial seed production. In Zimbabwe, the system works well for crops like maize, wheat, barley, tobacco, and horticultural crops. However, for sorghum, millets, and other crops of limited commercial interest, commercial seed production is very limited. As a result, farmers lack access to seed of improved varieties. This is of concern because these are the crops grown by smallholder farmers in marginal areas. The majority still use local landrace varieties that are characterized by late maturity, low yields, and disease susceptibility; and this contributes to widespread food insecurity in many rural areas.

Plant breeding

In the late 1960s the Department of Research and Specialist Services (DR&SS) of the Ministry of Lands and Agriculture established a sorghum and millets research program with a mandate to develop improved varieties and appropriate crop management practices. The pedigree breeding method is used for sorghum and finger millet improvement, and the synthetic variety method for pearl millet. Mutation breeding and genetic male-sterility methods are used to increase variation in finger millet. There is a strong hybrid development program for sorghum.

Breeding work on sorghum and millets is almost entirely a public-sector activity, with very little private sector participation. Two private firms, Seed Co. and Pannar Seeds, market sorghum varieties in Zimbabwe, but their research work is carried out by sister companies in South Africa. These companies tend to focus on red and brown sorghums with good brewing qualities, because the market for sorghum beer is very large and lucrative.

Variety release

Authority to release a new variety is ordinarily vested in the Variety Release Committee, comprising representatives from various organizations—Seed Services Department, DR&SS, extension, farmers' organizations, seed companies, and associations of commercial seed producers and millers. The breeder must present evidence that the new variety will prove useful in some specified area(s). Evidence must be based on performance under varied environmental conditions, with precise data from trials conducted both on-station and on-farm, in which the variety has been compared with standard varieties over a period of years at several locations. To date nine improved sorghum and millet varieties (4 sorghum, 3 pearl millet, and 2 finger millet) are available for commercial production in Zimbabwe.

Seed certification

The purpose of seed certification, according to the International Crop Improvement Association, is "... to maintain and make available to the public, through certification, high quality seeds and propagating materials of superior crop varieties so grown and distributed as to ensure genetic identity and genetic purity. Only those varieties that are approved by a State or Governmental agricultural experiment station and accepted by the certifying agency shall be eligible for certification." The certifying agency in Zimbabwe is the Seed Services Department. Seed certification is designed not only to maintain genetic purity of superior varieties, but also to set reasonable standards of seed quality and condition. Factors such as weed seeds, seedborne diseases, mechanical purity, viability, and other grading considerations are also important. There are four recognized classes of seed—Breeder, Foundation, Registered, and Certified seed.

Very little Certified seed of improved sorghum and millet varieties is available in the market. This is mainly because seed companies find it uneconomical to produce Certified seed of these crops, in turn because farmers tend to retain seed from their previous harvest. This implies that sales will be high only during the first one or two seasons after release, and dwindle thereafter.

Commercial seed production

The National Sorghum and Millets Research Program has been working with SMIP and other NGOs to solve the problem of seed nonavailability. The approach is to develop community-based seed production schemes that will operate in a manner similar to the contracts between seed companies and large-scale commercial maize seed growers. Community-based schemes envisage the development of contracts between seed companies and small-scale farmers or farmer groups. The farmer will produce pure, high-quality seed for the company, and the company will inspect the seed production plots to monitor quality, as they do with commercial farmers. Government and ICRISAT scientists have trained farmers on seed production techniques at the Matopos Research Station.

With adequate training, it is expected that very little seed will be rejected on the grounds of contamination if farmers follow the correct procedures.

Currently, such contract schemes are operational in communal lands in Chivi (seed of sorghum variety Macia) and Tsholotsho (pearl millet PMV 3). The seed companies involved are Pannar Seeds and Seed Co. Donor agencies (notably GTZ) and NGOs like the Organization of Rural Associations for Progress (ORAP), COMMUTEC, and the Intermediate Technology Development Group (ITDG) play a pivotal role in forming farmer groups to produce seed. The government extension service (AGRITEX) provides essential supervisory assistance and the benefits of their long-standing experience in working with farmers.

The primary source of seed is the Matopos Research Station, where both ICRISAT and the National Sorghum and Millets Research Program are based. Both institutions produce limited quantities of Foundation seed of released varieties (Table 1). This seed is sold to seed growers at cost, to keep the Foundation seed production scheme at Matopos running on a self-sustaining basis.

Table 1. Foundation seed production at Matopos Research Station

Variety	1997/98 season (kg)	1998/99 season (kg)
SV 1	-	295
SV 2	1200	883
SV 3	1020	354
SV 4	1400	2499
PMV 1	-	348
PMV 2	700	440
PMV 3	1200	113

This system of producing seed on-farm seems to be working very well and is self-sustaining. We aim to further encourage the development of such community-based schemes, until seed production is sufficient for national needs.

Constraints

A number of varieties have been developed by the national program, and are being tested at research stations. But very little testing is done on-farm, mainly because transport constraints prevent regular visits to on-farm sites. This is a serious constraint—scientists are unable to become fully familiar with the environments in which their varieties will be grown, and performance data from on-station trials are not always a good indicator of performance under "real" conditions. Assistance with transport to conduct on-farm testing will strengthen the national program's efforts and accelerate the process of getting improved varieties to farmers.

The way forward

With the available resources, the national program will continue to train smallholder farmers to grow seed on their own fields. This seems to be the best way to improve seed availability of improved varieties. The larger the number of trained farmers, the greater the availability of seed, and the better the adoption of any subsequent variety releases.

Commercialization of Sorghum Milling in Botswana

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During the past decade, commercial sorghum processing in Botswana has grown rapidly. In 1989, the country had 36 small-scale sorghum mills, most operating on a service basis, i.e. milling grain by the bucket or bag on behalf of individual consumers. By 1999, the number of small- and medium-scale sorghum mills had increased four-fold. The majority of these mills are now buying grain for processing and sale through local retail shops and supermarkets. The quantity of sorghum being commercially milled has increased from an estimated 17 000 t to 60 000 t over this same period. In consequence, the status of sorghum has changed from being a food security crop largely consumed in rural areas, to a commercial crop competing in the urban food market.

A SMIP study (Commercialization of Sorghum in Botswana: Trends and Prospects, in press) reviews the factors underlying the growth of the sorghum milling industry in Botswana, and the prospects for further market expansion. Four major factors underlie the growth. First, there is a widespread preference among domestic consumers for sorghum meal. The recent growth of the sorghum milling industry has allowed sorghum to compete with maize meal as a commercial food product. The simple availability of sorghum meal on the retail market, at a price little different from maize meal, has led to a decline in the growth of maize consumption and possibly a decline in absolute maize consumption levels.

Second, a grain dehulling and milling technology was readily available, and a local parastatal made strong efforts to encourage the use of this technology. This technology provided good quality meal despite variability in the quality of sorghum grain.

Third, the Government of Botswana provided the industry financial support, encouraging investment in new technology and expansion. Government grants sharply limited the risks faced by new entrepreneurs, allowed millers to learn their craft, and encouraged spillover effects on the manufacture of dehulling and milling equipment. Finally, the growth of the sorghum milling industry depended on the consistent availability of grain of acceptable quality, to keep mills functioning throughout the year. This grain is almost entirely imported from South Africa. Sorghum production in Botswana cannot compete with these imports, mainly because of low productivity. Sorghum yields in Botswana average less than 250 kg ha^{-1}. The returns to labor invested in sorghum production by the smallholder sector are generally lower than the rural wage rate. Production levels are highly variable and grain prices in the local market are high. It is therefore unlikely that domestic sorghum production will ever contribute more than a small share of industry requirements.

Many aspects of the Botswana case are unique, including the relative strength of consumer demand for sorghum meal, and the magnitude of government financial support for development of the industry. However, the stimulus created by linking technology, finance, and raw material supply is broadly replicable across the SADC region.

Vol. 2, No. 2 (Dec 2000)

Improved Pearl Millet Varieties Released in Mozambique

Three improved pearl millet varieties, SDMV 91018 (Kuphanjala 2), SDMV 90031 (Kuphanjala 1), and SDMV 89005 (Changara, Chokwe) were released in Mozambique by the National Variety Committee in March 2000. The varieties are recommended for all pearl millet growing ecologies of Mozambique, and are particularly well adapted to conditions in Zambezia, Nampula, and Tete Provinces. During trials, they outperformed local varieties by 30-50%.

SDMV 91018 was developed by SMIP at Matopos Research Station and at its Muzarabani off-season location in Zimbabwe, from 7 Nigerian progenies: P31125-2, P31231-5, P31149-5, P31141-3, P31120-11, P31161-3, and P31231-2. These constituent progenies were crossed in a diallele fashion during the 1987/88 season. During the 1989/90 season, equal proportions of the resultant crosses were space-planted at Muzarabani in isolation for random mating. Fifty single plants of similar height and time to maturity with good tillering ability were selected. Equal seed quantities from the populations were mixed and planted in isolation at Matopos during the 1990/91 season. The resulting variety, SDMV 91018, was promoted to regional collaborative trials and was First tested in Mozambique during the 1991/92 season.

SDMV 90031 was developed by SMIP at Matopos. It is a product of an intervarietal recombination (of all possible combinations including reciprocals) of progenies from 5 varieties: SDMV 89003, SDMV 89004, SDMV 89005, ICMV 88908, and SDPM 2264. Three of the constituent parents have been released in three SADC countries. SDMV 89004 was released in Zimbabwe as PMV 2, SDMV 89005 in Malawi as Tupatupa, and ICMV 88908 in Namibia as Okashana 1. Initial crosses to develop SDMV 90031 were made during the 1989/90 season. Equal proportions of each resultant cross were mixed to constitute a bulk. The bulk was space-planted in isolation during the 1990 off-season and selected for high tillering ability, and uniformity in time to maturity and height. Altogether 120 selected progenies were bulked to constitute SDMV 90031. This variety was first tested in regional collaborative trials, which included Mozambique, during the 1991/92 season.

SDMV 89005 was developed by SMIP at Matopos from ICMS 8359. The latter is one of six germplasm accessions identified by SMIP following multilocational evaluation of a wide range of germplasm materials introduced from different parts of the world, from 1984 to 1995.

SDMV 89005 was selected through Grid Mass Selection by random mating during 1986/87, 1987 off-season, and 1987/88. Selection was based on long heads (30-35 cm), compact panicles, high tillering ability (5-7 productive tillers per plant), and complete elimination of bristles. In the process, the time to maturity was delayed by about 1 week. The final selection of 150 plants was done during the 1988/89 season. These plants were separately randomly mated in an off-season nursery in 1989 to constitute the variety SDMV 89005. The new variety was released in Malawi as Tupatupa in 1996.

Schools for Seed: a New Approach in Tanzania

Shortage of seed is a major constraint to the adoption of improved sorghum and pearl millet varieties in Southern Africa. ICRISAT and its partners in Tanzania have come up with a new initiative, the schools-for-seed approach, to resolve this issue. Two ICRISAT scientists are involved — Dr Emmanuel Monyo, who is responsible for seed systems work under SMIP, and Dr Mary Mgonja, coordinator of SMINET.

The approach is based on the use of primary schools in rural communities as centers for multiplying and distributing (i.e., selling) seed of improved varieties. One hundred schools, each with more than 500 pupils, have been selected in two drought-prone districts (Dodoma and Singida) in central Tanzania to test the approach on a pilot scale. The selected schools have previously been involved in a school-feeding program initiated by the Christian Council of Tanzania (CCT) in response to a prolonged drought. With this past experience and the support from the seeds initiative, it is expected that participating schools will soon improve the availability of good quality, inexpensive seed of sorghum and pearl millet varieties released in the country, and enhance access to this seed by smallholder farmers in the vicinity of the schools. Teachers at the schools have been trained in seed production techniques, and each school has been provided with initial supplies of foundation seed of the sorghum variety Pato and pearl millet variety Okoa for multiplication. Each school has allocated at least 1 ha to the seed multiplication initiative.

Seed centers for tomorrow—rural primary schools will grow and distribute seed of improved varieties, enabling the surrounding communities to improve productivity and food security.

Activities to disseminate information on the schools-for-seed concept have also begun. Highlights include a field day organized in May 2000 to promote the concept more widely and facilitate its adoption in other districts of Tanzania and other countries in the region. The field day was hosted by the Regional Commissioner for Singida, Lt Colonel A Tarimo, and the District Executive Director, Mr A Mwegoha. It was attended by 31 participants including administrative and extension staff from 6 districts in Tanzania, and researchers and seed specialists from Malawi, Mozambique, and Botswana. The field day included a visit to 13 seed plots with a total area of 158 ha. These plots are expected to produce enough seed for 500-700 families.

The initiative is receiving considerable support from communities in the target areas. The success rate is estimated at about 60%, remarkably high for an operation in its first season. Public support is largely due to the fact that ownership of the project is vested in the communities. This is fostered through use of village administrative structures for planning and implementing project activities. Consequently, problems such as isolation distances (for example, convincing farmers adjoining a seed plot to grow a different crop) have been reduced.

A number of benefits are expected to accrue to the participating communities, in addition to improved availability of seed. School children, many of whom will become fanners when they leave school, will gain from the practical experience the project provides (agriculture is part of the curriculum). Schools will earn income from seed sales, and the community as a whole will benefit from the higher productivity and better food security from the improved varieties.

Better Grain-cleaning Equipment for Sorghum and Pearl Millet

In smallholder farming areas of Southern Africa, sorghum and pearl millet arc commonly threshed by pounding the grain heads with sticks and sweeping up the grain from the ground. One result is that the grain becomes contaminated with sand, small stones, and other foreign matter. If it is to be used for food, the grain must then be cleaned prior to processing. The technologies commonly used for such grain cleaning (generally including the washing and drying of grain) are time-consuming and expensive. Yet without such cleaning, sorghum or pearl millet meal, in particular, remains likely to be contaminated with foreign matter. This severely limits development of the market for meal.

SMIP commissioned an engineering consultant to help identify a more practical solution. Following a review of the problem with millers in Zimbabwe and Botswana, the consultant identified the need for equipment that combines at least two cleaning processes — sieving and aspiration.

After extensive international enquiries, the consultant identified two optional grain cleaning devices. The multinational grain machinery supplier, Buhler, offers a combined sieving, sorting, destoning, and aspiration system, suited to larger grain processing plants. However, this equipment sells for at least US$ 50,000 ex-works in Switzerland. Alternatively, small- and medium-scale millers can purchase a vibratory cleaner and aspiration system from Facet Engineering in South Africa. This sells for approximately US$ 6500 ex-works.

The cleaner from Facet was designed for the small-scale wheat milling industry in South Africa, but can be used for virtually any type of grain by adjusting sieve sizes, angles, and vibratory speed. The cleaner was successfully tested at Induna Foods in Bulawayo, Zimbabwe, on sorghum, pearl millet, and the smaller-grained finger millet. Both large and small contaminants were quickly and efficiently extracted. This equipment is capable of cleaning up to 5 t per hour of wheat, and a similar output is viewed possible for sorghum and pearl millet.

A copy of the consultant's report, and further information about this grain cleaner, can be obtained from SMIP. In addition, a marketing pamphlet can be obtained from SMIP, or from the manufacturer, Facet Engineering, PO Box 971, Honeydew, 2040, South Africa.

Sorghum and Pearl Millet Improvement Research in the SADC Region — Future Needs and Strategies

The Sorghum and Millet Improvement Program (SMIP) has been working with national programs and other partners in the SADC region for the past 17 years to develop and disseminate sorghum and pearl millet technologies. A wealth of technologies and information have been generated, research infrastructure developed, and a number of national program scientists trained. SMIP is now in its fourth and final phase, which ends in 2003. The thrust in Phase IV's agenda is to build on past successes, with an emphasis on promoting complementary investments in seed delivery, crop management, grain marketing, and commercialization to stimulate demand for sorghum and pearl millet, in collaboration with a broad range of partners.

With Phase IV drawing to an end, it became imperative to make preparations for sustaining sorghum and pearl millet R&D beyond SMIP. To this end, ICRISAT and SMIP supported a workshop that sought to establish how national programs and other stakeholders in the region will continue to have access to new sorghum and pearl millet technology in the next 10-15 years. The workshop "SADC regional needs and strategies for sorghum and millets crop improvement" was held during 16-18 Oct 2000 at Matopos Research Station, Zimbabwe. The main objective was to verify specific regional needs for sorghum and millet crop improvement expressed in previous workshops and to develop strategies for future activities. The workshop was attended by various stakeholder groups including national program breeders from a number of SADC countries, representatives of NGOs, private seed companies, INTSORMIL, the SADC Food Security Technical Advisory Unit, and donors (USAID, GTZ, FAO). ICRISAT was represented by the Director of the Genetic Resources and Enhancement Program.

The workshop concluded with proposals of action plans for a regionalized crop improvement program (variety/hybrid development, testing, and release) and a proposal for a sustainable resource base. The guiding principles for the proposed action plans are as follows:

- Sorghum and pearl millet research should contribute to household food security and poverty alleviation.
- Commercialization of the production and utilization of sorghum and pearl millet should aim to achieve income growth.

- The future of the sorghum and pearl millet sector should be guided by constraints in the complete food cycle.

Participants also agreed that issues raised and ideas generated at the workshop should be put together into a concept note for presentation to the SACCAR Technical Committee for Agricultural Research. The paper would be used for sourcing funds from donors and seeking commitment and support from directors of research in SADC national programs.

Linking Promotion of Improved Sorghum and Pearl Millet Varieties with Community Based Seed Multiplication: the Rural Livelihoods Programme

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Abstract

Five NGOs (Oxfam Canada, Management Outreach Training Services for Rural and Urban Development [MOTSRUD], Dabane Trust, Zimbabwe Project Trust [ZPT], and Organization of Rural Associations for Progress [ORAP]) are collaborating on a pilot program on rural livelihoods in Zimbabwe. The program aims to improve nutrition levels and reduce vulnerability to drought in 15 target rural communities in drought-prone regions. SMIP was requested to participate because of its expertise on sorghum and pearl millet — crops that have a comparative advantage in drought-prone areas. SMIP's role is to provide improved varieties and training on small-scale seed production techniques to farmers, project managers, and extension workers involved in the program.

To date, the program has disseminated information to about 30 000 farmers (including 600 women) on the benefits of using improved varieties and sustainable farming practices. A central seed bank and 15 community seed banks (in each target community) have been established. The focus of the program is therefore changing. More emphasis should be directed towards ensuring that planting at community level is done in a timely manner, improving methods of grain processing and storage, and on developing markets for the anticipated excess grain.

Introduction

The program on rural livelihoods was initiated in five drought-prone areas in Zimbabwe — Mudzi, Chiredzi (Save valley), Matobo, Insiza, and Binga districts. In these areas, sorghum and pearl millet have a comparative advantage over maize because they require much less water. In the past 19 years, rainfall patterns in these areas were: four major droughts, when little or no grain was harvested; 4 years of good rains and good harvests of sorghum, pearl millet, and maize; and 11 years of mediocre rains in which maize yields were minimal or non-existent, but sorghum and pearl millet yields were adequate to meet household food security needs as well as provide surplus grain for storage or sale. In such an environment, farmers who plant maize only will go hungry. Those who plant enough sorghum and pearl millet will be food secure at minimum, and in many cases can produce surpluses for sale.

One of the major constraints to increased sorghum and pearl millet production in these areas, as well as throughout the country, is unavailability of seed. In contrast, maize seed is readily available in unlimited quantities. To improve food security in the target communities, the livelihoods program's major strategy is therefore to make sorghum and pearl millet seed available at the local level. ICRISAT was asked to train 'master' farmers to multiply seed and provide them with good quality seed to multiply.

Objectives

The livelihoods program aims primarily to benefit poor rural women farmers. Its long-term goal is to increase nutrition levels and reduce vulnerability to drought in the target communities. This goal can be achieved by increasing sorghum and pearl millet production, leading to a reduction in the need for food aid. In addition to promoting the production of small grains, the program has other components including health promotion (malaria prevention), fortification of grains, promotion of family gardens, and capacity building projects. This report focuses on the small grains production activities in which SMIP is involved. Impact indicators of this program component include an increase in sorghum and pearl millet area, and in the proportion of sorghum and pearl millet grain in the total harvest, from 10% to 30%.

Three major activities have been conducted under the small grains project. These include education and awareness campaigns, development and promotion of seed banks, and outreach and training programs. Varieties that the project worked on include sorghum varieties Macia and Larsvyt 46-85 and pearl millet varieties PMV 3, Okashana 1, and Okashana 2.

Education and awareness campaigns

Farmers were exposed to and trained on quality control aspects of seed production. SMIP provided seed for multiplication. Farmers paid for the seed either in cash (Z$10 per kilogram up-front) or in kind, i.e., 20 kg grain per kilogram of seed, payable after harvest. This system of payment was designed to ensure that quality seed is produced and distributed, while ensuring that the project becomes sustainable.

A successful seed fair was held in March 1999 for farmers from ZPT, MOTSRUD, Dabane Trust, and ORAP projects in Siachilaba (Binga) to increase their awareness of available varieties. A sorghum and pearl millet recipe book was compiled to help promote a wide variety of traditional methods of cooking small grains and other nutritious local foods.

The campaigns reached about 30 500 farmers, exposing them to the benefits of growing and producing good quality seed of improved sorghum and pearl millet varieties and use of sustainable farming practices. Thirty 'master' farmers participated in the training courses on seed production.

Seed banks

Fifteen farmer seed collection points/banks with a holding capacity of 15 t each were established in each target community. The seed banks are run by a food security/small grains committee which is also in charge of a loan revolving fund made up of the commitment fees (Z$10 each) contributed by participating farmers. The money is used to purchase seed and storage chemicals.

Substantial quantities of seed were collected: ORAP collected 800 kg sorghum and pearl millet from Insiza, 1.4 t from Matobo, and 2.4 t from Binga; Dabane Trust collected 1.2 t sorghum and 800 kg pearl millet from their three areas of operation; and MOTSRUD collected 3 t. Similarly, large quantities of seed were collected as payment for the seed "loan". ZPT collected 1.95 t, Dabane Trust collected 500 kg sorghum and 150 kg millet, MOTSRUD collected 1.075 t, and ORAP 2.4 t. Of all seed produced, only that from the 286 farmers under the supervision of ZPT was of poor quality. This was a result of excessive rainfall received in the project area.

Five seed bank 'cocoons', each with a storage capacity of 5 t, were purchased for each of the implementing NGOs.

Outreach and training

SMIP trained field officers from participating NGOs on basic agronomic practices in sorghum and pearl millet seed production. Areas covered include isolation, fertilizer application, planting and thinning, weeding, pest and disease management, rogueing of off-types, harvesting, and general crop management. A training workshop on sorghum and pearl millet seed production was held at Matopos Research Station for extension personnel, program managers, field coordinators, and 'master' farmers from the 15 target communities.

A 2-day sorghum and pearl millet seed production workshop was conducted at Matopos Research Station, and attended by 34 farmers (18 women, 16 men) from the 15 target communities, extension personnel, and program managers and field coordinators from the participating NGOs. The course included a soyabean production training session facilitated by the University of Zimbabwe.

Conclusion and future strategies

The program's target was to reach about 30 000 farmers in the 1998/99 season — raise their awareness and understanding of the benefits of using early-maturing sorghum and pearl millet varieties. Project participants included 600 women. All the project farmers are now capable of using sustainable farming practices, which include the use of farm manure, appropriate plant spacing and population, and weed control. Fifteen community seed banks were established in target areas with a central bank for seed distribution. Once farmers begin to plant improved varieties, the demand for good quality seed will increase. The 'master' farmers trained under this program are expected to be pivotal in assisting the community to replenish their seed banks with good quality seed.

The availability of good quality seed within the target communities means that farmers will produce more and the need to utilize labor saving devices like village threshing machines will increase. Equally important will be the need to improve the storage and processing of grain and to find markets for the surplus grain.

Commercializing Sorghum in Tanzania

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The Tanzanian Ministry of Agriculture and Cooperatives seeks to strengthen the nation's agro-economy by promoting the expansion and diversification of commercial grain processing. One aspect of this strategy is to promote the commercialization of traditional food grains such as sorghum and pearl millet.

In 1999, SMIP-sponsored consultations with milling, brewing, and animal feed companies indicated that sorghum could readily replace much of the maize currently being used by these companies. This led to the formulation of a pilot project with a brewery, Darbrew Ltd, to contract traders for the supply of high quality sorghum grain from small-scale farmers in the Dodoma region. During the 1999/2000 cropping season, farmers were encouraged to grow a sorghum variety suited to the needs of the brewery. Traders in the region were then encouraged to purchase, assemble, and transport the grain to Dar es Salaam.

Within 2 months of the 2000 harvest, the brewery had purchased over 90 t of sorghum grain. A new sorghum-based beer is on the Dar es Salaam market, and the brewery is considering initiating sorghum beer production in other parts of the country. Additional sorghum grain purchases are expected in the months ahead.

One by-product of these efforts has been the recognition that the new sorghum variety Pato offers excellent brewing characteristics and is a good drought-tolerant variety. Many farmers in the Dodoma region lost their maize and traditional sorghum crops to drought this past season, but fields under Pato performed well. In consequence, the Ministry of Agriculture and Cooperatives is working with SMIP to evaluate several options for speeding up the production and distribution of Pato seed.

SMIP also organized a pilot program to evaluate opportunities for expanding the market for sorghum meal. The 1999 industry consultations found that sorghum meal was being sold on the Dar es Salaam market at three to four times the price of maize meal.

The high price, relative to a close market substitute, severely limited consumer demand. The assessment revealed that high sorghum meal prices resulted from the lack of adequate supplies of grain, high costs of grain cleaning, and uncertainty about consumer demand.

SMIP responded by initiating a pilot program with the company Power Foods. The pilot program will evaluate taste preferences for alternative types of sorghum meal, assess packaging options, and test market sorghum meal at varying prices. Support from outside advisors was also sought to identify opportunities for reducing grain cleaning and milling costs.

In sensory taste tests, Pato was viewed to be superior to a randomly chosen traditional sorghum variety. Consumers expressed satisfaction with the taste, aroma, and consistency of Pato in both stiff and soft breakfast porridge. However, most consumers marginally preferred maize for stiff porridge.

In in-store retail trade surveys, the majority (52%) of buyers stated a preference for paper packaging. However, many (45%) also expressed a preference for plastic packaging. This result may be influenced by the fact that maize and sorghum meal have traditionally been sold in paper packages.

Most respondents indicated that this was the first time they had bought sorghum meal. The product being purchased was mainly used for preparing stiff porridge (*ugali*) and soft porridge (*uji).*

Unexpectedly, the majority of respondents also indicated that sorghum meal is consumed mainly by children. Almost all buyers (98%) indicated that they would buy sorghum meal again.

Over the period of the study, Power Foods sold more than 7 t of sorghum meal. Based on discussions with retailers, consumers at lower-price shops in the city are particularly price sensitive. Here, significant quantities of sorghum will be purchased only if the price is less than or equal to the maize meal price. This will be very difficult given the current cost structure for sorghum grain production, cleaning, and processing. Retailers and consumers in medium and higher-price shops acknowledge the existence of a niche market for sorghum meal at higher prices.

However, there remains confusion about pricing. Sorghum meal has traditionally been sold for Tsh 1000 per kg. During the period of the survey, sales were made at Tsh 300 to 500 per kg, compared with Tsh 250-300 for maize meal. A new sorghum meal product was launched on the market by a competing miller, and sold for Tsh 600-800 per kg. Retailers expressed concern to keep the sorghum meal price as low as possible, but some commented that too low a price may signal a lower quality product to consumers.

More market education will be required. Correspondingly, Power Foods took advantage of the national trade fair and the agricultural show to advertise its products.

Further information on this work can be obtained from J. A. B. Kiriwaggulu, Marketing Development Bureau, Ministry of Agriculture, PO Box 2, Dar es Salaam, Tanzania.

Stratification of Pearl Millet Testing Sites in the SADC Region

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Introduction

Maximization of crop productivity requires accurate selection and targeting of cultivars for appropriate production areas. The number and location of testing sites are critical factors that affect the efficiency of and potential gains from breeding. The selected testing sites must be representative of the conditions of target production areas. Within a large region such as SADC, knowledge of underlying production zones within the region could help not only in choosing appropriate testing sites, but also in objective targeting of cultivars for production (Peterson 1992). The availability of long-term yield data from regional trials conducted in the SADC region over the past decade provides a unique opportunity to identify intra-regional production zones based on grouping of previously used testing sites with respect to their similarities in cultivar response to varying production conditions.

