Impact of Genetic Improvement in Sorghum and Pearl Millet: Developing Country Experiences

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Abstract

Achievements have been made in genetic improvement technology in sorghum and pearl millet in many countries of southern Africa, particularly Botswana, Namibia, Zambia, and Zimbabwe. In the ten-year period 1984-85 to 1994-95, ICRISAT's germplasm and associated breeding efforts of the SADC (Southern Africa Development Community)/ICRISAT Sorghum and Millet Improvement Program (SMIP), in collaboration with the National Agricultural Research Systems (NARS) scientists, have resulted in the release of 32 improved varieties and hybrids of sorghum and pearl millet in eight countries of southern Africa. These releases are more than double (250%) those released in the ten years from 1973-74 to 1983-84. Eighty-seven percent of the releases contain ICRISAT materials. Cultivars released in the four countries used as case study experiences in this paper (Botswana, Namibia, Zambia, and Zimbabwe) account for 20 (63%) of the total 32 sorghum and pearl millet cultivars in the region. Of the 20 released cultivars, eight (40%) have been adopted and are presently being grown by farmers. Adoption studies carried out through surveys by SADC/ICRISAT SMIP, based on seed sales and distribution, and estimates by breeders in the region, based on quantities of seed produced, indicate a variable diffusion pattern in the four countries, with rates of diffusion ranging from one year (for Phofu sorghum variety in Botswana, Okashana 1 pearl millet variety in Namibia, and PMV 2 pearl millet variety in Zimbabwe), through two years (for Kuyuma sorghum variety in Zambia) to five years (for SV2 sorghum variety in Zimbabwe). The areas of current coverage follow a similar dramatic pattern. In Botswana, variety Phofu covered 25% of the total sorghum area (22, 000 ha) within the one year of diffusion, while variety Okashana 1 covered 14% of the total pearl millet area (47, 000 ha) in Namibia. A 36% farm coverage was recorded for variety SV 2 after three years of significant diffusion in Zimbabwe following emergency seed production.

In monitoring the release, on-going adoption, and impact of improved varieties in SADC countries, survey data (1994-95 to 1995-96) from SADC/ICRISAT SMIP indicate an internal rate of return of 27-34% and a stream of net benefits ranging from $ 7.8-28.9 million in Zimbabwe for SV 2 and PMV 2. In Namibia, a rate of return of 13% with net benefit of $ 0.04 million was calculated (Anandajayasekeram et al., 1995). Impact assessments of the other released improved varieties in Botswana and Zambia are still

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going on. The presently moderate impacts generated at farm level by these new improved varieties as a result of genetic improvement (involving research and development activities) has been enhanced and promoted by several important factors: 1) the introduction and development of improved germplasm with farmer-preferred traits of early maturity, drought resistance, and acceptable good quality in grain; 2) seed production; 3) effective on-farm testing for farmer verification; and 4) breeder participation and commitment in technology transfer and exchange.

Conventional breeding programs always have resulted in the development of improved genetic stock, breeding lines, and populations, as well as the release of improved varieties. While these constitute achievements of the programs, they alone do not generate impact. Previous trends in genetic enhancement have been the generation of improved germplasm and the testing of this technology. These breeders' activities are usually followed by release of improved germplasm in the form of varieties or hybrid parents as end products after on-station evaluation. The consequence of this approach ending at variety release, with no planned push of the products into farmers' fields, has been the limited adoption of the series of variety releases by end-users, the farmers. This shortfall has been a major constraint to increased production and productivity of improved sorghum and pearl millet varieties especially in developing countries.

Present trends in genetic enhancement research have shown that targeted and more appropriate variety releases, which can result in increased production of the improved varieties, can be achieved by increased adoption of the technologies by farmers, through on-farm testing and farmer verification (Chintu et al., 1996a and 1996b; Ipinge et al., 1996; Matanyaire and Gupta, 1996; Mangombe and Mushonga, 1996; SADC/ICRISAT SMIP, 1995 and 1996).

The transfer of improved variety technologies into farmers' fields has addressed the need to incorporate preferences of farmers who will accept, adopt, and produce the new improved varieties. It has been shown (Anandajayasekeram et al., 1995; Jenkins et al., 1996) that the incorporation of technology transfer activities into genetic improvement of sorghum and pearl millet, following technology development and testing, has greatly enhanced the release of more farmer-preferred varieties in southern Africa. This innovative strategy has led to the increased adoption for production of the new improved sorghum and pearl millet varieties and hybrids released in national programs.

