Sorghum Improvement

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

Abstract

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

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

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

Introduction

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

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

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

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

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

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

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

Methodology

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

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

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

Accomplishments

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

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

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

1. ICRISAT Latin American Sorghum Improvement Program.

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

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

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

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

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

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

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

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

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

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

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

Cultivar development and testing

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Productivity, adaptation, and farmer participation

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

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

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

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

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

Improved cultivar releases

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

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

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

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

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

Assessment of grain quality for several end uses

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

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

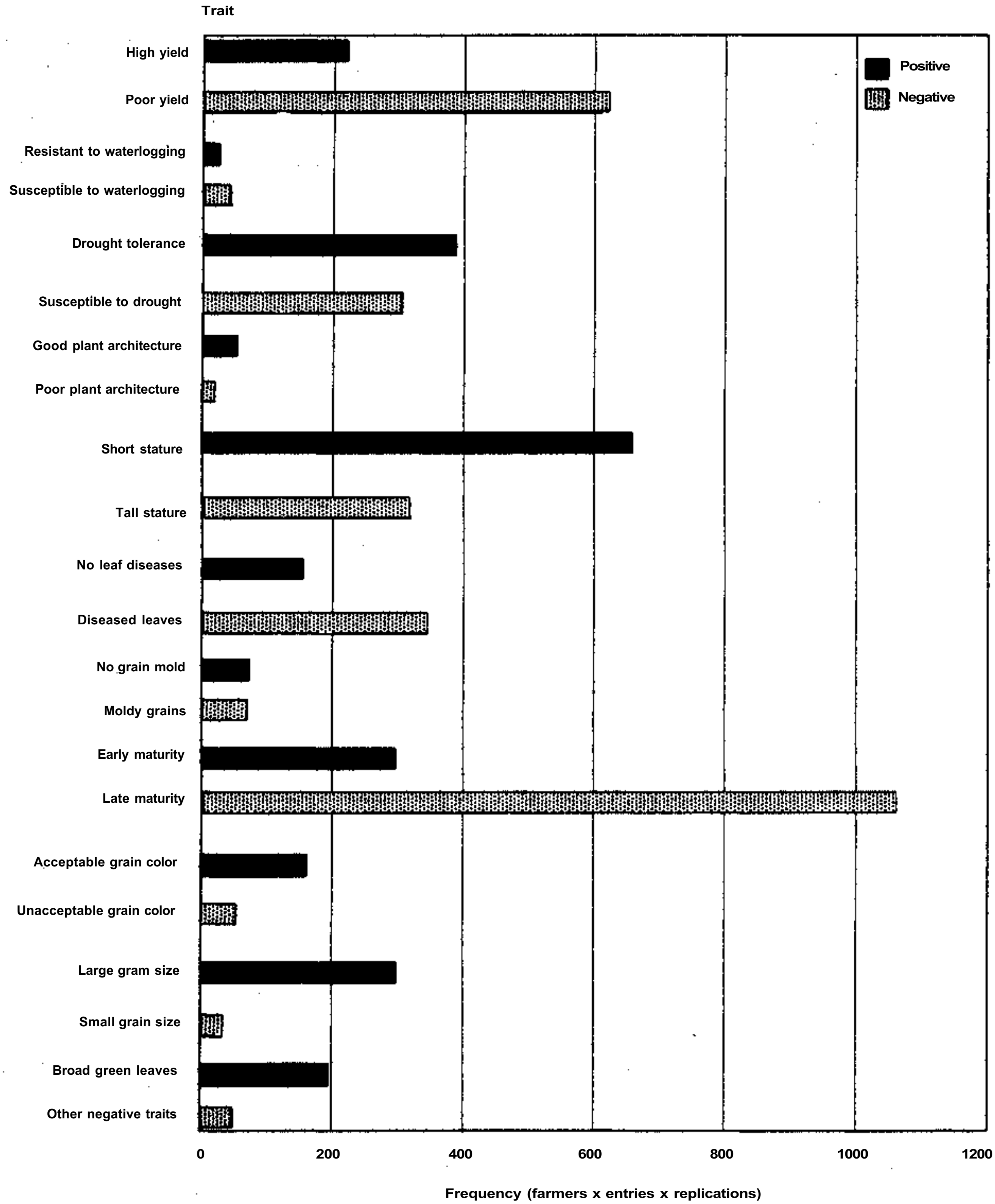

Figure 2. Positive and negative traits of sorghum cultivars most frequently mentioned and identified by farmers at Matopos and Lucydale, Zimbabwe, 1993/94 and 1994/95 (ICRISAT 1997).

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

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

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

Table 7. Grain quality traits in different sorghum types.

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

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

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

Networking in SMIP

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

Regional networking

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

New linkages

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

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

Bilateral cooperation

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

Implications for impact

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

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

Intermediate products. Intermediate-level impacts include the following:

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

Areas of concern

Progress has been limited in three areas.

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

The future

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

Productivity increases through

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

Increased commercialization through

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

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15 Years of Pearl Millet Improvement in the SADC Region

E S Monyo (SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP), Matopos Research Station, PO Box 776, Bulawayo, Zimbabwe)

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