Plant breeders, over the years, often change both the genotypes and the locations in regional trials. Unlike the well-designed balanced genotype x location x year (GLY) investigations, where genotypes and locations remain the same over years, the analysis of regional trials is statistically more difficult due to highly unbalanced GLY data. Statistical techniques, developed over the last decade to stratify testing sites according to similarities in cultivar response, attempt to account for this imbalance in GLY data basically through averaging of location proximity matrices across years. This approach minimizes the influence of missing data and short-term weather events or rare disease epidemics on relative relationships among the testing sites (Peterson 1992).

Based on this basic approach, Peterson (1992) and Peterson and Pfeiffer (1989) applied factor analysis on the average correlation matrix to stratify international winter wheat testing sites using 17 years of trial data. The average correlation matrix was derived from the correlation matrices from individual trial years, the correlations within a year being computed between cultivar yields for pairs of locations. DeLacy et al. (1990) used the pattern analysis technique (Williams 1976) to stratify Australian cotton testing sites based on 6 years' data. They computed squared Euclidean distance (SED) between locations for each year and averaged the SEDs across years to produce a single average dissimilarity matrix for site classification. The individual years' dissimilarity matrices were either simply averaged or weighted by the number of genotypes grown in different years to obtain the single average dissimilarity matrix.

The objective of this research was to stratify the pearl millet testing sites in the SADC region based on available historical yield data from regional trials. This information allowed the identification of key benchmark testing sites representative of the underlying production zones in the SADC region. The site-stratification so obtained will also help to effectively use and target exchange of germplasm and information.

Materials and methods

Data from 90 pearl millet multi-environment trials (MET) conducted at 25 sites over 9 years, was split into two sets: Set 1 (1989/90 to 1992/93) included introductory genetic materials. Set 2 (1994/95 to 1998/99) included advanced genetic materials. Sequential Retrospective (SeqRet) pattern analysis was applied to stratify the test sites according to their similarity of genotype-yield differentiation patterns. This methodology is outlined in DeLacy et al. (1990). The SeqRet package and its manual are available at the website http://pig.ag.uq.edu.au/qgpb.

Results and discussion

Site stratification analysis from Set 1 and Set 2 partitioned the testing sites into six and five groups with R^2 values of 76% and 79% respectively. Analysis of the cumulative dataset (1989/90 to 1998/99) clustered the 25 sites into six

Table 1. Biophysical characteristics of SADC pearl millet test sites

Site	Country	Soil type	SWHC	pH	Drainage	Longitude	Latitude	Altitude (m)	Annual rainfall (mm)	First month	Min temp (°C)	Max temp (°C)	LGP (months)
Sebele (seb)	Botswana	M/F	H	6.4	MWD	26.0	−24.6	976	495	11	12	28	2
Maun (mau)	Botswana	C	M	6.6	WD	23.4	−20.0	898	445	12	15	31	3
Kasinthula (kas)	Malawi	F	M	6.6	PPD	34.8	−16.1	122	793	12	19	32	4
Ngabu (nga)	Malawi	F	H	7.3	ID	34.9	−16.5	115	760	11	19	32	4
Umbeluzi (umb)	Mozambique	M	H	6.4	WD	32.3	−26.0	64	667	12	17	29	5
Bagani (bag)	Namibia	C	VL	6.4	ID	20.7	−18.1	1049	551	12	14	30	4
Katima (kat)	Namibia	C	VL	6.4	ED	24.3	−17.6	966	682	12	13	30	4
Mahanene (mah)	Namibia	C/M	M	6.4	WD	15.2	−17.5	1110	505	11	13	29	3
Mashare (mash)	Namibia	M	M	6.6	ID	20.2	−17.9	1061	568	1	14	31	4
Ogongo (ogo)	Namibia	C	VL	6.4	SED	14.6	−17.9	1225	403	1	12	26	3
Okashana (oka)	Namibia	C	VL	8.5	WD	16.5	−18.3	1097	446	1	15	31	3
Hombolo (hom)	Tanzania	C/M	M	5.4	MD	35.9	−6.0	1019	562	12	16	30	4
Ilonga (ilo)	Tanzania	F	M	5.7	WD	37.0	−6.8	914	978	11	16	28	6
Ukiriguru (uki)	Tanzania	C/M	M	5.4	ID	33.0	−2.7	1239	952	11	17	28	7
Kaoma (kao)	Zambia	C	VL	6.4	ED	24.4	−14.4	1041	967	11	14	29	5
Longe (lon)	Zambia	C	L	4.8	WD	24.9	−14.9	1124	930	11	13	29	5
Simulumbe (sim)	Zambia	C	L	4.3	ED	23.8	−14.6	1017	968	11	15	29	5
Panmure (pan)	Zimbabwe	M	M	6.4	MWD	31.6	−17.3	1037	817	11	13	27	5
Kadoma (kad)	Zimbabwe	F	H	6.3	MWD	29.9	−18.3	1107	735	12	14	28	5
Lucydale (luc)	Zimbabwe	C	M	6.4	MD	28.5	−20.4	1416	591	11	12	25	4
Makoholi (mak)	Zimbabwe	M	M	6.4	MWD	30.8	−19.8	1111	628	12	13	26	5
Matopos (mat)	Zimbabwe	F	H	6.4	MD	28.5	−20.4	1416	591	11	12	25	4
Muzarabani (muz)	Zimbabwe	M	H	6.4	MWD	31.0	−16.4	427	665	12	17	32	3

Soil type: M = Medium, F = Fine, C = Coarse
SWHC = Soil water-holding capacity; H = High, M = Medium, L = Low, VL = Very low
Drainage: WD = Well drained, ID = Imperfectly drained, MD = Moderately drained, MWD = Moderately well drained, PD = Poorly drained; ED = Excessively drained, SED = Somewhat excessively drained
LGP = Length of growing period

groups with R^2=76% and captured the major patterns of site similarities found in Set 1 and Set 2 (Fig. 1, Table 1). Based on the plant breeders' experience gained from running many years of MET, the cumulative dataset was more informative in judging the relevance of site-stratification results. Despite a highly imbalanced historical pearl millet MET dataset, SeqRet pattern analysis provided an objective basis for stratifying the test sites and thus choosing an optimum number of sites for future testing of genotypes.

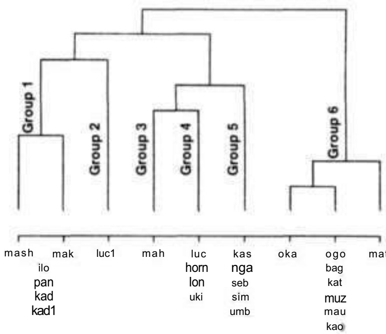

Figure 1. Dendrogram of cumulative classification of sites (1989/90 to 1998/99) based on grain yield (site codes shown in Table 1)

Conclusions

The results obtained from the cumulative dataset imply that further testing can be restricted to a few benchmark sites picked from each of the six groups representing six production zones within the SADC region. NARS scientists have expressed interest in using the SeqRet pattern analysis procedure to analyze their own MET data for national site stratification.

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Development of Sorghum Varieties through Participatory Plant Breeding in Malawi

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Introduction

In conventional plant breeding, farmers are invited to the research station once a year to evaluate new improved cultivars. Participatory plant breeding (PPB) uses a different approach — farmers are more closely involved in technology development, working with the breeder from an early stage in the breeding process. This farmer participation increases the chances of adoption of cultivars thus developed, and thus increases the expected returns from investments in plant breeding.

The Department of Agricultural Research, Ministry of Agriculture and Irrigation, Malawi, initiated a project during the 1997/98 season in which PPB was used in sorghum breeding for the first time. The objective of this work was to develop diversified sorghum populations and lines that incorporate farmer-preferred plant and grain traits.

Activities for the 1997/98 season were conducted at Kasinthula Research Station with 25 farmers (men and women) and at Ngabu Research Station with 20 farmers. These farmers evaluated 55 sorghum genotypes, and identified 8 genotypes as possessing traits they preferred most (Chintu 1998). During the 1998/99 season, PPB activities involved 23 farmers at Chitala and 16 farmers at Kasinthula. The farmers evaluated 101 genotypes and selected 20. However, farmers differed in traits that they considered most valuable (Chintu 1999).

We report below on on-farm PPB activities conducted in the Shire Valley and Salima Agricultural Development Divisions (ADDs) during the 1999/2000 season.

Materials and methods

On-farm PPB experiments were established in community plots at Chitala East, Kalambe West, and Kalambe Central in Salima ADD; and Mulomba, Mbande, and Mwasiya in Shire Valley ADD during the 1999/2000 season. Twenty farmers (3 women, 17 men) were involved in Shire Valley and 72 farmers (48 women, 24 men) in Salima. The trials evaluated 20 sorghum varieties selected by farmers from a number of genotypes, including landraces, during the 1998/99 season. These were laid out in randomized complete block design experiments with 3 replications. Each variety was planted on 2 rows x 5 m plots. Plot size was 7.5 m^2. The plots were planted in mid January and harvested in mid May 2000.

Farmers carried out all cultural operations—land preparation, planting, thinning, weeding, fertilizer application, harvesting, and grain processing—as advised by their sectional field assistants. Farmer selection of the most preferred traits was done at flowering, physiological maturity, harvest, and post harvest stages.

Field observations and evaluations. All community plots had good crop establishment. Gaps were filled with transplants to maintain the correct stand of 72 plants per plot. Farmers evaluated several traits including crop growth, time to maturity, tillering, plant height, stem thickness, lodging, drought tolerance, resistance to field insects, yielding ability, and grain quality (size, color). Each variety was evaluated on a plot-by-plot basis on a 1-5 scale, where 1 = poor, 2 = fair, 3 = average, 4 = good, 5 = excellent. A team on gender assessment and the project scientist in each ADD coordinated the evaluations.

Harvesting, grain processing, and evaluation. A sample of 10 heads was taken from each plot row at harvest, threshed, and the grain used to determine the grain yield of each variety. The remaining heads were harvested separately and the grain used in various food products (Table 1) prepared by the farmers themselves. The products were evaluated for taste during open days. The taste evaluations were also scored on a 1-5 scale as above. The tests were conducted only in Salima ADD.

Data recording and analysis. All data were analyzed using the MSTATC statistical package. Regression analysis was conducted to determine the relationship between yielding ability and actual grain yield (i.e., farmers' estimate of expected yield versus yield actually obtained) and also between actual grain yield and maturity duration.

Table 1. Food products prepared from sorghum.

Food type	Processing and preparation
Thick porridge (*Nsima*)	A 1-kg grain sample was used. The grain was pounded, winnowed, washed, dried, and milled into flour with an electric mortar. The flour was used to prepare a thick porridge. This was done for all varieties.
Boiled grain (*Ntakula*)	A 200-g grain sample was used. The grain was cleaned and boiled in water.
Polished grain (*Ntakula*)	A 200-g grain sample was used. The grain was polished, then washed and cooked together with groundnut flour.
Grain pops (*Mbulumbulu*)	A 200-g grain sample was used. The grain was cleaned and roasted using the traditional method, i.e., on a hot pan placed over a fire.

Results and discussion

Salima ADD. Using ANOVA, significant varietal differences ($P<0.05$ and $P<0.01$) were observed in maturity duration, pops (taste and quality), grain (size, color, quality, yield ability), and actual grain yield. Selection for grain yield was significantly correlated ($P<0.01$) with selection for yield ability and time to maturity. Most of the varieties received high scores (from both men and women) for many traits. For example, 11 varieties scored 5 for maturity duration, 16 scored 5 for grain size, 10 scored 5 for grain quality, and 9 scored 5 for yield ability. Among the 9 varieties that scored 5 for yield ability, 8 gave grain yields of >2.47 t ha^{-1}, which was the trial average across sites.

Table 2. Performance and farmer ratings of the four best sorghum varieties, Salima and Shire Valley ADDs, 1999/2000 season

	Salima ADD			Shire Valley ADD	
Accession number	Farmer rating	Yield (kg ha^{-1})	Days to phys. maturity	Farmer rating	Yield (kg ha^{-1})
Acc 1052	4-5	3485	106	3-5	2358
Acc 952	3-5	2805	112	4-5	1797
Acc 953	3-5	3045	121	5	2118
Acc 1002	4-5	3651	130	5	2146
Location mean		2465	132.6		1428
LSD		1015	-		na
CV (%)		24.9	-		na
P(0.05)		***	as		na

Mean. LSD, CV, shown for all 20 varieties tested

Farmer ratings on 1-5 scale where 1 = poor, 5 = excellent. Varieties were rated for several traits: plant growth, earliness, expected yield, plant height, stem thickness, resistance to lodging, drought and insect pests, grain size, color and quality

Details on farmer ratings are not shown, contact author for more information

Shire Valley ADD. Significant varietal differences ($P<0.05$ and $P<0.01$) were observed in crop growth, plant height, stem thickness, resistance to lodging, drought, and field insects, and yield ability. As in Salima ADD, several varieties received high scores for important traits. For example, 8 varieties scored 5 for maturity, 8 scored 5 for plant height, 13 scored 5 for resistance to drought, and 7 scored 5 for yield. Six of the high-yielding varieties gave yields >1.43 t ha^{-1}, which was the average across sites.

Farmer participation in variety development helps ensure that new technologies are relevant and suitable for smallholder conditions

Selection of preferred varieties

Farmers evaluated the varieties on the basis of several preferred plant and grain traits. Final selection of the best varieties was based on the most important traits — plant height, maturity duration, resistance to drought, grain (size, color), yield ability, and actual grain yield. Six varieties — Accessions 1052, 952, 953, 967, 1002, and 756 — were the most preferred in Salima ADD, and five varieties - Accessions 1052,952,953, 1002 and 965 — in Shire Valley ADD. Thus, four varieties (Accessions 1052, 952, 953, and 1002) enjoyed wide farmer preference, being selected in both ADDs (Table 2).

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Sorghum Research Reports

Genetics and Plant Breeding

Sorghum (*Maicillo*) in El Salvador, Central America

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Sorghum [*Sorghum bicolor* (L.) Moench], commonly known as *maicillo* in El Salvdor, is the second most important staple grain crop in this country following maize (*Zea mays* L.). El Salvador is the major producer of sorghum in Central America with 123,000 ha sown annually to the crop. Of this area, 71.5% is sown to landrace varieties known as *maicillos criollos,* and the remaining 28.5% is sown to improved varieties—principally those released by the Centro Nacional de Tecnologia Agropecuaria y Forestal (CENTA), the major public-sector agricultural research institution in the country. Annual grain sorghum production in El Salvador is 184,500 t, and average yields are 1.52 t ha^{-1} . During the past 10 years the area sown to sorghum in El Salvador has reduced by 9% while national production has increased by 13% thanks to yield increases of 23%. National demand for grain sorghum has increased at a rate of 3% $annum^{-1}$ during the period, with 77% of current grain sorghum demand being for livestock feed and the remaining 23% being for direct use as human food. El Salvador is essentially self-sufficient for grain sorghum. The principal factor contributing to the recent increase in sorghum production and yield in El Salvador has been the increased use of improved cultivars released by CENTA over the past 15 years, that are now grown on about 25% of the area sown to the crop in this country.

CENTA has released six improved sorghum genotypes: CENTA S-l (1970), CENTA S-2 (1976), ISIAP Dorado (1981), CENTA SS-41 (1982), CENTA Texistepeque (1987), CENTA Oriental (1987), CENTA SS-43 (1991), CENTA Soberano and CENTA R.C.V. (1996), and CENTA Jocoro (1997). These cultivars have been adopted principally in monoculture sowings on the coastal plain and other gently rolling lands. As 71.5% of the sorghum area in El Salvador is sown to photoperiod-sensitive landrace cultivars grown in association with maize, often on hillsides, the principal objective of the CENTA sorghum breeding program is to now improve cultivars suitable for use in these production systems. Improved open-pollinated sorghum cultivar CENTA Texistepeque is a photoperiod-sensitive *criollo* derived from the cross CENTA S-1 x Sapo. It has 2-dwarf plant height, purple plant color, and white grain. Adoption of this improved photoperiod-sensitive cultivar has been primarily for grain and silage production as a sole crop. ISIAP Dorado is based on a single-plant selection made in segregating materials at ICRISAT-India in 1979. It is a photoperiod-insensitive, 3-dwarf, open-pollinated cultivar with tan plant color and bold, hard, white grain. Since its release in El Salvador, ISIAP Dorado has been extensively used in sorghum breeding programs worldwide as a source of large, hard, while grain in a high-yielding (for its height) genetic background. Open-pollinated, photoperiod-insensitive sorghum cultivar CENTA S-2 is derived from crosses of materials from Mexico. CENTA SS-41 is a sorghum x Sudangrass [*Sorghum bicolor* (L.) Moench] forage hybrid produced from the cross ATx623 x Sweet Sudan. CENTA Oriental is derived from selections made in M 90361, an elite, while-grained breeding line introduced from ICRISAT-India. The more recently released open-pollinated grain cultivars—CENTA Soberano, CENTA R.C.V., and CENTA Jocoro were bred in the erstwhile ICRISAT Latin American Sorghum Improvement (LASIP), that was based at the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) with headquarters at El Batan, Mexico. These three genotypes were originally provided to the CENTA program by LASIP in 1990 and their pedigrees are:

Release name	Experimental name	Pedigree
CENTA Soberano	ICSV-LM 90502	(M 36285 x 77CS-1)-bk-5-1-2-3-1-bk
CENTA R.C.V.	ICSV-LM 90503	(M 35585 x CS 3541 crosses 31)-bk-5-2-2-3-1 -1-1-bk
CENTA Jocoro	ICSV-LM 90508	(PP 290 x 852-2235)-bk-46-3-1 -bk

They are derived from crosses of breeding lines received from ICRISAT and Texas A&M University.

In 1999 photoperiod-insensitive grain sorghum genotypes were sown on 35,000 ha in El Salvador and produced an average of 2.6 t ha^{-1}. The most commonly sown cultivars were CENTA S-2 (40%), CENTA R.C.V. (30%), CENTA Texistepeque (15% sown for forage), CENTA Soberano (10%), and ISIAP Dorado (5%). About 60% of farmers use certified seed of these cultivars and 40% use their own seed. Acceptance of these cultivars continues to grow, and it is expected that they will be sown on an even larger scale in future.

Utilization of new sorghum cultivars since 1970 has led to interest in the production of Certified Seed from several private companies. Their involvement began in 1978 with multiplication of CENTA S-2. Currently, there are three organizations in El Salvador—two private and one public—that produce some 280 t of Certified Seed of sorghum for the national market. Table 1 presents information on production of sorghum Certified Seed in El Salvador for the past 5 years.

In 1999, some 88,000 ha of photoperiod-sensitive landrace sorghums were sown in El Salvador. These produced 93,500 t of grain with an average yield of 0.94 t ha^{-1}. It is clear that the future of sorghum improvement research in El Salvador is to improve the productivity of these photoperiod-sensitive *criollo* landrace cultivars, building on their adaptation to systems of intercropping with maize (where photoperiod-sensitive sorghum serves as a food security crop in case the earlier-maturing maize fails due to drought, disease, or insect pests). Grain yields of these sorghums can be increased by using good weed control practices, applying modest levels of fertilizers, and sowing genotypes with improved grain yield potential, disease resistance, and drought tolerance. Both LASIP and the Intenational Sorghum/Millet Collaborative Research Support Program (INTSORMIL) have in the past worked to improve these photoperiod-sensitive sorghums, with positive results. In El Salvador at present three improved photoperiod-sensitive sorghums are in validation trials prior to their possible release. These are 86 EON 226, 85 SCP 805, and ES-790. It is expected that in 2001 at least one of these three will be released for cultivation by farmers. These varieties were bred by S_2 family-based recurrent selection focused on improving number and mass of grain $panicle^{-1}$. In this manner it was possible to improve grain yield by 13%. When combined with improved weed control and application of 40 kg N ha^{-1}, use of these improved cultivars can increase productivity by 25-30%.

At CENTA everything is prepared to start the 2001 crop season with a campaign to stimulate use of these improved sorghum cultivars in combination with improved weed control and soil fertility management practices.

Table 1. Producing agencies, sorghum cultivars, and Certified Seed production (metric tons) in El Salvador, 1995-99.

		Certified seed production (t)					
Producing agency	Cultivar (Release year)	1995	1996	1997	1998	1999	Total
ACPA Lombardia de R.L.							
Grain cultivars							
	CENTA S-2(1976)	27	49	37	13	45	171
	ISIAP Dorado (1981)	18	31	33	-	-	82
	CENTA Oriental (1987)	-	-	-	-	-	0
	CENTA Soberano(1996)	-	-	30	23	22	75
	CENTA R.C.V.(1996)	-	-	-	17	27	44
	CENTA Jocoro (1997)	-	-	-	-	-	0
	Subtotal	**45**	**80**	**100**	**53**	**94**	**372**
Forage cultivars							
	CENTA SS-41 (1982)	7	18	5	-	-	30
	CENTA SS-43 (1991)	-		-	-	-	0
	Subtotal	**7**	**18**	**5**	**-**	**-**	**30**
	Agency total	**52**	**98**	**105**	**53**	**94**	**402**
PROSELA, S.A. de C.V.							
Grain cultivars							
	CENTA S-2 (1976)	40	45	80	23	55	243
	ISIAP Dorado (1981)	18	54	71	-	-	153
	CENTA Oriental (1987)	-	-	-	-	-	0
	CENTA Soberano(1996)	-	-	20	23	61	104
	CENTA R.C.V. (1996)		14	-	46	47	107
	CENTA Jocoro (1997)	-	-	-	38	22	60
	Subtotal	**58**	**113**	**171**	**130**	**185**	**667**

Table 1. (Continued)

		Certified seed production (t)					
Producing agency	Cultivar (Release year)	1995	1996	1997	1998	1999	Total
Forage cultivars							
	CENTA SS-41 (1982)	-	-	-	-	-	-
	CENTA SS-43 (1991)	-	-	-	-	-	-
	Subtotal	**0**	**0**	**0**	**0**	**0**	**0**
	Agency total	**58**	**113**	**171**	**130**	**185**	**667**
CENTA							
Grain cultivars							
	CENTA S-2 (1976	-	-	-	-	-	-
	ISIAP Dorado (1981)	-	4	-	-	-	4
	CENTA Oriental (1987)	-	-	-	5	-	5
	CENTA Soberano(1996)	9	-	-	-	-	9
	CENTA R.C.V. (1996)	5	-	-	-	-	5
	CENTA Jocoro (1997)	-	-	-	-	-	0
	Subtotal	14	4	0	5	0	23
Forage cultivars							
	CENTA SS-41 (1982)	-	-	-	-	-	0
	CENTA SS-43 (1991)	-	-	-	2	-	2
	Subtotal	0	0	0	2	0	2
	Agency total	14	4	0	7	0	25
Across-agency totals							
	CENTA S-2 (1976)	67	94	117	36	100	414
	ISIAP Dorado (1981)	36	89	104	-	-	229
	CENTA Oriental (1987)	-	-	-	5	-	5
	CENTA Soberano(1996)	9	-	50	46	83	188
	CENTA R.C.V. (1996)	5	14	-	63	74	156
	CENTA Jocoro (1997)	-	-	-	38	22	60
	CENTA SS-41 (1982)	7	18	5	-	-	30
	CENTA SS-43 (1991)	-	-	-	2	-	2
	Grand total	124	215	276	190	289	1084

Source: Direccion General de Sanidad Vegetal y Animal, Departmento Certification de Semillas y Plantas, El Salvador, Central America.

Dominant Male-Sterility Mutation Induced in Sorghum Tissue Culture and its Inhibition

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Genetic variation induced by tissue culture conditions is one of the most effective tools for induction of male-sterile (ms) mutants. Previously, we have reported on regenerating ms-mutants from callus cultures obtained from haploid and autodiploid plants of sorghum *[Sorghum bicolor* (L.) Moench] cv Milo-145 (Elkonin et al. 1993). Based on maternal inheritance of male sterility in crosses with A_1 cytoplasm fertility restorer S-732, non-Mendelian ratios of male-fertile, partially and completely male-sterile offspring in the progenies of self-pollinated semi-sterile plants, and somatic segregation of male-sterility factors in semi-sterile plants, we theorized the cytoplasmic location of the induced mutation (Elkonin et al. 1994). The appearance of homozygous fertile plants in backcross generations under repeated backcrosses with S-723 was explained as being due to the instability of this mutation. In testcrosses with some cultivars, we observed restoration of male fertility while in testcrosses with others male-sterility was maintained in the F_1 and BC-generations but male-fertile plants also appeared in the majority of families.

Such expression of male sterility could be also explained by the action of a dominant nuclear gene (*Ms*); the male-sterile plants from backcross generations are heterozygotes (*Ms/ms*), while fertile segregants are homozygotes (*ms/ms*). Most cultivars have the recessive allele of this gene and where crossed with male-sterile plants produce both sterile and fertile F_1 hybrids. Other cultivars that restore male fertility, may have either another dominant non-allelic genes(s) (*Rf-Ms*), that can suppress the male-sterility inducing gene, or an over-dominant fertility-restoring allele (*Mf*) of the mutant gene. This type of male sterility conditioned by a nuclear dominant gene, and its restoration by a non-allelic dominant inhibitory gene has been described in *Brassica napus* L. (Zhou and Bai 1994).

To demonstrate the nuclear location of our sterility mutation, we studied its transmission through the pollen of restored F_1 hybrids. Emasculated plants of sterility-maintaining cv Belenkyi (*ms/ms*) were crossed with fertile hybrids msS-723(BC6)/KVV-181 (*Mf/ms* or *Ms/ms, Rf/rf*). Two progenies obtained from in these crosses segregated for male-sterile and fertile plants, indicating the presence of a nuclear gene inducing this type of male sterility (Table 1). Self-pollinated male-fertile hybrid F_1 parents also segregated male-sterile plants in the F_2 generation, thus confirming the testcross data.

In order to reveal the allelic relationships of fertility-restoring and sterility-inducing genes, we crossed male-sterile plants segregating in the F_2 progeny of fertile hybrid msS-723(BC6)/Ksyusha with sterility-maintaining cv Volzhskoe-4w. In the case of the non-allelic fertility-restoring gene model the maternal male-sterile plants should have *Ms/-, rf/rf* genotypes, and the sterility-maintainer should have *ms/ms, rf/rf* genotypes. All plants in the testcross with maternal plants *Ms/Ms, rf/rf* should be sterile, while those in the testcross with *Ms/ms, rf/rf* plants should produce both sterile and fertile offspring in the ratio 1:1. In the case of multiple alleles in the mutant locus (*Mf>Ms>ms*) all the male-sterile plants from the F_2 should have genotype *Ms/Ms;* if crossed with fertility maintainer (*ms/ms*) they should produce only male-sterile F_1 hybrids.

In all three crosses of male-sterile plants with the sterility-maintainer, male-fertile plants segregation occurred for both for male-fertility and male-sterility so the model of multiple alleles was rejected (Table 2). The ratio of male-fertile to male-sterile plants fitted both 1:1 and 3:1 ratios depending on the mode of grouping semi-sterile forms. The presence of semi-sterile plants indicated that fertility restoration in this type of male sterility is governed by a few, rather than by one, non-allelic genes that inhibit the action of the dominant nuclear gene *Ms.*

Table 1. Segregation in F_2 populations of restored sorghum hybrid msS-723(BC6)/KVV-181 bearing tissue culture induced mutation of male sterility, and its testcross with sterility maintaining cv Belenkyi *(ms/ms)*

	Number of plants			X^2	
Hybrid combination	Fertile (f)	Semi-sterile(ss)	Sterile(s)	1:1	3:1[1]
Belenkyi/[msS-732(BC6)/KVV-181] 1	10		14	0.667	-
MsS-723(BC6)/KVV-181, 1.selfed	13	1	5	-	0.017
Belenkyi/[msS-732(BC6)/KVV-181] 1	9		5	1.143	-
MsS-723(BC6)/KVV-181, 2, sclfcd	10	7	5	-	0.015

1. (f + ss):s = ratio fertile + semi-sterile to sterile.