It therefore should be the breeder's responsibility to participate in and champion the move of outputs from genetic improvement into farmers' fields for increased adoption and production. This is the demand of contemporary genetic enhancement in the improvement of sorghum and pearl millet — that is, breeding for impact!

The purpose of this paper is to show the type, quality, and quantity of impact generated from genetic improvement of sorghum and pearl millet and share our experiences of developing countries from southern Africa sub-region. The strategy we used will be described, and our achievements highlighted. We will present case studies from four countries of the southern Africa sub-region. The four southern African countries include Botswana (for sorghum), Namibia (for pearl millet), Zambia (for sorghum), and Zimbabwe (for sorghum and pearl millet).

Method

Breeding for impact involves a sequence of significant events in a time-phased and overlapping series of progressive activities. The strategy used in southern Africa by the SADC (Southern Africa Development Community)/ ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Sorghum and Millet Improvement Program (SMIP), has involved, first, the rationalization of the genetic improvement objectives, followed by a systematic and logical breeding, selection, and testing program.

Rationalization of Breeding Objectives

Based on the initial progress made by the SADC/ICRISAT SMIP in southern Africa during the first two phases (1983-84 to 1993-94) in the development of improved varieties, populations, and breeding lines, the objectives of the genetic improvement program for sorghum and pearl millet for the third phase (1994-95 to 1998) were rationalized. The purpose of the rationalization exercise was to improve on the conventional successes of the genetic improvement program by moving forward from the approach of developing and releasing cultivars and breeding lines to the present strategy of ensuring not only that the cultivars developed are adopted, released, and produced by farmers, but also that the breeding lines are effectively utilized by breeders in collaborative partnership.

The rationalized objectives of the SADC/ICRISAT SMIP breeding program since1994, after improved varieties became available, are:

1) To continue to breed improved varieties and to collect and exchange germplasm with particular reference to drought.

2) To facilitate the transfer of technologies to small-scale farmers through the National Agricultural Research Systems (NARS) and linkages with Non-Governmental Organizations (NGOs), seed companies, and other partner institutions.

3) To evaluate grain quality for various end-uses.

4) To improve the productivity of NARS and NGO research and development in crop improvement through in-country and regional training, collaborative activities, and joint work planning in genetic improvement of sorghum and pearl millet.

One additional aspect of the rationalized objectives is that they have a production system focus targeted at two main production systems: 1) the lowland drought, short season (<100 days) sorghum/millet/rangeland system; and 2) the semi-arid, often-droughted, intermediate season (100-125 and 125-150 days) sorghum/maize/rangeland/millet/legumes system.

Events and Process

The sequence of time-phased events and overlapping series of activities for generation of impact in genetic improvement include: technology development, technology testing, and technology transfer and exchange. Table 1 shows the events and overlapping sets of activities involved. (Note: All tables appear at the end of this article.) The sets of activities within each event determine the type of outputs from the genetic improvement process. Germplasm movement and utilization generate the breeding lines, populations, and cultivars, including pure line varieties, hybrid parents and hybrids, for testing. Technology testing both on-station in experiment stations and on-farm in farmers' fields, evaluates the performance and adaptation for productivity of the genetic products. Technology transfer and exchange events are based on the good and tested genetic products resulting from technology generation and testing. Farmer verification and preference tests usually enhance the progress and success of technology transfer activities. In the southern Africa region, the systematic progression for breeding, testing, and selection process as a strategy for technology testing is shown in Figures 1 and 2. As shown in Table 1 and Figures 1 and 2, the approach for genetic improvement to generate impact has been multidisciplinary and depends on collaborative partnership with the national programs and their NGOs in developing countries of southern Africa. The national program in Zambia has been more aggressive in this process.

Results and Discussion

Progress in Genetic Improvement in Southern Africa

Significant achievements have been made in the breeding and release for production of improved sorghum and pearl millet cultivars in the SADC region. The successes achieved have been due to the collaborative efforts of the regional SADC/ICRISAT SMIP and some (NARS) in the region. Specifically, successes achieved in some of the NARS have generated impact at both scientific and farmer levels in their respective countries.

