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15 Years of Pearl Millet Improvement in the SADC Region

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Abstract

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

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

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

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

Introduction

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

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

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

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

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

Summary of achievements

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

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

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

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

Germplasm exchange

SADC germplasm

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

International germplasm and breeding lines

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

Role of SMIP in the supply of germplasm to SADC

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

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

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

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

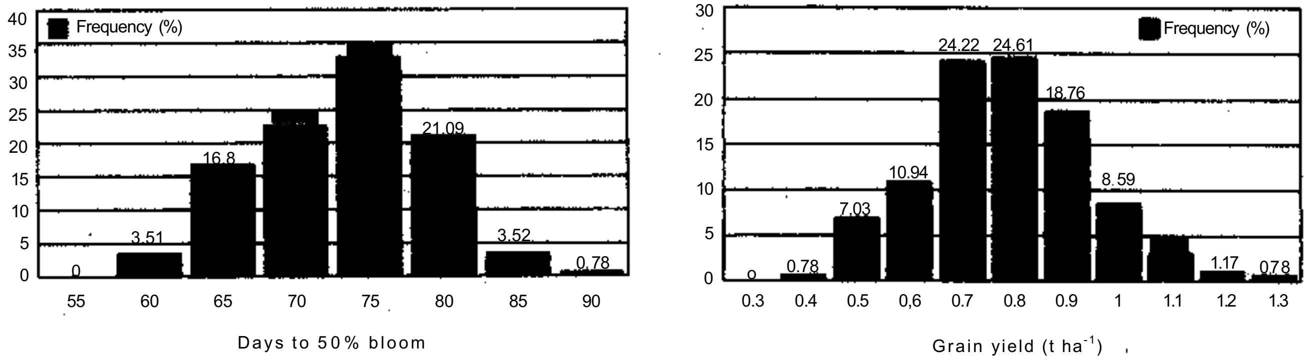
regional breeding programs. During the past 15 years, SMIP has acquired from NARS a total of 3599 different accessions (germplasm and breeding lines) for use in breeding: Zimbabwe (1362), Namibia (994), Tanzania (527), Malawi (467), Botswana (96), Zambia (77), and Mozambique (76).

Varietal improvement

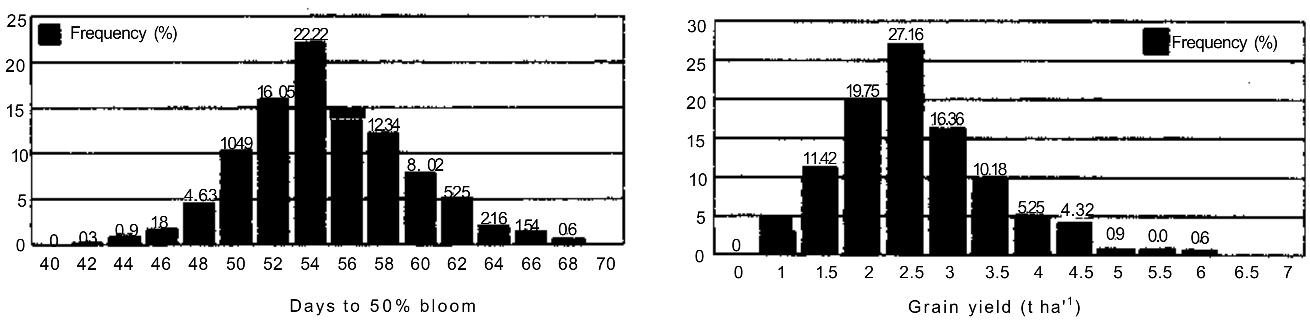
Genetic diversification and population breeding

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

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



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



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

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

Breeding varieties, hybrids, and hybrid parents

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

Breeding hybrids

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

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

1. Variety cross hybrids. The ideal combination is when the female is a late dwarf, and the male (pollen) variety is slightly earlier but tall. The hybrid is expected to be much earlier and taller than any selfed female plants. We have not been very successful thus far with seed production mainly due to drought and problems of synchronization of flowering.
2. Topcross hybrids. This approach requires that at least one of the parents is a variety. Topcross hybrids are more heterogeneous than single crosses and thus are expected to be less vulnerable to diseases. Topcross hybrids are already proving to be popular, especially

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

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

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

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

Grain quality evaluation in pearl millet

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

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

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

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

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

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

Network activities

Bilateral collaborative research

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

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

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

The main components of the project included:

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

Achievements

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

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

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

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

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

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

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

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

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

Achievements

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

Regional collaborative trials

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Targeting NARS breeding programs to farmers' needs

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Plant protection

Identification of major diseases and their hot spots

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

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

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

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

Five diseases were of importance:

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

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

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

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

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

Adaptation and development of screening techniques

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

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

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

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

Identification of sources of resistance

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

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

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

Insect pests

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

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

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

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

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

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

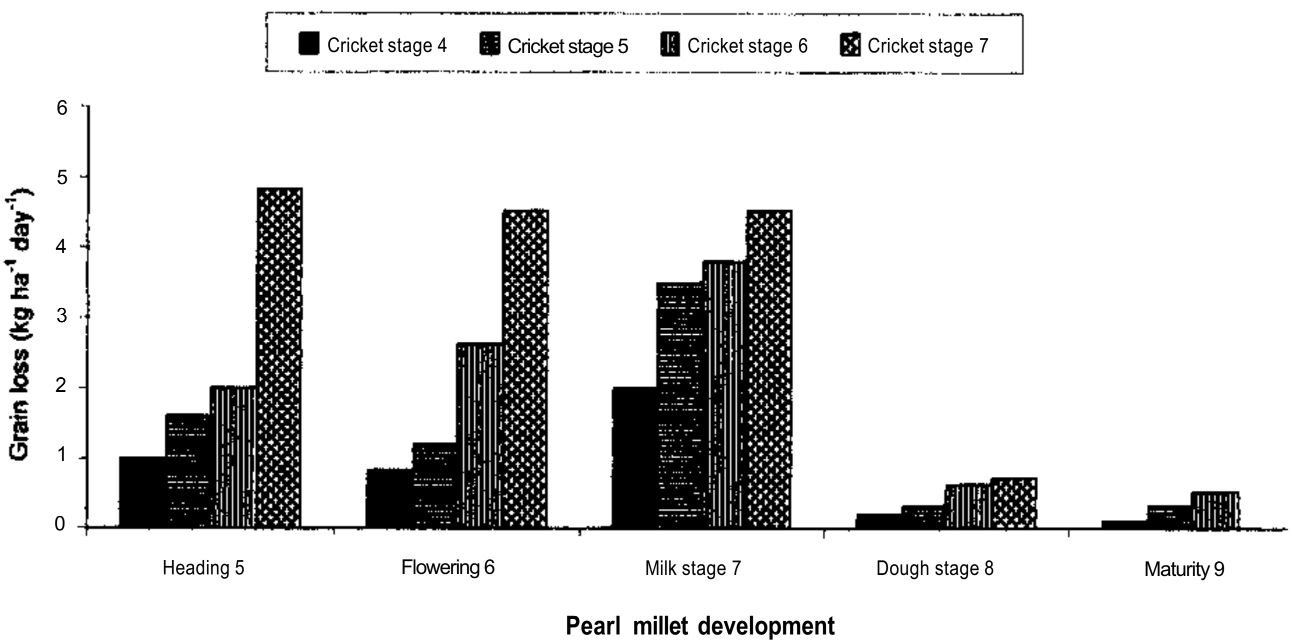


Figure 5. Grain damage, i.e., food intake (kg ha^{-1}) day^{-1}, by cricket stages 4-7 at pearl millet development stages 5-9 (Wohlleber 1996).

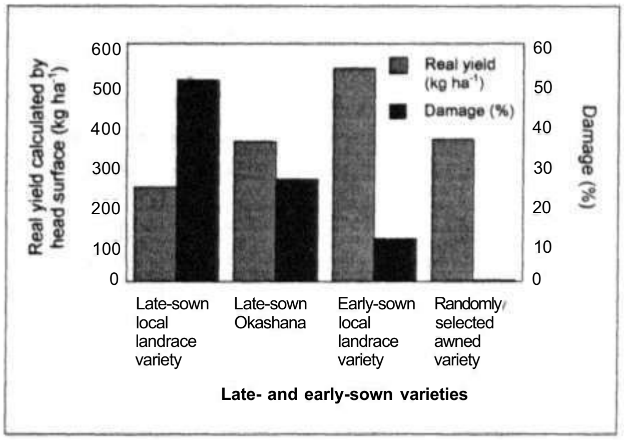


Figure 6. Yield loss in pearl millet caused by crickets for different sowing dates and varieties expressed in percentage and kg ha^{-1}.

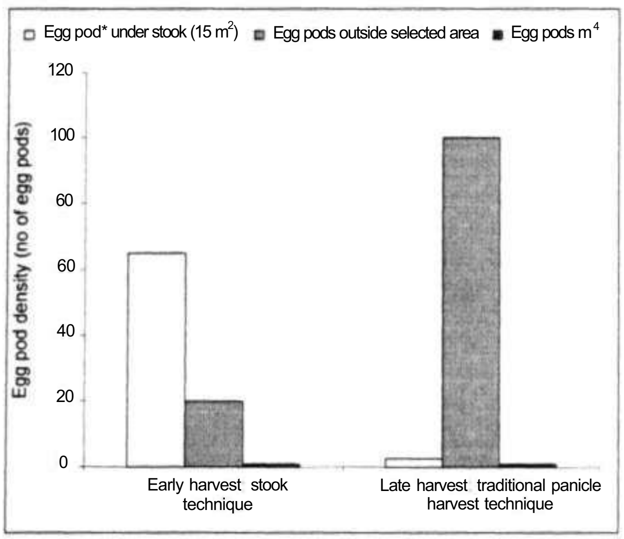


Figure 7. Number of egg pods found under stooks (15 m^2) and surrounding area (385 m^2) compared with egg pods found in a traditionally harvested area (15 m^2, selected) and the surrounding area (385 m^2) (Wohlleber 1996).

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

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

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

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

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

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

Change in harvest procedure

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

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

Future directions

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

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

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

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

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

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

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Abstract

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

Introduction

Sorghum (*Sorghum hicolor* (L.) Moench) and pearl millet (*Pennisetum glaucum* (L.) R. Br.) account for 15% of cereal grain area and 9% of cereal grain production in