Table 2. Segregation in testcrosses of male-sterile sorghum plants from the F_2 population of S-32(BC6)/Ksyusha pollinated with sterility-maintaining cv Volzhshoe-4W

	Number of plants			X^2	
Cross	Fertile (f)	Semi-sterile (ss)	Sterile (s)	If:I(ss+s)	3(f+ss):Is
1	24	12	17	0.472	1.415
2	27	2	14	2.814	1.310
3	17	10	12	0.641	0.692

Acknowledgments

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Cytoplasmic Reversions as a Possible Mechanism of Male-Fertility Restoration in the 9E CMS-inducing Cytoplasm of Sorghum

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CMS-inducing cytoplasm 9E (IS 17218) was described for the first time by Webster and Singh (1964) and is one of the least-investigated and most interesting of the sorghum [*Sorghum bicolor* (L.) Moench] cytoplasms. This cytoplasm induces formation of large non-dehiscent anthers that contain significant amounts of stainable, but non-functional pollen. In previous studies, we have revealed that 9E cytoplasm is characterized by a sporophytic mode of restoration of male fertility that is controlled by one or two dominant genes in different fertility-restoring lines (Elkonin et al. 1998). In addition, we have also observed two unusual phenomena: 1. The appearance of fertile revertants in late-backcross generations in different hybrid combinations (in different CMS-lines [9E]Tx398 and [9E]Milo-10); and 2. the absence of fertility restoration from the cross of the new. CMS-line [9E]Milo-10 (obtained by Milo-10 genome transfer to progenitor CMS-line [9E]Tx398), by the fertile line [9E]KVV-263 that was selected from the restored F_1 hybrid [9E]Tx398/KVV-122 (this cross should have possessed dominant fertility-restoring genes). We speculate that both of these phenomena might be caused by the mutation of cytoplasmic CMS-associated genes under the influence of the nuclear genome of the recurrent male parent.

Additional data supporting this speculation were obtained from an analysis of inheritance of fertility restoration in the cross [9E]HTG-614/Perspectivnoe-l. CMS-line [9E]HTG-614 was obtained by backcrossing HTG-614 to [9E]Tx398. Fertile, semi-sterile, and sterile plants were observed in the F_1 (Table 1). Self-pollinated

Table 1. Inheritance of male fertility in the cross [9E]HTG-614/Persp ectivnoe-I

Generation/Hybrid combination	Number of plants		
	Fertile	Semi-sterile	Sterile
F_1	3	15	7
F_2	14	-	-
$F_3(F_2 1)$	11	-	-
$(F_2 2)$	7	-	-
$F_4(F_3 1)$	2	4	2
[9E]HTG-614/F_2 1	-	-	4
[9E]Milo-10/F_3 1	-	-	14
[9E]Milo-10/$F_3$2	-	-	21

progeny of the fertile plants did not segregate in either the F_2 or F_3. In a few of the F_4 progenies, a few sterile plants selected from the progeny of one F_3 plant did segregate. Assuming that these fertile plants bear dominant fertility-restoring genes, their hybrids with [9E] CMS-lines should also express male fertility. However, in the testcross progenies of fertile plants from the F_2 and F_3 generations with [9E]HTG-614 and [9E]Milo-10 CMS-lines, all plants were sterile.

The male fertility of restored plants in this hybrid combination was not transmitted through the pollen. Although these plants appeared in the F_1, their fertility was perhaps not conditioned by dominant fertility-restoring genes, but rather it was induced by cytoplasmic reversions. Probably, the 9E cytoplasm reversions inducing fertility restoration could occur in both the late backcross generations and in the F_1. It should be noted that the appearance of cytoplasmic reversions in the F_1 strongly resembles fertility restoration under the influence of nuclear dominant fertility-restoring genes. We believe that the induction of cytoplasmic reversions could be the mechanism of action of these genes; once this reversion occurs, the nuclear gene is either changed or lost and does not transmit through the pollen. Under this supposition, the absence of fertility restoration in the cross [9E]Milo-10/[9E]KVV-263 described above, might be expected if the line [9E]KVV-263 were a cytoplasmic revertant. In any case, the appearance of fertile plants in hybrid populations in the 9E cytoplasm (often in Mendelian ratios with sterile plants) maintains their fertility under self-pollination, but never transmits it through pollen. This represents an interesting and poorly understood genetic phenomenon, and strongly resembles a similar mechanism described in CMS-S maize (Gabay-Laughnan et al. 1995).

Acknowledgments

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New Grain Sorghum Cytoplasmic Male-Sterile Line A_2V_4A and F_1 Hybrid Jinza No. 12 for Northwest China

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From the very beginning of sorghum [*Sorghum bicolor* (L.) Moench] hybrid utilization, all sorghum hybrids have been based on the A_1 (milo) cytoplasmic male-sterility (cms) system. The use of this single cytoplasm shows remarkable frailty in heredity and conceals dangers in production. The crushing blow dealt by leaf blight disease [*Exserohilum turcicum* (Pass.) Leonard and Suggs.] to maize production in a large area in the United States of America in 1970 was a result of using a single cytoplasm. To prevent this phenomenon occurring in sorghum, a study on milo-cytoplasmic male sterility and its use in hybrid selection was undertaken in the USA in the 1970s (Ross and Hackerott 1972; Schertz et al. 1981). Six cytoplasmic male-sterility sources that differ from A_1 cytoplasm have been developed. However, to date, non-milo cytoplasm hybrids have not been released for commercial cultivation. Because a single cytoplasmic male-sterility system has been used for sorghum hybrids for a long time in China, our study was initiated at the beginning of the 1980s. Using material introduced from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), with further breeding year after year in China, a series of non-milo-cytoplasm male-sterile lines have been developed and used in hybrid breeding. Among the sorghum hybrids thus developed is Jinza No. 12, a high-yielding, drought-resistant and disease-resistant hybrid that is early-maturing. The hybrid is produced from the combination of male-sterile line A_2V_4A and Chinese sorghum restorer line 1383-2. This hybrid has proven to be suitable in both dry and cool areas of central and southern Shanxi, and in arid and semi-arid regions of southwest China.

Male-sterile line A_2V_4A main traits

The cms line, A_2V_4A has been selected through continuous backcrossing with A_2TAM428 as the original cytoplasm donor and 'Piklet', introduced from ICRISAT, as recurrent parent. It has a plant height of 130 cm, panicle length of 25 cm, 1000-seed mass of 26.5 g with grain protein content of 12.36%, lysine content of 0.53% of protein, and pearl-white seed. Its male sterility is stable and the line is strongly vigorous. It is disease- and pest-resistant and tolerant to environmental stress.

Stable fertility restriction

Devi and Murty (1993) observed that some A_2 based cms lines had 40-70% partial fertility restoration in the rainy season in India. In contrast, in the northeast, north, northwest, and southwest regions of China, 3 years testing from 1987 to 1989 showed that A_2 cytoplasm provided very stable fertility restoration in hybrids and no self-fertility appeared in the A-lines.

Long stigma receptivity

From 1987-89, stigma receptivity tests were made on the important cms lines at locations across the whole of China. Among 6 cms lines studied, A_2V_4A maintained a relatively high seed-setting rate after pollination from the 3^{rd} day to the 12^{lh} day after anthesis. It had a seed set of 54.9% when pollinated after the 12^{th} day, 22.2% higher than that of the control (Table 1). This suggested that A_2V_4A's stigma has a long pollen-receiving capability that facilitates hybrid seed production.

High seed production

A_2V_4A's florets do not abort, so it produces 40% more seed than A_1Tx31974A and A_1Tx378A. Statistical data showed that under conditions of low temperature and low sunshine A_1Tx31974A and A_1Tx378A may have 100% plants with abortive florets, and abortion ratios of 40-50%.

Table 1. **Seed setting percentage in different sorghum male-sterile lines, following pollination at various times (d) after anthesis, Shanxi, China**

Male-sterile lines	Pollination (days after anthesis)									
	3	4	5	6	7	8	9	10	11	12
A_2V_4A	98.6	97.8	97.8	97.0	91.3	87.6	80.0	71.1	60.0	54.9
$A_1$21A	96.5	91.5	88.3	70.8	59.2	42.5	36.5	30.5	15.0	8.0
$A_1$22A	95.0	93.0	90.3	82.0	70.5	48.0	40.0	38.6	26.5	14.0
$A_1$232EA	98.2	98.2	97.5	96.2	85.0	79.0	76.0	67.5	48.3	43.0
$A_1$421A	-	92.4	89.2	86.6	76.6	63.3	52.0	55.0	30.0	15.0
Control										
A_1Tx622	94.7	92.8	87.8	83.3	78.3	69.0	62.7	60.0	51.0	32.7

Main characteristics of Jinza No. 12

Drought tolerance. Jinza No. 12 has greater yield potential in hilly shallow soil than Jinza No. 4, or Jinza 405. In the Shanxi Sci-tech Drought Management Program at the Dongjiashan experimental site in 1992 it produced 31.1% more grain than Jinza No. 4. At the Liuyu experimental site it created a local record by producing 12,000 kg ha^{-1}.

Disease resistance and aphid tolerance. Jinza No. 4 and Jinza 405 are being cultivated in northwest China, where they are severely infested with aphids and smut. Jinza 405 is highly sensitive to aphid infestation, whenever it occurs. Unless immediate control measures are implemented, the yield of Jinza 405 decreases, even to the extent of total crop loss. Jinza No. 12 however was immune to smut, tolerant of aphids and in most cases, did not suffer yield loss.

Adapted to a wide range of environments. Jinza No. 12 is of medium maturity and could adapt better than Jinza No. 4 and Jinza 405. A comprehensive testing of 7 sorghum varieties at 9 experimental sites has suggested that compared to Jinza No. 4 and Jinza 405, Jinza No. 12 has very good stability and strong adaptability to various ecological environments.

Since the development of Jinza No. 12, it has been put into rapid commercial production and is becoming a leading cultivar in Shanxi, Gansu, and Xinjiang Provinces. It is being gradually extended to northern, southern, and southwest regions in China. It is now sown annually on circa 200,000 ha, accounting for one sixth of the sorghum area in all China.

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Agronomy

Evaluation of Suitable Weed Management Practices for a Sorghum-based Intercropping System under Irrigated Conditions

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Sorghum [*Sorghum bicolor* (L.) Moench] is an important grain crop in the semi-arid tropics. Weed competition is a major constraint resulting in yield reductions of between 30 and 75% (Lopez and Galctto 1983). Intercropping is remunerative and sorghum is commonly intercropped with pulses. Such intercropping could be considered a potential way to manage weeds, so the present investigation was

Table 1. Effect of intercropping and weed management practices on weeds and crop yields, Killikulam, India (pooled data from summer and winter seasons, 1997)

Treatments	Weed dry matter (kg ha^{-1})	Weed-smothering effect (%)	Sorghum yield parameters: Panicle length (cm)	Grains $panicle^{-1}$	1000-grain mass (g)	Yield (kg ha^{-1}): Sorghum	Black gram	Cowpea	LER
Intercropping systems									
Sole sorghum	372.1	–	23.3	1295	28.19	4760	–	–	–
Sorghum + blackgram	269.4	27.2	22.7	1235	27.82	4412	531	–	1.42
Sorghum + cowpea	239.7	35.4	21.2	1181	27.67	4234	–	395	1.33
CD ($P < 0.05$)	8.2	–	0.60	36	0.58	133	–	–	–
Weed management practices									
Butachlor 1.0 kg ha^{-1} + hoeing 40 DAS	224.6	28.8	22.3	1239	27.61	4462	510	378	1.40
Fluchloralin 1.0 kg ha^{-1} + hoeing 40 DAS	251.1	32.2	21.9	1214	27.33	4388	459	341	1.35
Pendimethalin 1.0 kg ha^{-1} + hoeing 40 DAS	175.4	31.7	24.0	1332	28.17	4795	597	443	1.47
Metolachlor 1.0 kg ha^{-1} + hoeing 40 DAS	107.8	30.7	26.6	1477	28.74	5302	621	461	1.49
Isoproturon 0.6 kg ha^{-1} + hoeing 40 DAS	134.7	35.8	25.3	1403	28.45	5044	610	452	1.48
Hoeing 20 and 40 DAS	206.2	31.9	22.8	1265	27.89	4553	526	390	1.41
Unweeded control	956.0	32.0	12.4	722	27.06	2521	393	299	1.04
CD ($P < 0.05$)	9.4	–	0.51	28.0	0.44	102	21	15	–

carried out to evaluate suitable weed management practices for a sorghum-based intercropping system. The trial was conducted under irrigated conditions at the Agricultural College and Research Institute, Killikulam during the summer and winter seasons of 1997. The soil in the experimental field was a sandy clay loam with a pH of 7.4, low in available nitrogen (153.6 kg N ha^{-1}), with a moderate level of available phosphorus (12.3 kg $P_2O_5 ha^{-1}$) and high in available potassium (282.5 kg K_2O ha^{-1}). The weed flora found in the experimental field included the grasses: *Eleusine indica* L., *Dactylocatenium aegyptium* Beav., *Echinochloa colonum* L., and *Cynodon dactylon* L., the sedge *Cyperus rotundus* L., and the broadleaved weeds: *Trianthema portulacastrum* L., *Trianthema monogyna* L., *Boerhaavia diffusa* L., *Phyllanthus niruri* L., *Phyllanthus maderaspatersis* L., *Digera arvensis* Forsk, and *Cynotis cucullata* L. Experiments were laid out in a split-plot design with three replicates. Three cropping systems were the main plots and seven weed management practices the subplots.

Sole-crop sorghum cv CO 26 was sown at a spacing of 45 x 15 cm. For the intercrops, sorghum was sown in paired rows (60/2 x 15 cm). Black gram [*Vigna mungo* (L.) Hepper] cv CO 5 (30 x 10 cm) and cowpea *[Vigna unguiculata* (L.) Walp.] cv CO 4 (30 x 20 cm) were sown in between pairs of sorghum rows in an additive series at a ratio of 2:1. Fertilizer was applied at the recommended rate of 90 N:45 P:45 K kg ha^{-1}. Weed control treatments are indicated in Table 1. All herbicides were sprayed 3 days after sowing (DAS) with knapsack sprayers fitted with flood-jet nozzles using 500 L of water.

Results

Weed dry matter, weed control efficiency, yield parameters, and sorghum yields were significantly affected by both intercropping systems and weed management practices. Among the intercropping systems, intercropping of sorghum and cowpea in a 2:1 ratio caused a significant reduction in weed dry matter production and had a higher weed-smothering efficiency than other treatments (Table 1).

The sole sorghum crop recorded higher weed dry matter, lower weed-smothering efficiency, and such higher yield parameters as panicle length, number of grains $panicle^{-1}$, 1000-grain mass, and grain yield than the intercrops. Among the weed management practices, the unweeded control had higher weed dry matter, and lower crop yield parameters and yield than the other treatments. Metolachlor (1.0 kg ha^{-1}) plus hoeing at 40 DAS resulted in low weed dry matter, higher weed-smothering efficiency, and maximum crop yield parameters and yield. This treatment was followed by isoproturon (0.6 kg ha^{-1}) plus hoeing at 40 DAS. The interactions between intercropping systems and weed management practices were significant. Highest intercrop yields (black gram and cowpea) were recorded following the metolachlor (1.0 kg ha^{-1}) plus hoeing at 40 DAS treatment. The highest land equivalent ratio (LER) was recorded in the sorghum + black gram intercropping system. Applications of metolachlor (1.0 kg ha^{-1}) plus hoeing at 40 DAS resulted in a high LER. It can be concluded that an intercrop of sorghum with black gram treated with metolachlor is the best way to achieve maximum yield and monetary return under the conditions of the experiment.

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Pests and Diseases

New Sources of Resistance to Sorghum Midge in Burkina Faso

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Introduction

Sorghum [*Sorghum bicolor*(*L.*) Moench] is the main cereal crop in Burkina Faso, with an average annual production during 1992-94 of 1.25 million tons (FAO and ICRISAT, 1996). The major biotic constraints to its cultivation are insect pests, diseases, and *Striga* spp. The sorghum midge (*Stenodiplosis sorghicola* Coquillett) is the most important pest of the crop in the southern, central, and eastern regions of the country (Bonzictal. 1984;Nwanze 1988). A survey conducted in eastern and central regions in 1999, revealed that farmers have to grow early-maturing red sorghum or other cereal crops maize (*Zea mays* L.) and pearl millet [*Pennisetum glaucum* (L.) R. Br.] in order to avoid the midge problems they experience on late-maturing sorghum. To reduce infestation and losses, the most appropriate and sustainable insect control strategy for subsistence farmers is based on insect-resistant cultivars combined with cultural practices. However, resistant varieties developed on other continents by scientists, including those working at international agricultural research centers, have not solved midge problems in most African countries. Such resistant varieties turned out to be susceptible to such other biotic constraints as foliar diseases, grain molds, and head bugs *(Eurystylus oldii* Poppius) that eventually translated into poor grain quality for traditional dishes like *to.* In addition, breakdown of resistance to sorghum midge in such varieties has been reported from Kenya (Sharma et al. 1999). It is therefore critical to develop midge-resistant varieties that are well-adapted to African conditions, and tolerant to other biotic constraints. Alternative ways of breeding for midge resistance include crossing exotic or local sources of resistance with high-yielding and well-adapted varieties. This paper reports the results of a search for new sources of midge resistance among local sorghum cultivars, carried out from 1996-99 in Burkina Faso.

Materials and methods

More than 200 local landraces from Burkina Faso and other West African countries were screened under natural midge infestation. The best 40 varieties selected for their low midge damage scores, were tested along with 10 susceptible and resistant controls during the 1999 rainy season, in a randomised complete-block design with two replications. The experiment was carried out at two locations known to be midge 'hot-spots', namely Kouare (eastern region) and Farako-Ba (western region). The varieties were sown in 10-m long, single-row plots. Spacing between rows was 0.8 m and within rows, 0.40 m. Border lines of a susceptible variety were sown 15 days before the test cultivars as 'infestor rows', in order to increase natural midge populations. Local landrace 439 and improved variety Sariaso 10 were used as susceptible controls while ICSV 745 (Sharma et al. 1992) was used as a resistant control. Plots were thinned to one plant per hill. Fertilizer was applied as follows: 100 kg ha^{-1} of a complex NPK (14:23:14) at thinning, and 50 kg ha^{-1} of urea (46% N) at panicle initiation. Time to 50% anthesis was recorded. Midge damage was evaluated as described by Sharma et al. (1992). Data was expressed as the percentage of midge-damaged spikelets based on the observation of 500 spikelets per plot. At crop maturity, midge damage was evaluated by visually rating five plants per plot, using a 1-9 scale (Sharma et al. 1992) where 1 = less than 10%, and 9 = more than 80% chaffy spikelets. Data were subjected to analysis of variance after arcsine transformation, using STATITCF software (ITCF 1991).

Results and discussion

Results obtained on the best 10 varieties, namely those combining a midge incidence of less than 10% damaged spikelets, and a visual score of less than 2 at both locations, are given in Table 1. Time to 50% anthesis varied with locations and ranged from 49 days (cultivar 533) to 92 days (G 1645). The average percentage of midge-damaged spikelets varied at Kouare' from 0% (ICSV 745) to 45.3% (susceptible control landrace 439). At Farako-Ba, the percentage of damaged spikelets ranged from 0.4% on ICSV 745 to 31.8% on the improved variety Sariaso 10 used as a susceptible control. Visual scores varied from 1 (ICSV 745) to 2.6 (G 1645) on resistant entries at Kouare, while at Farako-Ba, they ranged from 1 (ICSV 745) to 1.7 (Tenlopieno). On susceptible controls, visual scores varied from 7 to 9 at Kouare and from 3.9 to 4.3 at Farako-Ba. Tenlopieno (originating from eastern Burkina) showed the highest percentage of damaged spikelets both at Kouare and Farako-Ba with an average of 15.5% over 3 years of tests (1996-98). However, this cultivar showed low visual midge damage scores (1.2 and 1.7); in addition, it is tolerant of *E. oldii* damage. Wanmiougou and G 1647 showed low and stable midge damage scores across locations. In 1999, their damage ratings were 0.5% for Kouare, and 1.5% and 3.5% at Farako-Ba; the average damage ratings over 3 years were 1.1% at Kouarte and 0.1 % at Farako-Ba. Visual scores varied from 1 to 1.4 at both locations. It should further be noted that sources of resistance to midge were identified within various sorghum races. These results obtained over 4 years of tests under high natural midge infestations constitute an important step in breeding for resistance to midge using local sources of resistance. Further investigations will be conducted under artificial infestation to elucidate the mechanisms of resistance to sorghum midge that are involved in each variety.

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Table 1. Midge damage on new sources of resistance to sorghum midge (*Stenodiplosis sorghicola*) under natural conditions, Burkina Faso, 1996–99

Variety	Race	Origin[1]	Time to 50% anthesis (days) Kouaré 1999	Farako-Bâ 1999	Damaged spikelets (%)[2,3] Kouaré 1999	Farako-Bâ 1999[4]	Average 1996–98	Visual score[5] Kouaré 1999	Farako-Bâ 1999
Wanmiougou	durra	BKF	82	73	0.5 (3.85)	1.5 (7.03)	1.1	1.3	1.4
G1647	guinea-caudatum	CMR	90	81	0.5 (2.87)	3.0 (9.92)	0.1	1.4	1.0
841	guinea	BKF	60	61	0.7 (4.68)	5.6 (11.83)	4.7	2.3	1.2
G1645	guinea	CMR	92	77	2.0 (8.13)	1.5 (7.00)	1.5	2.6	1.0
971	caudatum	BKF	68	61	3.2 (7.33)	7.2 (15.35)	4.5	1.4	1.3
Tenlopieno	guinea	BKF	77	66	7.7 (15.87)	8.5 (16.94)	15.5	1.2	1.7
Kabega 1	durra	BKF	84	ne	1.5 (4.99)	ne	0.2	1.2	ne
533	durra	BKF	49	ne	1.6 (3.63)	ne	6.9	1.0	ne
495	guinea	BKF	70	ne	3.7 (9.48)	ne	5.4	1.0	ne
Fada 1	guinea	BKF	81	76	4.1 (11.27)	8.0 (16.43)	6.6	1.9	1.2
Controls									
ICSV 745[6]	caudatum	IND	66	68	0 (0)	0.4 (3.63)	–	1.0	1.1
Sariaso 10[7]	caudatum	BKF	72	63	29.5 (32.80)	31.8 (32.75)	36.2	7.0	4.3
439	guinea-caudatum	BKF	72	63	45.3 (42.30)	29.2 (32.70)	82.7	9.0	3.9
SE[8]			±3.1	±3.74	(±9.21)	(±6.81)		±1.26	±0.90

1. BKF= Burkina Faso, CMR= Cameroon, IND= India
2. Percentage of midge-damaged spikelets in 500 spikelets sampled 15 days after anthesis
3. Means in parentheses are arcsine-transformed values
4. ne= no emergence at Farako-Bâ
5. Damage scored on a 1–9 visual rating scale, where 1 = <10% , and 9 = > 80% chafty spikelets
6. Resistant control
7. Susceptible control
8. SE, mean, and CV resulted from analysis of variance carried out on results of 40 test varieties and 10 controls.

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Inheritance of Resistance to Sorghum Midge and Leaf Disease in Sorghum in Kenya

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Introduction

Sorghum [*Sorghum bicolor*(L.) Moench] is one of the most important cereal crops in the semi-arid tropics (SAT). Of the over 150 species of insects that damage the sorghum crop, the sorghum midge *(Stenodiplosis sorghicola* Coquillett), is the most important pest in the Lake Victoria basin area of eastern Africa. Leaf diseases such as anthracnose [*Colletotrichum graminicola* (Cesti.) Wilson], zonate leaf spot [*Gloeocercospora sorghi* (Bains and Edgerton)], leaf blight *[Exserohilum turcicum* (Pass.) Leonard and Suggs.], and rust (*Puccinia purpurea* Cooke) also constitute important constraints to increasing the production and productivity of sorghum in this region.

Nearly 15,000 sorghum germplasm accessions have been screened for resistance to sorghum midge at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India; and 25 lines have been found to be resistant across seasons and locations in India (Sharma et al. 1993). Most of the high-yielding, midge-resistant lines derived from cv DJ 6514 have shown a susceptible reaction to sorghum midge at Alupe, Kenya (Sharma et al. 1998). To investigate the interactions between midge-resistant and midge-susceptible cytoplasmic male-sterile (cms) lines and restorers for expression of resistance to sorghum midge and leaf diseases, a set of 36 F_1 hybrids and their parents [12 restorers showing resistance to sorghum midge in India, and three cms lines (ICSA 88019 and ICSA 88020—resistant to sorghum midge in India, and ICSA 42—a susceptible control)] were tested at Alupe, Kenya in 1994 to determine whether the restorers showing resistance to sorghum midge/leaf diseases combined with the cms lines to produce hybrids with resistance to these pests. Such information is important when selecting parents for transferring resistance into high-yielding varieties and hybrids to increase the production and productivity of sorghum in eastern Africa.

Materials and methods

Gene action for sorghum midge resistance was studied on two midge-resistant (ICSA 88019 and ICSA 88020) (Agrawal et al. 1996) and one commercial midge-susceptible (ICSA 42) cms lines. Twelve genotypes identified as resistant to sorghum midge in India (Sharma et al. 1993) were used as restorers. Thirty-six F_1 hybrids and their parents were sown in a randomized complete block design at Alupe, Kenya during the 1994 short rainy season, in three replications. Each entry was sown in a 4-m long, two-row plot. The experiment was sown twice at an interval of 10 days to avoid escapes, and maximize insect/ disease incidence on the crop. The crop was raised following normal agronomic practices. No insecticide was applied during the reproductive phase of the crop. At maturity, the panicles were evaluated visually for sorghum midge damage (damage rating, DR) on a 1 to 9 scale (1 = <10%, 2 = 11-20%, 3 = 21-30%, 4 = 31-40%, 5 = 41-50%, 6 = 51-60%, 7 = 61-70%, 8 = 71-80%, and 9 = >80% midge-damaged spikelets). Leaf disease (anthracnose, rust, leaf blight, and zonate leaf spot) severity (LDS) was evaluated on a 1 to 9 scale (1 = <10%, 2 = 11-20%, 3 = 21-30%, 4 = 31-40%, 5 = 41-50%, 6 = 51-60%, 7 = 61-70%, 8 = 71-80%, and 9 = >80% of the leaf area infected). Overall LDS was recorded in both the sowings, while individual LDS was recorded only in first sowing, when the LDS was greater than that in the second sowing. The material was also evaluated for agronomic desirability (agronomic score, AS) on a 1-5 scale (1 = agronomically desirable phenotype with high yield potential, 2 = agronomically desirable plant type with moderate yield potential, 3 = tall plant type with moderate yield potential, 4 = tall plant type with low yield potential but acceptable grain quality, and 5= tall plant type with poor yield potential and/or grain quality).

Data on sorghum midge damage (DR), and LDS were subjected to analysis of variance. Significant differences between the treatment means were judged by the F-test, and the treatment means were compared using least significant difference (LSD) at $P<0.05$. Combining ability analysis was carried out according to Kempthorne (1957). The sums of squares due to F_1 hybrids was partitioned into the sums of squares due to lines, testers, and their interaction. The F-test was applied to test the significance of line x tester interaction, and if significant, mean squares for the line x tester interaction was used to test the significance of the lines and the testers. The contribution of lines, testers, and their interactions to the total variability for each character was computed to assess their relative importance. The main effects of the lines and testers were equal to general combining ability (GCA), and female interaction with a specific tester was equivalent to specific combining ability (SCA) (Hallauer and Miranda 1981). The standard errors of GCA for the lines and testers were calculated to test the significance of these effects.