Tables 2, 3, 4, 4a, and 5 show the sorghum and pearl millet varieties released in the four target countries for case study (Botswana, Namibia, Zambia and Zimbabwe, respectively) during the ten-year period 1984-85 to 1994-95. Table 6 shows the trend of achievements from prior to 1983 to the period 1984-85 to 1994-95. Table 8 shows the successes achieved in germplasm movement to and from the four target countries. Tables 9, 10, 11, and 12 show the summary yield (t ha^{-1}) and maturity (days to 50% heading) of the released varieties in Botswana, Namibia, Zambia, and Zimbabwe, respectively.

Botswana

In 1994, four new sorghum cultivars were released by the National Variety Release Committee. These cultivars include three pure line varieties (Phofu, Mahube and Mmabaitse) and one single cross hybrid (BSH1) (Table 2). This hybrid is the first ever released in the country. Breeder seeds are being maintained in the country and the backup activity of SADC/ICRISAT SMIP. In 1995 commercial farmers started large-scale production of the foundation seed of variety Phofu in the Pandamatenga area of the country on 400 ha, with backup technical support from the national breeder, the sorghum and pearl millet improvement team in the country,

	Germplasm Acquisition ↓	
	Breeding and Observation Nurseries -Farmer Participation ↓	Initial screening Germplasm evaluation
SMIP nurseries Country crossing blocks	**Crossing Program** **Backcrossing Program** ↓	Line development Hybrid parent development
Breeding lines SMIP nurseries and semi-finished products selected by advanced NARS into their nurseries	**F4/F5 Lines** **Modified Pedigree Breeding** ↓	Early generation testing in one location
SMIP nurseries	**F6/F7 Lines**	Advanced generation testing in 1-2 locations. Head bagging of 2-3 plants/line for seed increase
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
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
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
	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.
Breeder seed increase. Seed production training by SMIP regional and in-country	**National Program Testing** ↓	NARS activity in national experiment stations, multilocations, advanced testing, compilation of data. 2 years
Large-scale seed production (NARS and Industry)	**(On-farm Testing)** ↓	Major farmer involvement to identify farmer preferences and release of varieties by NARS. 2 years, multifarm locations
More breeder seed increase (NARS and SMIP)	**On-farm Verification** ↓	NARS/SMIP activity.
Variety description and production of leaflets	**Cultivar Release, Seed Multiplication** **Farmer Adoption and Production**	NARS activity facilitated by SMIP

Figure 1. **Progression for breeding, testing and selection process in southern Africa (SADC region) for sorghum by SADC/ICRISAT SMIP.**

	Germplasm Acquisition ↓	
	Breeding and Germplasm Nurseries -Farmer Participation ↓	Initial screening
Crossing block	**Line Selection** **Crossing Program** **Backcrossing Program** ↓	Genetic diversification
SMIP nurseries	**Pedigree Program** **Genepool Formation** **Population Development** ↓	Genetic diversification and characterization. Generation advance Shuttle breeding
SMIP nurseries	**Recurrent Selection** -inbred line selection **Progeny/Line trials** -S_1 progeny trials **Testcross Trials** **Top Cross Trials** ↓	Population improvement Early generation testing Hybrid parent development and testing
Breeding lines and semi-finished products selected by advanced NARS into their nurseries	**Progenies/Line Recombination** -composite variety development -synthetics development -hybrid development ↓	
NARS specific selections	**Preliminary Cultivar Testing** -new varieties, new hybrids -new seed parent lines ↓	1-2 years 2 locations
NARS selections into their national variety trials	**Advanced Cultivar Testing** ↓	1st stage regional collaborative trials of SMIP and NARS selected entries. Beginning of multilocational trials: 6-10 locations
	Bilateral Cooperative Trials -specific to requesting NARS **Regional Collaborative Trials** -across all countries ↓	2-3 years for variety replacement 6-10 locations in SMIP and cooperating countries
Breeder seed production and training in seed production	**National Program Testing** ↓	NARS activity in national testing sites for pre-release
Variety description Breeder seed production	**On-Farm Verification** **(On-Farm Testing)** ↓	NARS activity facilitated by SMIP with a major component of farmer involvement to identify varieties for release (2 years)
Large-scale seed production (NARS and Industry)	**Cultivar Release, Seed Multiplication** **Farmer Adoption and Production**	NARS activity facilitated by SMIP

Figure 2. Progression for breeding, testing and selection process in southern Africa (SADC region)

and SMIP in Matopos. Seeds of varieties Phofu (400 ha), Mmabaitse (120 ha), Mahumbe (24 ha) and the hybrid BSH1 (58 ha) with its parents (52 ha) were produced.