Results

Sorghum midge. Restorers IS 22778, IS 18698, and IS 8891 showed moderate levels of resistance to sorghum midge (DR 3.0-5.4 compared with 9.0 in IS 12608C) (Table 1). IS 27103 and DJ 6514 showed moderate levels of susceptibility to sorghum midge (DR 6.3-7.0). B-lines ICSB 88019 and ICSB 88020 also showed moderate levels of susceptibility (DR 5.7-7.7), but ICSB 42 was highly susceptible (DR 9.0). Sorghum midge damage in the hybrids was generally high. Hybrids ICSA 88019 x IS 21703, ICSA 88019 x IS 8891, ICSA 88019 x ICSV 197, ICSA 88019 x DJ 6514, and ICSA 88020 x IS 27103 showed moderate levels of susceptibility to sorghum

Table 1. Sorghum midge damage, leaf diseases severity, and agronomic score of maintainers of three cytoplasmic male-sterile sorghum lines and 12 restorers over two sowings at Alupe, Kenya, short rainy season, 1994

	DR[1]		LDS[2]				OLDS[3]		AS[4]	
Genotypes	S1[5]	S2	ANTH	LB	ZLS	RUS	S1	S2	S1	S2
Restorers										
IS 2579C	8.0	7.0	4.7	7.1	4.4	5.1	8.7	8.0	4.3	4.3
IS 27103	7.0	6.7	1.0	1.3	2.7	3.0	2.3	3.3	3.7	4.7
IS 21881	7.5	6.3	5.7	6.3	5.7	3.2	8.7	9.0	4.0	3.0
IS 8721	8.7	7.7	7.3	6.0	3.3	4.7	7.7	7.0	2.7	2.0
IS 8100C	7.3	7.7	4.3	6.3	3.7	4.7	6.0	6.7	3.0	3.0
IS 22778	5.4	5.3	6,0	5.0	6.3	6.7	6.3	8.7	5.0	5.0
IS 12608	9.0	9.0	6.7	7.0	6.0	7.0	8.7	9.0	3.0	2.7
IS 8891	4.3	4.0	1.3	4.7	5.0	5.0	4.7	5.0	5.0	4.3
IS 18698	3.0	3.3	1.0	8.7	4.3	3.2	5.0	5.0	5.0	3.3
ICSV 197	8.7	7.7	1.3	6.0	3.7	5.7	4.7	4.0	2.0	3.0
DJ 6514	7.0	6.3	1.3	2.0	3.7	5.7	3.0	3.3	3.0	4.7
ICSV 745	8.7	8.3	1.3	4.7	3.3	5.3	6.3	6.7	3.3	2.3
Maintainer lines										
ICSB 88019	7.7	7.3	1.0	3.0	3.3	3.0	4.4	3.7	4.3	4.0
ICSB 88020	7.0	5.7	1.3	3.0	3.3	3.3	3.7	4.0	4.3	3.3
ICSB 42	9.0	9.0	1.7	3.3	4.3	4.7	7.3	7.3	2.0	1.7
Mean	8.1	7.6	2.2	4.0	4.4	5.1	7.8	5.4	2.9	2.7
SE	±0.33	±0.53	±0.76	±0.68	±0.50	±0.71	±0.32	±0.51	±0.38	±0.36

1. DR = Midge damage rating (1 = < 10% midge damage, and 9 = >80% midge damage)
2. LDS = leaf diseases severity (ANTH = anthracnose. LB = leaf blight, ZLS = zonate leaf spot, and RUS = rust) (1 = <10% leaf area infected, and 9 = >80% leaf area infected)
3. OLDS = overall leaf diseases severity
4. AS = agronomic score (1 = good, and 5 = poor)
5. SI = crop sown on 21 September 1994; S2 = crop sown on 29 September 1994.

Table 2. Mean squares for lines X testers analysis for sorghum midge damage, leaf diseases severity, and agronomic expression at Alupe, Kenya, short rainy season, 1994

Sources of variation	DR[1]			LDS[2]				OLDS[3]		AS[4]	
	df	S1[5]	S2	ANTH	LB	ZLS	RUS	S1	S2	S1	S2
Parents	14	9.2**[6]	8.2**	17.2**	13.0**	3.8**	6.2**	13.3**	13.4**	3.2**	3.2**
Lines	2	6.4*	8.1**	9.2**	41.6**	8.2**	27.8**	15.0**	22.6**	2.5**	0.6
Testers	11	1.5**	2.4**	8.7**	6.0**	9.4**	7.6**	7.3**	11.4**	4.9**	4.3**
Lines x testers	22	0.8*	1.3[a]	2.6**	1.7	1.00	2.3	2.5**	2.9**	0.6	0.7*
Error	152	0.3	0.8	1.8	1.4	0.8	1.5	0.8	0.6	0.4	0.4
Proportional contribution to the total variance (%)											
Lines		27.6	23.0	10.8	44.8	11.1	29.2	18.1	19.4	7.0	1.8
Testers		35.5	36.6	56.0	35.3	72.9	44.2	48.7	53.6	75.9	73.3
Lines x testers		36.9	40.5	33.2	19.9	15.5	26.6	33.2	27.0	17.1	24.9

1. DR = Midge damage rating (1 <10%, and 9 = > 80% midge damage)
2. LDS = leaf diseases severity (ANTH = anthracnose, LB = leaf blight. ZLS = zonate leaf spot, and RUS = rust) (1 = <10% leaf area infected, and 9 = >80% leaf area infected)
3. OLDS = overall leaf diseases severity
4. AS = agronomic score (1 = good, and 5 = poor)
5. S1 = crop sown on 21 September 1994; S2 = crop sown on 29 September 1994
6. Mean squares significant * P<0.05 and ** P<0.01, a = significant at P<0.07.

midge. Mean squares for parents, lines, testers, and lines x testers were significant (Table 2). The relative contribution of lines x testers and the testers to observed variation was higher (35.5-40.5%) than the lines (23.0-27.6%). The contribution of GCA effects was greater than that of the SCA effects. GCA effects were significant and positive for susceptibility to midge in 1CSA 42, while such effects were significant and negative for ICSA 88019 (Table 3). Amongst the testers, the GCA effects were significant and positive for IS 12608C, IS 2579C, IS 8721, and ICSV 745, and significant and negative for IS 27103, IS 21881, and ICSV 197 in one or both sowings. SCA effects for sorghum midge damage were significant and positive for ICSA 88019 x IS 22778, ICSA 88020 x IS 8721, ICSA 88020 x DJ 6514, and ICSA 42 x IS 8100C, and significant and negative for ICSA 42 x IS 8721. Resistance to midge was predominantly governed by additive gene action.

Leaf diseases. Overall leaf diseases severity (OLDS) was low (≤5) in IS 27103, IS 8891, IS 18698, ICSV 197, DJ 6514, ICSB 88019, and ICSB 88020 (Table 1). Restorers IS 27103, IS 8891, ICSV 197, and DJ 6514, in combination with all three cms lines, resulted in hybrids resistant to leaf diseases. Genotypes ICSB 88019, ICSB 88020, IS 27103, IS 8891, ICSV 197, and DJ 6514 were resistant to anthracnose, zonate leaf spot, leaf blight, and rust. Mean squares for parents, lines, testers, and lines x testers (for overall LDS only) were significant (Table 2). The contribution of GCA effects was greater than that of SCA effects (except for anthracnose and zonate leaf spot, where restorers showed greater contribution than the lines and the lines x testers). The proportional contribution of the testers was greater than that of the lines (except for leaf blight as expected) since the number of testers was four times that of the lines. GCA effects were significant and negative for ICSA 88019, while such effects were positive for ICSA 42 (except for zonate leaf spot and rust) (Table 3). GCA effects of ICSA 88020 were significant and positive for zonate leaf spot and rust. GCA effects were significant and negative for DJ 6514, IS 27103, IS 8727 (except for rust), IS 18698, ICSV 197 and ICSV 745 (except for leaf blight), and IS 12608C (for leaf blight only), while such effects were positive for IS 21881 (except for rust), IS 8100C (except for anthracnose), IS 22778, and IS 12608C. SCA effects were significant for ICSA 42 x IS 18698. Resistance to OLDS was governed by additive gene action. Nonadditive gene action was important for resistance to anthracnose and zonate leaf spot, while there was a preponderance of additive of gene action for resistance to leaf blight and rust.

Agronomic desirability. Restorers IS 8721, IS 8100C, IS 22778, IS 12608, ICSV 197, and ICSV 745 showed moderate levels of agronomic desirability (AS 2.0-3.3) over the two sowings. Of these, only IS 22778 also showed

Table 3. General combining ability (GCA) effects of three cytoplasmic male-sterile sorghum lines and 12 restorers for sorghum midge damage, leaf diseases, and agronomic expression at Alupe, Kenya, short rainy season, 1994

	DR[1]		LDS[2]				OLDS[1]		AS[4]	
Lines/restorers	S1[5]	S2	ANTH	LB	ZLS	RUS	S1	S2	S1	S2
Lines										
ICSA 88019	-0.45*[6]	-0.31*	-0.55*	-0.91*	-0.50*	-0.71*	-0.72*	-0.81*	0.18	-0.01
ICSA 88020	0.07	-0.23	0.11	-0.27*	0.43*	0.98*	0.20	0.03	0.13	0.13
ICSA 42	0.38*	0.55*	0.44*	1.19*	0.07	0.27	0.52*	0.78*	-0.31*	-0.12
SE(gi)	±0.097	±0.152	±0.220	±0.196	±0.145	±0.206	0.147	±0.128	0.108	±0.103
SE (gi-gj)	±0.137	±0.215	±0.311	±0.276	±0.206	±0.412	0.208	±0.182	0.154	0.146
Restorers										
IS 2579C	0.46*	0.60*	2.22*	0.62*	-0.54	0.54	-0.33	0.14	-0.26	0.10
IS 27103	-0.54*	-0.40	-0.44*	-1.16*	-1.32*	-0.68	-1.22*	-1.41*	0.07	0.10
IS 21881	-0.42*	-0.40	1.00*	0.84*	0.57	-0.74	0.99*	1.03*	-0.96*	-0.23
IS 8721	0.47*	0.49*	-0.69*	0.01	-0.64*	1.26*	-0.03	-0.19	0.23	-0.45*
IS 8100C	0.24	-0.51	-0.33	0.94*	2.24*	0.65	0.89*	1.25*	-0.71*	-0.79*
IS 22778	-0.32	-0.18	0.56*	-0.27	0.35	1.54*	0.78*	1.03*	1.74*	1.32*
IS 12608	0.57*	0.05	1.11*	-0.83*	1.24*	0.87*	0.89*	1.92*	-0.82*	-1.01*
IS 8891	-0.21	0.05	-0.55*	0.28	0.46	-0.13	0.01	-0.08	0.41	0.66*
IS 18698	-0.32	0.94*	-0.66*	0.62*	-0.20	-1.13*	0.45	-0.42	0.18	0.44*
ICSV 197	-0.21	-0.84*	-0.78*	0.28	-0.98*	-0.57	-0.89*	1.19*	0.41	0.10
DJ 6514	-0.21	-0.06	-0.66*	-1.61*	-0.31	-0.69	-1.77*	-1.64*	0.29	0.55*
ICSV 745	0.46	0.27	-0.78*	0.28	-0.87*	-0.91*	0.23	-0.41	-0.59*	0.78*
SE(gi)	±0.194	±0.304	±0.220	±0.392	±0.291	±0.412	±0.295	±0.257	±0.217	±0.207
SE (gi-gj)	±0.274	±0.430	±0.623	±0.554	±0.412	±0.582	±0.416	±0.363	±0.307	±0.292

1. DR = Midge damage rating (1 = <10%, and 9 = >80% midge damage)
2. LDS = leaf diseases severity (ANTH = anthracnose, LB = leaf blight, ZLS = zonate leaf spot, and RUS = rust severity (1 = <10% leaf area infected, and 9 = >80% leaf area infected)
3. OLDS = overall leaf diseases severity
4. Agronomic score (1 = good, and 5 = poor)
5. S1 = crop sown on 21 September 1994; S2 = crop sown on 29 September 1994
6. * = GCA effects significant at $P<0.05$.

moderate levels of resistance to midge. The agronomic expressions of ICSB 88019 and ICSB 88020 were poorer than those of ICSB 42. Mean squares for parents, lines (in first sowing), testers, and lines x testers (in second sowing) were significant. Combining ability for agronomic desirability varied considerably over the two sowings. The proportional contribution of the testers was maximum (73.3-75.9%), followed by lines x testers (17.1-24.9%), and the lines (1.8-7.0%). GCA effects of the lines for AS were nonsignificant. Significant and positive GCA effects were observed for AS in the case of IS 8891, IS 18698, IS 22778, and DJ 6514; while IS 22881, IS 8100C, and IS 12608 showed significant and negative GCA effects in one or both the sowings.

Discussion

Of the 12 genotypes used as restorers that are resistant to sorghum midge at ICRISAT, Patancheru, India (Sharma et al. 1993), IS 22778, IS 18698, and IS 8891 showed moderate levels of resistance to sorghum midge in Kenya in this study. Genotypes DJ 6514, ICSV 197, and ICSV 745; that are highly resistant to sorghum midge in India, showed a susceptible reaction at Alupe, Kenya. The B-lines ICSB 88019 and ICSB 88020-resistant to sorghum midge in India (Agrawal et al. 1996), also showed a susceptible reaction in Kenya. The GCA effects of ICSA 88019 and ICSA 42 for susceptibility to midge were similar to those observed at ICRISAT, Patancheru, India (Sharma et al. 1996), while those of ICSA 88020 were in the opposite direction. Differences in the reactions of midge-resistant lines across locations may be partly due to the influence of the environment on the expression of resistance to midge, and/or the possible occurrence of a new biotype of sorghum midge in the region (Sharma et al. 1998). Resistance to midge was predominantly governed by additive gene action as observed earlier (Widstrom et al. 1984, Agrawal et al. 1988, Sharma et al. 1996). Restorers that showed resistance to midge at Alupe did not combine with midge-resistant cms lines ICSA 88019 and ICSA 88020 to produce midge-resistant hybrids. Therefore, it is essential to transfer resistance to sorghum midge into both parents to produce midge-resistant hybrids for eastern Africa. A start has been made in this direction by screening and selecting the sorghum head pest population (developed at ICRISAT, Patancheru, India) at Alupe. Most of the lines identified as resistant to midge have been introgressed into this population, and there is a good possibility of deriving progenies from this gene pool with resistance to midge at Alupe.

Restorer lines IS 27103, IS 8891, ICSV 197, and DJ 6414 produced leaf disease resistant hybrids in combination with all the three cms lines, indicating that resistance to some of the leaf diseases is dominant. Resistance to anthracnose was governed by nonadditive gene action. Earlier studies have shown that resistance to anthracnose is controlled by a single dominant gene (Reddy and Singh 1992), and that cytoplasm has no influence on expression of resistance. Resistance to leaf blight is polygenic—characterized by few small lesions, and monogenic—characterized by hypersensitive fleck and little or no lesion development. Drolson (1954) reported that resistance to leaf blight is polygenic and recessive, while Frederickson et al. (1978) and Tarumoto et al. (1977) observed that resistance was monogenic and dominant. Cytoplasm has no influence on the expression of resistance to leaf blight (Sifuentes et al. 1992). Resistance genes from different sources behave differently, and are not allelic. The reported studies showed that resistance to leaf blight is controlled by additive gene action. Indira et al. (1983) reported that tan x tan crosses are more resistant to rust than the tan x purple, and purple x purple crosses. Resistance is dominant and is governed by one or two major genes (Anahosur 1992). The present studies showed that resistance to rust can also be inherited additively. Genotypes ICSB 88019, ICSB 88020, IS 27103, IS 8891, ICSV 197 (except for leaf blight), IS 18698 (except for leaf blight), and DJ 6514 were resistant to leaf diseases, and can be used as sources of multiple resistance to sorghum midge and leaf diseases in sorghum improvement programs.

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Color Variation in the African Sorghum Head Bug

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Sorghum [*Sorghum bicolor* (L.) Moench] is an important cereal crop in West Africa. It is damaged by over 150 species of insects worldwide, of which *Eurystylus oldi* Poppius (Heteroptera: Miridae) is one of the most damaging pests in West and Central Africa (Ratnadass et al. 1994). Published reports of *Eurystylus* spp. on sorghum suggest a complex of species are involved in West Africa. *Eurystylus marginatus* Odh. was recorded as the dominant species in Mali (Doumbia and Bonzi 1985), *E. rufocunealis* Poppius in Nigeria (MacFarlane 1989), *E. risbeci* Sch. in Senegal (Risbec 1950), *E. marginatus* in Niger (Steck et al. 1989), and *E. immaculatus* Odh. in Nigeria and Mali (Sharma et al. 1992, 1994; Ratnadass et al. 1994). However, based on head bug collections from several locations in West Africa, Stonedahl (1995) reported that the major head bug species infesting sorghum in West Africa is *E. oldi* Poppius, with *E. bellevoyei* Reuter sometimes occurring as a minor pest. Previous identifications of *E. marginatus* were misidentifications, while *E. risbeci* and *E. immaculatus* are synonyms of *E. oldi.* This confusion about species identity has, to an extent, been due to various color morphs of *E. oldi,* and to different names being assigned by taxonomists at different times/locations.

Few farmers recognize head bugs on sorghum, and most are not familiar with the nature of the damage these insects cause. Agronomists and breeders in general are unaware of head bugs, and their damage potential. This ignorance is attributable to the relatively small size of the insects, and the fact that both nymphs and adults tend to assume the same color as that of the panicle/grain. There is therefore a need to educate farmers/extension workers, agronomists, and breeders on the identification and pest status of *E. oldi* in West and Central Africa. In this paper color variation in *E. oldi* in relation to panicle/grain color in sorghum is reported.

In 1989, first- and second-instar head bug nymphs collected from sorghum panicles in the field in Nigeria and Mali, were sorted into red, red-brown, and green color morphs. The nymphs were reared on green or red-colored sorghum grain, corresponding to 'white' and 'brown' grain classes. Red-colored nymphs reared on red grain developed into reddish adults with bluish-green undersides, while the green nymphs reared on green grain developed into greenish-brown adults with bluish-green undersides. Red-brown nymphs reared on green grain became brown-black adults, with light green undersides. Red nymphs reared on green grain became light green or red, while green nymphs reared on red grain developed into light green adults. Dark brown nymphs reared on green grain became brown-red adults.

Observations on the changes in color of the nymphs and adults were confirmed during the 1999 rainy season at Samanko, Mali. The green first-instar nymphs collected from white- or tan-grained sorghum cultivars S 34 or ICSV 197, that have green immature grain, developed into greenish-brown adults with bluish-green undersides when reared on the maturing green grains of the same white- or tan-grained cultivars, or of chalky-grained cv Nagawhite. The green first-instar nymphs collected from white- or tan-grained sorghum cultivars, S 34 or ICSV 197, developed into reddish-brown adults with bluish-green undersides with distinct red markings on their abdominal segments, when reared on the maturing red grains of Sorvato 28 or Framida (which is actually brown-grained: its grain has both a pigmented testa and a red pericarp).

The green third-instar nymphs collected from panicles of the tan-grained sorghum cultivar ICSH 89002 developed into greenish-brown adults with bluish-green undersides when reared on the maturing green grains of the same tan-grained cultivar. However, the nymphs developed into light green adults when reared on the maturing red-brown grains of Framida. The red third-instar nymphs collected from panicles of the red-brown grained sorghum Framida developed into reddish-brown adults with light green undersides in males, and bluish-green females with red markings on their abdominal segments, when reared either on the maturing red grains of the same cultivar, or on maturing green grains of tan-grained ICSH 89002.

Thus, the color of the head bugs changed with the color of the food they consumed. However, there were a few exceptions, that might be due to changes in grain pigmentation during development, that might not be apparent in the immature grain fed to the nymphs. These observations suggested that the different species reported earlier on sorghum are in fact the color morphs of the same species, as confirmed by the taxonomic studies of Stonedahl(1995).

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Predation by *Cheilomenes propinqua* on Corn Leaf Aphid

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Introduction

The corn leaf aphid, *Rhopalosiphum maidis* Fitch (Homoptera: Aphididae), is among the insect pests of sorghum [*Sorghum bicolor* (L.) Moench] that cause economically important damage to the crop (Teetes et al. 1983). Direct damage, observed during attacks by large colonies of *R. maidis* on young sorghum plants, can kill seedlings. Indirect damage includes both secretion of a honeydew that favors the development of molds, and transmission of such viruses as the sorghum dwarf mosaic virus (SDMV) (Hagen and van den Bosh 1968).

Extensive use of broad-spectrum chemical pesticides, usually prescribed to minimize insect pest damage on sorghum, is rarely cost effective and often leads to the development of resistance within populations of *R. maidis* (Young and Teetes 1977). Hence, there is an urgent need that alternative control methods to chemicals be developed and made available to farmers.

Cheilomenes propinqua Mulsant (Coleoptera: Coccinellidae) is a polyphagous predator widely distributed in Africa (IIE 1996). It is a potential biological control agent for *R. maidis.* However, attempts to include *C. propinqua* in a biological control program require (as for any other predator) that adequately designed studies gather detail information on its vital functions, including its numerical and functional responses. Holling (1963) defined the functional response of a predator as its ability to linearly increase its consumption in response to increasing population densities of the prey. Thus, the predation effectiveness, or voracity of a predator, is a key component of its functional response.

This paper summarizes results on laboratory evaluation of the predation effectiveness of *C. propinqua* adults and larvae on *R. maidis.*

Materials and methods

In 1997 and 1998 *C. propinqua* and *R. maidis* were collected from field-grown sorghum plants at the University of Ouagadougou's Research Station, located 20 km from Ouagadougou, Burkina Faso.

Aphid prey were captured by excising sorghum leaves on which they had formed large colonies. Excised leaf pieces were then carefully placed in 1.5-L, covered.

ventilated plastic bottles and taken to the laboratory. Using a small suction pump, field-collected coccinellid larvae and adults were transferred into glass vials, 3 cm diameter x 10 cm long, capped with plastic lids. The lids of the glass vials were ventilated with several holes covered with fine-mesh screening to provide adequate aeration while preventing the coccinellids from escaping. The vials were rapidly transferred to the laboratory.

The laboratory effectiveness of *C. propinqua* as a predator on *R. maidis* was examined, on six dates in 1997 and three dates in 1998, in arenas made of petri dishes. On each trial date, larvae or adults that had been starved overnight were isolated singly for 24 h in 9-cm petri dishes, each containing 25, 50, 75, or 100 aphids. The following five treatments were arranged in a Fisher's randomized-block design, with four replications:

TO = control treatment, petri dish with 75 aphids

Tl = petri dish with 25 aphids + 1 coccinellid larva, or adult

T2 = petri dish with 50 aphids + 1 coccinellid larva, or adult

T3 = petri dish with 75 aphids + 1 coccinellid larva, or adult

T4 = petri dish with 100 aphids + 1 coccinellid larva, or adult.

After 24 h, the predators were removed and the aphid mortality recorded, analyzed by analysis of variance (SAS Institute 1985) and the treatments compared using the Least Significant Difference test of Fisher (1947). Abbott's formula was also used to correct for the mortality (Abbott 1925) and corrected data were subjected to regression analysis.

Results and discussion

Coccinellid adult predation on *R. maidis*. Tables 1 and 2 compare the predation response of *C. propinqua* adults provided with aphid densities of 25,50,75, or 100, in 1997 and 1998. Aphid mortality was significantly higher in treatments that included the coccinellid adults than in control treatments. Also, the number of attacks in 24 h increased significantly and linearly as the number of prey increased (Tables 1 and 2) (Figure 1; SAS PROC REG, y = 0.87x; $P < 0.0001$ and $R^2 = 0.92$ in 1997; y = 0.78x; $P < 0.0001$ and $R^2 = 0.90$ in 1998). Coccinellid adult consumption rates, at all aphid densities, were high, and ranged from 82% to 85% in 1997 (Table 3), and from 76% to 97% in 1998 (Table 4).

Coccinellid larva predation on *R. maidis*. Predation data for *C. propinqua* larvae were comparable to those obtained with adults, in that aphid mortality was significantly higher in treatments with larvae than in control treatments (Tables 1 and 2). Similarly, larval consumption increased linearly with increased aphid densities (Figure 2; SAS PROC REG, y = 0.83x, $P < 0.0001$ and $R^2 = 0.96$ in 1997; y = 0.83x, $P < 0.0001$ and $R^2 = 0.94$ in 1998). Larval feeding was as efficient as that of adults and reduced aphid numbers by 80% to 93% in 1997, and 85% to 94% in 1998.

Overall results of this study show the adults and larvae of C. *propinqua* to be efficient predators of *R. maidis,* at both lower and higher population densities. Thus, it clearly appears that this coccinellid does possess an important predation potential for the corn leaf aphid.

Table 1. Mean number of aphids (*Rhopalosiphum maidis*) killed in 24 h with and without *Cheilomenes propinqua* predation, Burkina Faso, 1997

Treatment[2]	Number of aphids dead in control treatment													
	11/10/97		14/10/97		17/10/97		20/10/97		22/10/97		24/10/97		Mean[1]	
TO	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00e	0.04e
	Mean number of aphids killed in treatments including *C. propinqua*													
	Larva	Adult	Larva	Adult	Larva	Adult	Larva	Adult	Larva	Adult	Larva	Adult	Larva	Adult
T1	23.00	23.00	25.00	23.75	25.00	24.75	22.25	22.25	23.25	24.75	16.25	25.00	22.45d	23.92d
T2	44.00	46.75	47.50	47.00	47.50	47.00	23.25	23.25	49.50	50.00	40.00	48.75	41.96c	43.79c
T3	61.25	42.00	54.67	72.25	55.25	72.50	68.25	56.50	64.25	71.50	59.00	73.00	60.44b	64.62b
T4	86.25	66.75	81.00	94.75	81.00	94.50	94.00	79.90	82.75	98.50	72.75	82.75	82.95a	86.19a

1. Consumption means in the same column, followed by different alphabetical letters are significantly different ($P < 0.0001$), as determined by Fisher's (1947) LSD test.
2. TO = control treatment, petri dish with 75 aphids
   T1 = petri dish with 25 aphids + 1 coccinellid larva, or adult
   T2 = petri dish with 50 aphids + 1 coccinellid larva, or adult
   T3 = petri dish with 75 aphids + 1 coccinellid larva, or adult
   T4 = petri dish with 100 aphids + I coccinellid larva, or adult.

Table 2. Mean number of aphids (*Rhopalosiphum maidis*) killed in 24 h with and without *Cheilomenes propinqua* predation, Burkina Faso, 1998.

Treatment[2]	Number of aphids dead in control treatment							
	17/09/98		19/09/98		21/09/98		Mean[1]	
TO	5.00	0.25	1.50	5.50	2.50	2.75	3.00e	2.83d
	Mean number of aphids killed in treatments including *C. propinqua*							
	Larva	Adult	Larva	Adult	Larva	Adult	Larva	Adult
TI	24.75	24.75	22.75	23.00	23.13	25.00	23.54d	24.52c
T2	41.00	48.25	49.75	31.00	49.25	48.75	46.67c	43.67b
T3	69.00	66.00	75.00	67.50	55.25	64.50	66.42b	66.00a
T4	92.25	94.50	96.00	74.25	66.00	59.75	84.75a	76.00a

1,2 See footnotes, Table 1.

Table 3. Mortality rate of *Rhopalosiphum maidis* in petri dishes with and without *Cheilomenes propinqua* predation, Burkina Faso, 1997

Treatment[1]	Aphid mortality rate (%) in control treatment														
	11/10/97		14/10/97		17/10/97		20/10/97		22/10/97		24/10/97		Mean[1]		
TO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	Aphid mortality rate (%) in treatments including *C. propinqua*														
	Larva	Adult	Larva	Adult	Larva	Adult	Larva	Adult	Larva	Adult	Larva	Adult	Larva	Adult	
TI	92	92	100	95	100	99	89	89	93	99	65	100	93	96	T2
88	94	95	94	95	94	87	87	99	100	80	98	91	94	T3	81
56	73	96	74	97	91	75	86	95	79	97	81	86	T4	67	86
95	81	95	81	80	94	99	83	83	73	86	83				

1,2 See footnotes. Table

Table 4. Mortality rate of *Rhopalosiphum maidis* in petri dishes with and without *Cheilomenes propinqua* predation, Burkina Faso, 1998

Treatment[1]	Aphid mortality rate (%) in control treatment							
	17/09/98		19/09/98		21/09/98		Mean[1]	
TO	0.07	0.00	0.02	0.07	0.03	0.04	0.04	0.04
	Aphid mortality rate (%) in treatments including *C. propinqua*							
	Larva	Adult	Larva	Adult	Larva	Adult	Larva	Adult
T1	99	99	91	92	92	100	94	97
T2	82	96	99	62	98	97	93	85
T3	92	88	100	90	73	86	88	88
T4	92	94	95	74	66	60	85	76

1, 2 See footnotes, Table 1.

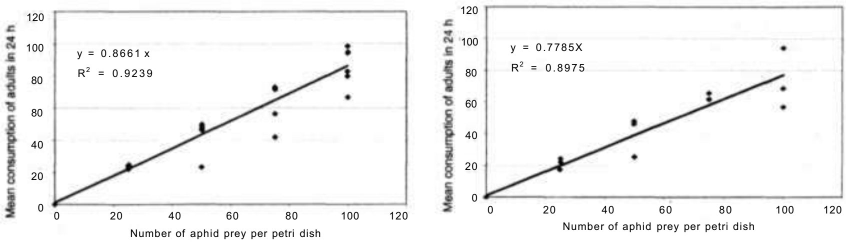

Figure 1. Number of aphid prey *Rhopalosiphum maidis* consumed in 24 h by *Cheilomenes propinqua* adults as a function of the number of prey provided in a. 1997, b. 1998

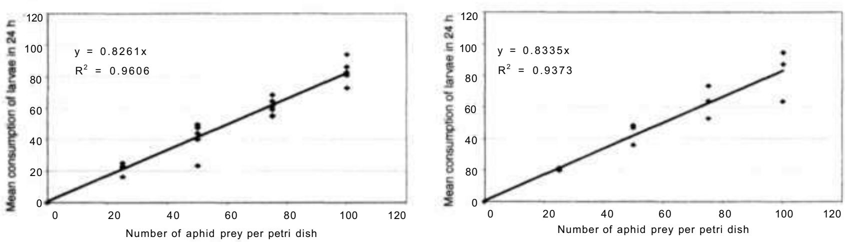

Figure 2. Number of aphid prey *Rhopalosiphum maidis* consumed in 24 h by *Cheilomenes propinqua* larvae as a function of the number of prey provided in a. 1997, b. 1998

Although previous studies had established the predation potential for several other arthropods, including *Lonchaea cortices* Taylor (Hulme 1989), *Bembidion quadrimaculatum* L. (Grafius and Warner 1989), *Podisus maculiventris* Say (Wiedenmann and O'Neil 1991) and *Amblyseius cucumeris* Oudemans (Shipp and Whitfield 1991), this study, to the best knowledge of the author, is the first of the kind conducted on *C. propinqua.*

As with any laboratory study, caution must be exercised when trying to extrapolate the results to the field. Indeed, this study did not consider several biotic factors capable of affecting the effectiveness of predation by *C. propinqua.* Among these are the behavior of the predator in field conditions, its fecundity, development time, and longevity.

Therefore, our next studies will attempt to evaluate the predation effectiveness of *C. propinqua* in the field and to establish the functional response of the predator.

Acknowledgment

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Field Evaluation of Sorghum Accessions for Resistance to Corn Leaf Aphid in Iran

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Introduction

Sorghum [Sorghum *bicolor* (L.) Moench] production has been increasing rapidly in Iran in the recent past, and the area cultivated to sorghum reached 30,000 hectares in 1997. Approximately 90% of this area is under forage sorghums. Grain sorghum for poultry and sweet sorghums for human consumption are also produced (Ajirlou 1997).

Due to environmental concerns, the adverse ecological impact of chemical pesticides, and the high costs associated with chemical control of insects, developing pest-resistant cultivars is the most effective and ecologically safe method of controlling insect pests.

Corn leaf aphid (*Rhopalosiphum maidis* Fitch) is a cosmopolitan pest and it infests maize *(Zea mays* L.), sorghum, rye (*Secale cereale* L.), and other cultivated and wild gramineae. Aphid feeding causes deformation of leaves. Aphids secrete honeydew that makes the leaf surface sticky, and allows sooty molds to grow on the leaves. A high population of aphids covering the panicle and surrounding leaves can reduce grain filling (Williams et al. 1978; Ortega 1987; Tajbakhsh 1996). Corn leaf aphid also plays an important role in the transmission of mosaic and dwarf viruses, that can cause economic losses. Sugarcane mosaic virus (SCMV) causes one of the important virus diseases of maize and sorghum in Iran, and is transmitted by corn leaf aphids. Symptoms of virus infection appear as scattered light and dark green spots with yellow or white stripes in between, on two or three upper leaves. Severe infection reduces plant height, and results in delayed flowering and loss of grain yield (Williams et al. 1978; Tajbakhsh 1996). Studies by Rustamani et al. (1992) indicated that the resistance to corn leaf aphid in sorghum cultivars is associated with aconitic acid. Gahukar (1993) introduced the resistant sorghum cv 51-69 to Senegal for use in plant breeding programs. In Madagascar, the varieties Kafir 29-49G, TM11, Wad Akr Akol 2, and Bazai 2 have been released as resistant to SCMV. However, the resistance in Bazai 2 is a hypersensitive reaction (Baudin 1977).

In the present study, sorghum germplasm accessions from the National Plant Gene Bank of Iran (NPGBI) were evaluated for resistance to corn leaf aphid under natural infestation in the field.

Materials and methods

A total of 129 sorghum accessions (107 Iranian and 22 imported) were sown at Karaj, Iran in May 1999. Each accession was sown in a 2-m row plot. The distance between the rows was 1 m, and the space between plants in row was 10 cm. Data on aphid damage were recorded at flowering, when high populations of corn leaf aphid were established on the plants. Resistance to the aphid was recorded as a score based on the descriptors of the International Plant Genetic Resources Institute (IPGRI), formerly the International Board for Plant Genetic Resources (IBPGR), and the International Crops Research Institute for the Semi-Arid Tropics (IBPGR and ICRISAT 1993). Scores:

1 = Highly resistant, without aphid infestation

3 = Resistant, only a low population of aphid on the youngest leaves and buds

5 = Moderately resistant, few colonies of aphids on the upper one-third of the plant

7 = Moderately susceptible, many aphids on the upper two-thirds of plant

9 = Susceptible, a dense infestation of aphids on all leaves, stems, and panicles.

The scores of 2. 4, 6, 8 were also considered for intermediate resistance types.

Natural infection by SCMV strain Shiraz Corn occurred among the sorghums during the experiment. To evaluate resistance to SCMV, scores were limited to 1,5, and 9 since precise and more-detailed evaluation for resistance to viral diseases is only possible by artificial virus inoculation under controlled conditions:

1 = Resistant, without virus symptoms

5 = Moderately resistant, virus symptoms were scarce or moderate

9 = Susceptible, virus symptoms developed as yellow or white stripes.

Results and discussion

Among the genotypes tested, 14 Iranian and 13 imported accessions showed high levels of resistance (scores 1 to 3) to corn leaf aphid. The Iranian sorghums known as Arzan Siah, had considerable resistance to the aphid and to SCMV. These sorghums had been collected from Ferdows and Tabas locations in Khorasan Province (Table 1). They are dwarfs with narrow dark green leaves and white midribs. Most of the resistant introduced accessions were from the Americas (Table 1). The majority of Iranian accessions had moderate resistance or susceptibility (score of 5 and 6) to corn leaf aphid (Fig. 1). This suggests a relative adaptation of local sorghums, that is usually specific to native landraces. The frequency of different resistance scores showed a normal curve among the Iranian accessions. This shows that there is sufficient variation among them (Fig. 1). The sorghums with sweet sap had higher aphid infestations than the others. As shown in Table 2, there was a positive correlation between sweet sorghums and susceptibility to corn leaf aphid.

Table 1. Name and origin of sorghums field-resistant to corn leaf aphid in the National Plant Gene Bank of Iran (NPGBI) collection, Karaj, Iran, 1999

NPGBI ID no.[1]	Country or organization	Field or donor's number	Province or state	Local name	Aphid resistance score	SCMV[2] resistance score
04090009	Iran		Sistan (Saravan)		3	9
04TN 0002	FAO				2	5
04TN 0003	FAO				1	
04TN 0004	FAO				2	
04TN 0005	FAO	30009			2	
04TN 0006	FAO	30011			3	
04TN 0017	Iran		Kerman (Kerman)	Zorrat oloofehee	3	
04TN 0022	USA	1466		Sorghum	1	
04TN 0023	USA	1461	Texas	Sorghum	1	
04TN 0026	USA	1458		Sorghum	3	
04TN0027	Argentina	1154		Sorghum	2	
04TN 0030	USA	1460	Texas (Dallas)	Sorghum	3	
04TN 0031	USA	1457		Sorghum	3	
04TN 0032	USA	1168		Sorghum	1	
04TN 0033	USA	1459		Sorghum	2	
04TN 0038	Iran	15	Kerman (Kerman)	Sorghum	2	
04TN 0073	Iran	90	Fars (Eghlid)	Sorghum	3	
04TN 0076	Iran	237	Fars (Kazeroon)	Ghorass	3	
04TN 0084	Iran	772	Khorasan (Tabas)	Sorghum	2	
04TN 0093	Iran	565	Khorasan (Ferdows)	Arzan Siah	2	
04TN 0094	Iran	731	Khorasan (Tabas)	Arzan Siah	3	
04TN 0099	Iran	196	Eelam (Dehloran)	Sorghum	1	
04TN 0108	Iran	43	Booshehr (Booshehr)	Sorghum	3	
04TN 0112	Iran	143	Golestan (Gorgan)	Sorghum jarooee	3	
04TN 0116	Iran	1614	Yazd (Yazd)	Sorghum	2	
04TN 0117	Iran	413	Kerman (Baft)	Sorghum	3	
04TN0121	Iran	1433	Khorasan (Birjnd)	Zorrat jarooee	2	

1. Seraj 1997 2. SCMV = Sugarcane mosaic virus.

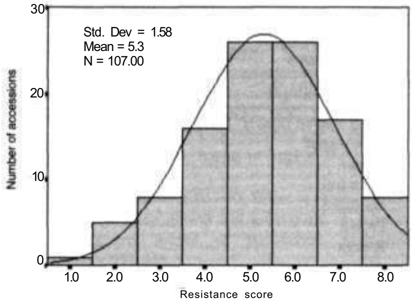

Figure 1. Distribution of corn leaf aphid resistance scores for Iranian sorghums

Table 2. Correlation coefficients between susceptibility to corn leaf aphid and other characters of sorghums, Iran, 1999

SCMV infection	0.612**
Days to harvest	0.198**
Stalk juiciness[1]	0.206*
Stalk sweetness[2]	0.174*
Midrib color[3]	0.106**
Waxy bloom[4]	0.101**
Time to flowering (d)	0.452**
Panicle compactness and shape[5]	0.471**
Seedling vigor[6]	0.246**
Lodging susceptibility[7]	0.197**
Senescence[8]	0.124**
Overall plant aspect"	-0.070 ns
No. of flowering stems	-0.511**
Panicle exsertion (cm)	0.021 ns
Panicle length (cm)	-0.150 ns
Panicle width (cm)	-0.222**
Stalk diameter at 50% flowering (cm)	0.416**
Plant height (cm)	0.104**

** significant at 1% ; * significant at 5% ; ns non-significant
1.0 = Not juicy (dry), 1 = Juicy
2. 1 = Insipid, 2 = Sweet
3. 1 = White, 2 = Dull green, 3 = Yellow
4. 3 = Slightly present, 9 = Completely bloomy
5. 1 = Very lax, 2 = Very loose erect primary branches, 4 - Loose erect primary branches, 6 = Semi-loose erect primary branches, 8 = Semi-compact elliptic, 9 = Compact
6. 3=Low, 7= High
7. 1 = Very low, 9 = Very high
8. 1 = Very slightly, 9 = Completely senescent
9. 1= Very poor, 9 = Very good.

Therefore, it seems that the high concentrations of sugars in these sorghums may be attractive to aphids.

Although many of the plant characteristics of sorghums had significant correlations with aphid resistance (Table 2), some of these correlations might be due to the effect of aphid damage rather than the genetic effects. Highly positive correlations between infestation rate of aphid and SCMV infection (Table 2) suggested that corn leaf aphid was the main virus vector in this region. The relationship between resistance level and the aconitic acid content might need to be studied in the future, as this factor could be used as a suitable reference for identification of cultivars resistant to corn leaf aphid.

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Sorghum Stripe Disease in Maharashtra: Incidence and Sources of Resistance

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Introduction

Sorghum stripe disease (SStD), a disease whose symptoms on sorghum [*Sorghum bicolor* (L.) Moench] are characterized by chlorotic stripes and bands, was shown to be caused by maize stripe virus Sorg (Peterschmitt et al. 1991). It is one of the important diseases of sorghum in India (Narayana and Muniyappa 1995; Revuru and Garud 1998). SStD is transmitted in the field by a delphacid plant hopper, *Peregrinus maidis* Ashmead. The objectives of the present investigation were to survey disease incidence and identify resistance sources in sorghum.

Materials and methods

Survey. A field survey for the incidence of SStD was carried out in Parbhani district, Maharashtra State during the 1998/99 rainy (*kharif*) and postrainy (*rabi*) seasons. The survey was based on visual symptoms. Ten plots, each 3 m^2, were chosen in each field to assess SStD incidence. The number of diseased plants were recorded and disease incidence (%) at each location determined.

Screening for resistance to SStD. Sorghum germplasm lines (2260) were sown in two replications at the Sorghum Research Station, Parbhani, and evaluated for resistance to SStD by visual scoring.

Results and discussion

Survey. The results from the survey (Table 1) showed that the incidence of SStD in Parbhani district during the rainy season ranged from 4% at Pokharni to 18% at Daithna. The incidence was comparatively low during the postrainy season. In rainy-season crops raised on the experimental station in Parbhani, disease incidence ranged from 2% to 9%, and in the postrainy seasons it ranged from 9% to 21 % (Table 2).

Screening for resistance to SStD. Out of 2260 sorghum germplasm lines evaluated, 98 did not express disease symptoms under field conditions. SStD incidence was below 10% in 119 lines and in 444 lines the incidence was over 50%.

Table 1. Incidence of sorghum stripe disease (SStD) at different locations in Parbhani district, Maharahstra, India, 1998/99

Location (village)	SStD incidence (%)
Rainy season (*kharif*) 1998	
Dharmapur	7.0-13.0
Takali	6.0-15.0
Pokharni	4.0-17.0
Daithana	7.0-18.0
Parwa	6.6-14.3
Kinola	8.0-14.0
Asola	7.0-15.6
Aval	8.0-12.6
Postrainy season (*rabi*) 1998/99	
Daithana	4.3-11.0
Gangakhed	9.0-11.3
Takali and Dharmapur	4.6-10.3
Jintur	5.3-11.0
Kolha, Parwa, Knola	2.3-11.3
Pathri	6.0-11.0
Aral	6.6-11.3
Vasmat	7.0-11.3

Table 2. Incidence of sorghum stripe disease (SStD) in rainy and post rainy seasons at Sorghum Research Station, Parbhani, Maharashtra, India, 1998/99

	Disease incidence (%)	
Genotype	Rainy season	Postrainy season
CSH I5R	5	9
SPV 1090	7	21
SPV 1155	5	9
CSV 14R	8	16
SPV 1215	7	9
Swati	6	11
SPV 1217	5	17
CSV 8R	4	10
SPH 695	8	21
CSH 13(R)	2	7
SPH 733	5	16
SPH 850	7	16
M 35-1	9	13
SPH 922	8	16
SPH 634	6	15
SPV 1210	6	11
SE	±2.6	±3.5
CD at 5%	7.5	10.2

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Identification of Different Sources of Genetic Resistance to Anthracnose in Sorghum

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Introduction

The production of grain sorghum is often severely limited in the warm, humid regions of the world due to anthracnose, a disease caused by the fungus *Colletotrichum graminicola* (*Ces.*)Wits. (Ali and Warren 1992). Due to the severity of the disease, several control measures have been developed, but the employment of host-plant resistance to avoid these losses has been suggested as the most effective disease control strategy (Rosenow and Frederiksen 1982).

Different numbers and patterns of inheritance of resistance genes for anthracnose have been suggested by various authors (Colemean and Stokes 1954; Jones 1979; Tenkouano 1993; Booraet al. 1998). Regardless of which strategy is used for gene pyramiding, new sources of resistance must be identified and their mode of inheritance must be characterized. The objective of this experiment was to determine if different sources of genetic resistance exist among 13 sorghum germplasm lines, and to determine the inheritance of anthracnose resistance in these germplasms.

Materials and methods

A set of sorghum conversion lines that had been identified as anthracnose-resistant were crossed among each other (R x R crosses) and to the susceptible parent BTx623 (R x S crosses). $F_{2:3}$ progeny rows were generated and evaluated in 1996,1999, and 2000. Five different anthracnose-susceptible controls were included to ensure that the disease was present throughout the experiment. The experimental materials were inoculated by applying a conidial suspension of *Colletotrichum graminicola* into the whorl of each plant with a backpack sprayer. All susceptible control plots exhibited symptoms of the disease within 2 weeks of inoculation. If all the progeny rows within a family were completely resistant, then the parents of that family have the same resistance gene(s), or resistance genes that are very tightly linked. The presence of completely susceptible and segregating progeny rows within a family would indicate that different resistance genes are present in the parents of that family. A plant was rated as susceptible if lesions with *C. graminicola* setae were detected on its leaves.

To determine the inheritance of anthracnose resistance, the observed ratio of resistant and susceptible plants in each segregating F_2 population was fitted to two different genetic models using the X^2 analysis for goodness-of-fit (A<0.05).

Results and discussion

The data from both years were relatively consistent, in that $F_{2:3}$ progeny rows from the same seed source scored as segregating or susceptible in 1996 had the same scores in 1999. There were a few changes in frequencies that were larger than expected (Table l). The exact cause for this variation is not known, but it could be due to environmental variability and the reaction of the individual genotypes to the pathogen.

The results from the R x R and R x S families indicate that different resistance genes exist in the parents of those families and 10 out of 13 lines were placed into one of the six groups (Table 2). Three lines could not be assigned to a group at this time. The data indicate that SC155-14E and SC84-14E have the same resistance gene(s) designated as Group 1, because the SC155-74E x SC84-14E $F_{2.3}$ progeny rows did not segregate (Table 1). Group 2 is composed of SC647-14E, SC166-*14E*, SC701-*14E*, and SC991-ME. Groups 1 and 2 are different because crosses between the two groups (SC155-*14E* x SC991-*14E* and SCI55-ME x SC647-/4E) have segregating and susceptible $F_{2.3}$ progeny rows (Table 1). SC748-5 is placed into Group 3 and SC137- *14E* into Group 6 (Tables 1,2, and 3). Segregation studies of crosses indicate that SC155-*14E*

Table 1. Observed numbers of resistant, segregating, and susceptible $F_{2:3}$ progeny rows for anthracnose resistance by resistant sorghum families in 1996,1999, and 2000

Family	Year	Number of $F_{2:3}$ families			Source of resistance[1]
		Resistant	Segregating	Susceptible	
SC155-*14*E x SC120-*14*E	1996	90	53	6	D
	1999	34	7	1	D
SC155-*14*E x SC84-*14*E	1996	49	1	0	S
	1999	50	0	0	S
SC155-*14*E x SC414-12E	1996	80	24	2	D
	1999	34	10	1	D
SC155-*14*E X SC748-5	1996	79	26	6	D
	1999	37	13	0	D
SC155-*14*E X SC991-*14*E	1996	81	20	4	D
	1999	31	18	1	D
SC155-*14*E x SC176-*14*E	1996	96	8	0	D
	1999	35	6	0	D
SC155-*14*E X SC137-*14*E	1996	45	2	0	D
	1999	31	16	3	D
SC155-*14*E x SC647-*14*E	1996	83	9	3	D
	1999	46	4	o	D
SC155-*14*E x SC326-6	2000	26	8	5	D
SC748-5X SC326-6	2000	30	6	0	D
SC748-5 X SC120-*14*E	2000	38	4	1	D
SC748-5 x SC137-*14*E	2000	47	4	0	D
SC991-*14*E x SC326-6	1996	77	23	0	D
	1999	33	6	0	D
SC991-*14*E X SC701-*14*E	1996	101	0	0	S
	1999	50	0	0	S
SC414-*14*E x SC991-*14*E	2000	48	12	0	D
SC414-*14*E X SC326-6	2000	36	6	1	D
SC137-*14*E x SC991-*14*E	2000	42	9	0	D
SC647-*14*E x SC166-*14*E	1996	70	1	0	S
	1999	40	0	o	S
SC647-*14*E X SC701-14E	1996	66	1	0	S
	1999	41	0	0	S
SC647-*14*E x SC326-6	1996	55	23	4	D
	1999	34	7	0	D
SC701-*14*E X SC748-5	1996	94	3	2	D
	1999	47	3	0	D
SC689-*14*EX SC166-*14*E	1996	54	26	3	D
	1999	34	5	2	D

1. D= SC lines with a different source of resistance, S= SC lines with the same resistance gene(s).

Table 2. Classification of the 13 sorghum germplasm lines into groups with different genetic resistance to anthracnose based on the evaluation of $F_{2:3}$ segregation data from specific crosses of the parents

Recessive Group 1	Dominant Group 2	Dominant Group 3	Recessive Group 4	Recessive Group 5	Dominant Group 6	Yet to be classified
SC155-*14*E	SC647-*14*E	SC748-5	SC414-*14*E	SC326-6	SC137-*14*E	SC120-*14*E
SC84-*14*E	SC166-*14*E					SC689-*14*E
	SC701-*14*E					SC176-*14*E
	SC991-*14*E					

Table 3. Segregation ratios of F_2 populations from crosses of anthracnose resistant sorghum germplasm lines by susceptible inbred BTx623

		Phenotype[1]				
		Observed		Expected (3:1)		
Cross	Resistance group	R	S	R	S	X^2 value
SC137-*14*E(G6)x BTx623	Group 6	143	37	135	45	1.90
BTx623 x SC137-*14*E(G6)	Group 6	137	60	148	49	3.29
BTx623 x SC991-*14*E(G2)	Group 2	166	52	164	54	0.10
BTx623 x SC166-*14*E(G2)	Group 2	42	20	46	16	1.74
BTx623 x SC748-5 (G3)	Group 3	235	60	221	74	3.54
BTx623 x SC689-*14*E	Unassigned	238	59	223	74	4.04*
SC155-*14*E (GI) x BTx623	Group 1	24	123	37	110	6.10*
SC326-6(G5)x BTx623	Group 5	54	192	61	185	1.07
BTx623x SC4*14*-72E(G4)	Group 4	43	155	49	149	0.98

1. R = Resistant. S = Susceptible. * $P(X^2 < 3.84$. df = 1)<0.05.

(Group 1), SC414-*14*E (Group 4) and SC326-6 (Group 5) have resistance genes different from each other.

The non-significant X^2 value for the crosses SC137- *14E* x BTx623,BTx623x SC991-*14*E,BT x 623 x SC166-*14*E and BTx623 x SC748-5 indicates that a single dominant gene for resistance is segregating in each of the F_2 populations (Table 3). The segregation ratios ohserved in the crosses of SC326-6 x BTx623 and BTx623 x SC414-*14E* fit a 3:1 susceptible : resistant ratio, indicating that resistance is conferred by a single recessive gene in these lines (Table 3). The segregation pattern in the BTx623 x SC689-*14*E cross indicates that resistance is dominant and likely controlled by a single gene, however the X^2 value for the data was marginally significant. In the SC155-*14*E x BTx623 cross segregation indicates that resistance is recessive, but the segregation ratios did not fit that expected for a single gene. Additional testing for each of these lines is needed to determine the pattern of inheritance.

Segregation ratios in resistant x susceptible F_2 progeny indicate that inheritance of anthracnose resistance in Groups 2, 3, and 6 is controlled by a single dominant gene (Table 3). In Groups 4 and 5 resistance to anthracnose is controlled by a single recessive gene (Table 3). In Group 1 resistance appears recessive and oligogenic, but the observed segregation did not fit simple models. Additional evaluation of this population is necessary.

Three lines could not be assigned to any group, but the data eliminate them from specific groups (Table 1). The dominant resistance from SC120-*14*E is different from Groups 1 and 3, but testing is required to determine if it fits in Group 2. SC 1*76-14E* does not fit Group 1 and it has not been crossed with lines from the remaining five groups (Table 1). Because SC689-*14*E has a single dominant gene for anthracnose resistance (Table 3), it does not belong to Groups 1, 4, or 5. When crossed with lines from Group 2, susceptible progenies were observed, indicating it does not fit in Group 2. Additional testing is needed to determine if it belongs to Group 3, Group 6, or a new group.

The results indicate at least six different sources of genetic resistance are present among the 13 resistant sorghum germplasm lines. These results are based on the

C. graminicola isolate 430BB-85 that is very aggressive and commonly present in Texas (Cardwell et al. 1989). Once the inheritance of different resistance genes is finalized, breeders can begin to utilize germplasm lines from the different groups to develop new sorghum cultivars with new and different resistance genes and/or with pyramided resistance. We have identified AFLP markers for resistance genes in SC155-*14E* and SC748-5 and confirmation of putative linkages is in progress.

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Effect of Two Mold-Causing Fungi on Germination of Sorghum Seed

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In Maharashtra, rainy-season sorghum [*Sorghum bicolor* (L.) Moench] is generally affected by grain mold when wet conditions occur when the grain matures during September and October. A complex of fungi cause grain mold, with *Fusarium* spp. and *Curvularia lunata* (Wakk.) Boedijn as the dominant species in this complex. A correlation study was conducted to determine the effects of these fungi on germination.

To detect the fungi associated with grain mold, 25 seeds of each of 13 sorghum genotypes were placed in previously sterilized petri dishes lined with wet blotting papers. The seed was from the 1998 rainy-season harvest. The petri dishes served as humid chambers to support fungal growth. The plates were incubated at 28-29°C for 8 days in an incubator with a 12-h alternate light and dark cycle. Seeds were infected and counted separately. The germination percentages were recorded for all genotypes using the rolled towel method.

Statistical analysis for percentage *Fusarium* spp. and *C. lunata* infection (Table 1) and their correlation with seed germination indicated that the *Fusarium* infection was significantly related to germination (r = -0.64**). Infection by *Curvularia* did not have any effect on seed germination (r = 0.28 ns). From this study it can be concluded that germination is drastically affected by infection with *Fusarium* spp.

Table 1. Seed infection of 13 sorghum genotypes by *Fusarium* spp. and *Curvularia lunula* and their effects on germination

Genotype	*Fusarium* spp. (%)	*Curvularia lunata* (%)	Germination (%)
CSV 13	26.0	19.0	18.0
SPV 1231	17.0	42.0	36.5
SPV 1293	56.5	28.0	11.0
SPV 1333	11.0	19.0	66.0
SPV 1022	31.5	24.0	12.0
CSV 15	47.5	52.5	6.0
SPV 1328	21.5	54.5	11.0
SPV 1430	15.5	31.5	19.0
SPV 1403	27.0	26.5	55.0
SPV 462	25.0	37.5	18.0
CSH 5	23.0	29.0	33.5
IS 14332	11.0	72.5	80.0
296B	38.0	7.5	6.0
SE	±2.4	±2.8	±2.5

Development of Grain Mold in Sorghum - Pigeonpea Intercropping Systems

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Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is a staple food crop in semi-arid tropical areas of Africa and India. It is also an important feed and forage crop in other parts of the world. Grain molds have became important diseases of sorghum in India and other sorghum-growing countries due to introduction of high-yielding, short-duration cultivars that mature and fill grain during rainy days. In Maharashtra, rainy-season sorghum is generally affected by grain molds following rainfall in September and October. Grain molds are caused by a complex of many fungi and the severity of mold development increases when a prolonged wet period delays harvesting (Garud et al. 1994). The present study was under taken to investigate the effect of intercropping on the development of grain molds.

Materials and methods

In the rainy season (*kharif*) of 1999 sorghum (cv Parbhani Sweta) and pigeonpea [*Cajanus cajan* (L.) Millsp.] (cv BSMR 736) were sown in 3:3 and 4:2 intercropping and as a sole crop of sorghum in separate experimental plots at the Sorghum Research Station, Parbhani, Maharashtra, India, in a randomized block design. Twelve panicles of sorghum were harvested from each plot and threshed separately.

The threshed grain were then separated into five intensity grades (TG 1 = least mold and TG 5 = most mold). The observations recorded were on the percentages of moldy grains, pink molded (*Fusarium* spp.), black molded grain [*Curvularia lunata* (Wakk.) Boedijn], *Phoma* infected, and the percentage of germination. The data were statistically analyzed.

Results and discussion

It is clear from the data in Table 1 that there were more moldy grains in the 3:3 intercrop than in the 4:2 intercrop and the sole crop. The sole crop had the least moldy grains. There were significantly more pink-molded grains in the 3:3 intercrop than in the 4:2 intercrop and the sole crop, but intercropping scheme had no significant effect on the percentage of black-molded grains. There was no significant effect of intercropping on the development of infection by *Phoma.* However, the germination of molded grains was significantly less in the 3:3 and 4:2 intercrops than in the sole crop (46.37%). The threshed grade (TG) ratings were also significantly higher in the two intercrops than in the sole crop.

From the above observations, it can be concluded that grain molds develop more in intercrops than in sole cropping systems. This may be due to a higher inoculum load, that was not disseminated because of the height of the pigeonpea intercrop (270 cm) and the conditions in intercropping being more humid than in the sole crop.