Available data collected on seed production and sales throughout the southern Africa region show that 3,000 mt of seed for these four cultivars were produced in Botswana during 1995 by the private and public sectors (SADC/ICRISAT, 1996). This significant seed production had been widely stimulated by government and donor investments in drought-relief programs. A two-year technical backstopping and in-country hybrid seed production training program by the SMIP breeder led to strengthened capacity of the Botswana NARS to be able to initially produce 35 tons of the BSH1 hybrid and its three parents in 1994.

Among the three releases, variety Phofu with white seeds and stay green trait (a combination of traits that make it useful for dual purpose of food and crop residue) is most popular among Botswana farmers. About two-thirds of the sorghum seed produced in 1995 (2000mt) is of this variety. The hybrid BSH1 (Botswana Sorghum Hybrid 1) has very good white bold seeds with excellent milling quality. The white flour from the milled grain is very sought after by the milling and food industry in Botswana, especially Foods (Botswana) Pvt. Ltd.

The summary yield (t ha^{-1}) and maturity (days to 50% heading) data for the four sorghum varieties and hybrid are shown in Table 9. In the on-station trials that spanned four years and two-four locations, variety Phofu (with an average 3.25 t ha^{-1}) and hybrid BSH1 (with an average 3.83 t ha^{-1}) significantly ($P >0.01$) outyield the control and farmer varieties including the popular Segaolane (with an average 2.34 t ha^{-1}), by a range of 17 to 75%. In on-farm trials, averaged across two years in nine villages and 108 farmers within three agricultural regions, variety Phofu (with an average 0.73 t ha^{-1}) outyielded farmer varieties, including Segaolane (with average of 0.51 t ha^{-1}), by -2 to 84%. The hybrid BSH1 was not tested on-farm as it was targeted for industrial processing in milling for flour and sorghum meal. It was therefore released based on its higher yield potential, very hard (4.5 out of 5.0 on grain hardness score) and excellent white grain quality for flour yield,and acceptable white flour color.

The variety Phofu was therefore released based on its early maturity, good yield potential, large-sized heads, good field grain quality (better white grain than the popular variety Segaolane, whose white grains turn black with extreme mold infection when exposed to late season moisture) and 99.9% farmer acceptance. These farmer-preferred traits are in addition to its stay green trait with broad leaves, which makes the variety useful for good quality crop residue. The other two varieties, though lower-yielding than the controls, have a niche in the production environment in the country. Variety Mahube is the earliest in the region, heading in only 58 days (taking only 95-100 days to physiological maturity), white variety Mmabaitse is earlier than the controls by over 10 days.

Namibia

The major success of genetic enhancement in Namibia was release of pearl millet variety Okashana 1 in 1990 (Table 3). Present survey data (SADC/ICRISAT,

1996) show that 125 mt of pearl millet seed were produced in 1995. As a result of consistent backstopping from SMIP in Matopos over the past four or five years, coupled with FAO-supported seed production activities in-country, Namibia is now self-sufficient in its seed production capabilities. Up to 313.5 mt of seed have been produced during this period.

Okashana-1 was selected by farmers because of its early maturity and drought tolerance (Table 10). It matures up to 10 days earlier than most of the local landraces thereby making it able to avoid terminal drought which characterizes much of northern Namibia. It has a big advantage over the local landraces in yield only in seasons characterized by severe drought and especially in the north western and north central regions where the rainfall season is short (less than 90 days). Much of the high yields reported in the table are a result of averaging out performance across the country where the northeastern part (Kavango and Caprivi) receives higher rainfall (500-700 mm) compared to the north central and northwestern parts (Owamboland) where Okashana-1 is more popular and rainfall averages only 350-400 mm. In these regions, which cultivate more than 75% of the total hectarage of pearl millet in Namibia, the yield superiority of Okashana-1 is sometimes double that of the local landraces in seasons of extreme drought because its early maturity can be as much as 2-3 weeks earlier than some landraces in the Owamboland region.