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Table 1. Development of grain molds in intercropped and sole-cropped sorghum[1], Parbhani, Maharashtra, India, rainy season 1999

Treatments	Moldy grain (%)	Pink moldy grain (%)	Black moldy grain (%)	*Phoma* infected grain (%)	Germination (%)	Threshed grade ratings[2]
3:3 intercrop	27.60	7.60	19.87	4.49	15.54	4.24
4:2 intercrop	23.33	3.82	19.17	3.67	26.63	3.75
Sole crop	21.19	3.20	10.76	4.49	46.37	3.35
SE	±1.55	±0.80	±1.77	±0.61	±4.37	±0.07
CD at 5%	4.56	2.34	5.19	NS	12.23	0.20

1. All figures are arcsine-transfornied values
2. Threshed grade values are given in 1-5 scale where 1 = minimum, and 5 = maximum.

Utilization

Use of Sorghum Starch Maltodextrin as a Fat Replacement in Low-calorie Foodstuffs

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In recent years, the adverse effects on human health of excessive dietary fat consumption have become universally known. Sorghum [*Sorghum bicolor* (L.) Moench] is rich source of starch that has good physicochemical and pasting characteristics and amylolytic susceptibility (Wankhede et al. 1989). It is considered a preferred stock for making maltodextrin that can act as a fat replacement and can be exploited in many food products without affecting their organoleptic (taste) qualities. Hence, sincere efforts were made to explore the possible use of sorghum starch maltodextrin as a fat replacement in low-calorie foodstuffs.

Sorghum grains (cv Parbhani Sweta) were procured from the Sorghum Research Station, Parbhani from the rainy-season harvest 1998. Proximate analysis was performed by standard procedures (AOAC 1990). Isolation and purification of starch was carried out by the method of Wankhede et al. (1989). The starch so prepared was subjected to acid hydrolysis to obtain maltodextrin with dextrose equivalent to 10 ± 2.

The sorghum grains were rich in starch (70.31 %). Their protein content was 9.01%, and their fat content 2.68%. The isolated starch contained 95.78% total carbohydrates and 1.05% protein after repeated purification. The sorghum starch maltodextrin moisture-free sample contained 98.72% total carbohydrate and negligible quantities of protein (0.70%) and fat (0.07%). The color of maltodextrin was bright white. It had a molecular weight of 1,75,000 ± 5,000, and irregularly shaped granules, 3-5 µm in diameter. This maltodextrin was used as a fat replacement for shortening in cookies and papaya toffee. The content ranged from 25 to 45% (weight/weight). The cookies and toffee were organoleptically evaluated by semi-trained taste panelists using a 9-point hedonic scale.

Results and discussion

The findings of the organoleptic evaluation indicated encouraging results. Good quality cookies could be prepared by replacing 35% of the shortening (weight/weight) with maltodextrin without affecting taste. High quality papaya toffees were also prepared with 25% of their vegetable fat replaced (weight/weight) with maltodextrin.

It can be concluded that good quality starch can be prepared from sorghum grain. This is a vital and potential raw material for the production of maltodextrin, and can be exploited for industrial/commercial use in different food products as a fat replacement. Maltodextrins are metabolized similarly to starch, and exhibit hypocholesterolemic activity—a study on this aspect is in progress.

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Variability in Nutritional Composition and *Roti-making* Quality Traits in Sorghum

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Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is a staple food grain in many Indian states. It is consumed in different forms and *roti* (unleavened bread) is the most common one in the state of Maharashtra. Consumer's acceptability of the grain for rori-making depends on the growing season, grain quality, and such organoleptic parameters such as *roti* color, texture, aroma, and taste (Subramanian and Jambunathan 1984). Although released improved hybrids and varieties have increased sorghum grain production, scant attention has been paid to improvement in nutritional quality and consumer acceptability in sorghum food products. In the present investigation the nutritional composition and raft-making qualities of some improved sorghum genotypes were studied in detail.

Materials and methods

In order to evaluate to nutritional and roti-making qualities of sorghum grain, samples were produced at the Sorghum Research Station, Parbhani during the rainy (*kharif*) season of 1999 under identical management. The samples were milled into flour in the laboratory and analysed for their proximate composition (i.e., moisture, crude fat, ash, protein, and fiber contents) according to AOAC (1990) procedures. Starch content was estimated by the method of McCready et al. (1950). Free and total sugars were determined using the method of Dubois et al. (1956) and *roti* were prepared as outlined by Murty and Subramanian (1981). The organoleptic properties of *roti* were scored in the laboratory by a semi-trained taste panel of 10 people. The *roti* color, texture, aroma, taste, and general appearance were scored on 1-9 hedonic scale (1 = dislike extremely and 9 = like extremely). The keeping quality of the *roti* was scored using the same scale after 12 h storage at room temperature in a bamboo basket (generally used in Maharashtra to store *roti).*

Results and discussion

Significant variations in the contents of protein, starch, free sugar, fiber, fat, and ash were observed in various sorghum genotypes (Table 1). Among the genotypes varieties PVK 823 (11.0%) and PVK 801 (10.4%) were found statistically superior to the others in protein content. The maximum percentages of starch (72.33%) and free sugar (2.81%) were observed in PVK 801 followed by PVK 823. The highest crude fiber, fat, and ash contents were recorded in hybrid CSH 9. On the basis of nutritional composition, approximate calorific value was calculated and found to be highest in PVK 801. In general, some of the varieties were found nutritionally superior to the hybrids, and these wide variations may be due to the genetic variability among these cultivars. Similar results were also reported by Desai et al. (1992).

The *roti*-making qualities of sorghum genotypes also varied significantly (Table 2). Among the genotypes evaluated PVK 801 was superior in color, aroma, general appearance, keeping quality, and overall acceptability. It was ranked first. However, variety PVK 823 had the best texture and taste values. The hybrids PKSH 213, CSH 9, and CSH 16 were found statistically inferior to the varieties tested in their *roti* quality characteristics that are directly related to their nutritional composition. Chavan and Nagarkar (1988) recorded similar genetic variability in the nutritional and *roti* qualities of sorghum grain.

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Table 1. Nutritional composition (%) of sorghum grains produced at Parbhani, Maharashtra, India, rainy season, 1999

Genotype	Moisture	Protein (Nx 6.25)	Starch	Soluble/ free sugars	Crude fiber	Crude fat	Ash	Approximate calorific value (Cal 100 g^{-1})
Varieties								
CSV 15	9.35	10.08	71.05	2.60	2.39	2.07	2.13	354
PVK 400	9.88	9.22	70.22	2.48	2.50	2.44	2.27	349
PVK 801	9.47	10.40	72.33	2.81	1.75	1.69	1.88	356
PVK 809	9.78	9.30	69.05	2.65	2.63	2.88	2.85	350
PVK 823	9.80	11.00	70.75	2.70	1.97	2.00	1.71	355
PVK 813-7	9.84	9.13	68.32	2.44	2.86	2.81	2.75	345
Hybrids								
PKSH 213	9.77	8.65	68.44	2.23	2.80	2.92	3.18	343
CSH 9	9.68	8.11	68.02	2.15	3.00	3.40	3.37	344
CSH 16	9.82	8.32	68.15	2.19	2.85	3.38	3.46	345
SE	±0.11	±0.25	±0.34	±0.06	±0.11	±0.12	±0.07	±1.4
CD at 5%	NS	0.76	1.01	0.19	0.34	0.35	0.20	4.2

Table 2. *Roti* quality characteristics of some rainy-season sorghum genotypes produced at Parbhani, Maharashtra, India, during 1999

Genotype	Color	Texture	Aroma	Taste	General appearance	Keeping quality	Overall acceptability	Rank
Varieties								
CSV 15	6.40	5.94	6.80	6.59	7.30	6.32	6.56	III
PVK 400	5.45	6.52	6.00	6.63	6.21	5.73	6.09	V
PVK8 01	7.60	6.33	7.52	7.37	7.80	6.57	7.20	I
PVK 809	5.80	6.72	6.63	6.22	6.33	6.05	6.29	IV
PVK 823	7.30	7.50	7.05	7.41	6.12	6.30	6.95	II
PVK 813-7	5.70	6.00	5.81	5.33	6.05	5.52	5.73	VI
Hybrids								
PKSH 213	6.14	4.55	5.15	6.02	5.15	4.48	5.25	VII
CSH 9	4.40	4.51	4.03	5.00	4.35	4.59	4.47	IX
CSH 16	5.22	4.30	5.00	5.09	5.61	4.06	4.88	VIII
SE	±0.20	±0.16	±0.19	±0.08	±0.22	±0.18	±0.11	-
CD at *5%*	0.61	0.49	0.56	0.25	0.67	0.54	0.31	-

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Millet Research Reports

Germplasm

Dauro Millet Germplasm Collection in Nigeria

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Introduction

Three types of pearl millet [*Pennisetum glaucum* (L.) R. Br.] are cultivated on about 5 million hectares in Nigeria (FAO 1992). *Gero,* the photoperiod-insensitive early-maturing type, is grown in the relatively dry (Sudano-Sahelian) Zone (500-900 mm annual rainfall) of northern Nigeria. *Maiwa* and *dauro,* the photoperiod-sensitive types, are cultivated in the medium to high rainfall areas (1000-1200 mm annual rainfall), with *dauro* being restricted to the areas on and around the Jos Plateau.

Much of the research on pearl millet in Nigeria has focused on *gero* and *maiwa,* with less attention to *dauro* whose potentials are worthy of exploitation. Indeed, although several millet germplasm collections have been made in the past (Appa Rao et al. 1994), the *dauro*-producing areas of Nigeria were not adequately covered. Consequently, the Lake Chad Research Institute (LCRI), that has the national mandate for the genetic improvement of pearl millet, did not have a single germplasm accession of *dauro* in its collection.

A collection trip was therefore made in 1997 to determine the economic importance of *dauro,* its role in the diet of people in the production areas, and the potential for exploiting its characteristics to improve local landraces of pearl millet in Nigeria. Simultaneously, a survey of the insect pests of photoperiod-sensitive pearl millets was made to complement earlier surveys (Harris 1962; Nwanze 1989; Dike and Ajayi 1997).

Collection

The collection team included a breeder from LCRI and entomologists from the Institute for Agricultural Research (IAR) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Kano. Collections were made from 24 to 27 November 1997. The team covered 47 towns and villages in 23 Local Government Areas of Kaduna, Plateau, and Nassarawa States, that represent the dauro-producing areas of Nigeria. Twenty-three farmers were interviewed. The collection was made by traveling along the highways and other motorable roads, stopping every 20 km to examine *dauro* millet farms. The coarse grid sampling method was followed, and samples were selected from farmers' fields. The objective of sampling was to collect at least one panicle of every variant occurring in the target population (individual fields) with a frequency greater than 0.05, as suggested by Marshall and Brown (1975). Of the 34 samples collected, 25 were *dauro* and 9 were *maiwa* (Table 1). Samples were listed in the sequence in which they were collected and prefixed DM97 (*dauro* millet collected in 1997) and MM97 (maiwa millet collected in 1997).

Differences between *dauro* and *maiwa*

Pearl millet types in Nigeria differ so much that Stapf and Hubbard (1934) classified short-duration millet as *Pennisetum typhoides* (Stapf and Hubb.) and long-duration millet as *P. maiwa* (Stapf and Hubb.). As they cross easily, they were later grouped into a single species *P. americanum* (L.) Leeke (Brunken 1977) and even later into *P. glaucum* (L.) R. Br. The two distinct forms of the photoperiod-sensitive types are called *maiwa* and *dauro.*

Maiwa is strongly photoperiod-sensitive and produces long panicles. It is direct-sown in the field between June and July, often intercropped with sorghum, on heavy soils in the relatively high rainfall areas of the Sudan and Guinea Savannas. The plant grows erect to more than 3 meters tall, tillers profusely, and has several long leaves covered by dense long hairs. It flowers in September or October, towards the end of the rains, irrespective of the date of sowing, and matures on residual soil moisture (Appa Rao el al. 1994). *Maiwa* is sometimes erroneously called *dauro* in several localities, particularly Langtang, Shendam, Lafiya, Akwanga, and Gwantu on the Jos Plateau.

Dauro is transplanted and produces very few tillers. It is usually grown at high altitudes and is strongly photoperiod-sensitive. Nurseries are raised on broadbeds in June/July. After 3-4 weeks, usually in August, seedlings are transplanted onto ridges. These ridges are made from old ridges from which the local early-maturing cowpea [*Vigna unguiculata* (L.) Walp.] *achisuru* is harvested in July. The haulms of cowpea are incorporated into the soil to serve as manure. *Dauro* matures in November, after the rains. Due to the thin nature of the stem and peduncle, the weight of the panicle causes the whole plant to bend. This characteristic is termed *doro* in the Hausa language and

Table 1. *Dauro* millet germplasm collected in Kaduna, Plateau, and Nassarawa States, Nigeria, 24-27 November 1997

Accession number[1]	Town/Village	Local government area	State
DM97001	Soba	Soba	Kaduna
DM97002	Soba	Soba	Kaduna
DM97003	Soba	Soba	Kaduna
DM97004	Dutsen Wai	Kuban	Kaduna
DM97005	Pambegua	Kuban	Kaduna
DM97006	Gidan Waya	Lere	Kaduna
DM97007	Kayardu	Lere	Kaduna
DM97008	Ganji	Lere	Kaduna
DM97009	Jengre	Basa	Plateau
DM97010	Bukuru	Jos South	Plateau
DM97011	Mangu	Mangu	Plateau
MM97012	Ashinge	Lafiya	Nassarawa
MM97013	Adogi	Lafiya	Nassarawa
MM97014	Lafiya	Lafiya	Nassarawa
MM97015	Gwantu	Sanga	Kaduna
MM97016	Angwan Rimi	Sanga	Kaduna
MM97017 (Gamba)	Angwan Mala Maku	Sanga	Kaduna
MM97018	Kanafi	Jama'a	Kaduna
DM97019	Kanafi	Jama'a	Kaduna
DM97020	Gidan Waya	Jama'a	Kaduna
DM97021	Kagoro	Kaura	Kaduna
DM97022	Kafanchan	Jama'a	Kaduna
DM97023	Malagum	Kaura	Kaduna
DM97024	Samaru Kataf	Zangon Kataf	Kaduna
DM97025 A	KADP Samaru Zone	Zangon Kataf	Kaduna
DM97025 B	KADP Samaru Zone	Zangon Kataf	Kaduna
DM97026	Fadiya Bakaf	Zangon Kataf	Kaduna
DM97027	Kurgiam	Zangon Kataf	Kaduna
DM97028	Angwan Mission	Kachia	Kaduna
DM97029	Crossing Katul	Kachia	Kaduna
MM97030	Makyali	Kajuru	Kaduna
DM97031	Danbangu	Kajuru	Kaduna
MM97032	Tashan Iche	Chikun	Kaduna
DM97033	Kudunsa	Kaduna south	Kaduna

1. Key to accession numbers: DM = *dauro* millet, MM = *maiwa* millet, 97 = Year of collection (i.e., 1997), 001-033 = Serial number within collection.

may have given this crop its name. It produces medium-sized panicles with grains that are partly corneous, attractive, and shiny. At harvest, *dauro* panicles are snapped along with a length of the peduncle and tied into bundles. These are stored unthreshed on rooftops and in grass barns.

Variability within *dauro* millet

There was considerable variation within a field for plant height (150-350 cm), time to flowering (70-90 days), days to maturity (100-120), panicle shape and length (20-45cm), and panicle thickness and compactness. Compared to *gero, dauro* is more uniform while *maiwa* is intermediate with respect to the leaf arrangement on its stem.

Agronomy of *dauro* millet

Dauro very effectively uses light, rainfall, and land. It is grown as a second crop after early-maturing cowpea. Farmers claimed that it requires less fertilizer than *maiwa.*

Geographical distribution *of dauro* production

Dauro was found in the following localities: Gidanwaya, Kafanchan, Kagoro, Zangon Kataf, Samaru-Kataf, Zonkwa, Kwoi, Keffi, Kachia, Saminaka, Jengre, and Crossing Katul. These are all in the Northern Guinea Savanna ecological Zone in the area described as Southern Kaduna in Kaduna State.

Production statistics

According to the Zonal Manager (Samaru-Kataf Zone) of the Kaduna State Agricultural Development Project (KADP), Kaduna State cultivates *dauro* on about 39,335 ha with an average total annual production of 56,954 t of grain. Grain yield varies from 810 to 840 kg ha^{-1}. Market price varied from Naira 14,272 to Naira 14,815 in 1996. Similar data were not available for Plateau and Nassarawa States.

Uses of *dauro*

The grains are used for a variety of local dishes, including *kunu, jura, kiko,* and *tuwo,* and for local beer which may be sweet or fermented.

Constraints to *dauro* production

Despite such desirable characteristics as bold grains and the yellow endosperm of some cultivars (the latter indicating the presence of vitamin A), the crop has suffered a decline in production over the years. Indeed, farmers now tend to grow maize where *dauro* would traditionally be the favored crop. In Kaduna State, for example, total production was 99,400 t in 1987, but this declined by 72% to 27,600 t in 1994. According to the farmers, this decline was due to the non-availability of improved seeds and improved agronomic practices, and to damage by insects and diseases. Since improved varieties of *dauro* are not available, farmers grow traditional cultivars, that are heavily attacked by downy mildew [*Sclerospora graninicola* (Sacc.) J. Schrot.] and stem borers *[Coniesta ignefusalis* Hampson (Lepidoptera: Crambidae)]. During this survey, downy mildew infection ranged from 10 to 13% of plants in most of the fields, while stem borer attack ranged from 5 to 25%. Seeds are obtained from the previous year's harvest or from the market. Such seed is usually contaminated with downy mildew, smut *[Moesziomyces penicillariae* (Bref.) K. Vanky], and ergot (*Claviceps fusiformis* Loveless).

Possible uses *of dauro* germplasm

Dauro is a good source of cold tolerance. Both *dauro* and *maiwa* are good sources of grain quality, particularly for improving grain size in *gero* millet. The *dauro* plant has high biomass productivity and can therefore be used as fodder for livestock feed, since it stays green until harvest.

Future collections

Collections in the future should explore the following route that the team could not cover during this survey: Kwoi-Keffi-Abuja-Kaduna.

Insect pests of *dauro* millet

Coniesta ignefusalis was the only stem borer found on *dauro* and *maiwa* millet during the survey. It infested 75.5% of the farms visited. *Dauro* and *maiwa* were either sown sole or inter-cropped in various combinations with cowpea, sorghum [*Sorghum bicolor* (L.) Moench], sweet potato *[Ipomoea batatas* (L.) Lam.], groundnut (*Arachis hypogaea* L.), bambara groundnut *[Vigna subterranea* (L.) Verdc], sesame (*Sesamum indicum* L.), okra *(Abelmoschus* spp.) and yam (*Dioscorea* spp.). Lower borer incidence was observed on millet in millet + sorghum + legumes + sesame (8%), and millet + sorghum + sesame (10%) than in other crop combinations. There was a higher stem borer attack on *maiwa* or *dauro* sown in July than on those sown in June or August.

The range of insects found on *dauro* and *maiwa* was similar to that observed on *gero* and *maiwa* in earlier surveys (Ajayi 1985; Ajayi and Uvah 1988; Dike and Ajayi 1997). They comprised Hymenoptera, including the stem borer parasitoid *Syzeuctus* sp.; Coleoptera, particularly flower-feeding beetles such as *Melyris abdominalis* Fabricius, *Coryna hermanniae* Fabricius, *Mylabris* spp., *Psalydolytta* spp., and *Cheilomenes sulphurea* Olivier; Hymenoptera, especially *Dysdercus* *voelkeri* Fabricius, *Agonoscelis erosa* Fabricius, *Nezara viridula* L., *Mirperus jaculus* Thunberg, *Lygaeus rivularis* German, *Clavigralla tomentoscicollis* Stal. *Anoplocnemis curvipes* Fabricius. *Eurystylus* sp., *Oxycarenus* sp., *Locris rubens* Erichson, *L. erythromela* Walker and *Poophilus costalis* Walker. Other insect groups were Diptera, mainly *Chrysomia* sp. and *Sarcophaga* sp.; Dermaptera, a species of *Forficula;* Orthoptera, including *Catantops stylifer* Krauss, *Dnopherula* sp., *Kraussaria angulifera* Krauss, *Pyrgomorpha vignaudi* Guerin, and *Zonocerus variegatus* L.; and Lepidoptera, represented by the millet head miner *Heliocheilus albipunctela* de Joannis. Crop loss assessments were not made during the survey. However, it has been reported that *C. hermanniae* can cause crop losses of 18 to 75%, depending on population density (Ajayi et al. 1998), while a combination of flower beetles and *Dysdercus* caused up to 69% grain yield loss in Ghana (Tanzubil and Yakubu 1997).

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Genetics and Plant Breeding

Global Population Diallel Crosses in Pearl Millet: A New Approach to Targeted Genetic Diversification

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The global millet diallel project

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) originated and was domesticated in what is now the Sudano-Sahelian Zone of West and Central Africa, but migrated to semi-arid areas of both South Asia and southern and eastern Africa at least a millennium ago. Although West Africa remains the center of maximum genetic diversity, there has been considerable evolution of the crop in its secondary centers of diversity, due both to the effects of climatic differences and to conscious and creative human selection. Important regional collections of pearl millet landraces and breeding lines were assembled by the Rockefeller Foundation in India in the early 1960s and of landrace cultivars in West Africa by the Institut francais de recherche scientifique pour le developpement en cooperation (ORSTOM). The first efforts to assemble a true global collection began only in the mid-1970s with the establishment of ICRISAT in India

The systematic use of these collections to broaden the base of national and regional breeding gene pools has been limited. Breeding efforts have largely concentrated on the exploitation of existing within-country, and (less often) within-region diversity. The exception has been the recent movement of materials from West Africa to Asia, and from Asia to southern Africa, following the assembly of the global pearl millet genetic resources collection and linked regional breeding programs by ICRISAT. This movement has largely been opportunistic, exploiting such specific landrace material as the *Iniadi* landrace of Togo/Ghana, (Andrews and Anand Kumar 1996) that confers a broad adaptation, permitting very easy inter-regional transfer.

Studies have demonstrated that the planned genetic diversification of adapted populations can produce superior base populations for the development of cultivars with improved grain and stover yields (Ouendeba et al. 1993). Recurrent selection in populations created from diverse sources is an effective and productive breeding strategy to develop superior open-pollinated varieties (Andrews et al. 1985) and hybrid parents. What is lacking is a systematic, inter-regional program to create new breeding populations from elite genetic material originating in historically separated regions of diversity, to broaden the genetic base of regional millet breeding programs.

ICRISAT millet scientists in southern Africa, western Africa, and India have initiated a new collaborative project—entitled the Global Pearl Millet Diallel Project—to initiate systematic diversification of elite regional germplasm, by making trait-based global diallel crosses. The project has three stages:

- Identifying elite landrace and breeding materials from each of the three major millet regions of diversity, that contain specific traits of importance for both adaptation and productivity, that would be of potential value to plant breeders in other regions
- Making targeted sets of diallel crosses among materials from different origins, selected by specific maturity or plant type criteria. The resulting F_1s will be supplied to regional networks, national agricultural research systems (NARS), and ICRISAT plant breeders for evaluation at their own locations, and selection of specific crosses to broaden their own gene pools
- Random-mating individual population crosses, selected by project collaborators, to produce new and diversified breeding populations for their own breeding programs, based on their own choices, and made in their own fields.

We expect that this project will result in a greater utilization and exploitation of existing elite genetic diversity (including adapted germplasm accessions) in all the three major regions of the crop's domestication, and consequently will enhance genetic diversity in national and regional pearl millet breeding programs. Specifically, this project should reduce genetic vulnerability to diseases and insect pests, provide a base for selective improvements in maturity, tillering, grain size, panicle length, etc., and ultimately increase the productivity of national and regional breeding program gene pools. These improvements should eventually result in a greater availability of varieties combining new traits and higher yield potential for farmers in the major millet-growing regions of Asia, West and Central Africa, and eastern and southern Africa.

Current status of the project

In 1998 and 1999 we assembled and evaluated at ICRISAT-India 72 elite populations and varieties from ICRISAT and NARS breeding programs in all three regions. In 2000 we produced the first of several planned population diallel crosses from selected parents from this collection—a 12 x 12 diallel of varieties bred from diversified *Iniadi* germplasm in each of the regions. The *Iniadi* type, originally from the Togo/Ghana/Burkina Faso border area of West Africa is characterized by early flowering, limited tillering, a broad panicle, and very large grain (Andrews and Anand Kumar 1996) [The *Iniadi* landrace is known by several names, depending upon the area of origin: *Igniari* (Togo), *Iniadi* (Burkina Faso), *Ignati* (Benin, Burkina Faso), and *Nara* (Ghana and Benin)]. It has proven to be especially well-adapted to poorer soil conditions and to terminal drought environments, where its low tillering habit results in a single, but productive panicle per plant. *Iniadi* germplasm is presently the single most widely used pearl millet germplasm type in the world, and has consequently been crossed to a broad range of local germplasm in all pearl millet-growing areas. Cultivars based on *Iniadi* germplasm are grown by farmers in many countries (Angola, Benin, Botswana, Chad, Eritrea, India, Kenya, Mali, Malawi, Mauritania, Namibia, Niger, Sudan, and Zimbabwe). *Iniadi* germplasm transmits its phenotype strongly to its progenies, but it is nevertheless easy to see

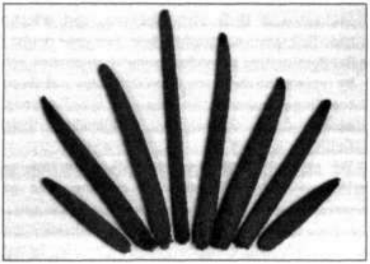

Figure 1. Variability in pearl millet panicle characteristics among the parents used in the global diallel of parents derived from crosses of *Iniadi* germplasm x locally adapted breeding lines and populations

useful variation in the basic phenotype resulting from crosses to various local germplasms and selections for locally preferred phenotypes (Figure 1).

The 12 *Iniadi-derived* parents selected for the diallel come from ICRISAT and NARS breeding programs in Asia, West Africa, and southern Africa, and have varying degrees of local parentage (Table 1). They were selected for use in the diallel on the basis of both their productivity (assessed in replicated trials at ICRISAT-India) and the diversity of their non-*Iniadi* parent(s). The productivity of tillers, rather than of the main shoot, was a major consideration, as variation in tiller biomass accounted for 80% of the variation in both grain and straw yields in the Indian-bred parents and for 60% of the variation in grain yield in the African sources. This suggests that an important consequence of the diversification of the

Table 1. Pearl millet populations and varieties derived from the *Iniadi* landrace, chosen as parents for the first global diallel cross. Yield component data are based on replicated observations, but were recorded from different experiments for the African and Indian-bred parents

Parent variety	Origin and description	Panicles plant^{-1}	Grains panicle^{-1}	100-seed mass (g)
GB 8735	Bred at ICRISAT-Niger, in collaboration with national programs of Chad and Mauritania, from a cross of *Iniadi* and *Souna* germplasm from Mali	2.9	2315	1.35
Gueriniari 1	Bred at ICRISAT-Niger from a cross between the Niger landrace *Guerguera* and *Iniadi* lines	2.4	3665	0.83
Iniari Composite	Bred at ICRISAT-Niger from a 1990 collection of *Iniadi* landraces from northern Togo	2.4	2070	1.58
ICMV-IS 903011	Bred at ICRISAT-Niger from a cross between the Niger landrace *Heinikire* and *Iniadi* lines	2.3	4475	0.72
SDMV 96051	Bred at ICRISAT Bulawayo from a cross between Okashana 1 and the Namibian landrace IP 18614	2.9	2215	1.18
SDMV 96063	Bred at the Mahanene Research Center, Namibia by the Namibian Ministry of Agriculture and ICRISAT-Zimbabwe, from the Maria Kaherero composite	3.2	3110	0.83
SDMV 96014	Bred at ICRISAT-Zimbabwe from a cross between Okashana 1 and the Namibian landrace IP 18364	2.8	3210	0.98
SDMV 95017	Bred at ICRISAT-Zimbabwe from a cross between Okashana 1 and the Namibian landrace IP 18498	2.8	2120	1.33
Medium Composite 88	Bred at ICRISAT-India from a cross of the ICRISAT Medium and Bold-Seeded Early Composites	4.3	2620	1.26
Early Composite 89	Bred at ICRISAT-India from the ICRISAT Early Composite and a variety from the Bold-Seeded Early Composite	4.8	3025	1.14
AIMP 92901	Bred by ICRISAT-India and the National Agricultural Research Project, Aurangabad, India, from the ICRISAT Bold-Seeded Early Composite and its outcrosses	2.9	3370	1.26
RCB-IC912	Bred by the Rajasthan Agricultural University, Jaipur, India, and ICRISAT-India, from the ICRISAT Early Composite 87	3.5	2810	1.05

original *Iniadi* germplasm through crossing to elite breeding materials in various breeding programs has been an improvement in its tillering ability. It is therefore likely that some of the individual crosses in the diallel will have improved tillering and thus permit selection of much better tillering lines from populations made by random-mating the crosses.