Zambia

Success in genetic enhancement of sorghum and pearl millet has been made in Zambia. Between 1987 and 1995 the country released seven cultivars, out of which three (WSH 287, MMSH 375 and MMSH 413) are single cross hybrids (Table 4). Of these hybrids, the earliest released one (WSH 287) is out of production. The two pure line varieties among the releases, Sima and Kuyuma with white seeds, are very popular with farmers in the dry parts of the country. The hybrid MMSH 413 with brown seeds is being selected by the brewing industry for its good malting quality. In 1994-95, more than 544 mt of seeds of the four cultivars were produced and sold to both domestic and export markets.

All five sorghum cultivars released in Zambia, though high-yielding on-station, are not better than the controls (Table 11). However, they have been released based on the target clients. The two hybrids MMSH 375 and MMSH 413 have good malting qualities (40.2 and 38.2 diastatic units per gram) for use in the brewing sector. The two varieties Sima and Kuyuma have very good white grains acceptable for food. Sima has very bold, translucent grains, though it is very late maturing (the days to 50% heading) relative to controls (average 77 days to 50% heading).

The two released pearl millet varieties, Lubasi and Kaufela, are both significantly (P>0.01) higher yielding (2.38 t ha^{-1} and 2.04 t ha^{-1}, respectively) and earlier maturing (62 and 60 days to 50% heading, respectively) than the controls (averaging 1.48 t ha^{-1} and 70 days to 50% heading) (Table 4a). On-farm data are not available. These varieties were released mainly for their potentially high yields and early maturity.

Zimbabwe

In Zimbabwe, genetic enhancement achievements have been made in both sorghum and pearl millet. Between 1987 and 1992, three sorghum cultivars (SV1, SV2 and ZWSH1) and two pearl millet cultivars were released (Table 5). However, the only hybrid, ZWSH1, was never produced. Both sorghum variety SV2 and pearl millet variety PMV2 are very popular with farmers in the dry agro-ecologic regions IV and V of the country, for their early maturity (115-120 days and 85-95 days, respectively) relative to the local varieties (160 days for sorghum and 110-120 days for pearl millet). Table 12 shows the summary yield (t ha^{-1}) and maturity (days to 50% heading) data for the three sorghum and two pearl millet cultivars released in Zimbabwe plus controls and farmer varieties. It is obvious that, on-station, the two varieties SV1 (yielding 4.06 t ha^{-1}) and SV2 (yielding on average 3.38 t ha^{-1}) outyield, significantly (P>0.01), the controls and farmer varieties (yielding on average 2.73 t ha^{-1}) by a yield range of 5% to 67%.

On-farm variety SV2 (averaging 2.15 t ha^{-1}) was better in yield than the controls and farmer varieties (averaging 1.56 t ha^{-1}) by about 37%. Variety SV1 was not included in on-farm trials. However, SV2 (heading in 63 days) is significantly (P>0.01) earlier maturing than the controls and farmer varieties (heading in 76 days). Early maturity is a most preferred trait of farmers in Southern Africa because of frequent droughts; the reason for which SV2 was released for assurance of food and insurance against drought. It is sure to provide food for the farming population, including women and children, early in the season.

Similar observations can be made for the two released pearl millet varieties, PMV-1 and PMV-2. When averaged across 25 on-station testing sites, PMV-1 provided about 13% more grain yield compared to the local (2.27 vs 2.01 t ha^{-1}), whereas PMV-2 was overall 40% superior (2.81 vs 2.01 t ha^{-1}). Under farmer's conditions however, PMV-2 more than doubled the yields of the local landraces, where as PMV-1 provided 37% more grain yields (2.28 vs 1.70 t ha^{-1} for PMV-1 and 1.07 t ha-1 for the local check).

Initial seed production in these popular releases was slow from 1987-1992, due to the erroneous belief of commercial seed producers in Zimbabwe that there was no demand for sorghum and pearl millet seed. However, with the popularization and present increased demand by farmers for their preferred varieties, more concerted efforts are being devoted to seed production in the country. According to available data from seed distribution and sales surveys (SADC/ICRISAT SMIP, 1996), about 1400 mt of SV2 seeds were commercially produced in Zimbabwe in 1995. These seeds were destined for distribution in Zimbabwe, Angola, and Mozambique for agricultural and drought recovery programs.

Adoption of Released Cultivars and Impact

Tables 2 through 5 show the 20 new cultivars of sorghum and pearl millet released by the national programs of Botswana, Namibia, Zambia, and Zimbabwe from 1984 through 1995. These cultivars have been differentially adopted by farmers in each country, resulting in variable impacts. The patterns of adoption leading to impact are evident in the same tables. Additionally, Table 6 shows a trend in relative achievements in the four countries for cultivar releases and the impact in cultivar releases due to collaboration with the regional SMIP during the 11-year period.

Prior to 1983 and before the inception of the SADC/ICRISAT SMIP, a total of 12 improved varieties of sorghum and pearl millet were released by three of the four target countries: Botswana (8 varieties), Zambia (2 varieties), and Zimbabwe (2 varieties) (Table 6; Anandajayasekeram et al., 1996). Of these, only nine varieties were produced; three of the Botswana releases were never produced. Namibia had no improved varieties during this period. However, during the next 11 years when SMIP was operating, the four countries improved in their capabilities for genetic enhancement and increased their releases of sorghum and pearl millet to 32 cultivars (varieties and hybrids), of which 27 are being produced (Table 6). The national programs have gained strength in breeding that leads to variety releases due in part (for Botswana, Namibia and Zimbabwe) to the technical assistance and facilitation of processes by the regional SADC/ICRISAT SMIP. During the 11-year period, ICRISAT's efforts in germplasm movement and associated breeding in collaboration with these SADC countries have contributed to the release of the cultivars.

The increase of variety releases from seven (six sorghum and one millet) prior to 1983 to 20 (14 sorghum and six millet) during the SMIP era — a more than 100% improvement made by the four countries — is a significant achievement and has a strong impact on genetic enhancement in the southern Africa region.

Noteworthy is the trend in these achievements for each of the countries studied (Table 6). While Namibia started producing its only improved pearl millet during the SMIP era (specifically in 1991 as shown in Table 3), Zambia moved mostly on its own from producing no sorghum and pearl millet varieties prior to 1983, to producing ten improved cultivars (seven sorghum and three pearl millet) between 1984 and 1995. Similar trends are shown in Zimbabwe and Botswana (which is still producing its only old pearl millet variety and eight sorghum varieties, with two old and three new sorghum varieties, and two new pearl millets).

Adoption and Impact Case Studies

Areas of expected coverage and estimates of current coverages for each of the released varieties in Botswana, Namibia, Zambia, and Zimbabwe, are shown in Tables 2 through 5. These estimates of adoption and impact should be considered preliminary, although some have been verified (SADC/ICRISAT SMIP, 1996). The SADC/ICRISAT SMIP is monitoring the adoption of the released improved cultivars and continues to collect data on seed production and distribution. The initial results of a regional survey on the release and adoption of new sorghum and pearl millet varieties indicate evidence of favorable adoption of some of these cultivars (Agrinews, 1996).

Botswana

The adoption pattern and rate of the four newly released sorghum cultivars in

Botswana are shown in Table 2. The year of first significant diffusion for three of the four cultivars was 1995, only one year after their release. The areas of expected coverage were estimated as 40,000-50,000 ha for Phofu, 20,000 ha for Mahube and 10,000-15,000 ha for the hybrid BSH1. These estimates were based on the seed multiplication activities before and after the releases, the areas that can be covered by the quantities of food quality seeds produced, and the strengthened capabilities of the national scientists and breeders to produce hybrid seeds. The mode of distribution of the seeds and its timing also play a role. A regional survey on adoption of the Phofu variety show an estimated 10,000 ha planted by farmers in 1995-96 (SADC/ICRISAT SMIP, 1996).

Based on available quantity of seeds, this 11.24% adoption survey estimate for Phofu is lower than the area of current estimated coverage (25%) (Table 2). The discrepancy is due to delayed and confused distribution of seeds to farmers. Variety Mahube and hybrid BSH1 were appropriately produced as expected, although the adoption surveys on them still have to be carried out. Variety Mmabaitse has no significant diffusion and has since not been produced, because of lack of farmer preference for the variety.

Evidence has thus been provided for a significant impact in Botswana for three of her four new sorghum releases. The main factors responsible for this impact have been intense and systematic in-country seed production, SMIP backstopping for breeder seed, and training in seed production, coupled with a rapid diffusion rate (one year only) due to farmer and industrial preferences for the cultivars. The farmers cited early maturity and stay reen trait for crop residue use; while industries prefer the new varieties for excellent white flour for food and good milling quantities.