Table 1 also provides a summary of the differences in the major yield components (panicles plant^{-1}, grains panicle^{-1}, and 100-grain mass) among the parents. The data for the parents bred in West and southern African and those bred in India cannot be directly compared as they were estimated from different experiments, but they provide a general idea of the differences among the parents chosen for the diallel. There is a good variation for all yield components, with sources of higher tillering capability (Medium Composite 88 and Early Composite 89), grain numbers per panicle (ICMV-IS 90311 and Gueriniari 1), and 100-grain mass (*Iniari* Composite, GB 8735, and SDMV 95017).

Availability of the diallel

Small amounts of seed of the *Iniadi* diallel, including parents, are available to interested public and private sector pearl millet scientists for evaluation, with the completion of a standard ICRISAT Materials Transfer Agreement (MTA) that can be downloaded from the ICRISAT website (http://grep.icrisat.cgiar.org/grep/mta.htm). The completed MTA should be e-mailed, faxed, or surface-mailed to the address below, accompanied by a seed import permit, if required by the national plant quarantine service, and the date by which the material is required (allow 6-8 weeks for quarantine clearance and shipping):

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ICRISAT would appreciate receiving a copy of any evaluation or other data recorded on the diallel entries.

ICRISAT would also be willing to supply 100 grams of random-mated seed of a few selected F_1s from the diallel for use in national or regional breeding programs, based on a formal request, accompanied by a signed MTA. If a particular F_1 has already been random-mated, the seed can be supplied immediately, if not, the seed will be supplied within 6 months of the receipt of the request.

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First Forage Pearl Millet Hybrid Release in India

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The first release of a forage pearl millet hybrid in India was made by a notification issued by the Government of India on 18 December 1997. The hybrid, developed by scientists of the Proagro Seed Company, Hyderabad, India, was tested as FMH-3 by the All India Coordinated Project for Research on Forage Crops for 3 years, (1994-96), and released as Proagro No. 1. The release proposal was submitted to the Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops, and was considered during the 29th meeting of this Committee on 24 October 1997. Proagro No. 1 has been recommended for cultivation throughout the pearl millet growing areas of India with irrigation during the hot dry summer season, under both rainfed and irrigated conditions during the rainy season, and for both single- or multi-cut purposes. It is highly resistant to downy mildew (caused by *Sclerospora graminicola* (Sacc.) J. Schrot.) and escapes ergot (caused by *Claviceps fusiformis* Loveless) and smut (caused by *Moesziomyces penicillariae* (Bref.) K. Vankyl as it is usually chopped at the booting stage.

Proagro No. 1 attains a plant height of approximately 170-190 cm. It has non-hairy nodes that are not covered by its non-hairy leaf sheaths. All plant parts (stems, nodes, leaf sheaths, and blades, etc). are green in color. The panicles are cylindrical with small bristles and shriveled anthers. It is a male-sterile hybrid and does not set its own grain. The hybrid has been purposely bred as a male-sterile so that the forage remains nutritious until chopped and the crop recovers well after a forage harvest. The hybrid is ready for a first harvest after 50 days of growth and can be harvested at monthly intervals until September. It produces enough forage for six cuttings if sown in March, and for three cuttings if sown in June.

In the All India Coordinated Yield Trials, Proagro No. 1 (FMH-3) produced 74.9 tha^{-1} green forage yield averaged over 30 environments and 15.7 t ha^{-1} dry matter yield under multi-cut management averaged over 20 environments. It produced 36.4 tha green forage and 7.55 tha^{-1} dry matter under single-cut management. Proagro company trials have shown that it has the potential to produce 130 t ha^{-1} of green forage if managed well under the multi-cut system.

The official release of this forage pearl millet hybrid in India has opened a new era of exploiting the phenomenon of heterosis for biomass production in this crop.

Germination Responses at Different Temperatures of Pearl Millet Genotypes Differing in Seed Size

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Introduction

Pearl millet [*Pennisetumglaucum* (L.) R. Br.] is valued for its ability to reliably produce high-quality grain and fodder under less than optimal conditions. In the Coastal Plain region of the USA it appears to be superior to other crops in its ability to establish under limited soil moisture (Smith et al. 1989). Rapid seed germination, an important component contributing to seedling vigor (Pollock and Roos 1972), should facilitate stand establishment in less than optimal conditions, particularly in cool soils. Developing forage pearl millets adapted to being sown in cool soils would increase pasture productivity. Seed mass is an easily measured variable that is often associated with seedling vigor. This study was conducted to determine if germination rate and total germination at various temperatures are related to seed mass in pearl millet.

Materials and methods

Fifty-eight selections differing in seed mass were derived from an intermating pearl millet population selected for grain yield and seed size. Seed mass was determined from three replications of 100 seeds of each selection. Two replications, each of 50 seeds of each selection were placed in petri dishes according to the International Seed Testing Association protocol (ISTA 1985), and incubated in the laboratory at 15°, 20°, and 30°C. Numbers of seed germinated were recorded daily. The percentage of germinated seed was transformed to probits and regressed against time. Time to 50% germination (G50) was determined from the regression. G50 and total germination were analyzed by analysis of variance and Fisher's LSD values were calculated. Correlation coefficients for different characters at various temperatures were calculated.

Results and discussion

Temperature, selection, and temperature x selection interaction were significant *($P<0.05$)* sources of variation for both G50 and total germination. Time to 50% germination was most rapid at 30°C and lowest at 15°C (Table 1). Total germination was greatest at 30°C and least at 15°C. G50 at 15°C was positively correlated with total germination at all temperatures (Table 2). G50 values at other temperatures were not good predictors of germination at 15°C. The 100-seed masses of the 58 selections ranged from 0.93 to 1.97 g. No correlations among germination parameters and seed mass existed at any temperature (Table 2).

Table 1. Mean and range of days to 50% germination (G50) and total germination (%) for pearl millets differing in seed size, incubated at different temperatures (°C)

	15°C		20°C		30°C	
Variable	G50 (days)	Germination (%)	G50 (days)	Germination (%)	G50 (days)	Germination (%)
Mean	6.9	60.7	4.3	69.9	1.8	72.7
Range	5.4-8.7	0.0-77.0	2.2-5.3	14.0-84.0	0.4-2.5	30.0-86.0
LSD (P<0.05)	0.9	0.1	0.9	0.2	0.7	0.2

Table 2. Correlation coefficients[1] between days to 50% germination (G50), germination (%), and seed mass of pearl millet genotypes incubated at different temperatures (°C)

	Correlation coefficients						
	G50 (days)			Germination (%)			100-seed mass (g)
	15°C	20°C	30°C	15°C	20°C	30°C	
G50 (days)							
15°C		-0.10	-0.11	0.50**	0.47**	0.48**	0.06
20°C			0.24	-0.16	-0.31*	-0.21	0.05
30°C				-0.22	-0.26*	-0.28*	0.14
Germination (%)							
15°C					0.77**	0.75**	0.07
20°C						0.79**	-0.02
30°C							0.02

1. * significant at *P*<0.05, ** significant at *P<0.01.*

Rice cultivars tested at four temperatures showed the most rapid germination at 30°C, but differed at lower temperatures, presumably because of the interacting effects of tolerance for low temperature (Krishnasamy and Seshu 1989). Similar temperature x selection interactions were found. Mortlock and Vanderlip (1989) reported that medium-sized pearl millet seed showed higher percentage germination over a wider temperature range than small or large seed. No such discernible relationship was observed in our data. We can conclude from our study that genotypic differences had more important effects on germination rate and total germination at different temperatures than seed size. If tolerance to early sowing is a desirable trait, selection must be made for germination parameters at low temperatures.

Acknowledgment

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Germination Response at Different Temperatures of Pearl Millet Inbreds Selected for Tolerance to Early Sowing

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Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is an important forage crop in the southern United States. Although it produces high yields of digestible dry matter, most of the biomass is produced in a short interval from approximately June through September. To lengthen the grazing period for pearl millet forage, it must be sown earlier or remain productive later in the season. A major problem in earlier spring sowings is seed germination at low temperature. Low temperature at sowing delays germination and plant emergence, and predisposes seedlings to soilborne diseases. Haryanto et al. (1997) found that germination percentage was reduced at 15°C. Germination and emergence of pearl millet at 16°C and below is associated with increased susceptibility to damping-off (Hart and Wells 1965; Wells and Winstead 1965). Limited studies on pearl millet adapted for early spring sowing are available. The objective of this investigation was to evaluate germination response patterns of 48 pearl millet inbreds at two temperatures, to identify genotypes capable of rapid germination at low temperatures.

Materials and methods

Forty-eight pearl millet inbreds were derived from a population subjected to recurrent selection for forage yield when sown early (March-April) in pathogen-infested soil (Wilson and Gates 1996). Fifty seeds were placed in petri dishes and incubated in the laboratory at 15°C and 30°C according to the ISTA protocol (1985). The numbers of germinated seed were recorded daily, and the experiment was repeated three times. The percentage of germinated seed was transformed to probits and regressed against time. Days to 50% germination (G50) was determined from the regression. G50 and total germination were analyzed by analysis of variance and Fisher's LSD values were calculated. Correlation coefficients for the germination parameters at various temperatures were calculated.

Results and discussion

Temperature, entry, and temperature x entry interaction were significant sources of variation for G50 and percentage germination. The mean and range extremes for G50 were greater at 15°C than at 30°C (Table 1). Percentage germination was less at 15°C than at 30°C, and was correlated across temperatures ($r = 0.92$, $P<0.01$). No correlation existed between G50 values and percentage germination values at either temperature. These pearl millets selected for forage yield after early sowing in cool soils germinated more rapidly (mean=5 days) at 15°C than pearl millets selected only for seed size (mean= 7 days) (Dahiya et al. ISMN 41: 66-67). Genotypes with both rapid germination (<4 days) at 15°C and comparatively high germination (>65%) have been identified. These selections may be useful sources of cool temperature tolerance for early sowing.

Table 1. Mean and range of days to 50% germination (G50), and percentage germination for pearl millets selected for forage yield after early sowing at Tifton, Georgia, USA and incubated in the laboratory at different temperatures (°C)

	15°C		30°C	
Variable	G50 (days)	Germination (%)	G50 (days)	Germination (%)
Mean	5.0	47.4	1.3	55.4
Range	3.2-6.5	14.0-73.3	0.3-2.0	2.7-83.3
LSD ($P<0.05$)	1.03	0.08	0.5	0.06

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Agronomy

Performance of Pearl Millet Variety LCIC-MVI in a Pearl Millet - Cowpea-based System in Nigeria

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Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is a very important cereal crop in Nigeria; grown on 5.2 m hectares with an annual production of 4.62 million tons of grain. Pearl millet occupies about 32% of the total area sown to cereals in Nigeria and accounts for 25% of the total cereal production in that country. The pearl millet in Nigeria represents more than a quarter of the area under this crop in Africa. These data are based on 3-year averages from 1992 to 1994 (Food and Agriculture Organization of the United Nations (FAO), and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) 1996). Improvement in pearl millet yields in developing countries, mainly in India, have occurred largely due to the adoption of improved varieties (both hybrid and open-pollinated) and only a little to the limited investments in fertility maintenance. Because of low sowing rates (4 to 5 kg ha^{-1}) and high multiplication rates (400 to 500 fold per generation), pearl millet improved varieties have been adopted fairly widely in India even by subsistence farmers. Contrary to those in Asia, most farmers in Africa still grow traditional pearl millet varieties. After 3 years of on-farm testing, farmers preferred an ICRISAT - NARS bred pearl millet variety, LCIC-MVI (popularly known as SOSAT-C88), released in Nigeria for general cultivation on 13 January 2000.

In the Sudanian Savanna Zone of northern Nigeria millet - cowpea intercropping is a predominant mixture present in some 22% of the Fields under cultivation (Henriet et al. 1997). The advantages of intercropping includes better use of available resources, yield stability, reduced crop losses due to weeds, pests and diseases, soil fertility maintenance due to reduced erosion and nutrient leaching, and balanced distribution of labor requirements (Norman 1974; Steiner 1982). These low-input traditional cropping systems have evolved over centuries of experience and are quite sustainable (Henriet et al. 1997), but low-yielding.

In this contribution, we report the performance of a new pearl millet cultivar sown with cowpea [*Vigna unguiculata* (L.) Walp.] in an improved pearl millet-cowpea system, jointly studied in on-farm trials, by ICRISAT, the Kano Agricultural and Rural Development Authority (KNARDA), Lake Chad Research Institute (LCRI), and farmers.

Materials and methods

The pearl millet-cowpea cropping system trial was conducted at four locations in Kano State during 1999. The locations were Gargai (11°53' N, 8°I4' E, Sudanian Zone), Gabasawa (12° 11' N, 8°54' E, Sahelian Zone), Panda (11°31' N, 8°04' E, Sudanian Zone), and Shiddar (12°25' N, 8°31' E, Sahelian Zone). At all four locations, rainy months are from June to October with peak rainfall in August. The rainfall during the growing season was 910 mm at Gargai, 900 mm at Panda, and 710 mm at both Gabasawa and Shiddar. The trial consisted of two treatments, with eight replications (farms as replicates) and sown in randomized complete-block design. Pearl millet varieties (both improved and local), and an improved cowpea cultivar were sown between 26 June and 29 July depending on the rains and location. Local cowpea cultivars are normally sown late and farmers sowed them until 28 August.

The First treatment was a traditional farming system commonly practiced by farmers in their various regions. Farmers sowed pearl millet and cowpea in 1:1 ratio (200 m^2 : 200 m^2) at Gabasawa, and Shiddar, and in 4:1 ratio (320 m^2 : 80 m^2) at Panda and Gargai. The second treatment was an improved cropping system of two rows of pearl millet (LCIC-MVI) to four rows of cowpea (IT 90K 277-2). The improved cropping system had 160 m^2 under pearl millet and 240 m^2 under cowpea. In the improved system, fertilizer (NPK 20:10:10) was applied at 200 kg ha^{-1} to pearl millet, 3 weeks after the seed was sown on the ridges. The row-to-row spacing was 100 cm. The plant-to-plant spacing for pearl millet was 50 cm, while for cowpea it was 25 cm. Data were recorded on grain yield, stover yield, and time to 50% flowering for both pearl millet and cowpea. Additional data on plant height and threshing percentage were recorded from pearl millet. Grain yield and stover yield data were converted into per ha before analysis.

Results and discussion

The results of the pearl millet/cowpea-based trial are presented in Tables 1 and 2. The pearl millet grain and stover yields were signiFicantly higher in the improved system than in the traditional system at each of the four locations. Based on means over four locations, the

Table 1. Performance data of improved pearl millet open-pollinated cv LCIC-MV1 in pearl millet-cowpea intercropping trial at individual locations and averaged over four locations in Nigeria, 1999

Traits	Gargai	Gebassawa	Panda	Shiddar	Mean
Grain yield (t ha^{-1})					
Improved system	1.54	1.94	1.31	2.17	1.74
Traditional system	0.41	1.47	0.61	1.23	0.93
LSD (*P*<0.05)	0.76	0.19	0.39	0.55	0.22
CV(%)	66.00	9.30	34.60	27.40	-
Stover yield (t ha^{-1})					
Improved system	3.56	4.73	2.78	3.20	3.57
Traditional system	1.98	3.89	1.61	2.22	2.43
LSD (*P*<0.05)	0.58	0.68	0.66	0.34	0.25
CV(%)	17.60	13.40	25.20	10.50	-
Threshing Percentage (%)					
Improved system	67.8	79.3	67.1	77.5	72.9
Traditional system	67.5	77.7	65.7	62.5	68.4
LSD (P<0.05)	4.0	2.2	4.5	10.9	2.8
CV(%)	5.1	2.4	5.8	13.2	-
Time to 50% flowering (days)					
Improved system	55.5	52.6	63.1	61.6	58.2
Traditional system	44.6	51.0	73.0	64.9	58.4
LSD (*P*<0.05)	6.8	10.9	8.6	3.9	3.5
CV (%)	11.5	17.9	10.7	5.2	-
Plant height (m)					
Improved system	1.46	2.02	2.08	1.90	1.86
Traditional system	1.57	2.51	2.47	2.30	2.21
LSD (*P*<0.05)	0.04	0.07	0.45	0.22	0.11
CV (%)	2.50	2.60	16.70	8.70	-

Table 2. Performance data of improved cowpea cv IT90K 277-2 in pearl millet-cowpea intercropping trial for individual locations and averaged over four locations in Nigeria, 1999

Traits	Gargai	Gebassawa	Panda	Shiddar	Mean
Grain yield (t ha^{-1})					
Improved system	1.54	1.94	1.31	2.17	1.74
Improved system	0.40	0.99	0.31	0.81	0.63
Traditional system	0.36	0.90	0.34	0.04	0.41
LSD (*P*<0.05)	0.19	0.32	0.13	0.26	0.10
CV (%)	38.30	28.00	34.30	47.80	-
Stover yield (t ha^{-1})					
Improved system	0.58	1.16	NR[1]	NR	0.87
Traditional system	0.32	1.18	NR	NR	0.75
LSD (*P*<0.05)	0.22	0.38	-	-	0.20
CV (%)	38.10	26.50	-	-	-
Time to 50% flowering (days)					
Improved system	42.4	44.1	37.7	NR	41.4
Traditional system	69.4	56.8	64.9	NR	63.7
LSD (*P*<0.05)	15.0	14.6	6.4	-	6.0
CV (%)	20.9	23.6	10.6	-	-

1.NR = Not recorded.

improved system produced almost double the grain yield (1.74 t vs 0.93 t ha^{-1}) of pearl millet and 47% more stover (3.57 t vs 2.43 t ha^{-1}) as compared to traditional systems. The cost of 200 kg fertilizer was ₦ 5200 and the cost of an application of fertilizer was ₦ 600 ha^{-1}. The value of extra grain produced (0.81 t ha^{-1}) was ₦ 9720 ha^{-1}. Considering only pearl millet grain yield, there was a net profit of ₦ 3920 ha^{-1}, assuming the cost of all other operations was equal. The local pearl millet variety was taller than LCIC-MV1 and both varieties took about 58 days to reach 50% flowering. Cowpea grain yields under traditional and improved systems were similar at each location except Shiddar.

Field days were organized at all the locations. Of the farmers interviewed 70% preferred 2 rows of pearl millet or sorghum with 2 rows of cowpea. All the participating farmers are smallholder farmers and like to secure their food first. Farmers also prefer to intercrop cereals with groundnut, or cereals with cereals to monocropping.

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Continuous Cropping and Fertilization Effects on Crop Yields in a Long-term Fertilizer Experiment

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The long-term effect of manures and fertilizers on the yields of finger millet [*Eleusine coracana* (L.) Gaertn.], maize (*Zea mays* L.), cowpea [*Vigna ungiculata* (L.) Walp.] in a rotation have been under study on a Vertic Ustropept soil in Coimbatore, India since 1972. This area enjoys a semi-arid tropical climate with mean temperatures of 31 °C (May-June) to 21°C (December-January). The experiment has ten treatments, replicated four times. The grain yields of finger millet and maize over 25 years are presented in Table 1. The continuous application of graded doses of NPK fertilizers significantly increased the grain

Table 1. Grain yield (t ha^{-1}) of finger millet and maize crops over 25 years in a long-term fertilizer experiment, Tamil Nadu Agricultural University (TNAU), Coimbatore, India, 1972-97

	Finger millet						Maize					
Treatments[1]	1972	1977	1982	1987	1992	1997	1972	1980	1982	1987	1992	1997
50% NPK	2.4	2.3	2.3	2.9	2.5	3.2	2.2	1.7	1.3	3.0	2.7	3.4
100% NPK	2.7	2.9	2.4	3.9	3.2	3.4	2.7	2.1	1.4	3.2	3.1	3.4
150% NPK	3.1	3.2	2.5	3.7	3.5	3.5	2.6	2.3	1.8	3.6	3.1	3.7
100%NPK + HW	3.1	3.1	2.0	3.8	3.2	2.8	2.6	2.4	1.6	3.2	2.9	3.0
100% NP	3.0	2.8	2.0	3.2	3.1	3.4	2.5	2.1	1.3	2.8	3.1	3.7
100% N	2.1	0.6	0.6	0.9	0.9	2.8	0.9	0.5	0.4	0.5	0.9	1.9
100%NPK + FYM	3.0	3.4	2.3	4.8	3.9	3.6	3.0	3.0	1.6	3.7	3.4	3.8
100% NPK (-S)	3.0	2.9	2.1	3.4	3.2	3.5	2.7	2.3	1.4	3.2	2.8	3.0
Control	1.6	0.5	0.4	0.9	0.9	2.3	0.5	0.5	0.4	0.4	0.7	1.9
CD (P<0.05)	0.5	0.2	0.4	0.6	0.2	0.7	0.6	0.3	0.2	0.6	0.2	0.3

1. HW = hand weeding; FYM = farmyard manure; S = sulfur
100% NPK = 90 kg N : 45 kg P_2O_5: 17.5 kg K,0 ha^{-1} for finger millet
100% NPK = 135 kg N : 67,5 kg P_2O_5: 35 kg K_2O ha^{-1} for maize.

yields of finger millet and maize. The control and nitrogen (N)-alone treatments showed marked declines in grain yields. The reduction of available phosphorus (P) due to the exclusion of P from the fertilizer schedule might have resulted in defective root development that had deleterious effects on growth and yield. The lack of response to applied potassium (K) can be attributed to the fact that these soils are rich in K and a continuous release of appreciable amounts of K from the soil reserve has occurred as a result of shifts in the soil equilibrium. There has also been addition of appreciable quantities of K (15 mg L^{-1}) through irrigation water. Hence, application of K is essential to maintain the soil-K reserve status, despite the present lack of crop response to this nutrient. Exclusion of sulfur from the fertilizer schedule did not have any deleterious effect on crop yields due to the gypsiferous nature of the soil and the appreciable quantities of sulfur (35 mg S L^{-1}) being added through irrigation water.

Application of 10 t farmyard manure (FYM) ha^{-1} along with 100% NPK resulted in the highest yields in all the crops over the years. FYM directly added appreciable amounts of major and micronutrients to the soil and thus contributed to enhanced yields. The improvement of such physical soil properties as water-holding capacity and moisture retention that accompanied FYM application provided more desirable soil conditions for root development, enhanced nutrient uptake, crop growth, and yield (Naphade et al. 1993). The increased availability of all the three major nutrients together with the granular and spongy soil conditions (Jaggi 1991) favored biological activity and could have contributed to better crop growth. The variations in the grain yield of the finger millet and maize crops in this study are the results of all the three nutrients individually and in combination with each other, and also due to the amounts of reserve and other available nutrients in the soil.

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Effects of Seed Protein and Storage Conditions on Germination and Seedling Characteristics of Pearl Millet Seeds

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Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br] is an annual warm-season cereal grown on about 28 million ha worldwide with the largest areas in India and the Sahel of West Africa. It is a nutritious grain crop grown mainly for human consumption, but also used to feed livestock and for fodder production. It is usually grown where it is too dry, the soil fertility is too low, and growing conditions are too harsh to grow most other grain crops. However, it responds favorably to good soil fertility and moisture conditions (Hanna 1998).

Seeds are stored for varying periods depending on the needs at both the farmer and researcher levels. Low temperature, relative humidity, and seed moisture content are known to increase seed longevity. The extent and rate of seed deterioration at the time of storage reflect the pre-storage history of the seed, e.g., weathering, mineral deficiency, time of harvest, harvest method, drying, handling, etc. Moore and Roos (1982) studied the viability of pearl millet seeds stored under different temperature and relative humidity conditions. Appa Rao et al. (1991) found that pearl millet seed can be stored for longer times at low temperatures than at ambient temperatures. Since little information is available on pearl millet seed viability during storage, the objective of this study was to determine the long-term effects of seed protein on seed viability and seedling characteristics. This report summarizes data after the first year of storage.

Materials and methods

Seeds from open-pollinated inflorescences of HGM-100, a F_1 grain hybrid, grown at the Coastal Plain Experiment Station, Tifton, Georgia, were harvested in August, 1998 and stored on 11 January 1999. Protein levels of 10.5, 13.5

Table 1. Germination (%) and seedling characteristics of pearl millet plants established from seed with differing protein levels stored at three temperatures

Variable	Germination (%)		Height (cm)	Green growth (g)		Dry growth (g)		Dry matter (%)	
	4 DAS	8 DAS		Shoot	Root	Shoot	Root	Shoot	Root
Temperature (° C)									
24	84	88	4.4	1.22	1.70	0.16	0.18	13	9
5	88	89	4.5	1.12	1.42	0.16	0.16	14	11
-9	85	87	4.7	1.20	1.74	0.17	0.17	15	10
LSD[1] (<0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Protein (%)									
10.5	87	89	4.24	1.07	1.40	0.14	0.15	14	10
13.5	83	85	4.52	1.14	1.62	0.16	0.15	15	9
16.5	88	89	4.84	1.33	1.74	0.18	0.21	14	10
LSD (<0.05)	NS	NS	0.52	0.16	NS	0.02	NS	1	NS

1. NS = not significant.

and 16.5% in seeds were produced by applying 28, 112, and 336 kg ha^{-1} nitrogen as ammonium nitrate to plants in the field at 28 days after sowing (DAS). Nitrogen treatments were arranged as a randomized complete-block experiment with five replications. After harvest, seeds were dried to 4% moisture in a forced-air oven and stored at room temperature (24° C), 5°C, and -9°C in airtight plastic bags. Seeds (100 for each treatment/replication) were sown in a greenhouse in steam-sterilized soil on 10 February 2000. The greenhouse was maintained at 30±3°C. Characteristics measured included: percentage emergence at 4 and 8 DAS, plant height 8 DAS, dry and green weight of shoots and roots 14 DAS (measured on 20 random plants per replication), and percentage dry matter (DM%).

Results and discussion

Data indicated that storage temperatures had no effect on the characteristics measured (Table 1) after 1 year of storage. However, plants from seeds with the highest protein content (16.5%) were significantly taller and produced more shoot growth (green and dry) than plants from seeds with lower protein levels. Means for DM% in the shoots were significantly different (Table 1), but such differences probably do not have practical value.

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Biotechnology

Towards Developing and Mapping of Microsatellite Markers in Pearl Millet

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Microsatellite markers (or simple sequence repeats, SSRs) have been shown to be highly polymorphic and have become the markers of choice in many species. Over 8000 SSRs have been mapped in the human genome (Schuler et al. 1996). In plants, SSRs have been developed in almost all crops, e.g., rice (*Oryza sativa* L), barley (*Hordeum vulgare* L), wheat (*Triticum aestivum* L.), maize (*Zea mays* L), soybean [*Glycine max* (L.) Merr], and cassava [*Manihot esculenta* (L.) Schoff]. We are now at the stage of developing and mapping SSRs in pearl millet *[Pennisetum glaucum* (L.) R. Br.].

Genomic DNA from the inbred line '81B' was digested with *Rsa*I. DNA fragments bearing SSRs were enriched following hybridization to biotinylated SSR motifs [such as (GT)] bound to streptavidin-coated paramagnetic

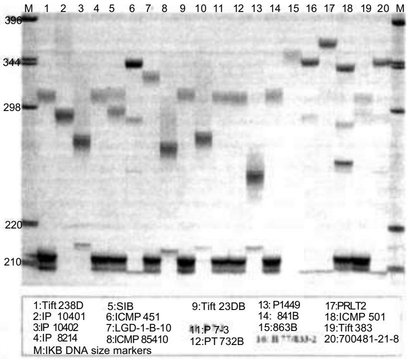

Figure 1. A SSR marker profile generated by using PSMP2001 in 20 pearl millet inbred lines. PCR products were separated on a 5% denaturing polyacrylymide gel and revealed by silver straining

beads, and washing under the application of a magnetic field. The vector pUC18 was used for library construction. About 20-30% of the clones in the constructed enriched library contained SSRs. In the first instance, clones were screened by hybridization for the presence of microsatellite motifs (CA/GT). A PCR screen was then used to check each putative SSR-bearing clone for the presence and position of a microsatellite (Bryan et al. 1997). Plasmid DNA was extracted from the positive clones, sequenced using the ABI BigDye Terminator sequencing kit, and analyzed on an ABI 377 DNA sequencer. In 25 of the 29 sequences analyzed to date, the microsatellite was flanked on each side by more than 50 nucleotides, and primer pairs were designed using the PRIMER program of the Genetics Computer Group (Madison, WI) Wisconsin Package version 9.1. Nineteen unique primer pairs were tested with four pearl millet inbred lines using a gradient-annealing temperature. Optimized PCR protocols were then applied for the generation of standard SSR profiles based on 20 pearl millet cultivars or lines. The preliminary survey revealed that about 52% (10 out of 19) of the designed primer pairs produced microsatellite products. Figure 1 shows the profile generated by microsatellite marker PSMP2001. Ten alleles were detected in 20 pearl millet cultivars at the *Xpsmp2001* locus.