Further adoption surveys and plans for an impact assessment are continuing with focus on farmers who planted the new varieties in the north, central, and southern parts of the country in the 1994-95 and 1995-96 seasons.

Namibia

Pearl millet variety Okashana 1 was released in 1990 in the far north of the country, which is the principal crop zone in Namibia (Table 3). The diffusion of this variety was very rapid, with the first significant diffusion recorded one year after its release. In 1992-93, the estimated rate of diffusion reached 9.5% based on seed sales, and 17.0% based on survey data (Table 7; Anandajayasekeran et al., 1995). This rapid rate reached 45% in 1994-95 in the two main production zones of Kavango and Owambo provinces (ICRISAT CCER Report, 1996).

The current area of coverage of Okashana 1 has been estimated at 47,000 ha, 14% of the total millet area (Table 3; SADC/ICRISAT, 1996). This scenario results in an internal rate of return of 13.3%, a calculated benefit of $350,000 (Table 7; Anandajayasekeran et al 1995). Further impact analysis of Okashana 1 in Namibia will be formally completed jointly by SMIP and Namibian scientists in 1996-97.

The exemplary rapid diffusion rate and internal rate of return in less than five years for the pearl millet variety Okashana 1 has been mainly due to farmer preference for its early maturity. This alleviates food problems under constant drought situations.

Zambia

The impact story of sorghum variety releases and production in Zambia takes a different form and shape. The first significant diffusion of the two most popular of the five releases, varieties Kuyuma and Sima, occurred two to three years after release in 1990, although farmers only started being aware of the varieties in 1996. Presently, initial results of a regional adoption survey show that the varieties Kuyuma and Sima each covers 5,000 ha (13% of current total sorghum area) (Table 4; SADC/ICRISAT SMIP, 1996). However, higher coverages of 50% were estimated for 1993-94 for all improved cultivars in the Siavonga district, the pilot area of the promotional campaign (Verma, 1996, personal correspondence).

Estimates of adoption for the three released hybrids are not available. One of them, WSH 287, is out of production, while the more popular of the remaining two, MMSH 413, is an export commodity and is used for opaque beer production. A rough estimate of current coverage for MMSH 413 is put at 700-800 ha (Verma, 1996, personal correspondence). According to the Zambia national statistics, 47,000 ha were planted to improved sorghum varieties and hybrids in 1995-96 (Verma, 1996, personal correspondence). The impact of these diffusion patterns in Zambia needs to be assessed. Presently, the Zambia NARS, SACCAR and SADC/ICRISAT SMIP are conducting a collaborative adoption impact study of new sorghum cultivars in Zambia.

It is worthwhile to note that impact is being generated from the new cultivar releases in Zambia due to combined efforts of the breeders, who champion the distribution and diffusion of seed, and the national seed company, Zamseed, whose commercial and export production focus is providing spillover effects to neighboring countries. Such spillover effects from the Zimbabwe commercial seed production activities in 1995-96 also are starting to show impact on neighboring countries, especially for drought relief.

Zimbabwe

The impacts of improved cultivar releases in Zimbabwe are recorded for both sorghum and pearl millet. Of the three sorghum cultivars released in 1987 and 1992 (Table 5), only SV 2 variety became popular with farmers. Of the two pearl millet releases, PMV 2 is the only variety that became popular. The pattern of diffusion and trends of impact are different in both situations, as shown in Table 5.

The sorghum variety SV 2, released in 1987, did not record any significant diffusion until 1992. However, this delayed diffusion (caused mainly by lack of seed) has not hindered its rapid and high adoption rate since 1992. Within three years, the area of expected coverage of 60,000 ha (54% of the total sorghum area) has almost been reached, with a current coverage of 40,000 ha (36% of the total sorghum area) (SADC/ICRISAT SMIP, 1996).

This phenomenal rate of adoption has been stimulated by the drought relief emergency seed production of 1992, which resulted in initial production of 493 mt of SV 2 and 161 mt of PMV 2. The project provided a large quantity of good quality seed to small farmers and contributed to improvement of their household food security, following the severe 1991-92 drought (ICRISAT, 1993).