To date, 10 SSRs have been generated. Five SSRs, showing polymorphism between 81B and ICMP 451, the two parents of the Word Reference Mapping Population, were mapped. They detected loci Xpsmp 2001 on pearl millet linkage group 5, *Xpsmp2006* (group 1), *Xpsmp2008* (group 4), *Xpsmp2013* (group 7). and *Xpsmp2018* (group 6). The initial data on the prevalence of microsatellites in pearl millet, their distribution over the genome and the detected levels of polymorphism, are very promising. We aim, over the next year, to produce sufficient SSR markers to cover the pearl millet genome. This will provide pearl millet geneticists and breeders with a user-friendly and highly efficient molecular marker system for exploitation in trait analysis, marker-assisted breeding, and variety identification. All primer pairs will be made publicly available via MilletGenes (http;//jiio5.jic.bbsrc.ac.uk:*8000/cgi-bin/ace/search/millet*).

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GUS Transient Gene Expression in Bombarded Pearl Millet Tissue

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Introduction

When developing a transformation protocol, the GUS transient assay, usually performed 24-48 hours after bombardment is a popular technique for optimizing transformation conditions. Although transient GUS expression does not always correlate with stable transformed plant recovery, it does indicate that the incoming DNA entered the nucleus of the target tissue. A good transient assay should contain many discrete GUS-staining foci. Previous work with pearl millet (*Pennisetum glaucum* (L.) R. Br.) (Taylor and Vasil 1991; Taylor et al. 1993) showed GUS transient expression after bombardment of immature embryos. Since then no other photographs of transient GUS expression in pearl millet have been published. In a continuing effort to develop an efficient pearl millet transformation protocol, immature embryos, florets from immature inflorescences, and embryogenic tissues derived from the apical meristem of germinated seeds were bombarded with the GUS gene. Preliminary experiments, mostly using the immature embryo, indicated the importance of using recently prepared X-Gluc stain and firing the gun with a 71-cm vacuum. Here we report conditions that consistently produce favorable transient assays.

Materials and methods

Plant material

All source tissue was obtained from the diploid F_1 pearl millet hybrid, cv HGM-100. Immature embryos (F_2 generation) were harvested 6-10 days after pollination, florets (F_1 generation) were shaved from inflorescences 2-5 mm in length and apical meristems (F_1 generation) were excised from seedlings germinated in vitro. Embryos, florets, and apical meristems were cultured on Murashige and Skoog (MS) medium plus 2, 2.5, and 5 mg L^{-1} 2,4-diclorophenoxyacetic acid (2,4-D), respectively. Target tissue was incubated on solid osmotic medium consisting of MS plus 2 mg L^{-1} 2,4-D and 0.25 M sucrose for 4 h pre- and 16 h post-bombardment. Embryos were bombarded 5-8 days after culture, embryogenic tissues from the apical meristem were bombarded as soon as they were available (usually 2-4 weeks after culture), and florets were bombarded once they started to swell and could be scraped off the medium (usually 2-3 weeks after culture).

Microprojectile bombardment

Bombardments were performed using the Biorad PDS-1000 helium-based gene gun. Plasmid pAHC25 that contains the *gus* gene fused to a maize-derived ubiquitin promoter was used for all bombardments. DNA (100-500 ng $shot^{-1}$) was precipitated onto 0.75 micron gold particles (30-90 µg $shot^{-1}$) following a modified Biorad protocol. Since the precipitation of DNA onto gold particles is thought to occur very rapidly with the addition of calcium chloride, when coating the gold particles, two tubes, one with DNA and gold and another with spermidine and calcium chloride were mixed together and immediately vortexed gently for 5 min. The DNA-coated gold was vortexed before loading each macrocarrier. When dispensing the gold, 8 µL was slowly spread onto the center of the macrocarrier resulting in a very slight, evenly distributed, gold residue that was visible on the dried macrocarrier. The tissue to be bombarded was arranged within a 2.5-5 cm diameter circle. The stopping screen was placed in the 2^{nd} and the target tissue in the 4^{th} slot of the gene gun, and the gun was fired when the vacuum pressure reached 71 cm. Bombardment pressures ranging from 6.2-10.7 x 10^6 pascal were used, and some samples were bombarded twice.

Transient expression

Transient GUS assays were performed 48 h after bombardment using a freshly prepared staining solution of 5 mM potassium ferricyanide, 5 mM potassium ferro-cyanide, 0.5% Triton X-100, and 0.05% X-Gluc in sodium phosphate buffer (pH 7.2). Tissue from each shot was selected from the center and two random locations of the bombardment circle and placed in a microcentrifuge tube with the stain. The tubes were incubated for up to 24 h at 37°C and then the tissue was cleared by replacing the stain with 70% ethanol.

Data collection

GUS-staining foci were counted from 9 separate bombardments. A small box (1 mm x l mm) was printed onto white paper and taped to the bottom of a petri dish. Two separate counts for number of GUS foci were obtained from tissue filling the box. The two counts were taken from different pieces of tissue. Since there was much variability for density of GUS foci among tissue from the same shot, the two counts were obtained from tissue that appeared to have the maximum number of GUS foci. Procedure GLM of SAS (SAS Institute, 1985) was used to check for significant differences in the mean number of GUS foci when data were grouped by individual bombardments, tissue type, and the number of times each culture was bombarded. Duncan's Multiple Range Test was used to separate treatment means.

Results and discussion

Multiple sets of parameters clearly are capable of producing a desirable transient assay. Most of the tested bombardment conditions produced similar transient assays, however; there were some individual shots that contained significantly more or less GUS-staining foci than others (Table 1, Figure 1). No significant difference in the mean number of GUS foci was detected when shots were grouped by tissue type, number of shots received, or bombardment pressure. Bombardment pressures ranging

Table 1. Mean number of GUS-staining foci from nine bombardments

Shoot number	Tissue	Number of shots	Pressure (pascal)	Count 1	Count 2	Mean[1]
421	Apical meristem	1	9.41×10^6	159	185	172 a
438	Apical meristem	2	7.6×10^6	171	116	143 ab
437	Apical meristem	2	6.2×10^6	160	112	136 ab
417	Embryo	1	10.7×10^6	143	109	126 ab
418	Embryo	1	10.7×10^6	82	159	121 ab
435	Floret	2	6.2×10^6	128	100	114 ab
420	Floret	1	9.41×10^6	121	82	102 ab
436	Apical meristem	2	6.2×10^6	95	69	82 b
428	Apical meristem	1	7.6×10^6	59	83	71 b

1. Means followed the same letter are not significantly different ($\alpha<0.05$) according to Duncan's Multiple Range Test.

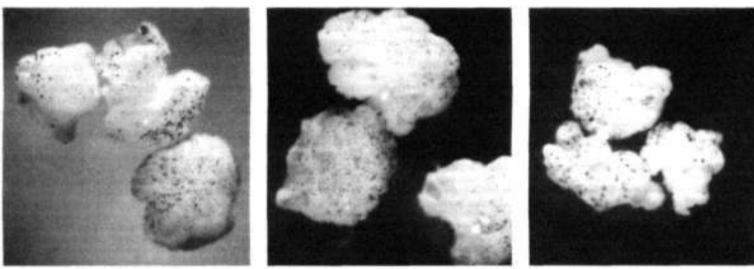

Figure 1. Transient GUS expression in bombarded pearl millet tissue. Shot number 417-embryo (left), 421-apical meristem (center) and 420-floret (right). Tissues within each group are not necessarily the same pieces used for data collection

from 6.2-10.7 $\times 10^6$ pascal all were capable of producing favorable transient assays. In general, we currently use 6.2-9.4 $\times$ 10^6 pascal on florets and very small embryogenic tissues from the apical meristem, and 7.6-9.4 $\times$ 10^6 pascal on embryos and older apical meristem tissues. Higher pressures are used on tissues that are more developed and denser such as embryos later than 7 days after culture and older embryogenic tissues from florets and apical meristems that are starting to form somatic embryos. It is currently not clear which tissue type and bombardment conditions will ultimately be the best for transformed plant recovery.

Acknowledgement

The technical skills of W Bloodworm are gratefully acknowledged.

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Screening for Drought Tolerance in Pearl Millet

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Under rainfed conditions plant population per unit area is the most important factor that ultimately determines grain yield. The ability of seeds to germinate and establish is a major yield-determining factor (Lawn and Williams 1987). Gill (1991) reported that varietal variation in osmotic adjustment exists, and in turn indicates the existence of variation in drought tolerance in pearl millet [*Pennisetum glaucum* (L.) R. Br.] at the variety level. In this study, the drought tolerance of hybrid X7 (released in 1997 by Tamil Nadu Agricultural University, Coimbatore) was assessed under laboratory conditions.

Germination tests carried out in such osmotica as polyethylene glycol (PEG) predict the relative germination ranking of cultivars in soil (Saint-Clair 1976). The performance of hybrid X7 was compared with that of hybrid X6 and composites Co7 and WC-C75, in a completely randomized design with four replications. An osmotic solution of -3 bars was prepared using PEG 6000 (Goswami and Baruah 1994) while distilled water served as a control. Seed germination was recorded on the 7th day and average germination percentage was calculated. In addition, root length, seedling height, dry mass of seedlings, and a vigor index were also observed (Table 1).

Germination was significantly reduced in the stress treatment (Table 1). Hybrid X7 recorded 2% more germination than hybrid X6 under both normal and stressed conditions. The roots, another important attribute of drought tolerance (Gregory and Squire 1979), were reduced in length by 44.7% in the stress treatment. Hybrid X7 recorded 40.7% longer roots under stressed conditions than the composite WC-C75, thus establishing its possibly superior drought tolerance over other cultivars. Gill (1991) stated that wide variation in rooting characteristics exists in pearl millet, that could be exploited to identify drought-tolerant plant types. The mean height of the seedlings was reduced by 45.5% in the stressed treatment. Hybrid X7 had 38.2% taller seedlings than WC-C75 under stress. The data computed for vigor index revealed a significant difference between the cultivars. Hybrid X7 recorded a 37.8% higher value for vigor index than did WC-C75 under stressed conditions. Ching (1973) reported that the more efficient physiological and biochemical activity of vigorous seedlings may result in higher yields.

The ability of hybrid X7 to produce longer roots coupled with its higher vigor index enabled this genotype to overcome the simulated drought stress more successfully than the other genotypes tested. Hybrid X7 (Jayaraman et al. 1997) was extensively evaluated at field level under rainfed conditions. All India Coordinated Trials conducted from 1989-95 and 270 rainfed trials revealed a 12% yield advantage of hybrid X7 over hybrid X6 and a 30% advantage over the composite Co7 (Table 1).

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Table 1. Germination and other physiological parameters under normal (N) and induced stress (S) treatments (T) in pearl millet cultivers (v), laboratory test, Tamil Nadu Agricultural University (TNAU), India, 1997

		Germination (%)		Root length (cm)		Seedling height (cm)		Dry mass of seedlings (g)		Vigor index	
Genotype		N	S	N	S	N	S	N	S	N	S
X7		99.5	98.0	10.89	6.53	17.90	10.71	0.058	0.074	1781.3	1049.6
X6		97.0	96.0	10.23	6.17	17.48	10.65	0.070	0.080	1695.6	1022.4
Co7		98.3	95.5	9.28	5.65	16.17	9.03	0.073	0.094	1589.5	862.4
WC-C75		99.8	98.3	11.18	4.64	18.43	7.75	0.093	0.101	1839.3	761.8
CD	T	0.636**		0.650**		0.755**		0.0065**		72.133**	
(P<0.05%)	v	0.900**		0.919 (NS)		1.068**		0.0092*		102.002 (NS)	
	T x V	1.272 (NS)		1.300*		1.510**		0.0131(NS)		144.268 (NS)	

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Pests and Diseases

Diallel Analysis of Chinch Bug Damage to Pearl Millet

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Introduction

The chinch bug (*Blissus leucopterus leucopterus* Say) complex has historically been a major pest of the Gramineae in central, eastern, and southern United States. Widespread damage by these insects has declined since the 1950s due to the cultivation of resistant varieties and the use of insecticides, but forage and turf grasses are still frequently damaged by chinch bug. The first reported infestation of pearl millet *[Pennisetum glaucum* (L.) R. Br] by chinch bug occurred in Oklahoma in 1977 (Starks et al. 1982). Since 1986, chinch bugs have become widespread during drought in pearl millet breeding nurseries at Tifton, Georgia. Foliar necrosis develops in pearl millet following chinch bug infestation. Because infestations occur during drought, the symptoms they cause are distinct from those of foliar diseases. Reducing chinch bug damage to pearl millet in the southeastern United States is necessary for stable crop production.

A severe infestation of chinch bug occurred in a yield trial consisting of five pearl millet varieties from West Africa and 10 F_1 populations from diallel crosses at Tifton, Georgia in 1990. The uniformity and severity of the infestation in this experiment provided an opportunity to determine if heritable resistance to chinch bug damage existed in these pearl millet genotypes.

Materials and methods

Ten hybrid populations were developed by making diallel crosses between five pearl millet varieties from West Africa (Table 1). The parents and hybrids were sown in 1990 in four-row, 4-m long plots in a randomized complete-block design with five replications.

Minimal rainfall from the end of June through July resulted in insignificant levels of foliar diseases. Chinch bug infestation was widespread in the plots and necrotic foliar symptoms characteristic of chinch bug damage developed. The percentage of necrotic foliage in both of the center two rows of each plot was individually estimated on 31 July 1990 when plants were in the late anthesis to early grain filling stages.

Data were analyzed by the general linear model procedure of SAS (SAS Institute Inc. 1982). Sums of squares were partitioned into replication, entry, and replication x entry effects. Analyses of arrays of crosses with a parent in common were performed to determine the performance of parents in hybrid combinations. Gardner and Eberhart's diallel analysis III (Gardner and Eberhart 1966) was used to estimate general (GCA) and specific (SCA) combining ability effects. Variance contributions due to GCA and SCA components were estimated according to Falconer (1981), and these values were used to estimate the contributions of additive and non-additive genetic variances to the hybrid genotypic variance.

Results and discussion

Entry was a significant source of variation in damage ratings. Foliar necrosis ranged from 17.3 to 25.2% on parents and from 21.4 to 35.6% on hybrids. The Ugandi x P3Kolo hybrid showed greater foliar necrosis than either parent (Table 1). Foliar necrosis in four hybrid populations was greater than the more-resistant parent, but did not

Table 1. Foliar necrosis caused by chinch bug feeding, and general combining ability effects of five pearl millet varieties from West Africa and hybrids from diallel crosses between the varieties

Variety or hybrid	Foliar necrosis (%)	Source[1]	Origin	General combining ability[2]
Iniari	21.1	ICRISAT	Togo	-1.11
x Mansori	27.1			
x Ex-Bornu	21.6			
x Ugandi	33.1			
x P3Kolo	28.3			
Mansori	17.5	ICRISAT	Sudan	0.09
x Ex-Bornu	27.3			
x Ugandi	30.5			
x P3Kolo	28.8			
Ex-Bornu	17.3	ICRISAT	Nigeria	-4.41**
x Ugandi	29.4			
x P3Kolo	21.9			
Ugandi	25.2	ICRISAT	Uganda	5.05**
x P3Kolo	35.6			
P3Kolo	18.7	INRAN	Niger	0.39
LSD (P<0.05)	10.2			

1. ICRISAT = International Crops Research Institute for the Semi-Arid Tropics; INRAN = Institut national de recherche agronomic du Niger
2. ** indicates the GCA effect differs from zero (P<0.01).

differ from the more-susceptible parent (P<0.05). Damage on five hybrids did not differ from either parent.

Analyses of individual arrays of hybrids with a common parent revealed differences in damage among the crosses involving either *Iniari* or P3Kolo with Ex-Bornu and Ugandi. The analyses of the arrays with a parent in common indicated that Ex-Bornu contributed greater levels of resistance to damage in some of these crosses than did Ugandi.

Differences in damage existed among some hybrids (Table 1). The GCA variance, attributable to additive genetic effects, was significant, while the SCA variance, attributable to dominance and epistatic genetic effects, was not significant in these hybrids.

The GCA effects of Ex-Bornu and Ugandi were significant (Table 1). The negative GCA effect of Ex-Bornu indicates that hybrids from this parent had less damage, and the positive GCA of Ugandi indicates that hybrids from this cultivar had more damage than the overall means of all hybrids. This is consistent with results obtained from the analyses of arrays of crosses with a common parent. No other GCA effects or SCA effects differed from zero.

Our results differ from a study of tolerance to chinch bug damage to pearl millet in Oklahoma, in which selections from an experimental population segregated for a single dominant gene (Starks et al. 1982). In our study, most of the hybrids were more susceptible than the more-resistant parent, suggesting a recessive or additive genetic control of tolerance in these genotypes. Genetic resistance to chinch bug damage is likely to provide the most effective means of control. Avoiding insecticide applications in breeding nurseries and yield trials could facilitate selecting pearl millets with resistance to or tolerance of chinch bug feeding.

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Utilization

Propionic Acid Treatment Prolongs Storage and Inhibits Lipolytic Processes in Cracked Pearl Millet Feed Grain

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Introduction

Harvesting pearl millet [*Pennisetum glacum* (L.) R. Br.) with a combine harvester often results in grain with high moisture contents that can contribute to problems from grain molds in storage (Jurjevic et al. 1999). Even in the absence of an obviously visible postharvest grain mold problem, pearl millet grain cracked to be used as livestock feed quickly turns rancid, as expressed by a rapid increase in its free fatty acids content (Kaced et al. 1984). Lipolytic processes can be the result of host or microbial enzymatic action. In the commercial feed stream, grain moisture control or mold inhibitors are the only factors that can reasonably be used to reduce postharvest grain molds. This experiment was conducted to test the hypothesis that propionic acid treatment will reduce grain mold development and lipid degradation in cracked pearl millet grain.

Materials and methods

Main treatments consisted of non-treated or propionic acid treated (15 m L kg^{-1} grain) intact or cracked grain at 18% moisture content. Grain was stored, either in insulated Dewar flasks (6.8 kg grain) to retain the heat resulting from microbial activity, or in non-insulated containers (1.6 kg grain). Treatments were replicated twice. Non-acid treated grain was discarded after 14 days due to excessive decay. Acid-treated grain was retained for further observation. Three samples were taken with a grain probe from each container at weekly intervals. Samples were ground to pass through a No. 20 sieve. Fatty acids were extracted from approximately 5 g of ground grain and quantified (as mg KOH required to neutralize free fatty acids from 100 g dry grain) according to the AOAC rapid protocol (1995). Data for fat acidity were analyzed by analysis of variance for a 2 x 2 x 2 factorial design. Sums of squares were partitioned into sampling date, replication, acid treatment, grain integrity (cracked vs. intact) and insulation main effects, and all possible two- and three-factor interactions. Within sampling date, main effect and treatment means were differentiated by Fisher's LSD.

Results and discussion

At the first sampling date, all non-acid treated samples were visibly molded (primarily by *Aspergillus glaucus* Link). By the 2nd week, sporulation by *A. flavus* and other *Aspergillus* species was evident and excessive rotting had occurred. Fat acidity values were greatest in non-treated cracked grain (Table 1). Cracking slightly increased fat

Table 1. Fat acidity values of treatments to evaluate propionic acid for reducing pearl millet grain molds and lipolytic activity

			Fat acidity value after days in storage		
Treatment	Grain	Insulation	7 d	14d	28 d
Non-treated	Intact	Insulated	51.9ef[1]	51.1de	-
Non-treated	Intact	Not insulated	46.9 f	46.2 e	-
Non-treated	Cracked	Insulated	143.7 b	111.4a	-
Non-treated	Cracked	Not insulated	157.9a	94.8 b	-
Propionic acid	Intact	Insulated	60.7de	58.6 cd	48.5 b
Propionic acid	Intact	Not insulated	63.4d	47.4 e	44.3 b
Propionic acid	Cracked	Insulated	73.8e	67.2 c	70.3 a
Propionic acid	Cracked	Not insulated	73.8c	62.8 c	63.3 a
LSD(P<0.05)			9.0	10.6	11.9

1. Values in a given column that are followed by the same letter are not significantly different according to Fisher's Least Significant Difference.

acidity values of acid-treated grain compared to intact grain, but no visible mold growth was evident. Insulation had minor, inconsistent effects on fat acidity values. In all treatments, fat acidity values tended to decline with time. These declines in fat acidity values in non-treated, cracked grain may be the result of fungi using free fatty acids as a carbon source. Declines in acid-treated grain may be the result of volatilization of propionic acid. The greater apparent fat acidity values associated with acid-treated grain were an artifact of treatment, and reflected the slightly greater amounts of KOH required to neutralize the extract. No visible fungal growth was observed on the acid-treated grain after 1 month, despite the high grain moisture content. Propionic acid appears to be an effective mold inhibitor for pearl millet feed grain and can also reduce lipolytic processes associated with cracked grain.

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Book Reviews

ICRISAT. 1998. Strengthening sorghum research collaboration in Asia: report of the Asian Sorghum Scientists' Meeting, 18-21 Nov 1997, Suphan Buri, Thailand. (Gowda, C.L.L., and Stenhouse, J.W., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 72 pp.
ISBN 92-9066-392-8.
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 (CLAN) -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 might be expected.

Yapi, A.M., Debrah, S.K., Dehala, G., and Njomaha, C. 1999. Impact of germplasm research spillovers: the case of sorghum variety S 35 in Cameroon and Chad. Impact Series no. 3. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 30 pp.
ISBN-92-9066-377-4.
LDC $6.00 HDC $ 16.00 India Rs 230.00

This study evaluates the impacts and research spillover effects of adoption of sorghum variety S 35, a pure line developed from the ICRISAT breeding program in India. It was later advanced in Nigeria and promoted and released in Cameroon in 1986 and Chad in 1989.

The net present value of benefits from S 35 research spillover in the African region was estimated to be US$ 15 million in Chad and US$ 4.6 million in Cameroon, representing internal rates of return of 95% in Chad and 75% in Cameroon. For greater effectiveness in sorghum technology development and transfer in the region, future research and policy actions should take greater advantage of research spillovers through more collaboration, communication, and networking between national, regional, and international research institutions.

Yapi, A.M., Dehala, G., Ngawara, K., and Issaka, A. 1999. Assessment of the economic impact of sorghum variety S 35 in Chad. Impact Series no. 6. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 34 pp.
ISBN 92-9066-408-8.
LDC$7.00 HDC$18.00 India Rs 250.00

The S 35 sorghum variety is a nonphotoperiod-sensitive, high-yielding, early-maturing, and drought-tolerant pure line that originated from ICRISAT's breeding program in India, and was later advanced and promoted in Cameroon and Chad. Its introduction into drought-prone areas of Chad has been very successful with a net present value of research investments estimated at US$ 15 million, representing an internal rate of return of 95%. Two crucial factors explain this apparent success: 1. germplasm research spillovers from ICRISAT and Cameroon's breeding programs substantially reduced the time lag in S 35 research and development in Chad; and 2. the FAO/UNDP-supported seed project at Gassi not only successfully multiplied S 35 seed on a large scale, but also distributed it to farmers by adopting the 'mini-doses' approach and involving the Bureau national de deVeloppement rural and NGOs. The three major constraints cited by farmers — susceptibility of the variety to bird attack, the high cost of seed, and low soil fertility — should assist in the formulation of future research priorities.

Gupta, S.C. 1999. Seed production procedures in sorghum and pearl millet. Information Bulletin no. 58. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 16 pp. ISBN 92-9066-415-0.
LDC $8.50 HDC $23.50 India Rs 340.00

Functional and healthy seed is one of the important factors in improving agricultural production. Farmer-based seed production programs for pearl millet and sorghum have been introduced in some of the developing countries (Senegal and Namibia) and are proving to be successful. The areas of responsibility in terms of producing improved cultivars (pure-line varieties, composites, and hybrids) are breeding, commercial seed production, and certification. While breeding is carried out by a research station, commercial production and distribution require an well-organized operation. Certification is carried out by independent agencies that monitor the quality and purity of the cultivar during production. The procedures for seed production of the open-pollinated varieties differ from those of hybrids. There are also differences in the seed production of both sorghum and pearl millet. Maintaining varietal purity of both the crops requires adequate precautions that need to be taken against physical admixtures during sowing, harvesting, threshing, and storage. Both pearl millet and sorghum have specific requirements for protection against contamination so that good quality seed can be produced.

Youm, O., Russell, D., and Hall, D.R. 1998. Use of pheromone traps for monitoring the millet stem borer (*Coniesta ignefusalis*). Information Bulletin no. 40. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 20 pp.
ISBN 92-9066-290-5.
LDC$10.50 HDC$28.50 India Rs395.00

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.

Wilson, J.P. 2000. Pearl millet diseases: a compilation of information on the known pathogens of pearl millet, *Pennisetum glaucum* (L.) R. Br. United States Department of Agriculture, Agricultural Research Service, Agricultural Handbook No. 716.60pp

Requests for a free copy can be e-mailed to
cgbr@tifton.cpes.peachnet.edu

Cultivation of pearl millet [*Pennisetum glaucum* (L.) R.Br.] for grain and forage is expanding into non-traditional areas in temperate and developed countries, where production constraints from diseases assume greater importance. The crop is host to numerous diseases caused by bacteria, fungi, viruses, nematodes, and parasitic plants. Information on symptoms, pathogen and disease characteristics, host range, geographic distribution, nomenclature discrepancies, and the likelihood of seed transmission for the pathogens are summarized. This bulletin provides useful information to plant pathologists, plant breeders, extension agents, and regulatory agencies for research, diagnosis, and policy-making decisions.

Khairwal, I.S., Rai, K.N., Andrews, D.J., and Harinarayana, G. (Eds.). 1999. Pearl millet breeding. New Delhi, India: Oxford & IBH Publishing Co. Pvt. Ltd. 525 pp. ISBN 81-204-1305-9.
Rs. 800.00

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is an important coarse-grained cereal, annually cultivated as a rainfed crop on about 26 million ha in the arid and semi-arid tropical areas of Africa and the Indian subcontinent. In these areas, it is grown in some of the harshest environments, albeit with low grain yields, where such other cereals as sorghum and maize fail to produce economic grain yields. Pearl millet responds well to management inputs and therefore has great potential to become an important component of intensive agriculture. It has already established its place as an irrigated summer crop in parts of India, and holds the promise of becoming an important component of agricultural systems in other Asian countries and the Americas.

Impressive advances have been made in the genetic improvement of pearl millet. There was a long-felt need for a comprehensive document that brings together the principles and research results relevant to the breeding and development of this crop. This book, edited by four breeders, each with more than 20 years of active research experience in national and international agricultural research systems, satisfies this need. Its 17 chapters written by experienced scientists from around the world. It covers a wide range of subjects including the crop's biology, evolution, genetic resources, breeding methods, biotechnology, seed production, and its importance in global agriculture. It is a valuable reference book for students, teachers and researchers, interested in the genetic improvement of this crop.

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Information for ISMN contributors

Publishing objectives

The International Sorghum and Millets Newsletter (ISMN) is published annually by the Sorghum Improvement Conference of North America (SICNA) and the International Oops Research Institute for the Semi-Arid Tropics (ICRISAT). It is intended to be 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.) Gaertn.), 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, tours, surveys, network activities, and recently launched or concluded projects.
- Details of recent publications, with full bibliographic information and 'mini reviews' whenever possible.
- Personal news (new appointments, awards, promotions, change of address, etc.).

How to format contributions—deadline 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 decimal place 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 including author/s, year, title of the article, full title of the journal, volume, issue, and page numbers (for journal articles), and place of publication and publishers (for books and conference proceedings) for every reference. Incomplete references will not be accepted.
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- Give the correct Latin name of every crop, pest, or pathogen at the first mention.
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- Contact the Editors for detailed guidelines on how to format text.
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