Similar but lower adoption rates were obtained from pearl millet variety PMV 2; current estimated coverage is 35,000 ha (14% of the total pearl millet area), relative to the expected area of coverage of 100,000 ha (41% of total). Lower adoption rates have occurred despite the significant diffusion rate of only one year after PMV 2's release in 1992. The response to pearl millet has not been as phenomenal as the response to sorghum due to complete lack of interest in pearl millet seed production after the 1992 emergency seed production exercise. In order to keep the adoption momentum going, the breeders in SMIP must produce large quantities of breeder seed to support the national program needs in Zimbabwe. An average of two to three tons of pure breeder seed, produced in isolated fields, were supplied to Zimbabwe NARS between 1992 and 1995 for both SV 2 and PMV 2 sorghum and pearl millet varieties.

The impact of these reported adoption trends of sorghum and pearl millet in Zimbabwe has been assessed. An analysis of the rate of return derived from sorghum and pearl millet genetic improvement in Zimbabwe indicated an internal rate of return of 27-34% and a stream of net benefits ranging from $7.8-28.9 million (SADC/ICRISAT SMIP, 1995). According to Anandajayasekeram et al. (1995), the diffusion estimates for SV 2, based on seed sales and survey data, are 29% and 30%, respectively (Table 7). They recorded internal rates of return of 25.8%, with benefits of $0.22-1.29 million.

It is interesting to note that farmers cited early maturity of SV 2 and PMV 2, not productivity gains, as the main reasons for their significant adoption.

Intermediate Outputs Contributing to Impact

Much of ICRISAT's genetic improvement effort in the regional SMIP program has been to offer intermediate genetic outputs that contribute to development of a wider range of finished products by the NARS. These include breeding stock and germplasm with various specialized traits and sources of resistance to alleviate constraints, both abiotic and biotic in nature. Table 8 shows the movement of such germplasm materials into the four case study countries in southern Africa. The materials from SMIP consist of direct reintroductions from ICRISAT into the region, and introductions from west and east Africa, Latin America, and the U.S. (INTSORMIL), totaling approximately 13,000 sorghum samples and 10,000 pearl millet samples. The remainder of the SMIP samples are generated and derived from all these sources, together with the indigenous farmers' collections in the region.

Since the inception of the regional SADC/ICRISAT SMIP in 1983-84, and during the 10-year research period 1984-85 to 1994-95, a total of 85,734 genetic materials of sorghum and pearl millet have moved into Botswana (8,654 samples), Namibia (3,212), Zambia (11,705), and Zimbabwe (62,168) (Table 8). The availability of diverse and variable germplasm of sorghum and pearl millet for genetic enhancement purposes increased by the following percentages: 25% for Botswana, 112% for Zambia, and 1,196% for Zimbabwe.

This provides evidence for an intermediate "scientific impact" that preceeded the impact on farmers' fields, due to germplasm movement and utilization. The increase in accessibility and availability of diverse and variable germplasm and breeding lines to the NARS in the southern Africa region has led to greater access to international technology. The SMIP project also has contributed to the awareness of the NARS breeders in these countries and their training in genetic enhancement; it also has strengthened their capacities and capabilities for the genetic improvement of sorghum and pearl millet.

Factors Enhancing Generation of Impact of Genetic Improvement of Sorghum and Pearl Millet

Several factors contribute, at different times and in different forms, to achieving impact through breeding at two main levels: the scientist (intermediate) level and the farm level. The several contributing factors to impact generation in the southern Africa region in general and the four countries (Botswana, Namibia, Zambia, and Zimbabwe) specifically, fall within the three main events of technology generation, technology testing, and technology transfer and exchange, as a series of overlapping and time-phased genetic improvement activities (Table 1). The main enhancing factors include:

1. Germplasm introduction, distribution, and utilization.

2. Availability of improved varieties and hybrids.

3. On-farm testing and farmer preference evaluation.

4. Emergency seed production of 1992, following the most severe drought of 1991.

5. Effective collaboration among all partners.

6. Long-term and committed donor support.

7. Commitment of breeders to champion their cause and their confidence in the improved technologies.

Germplasm Introduction, Distribution, and Utilization

The need for alternative crop technology in any crop environment and production system accounts for a great deal in its success. The past failures of maize, the main staple food, in the southern African region, due to consistent drought periods culminating in the 1981-82 drought coupled with the desire of the respective governments in the region to solve the drought problem that resulted in food deficits and loss of some farmers' indigenous germplasm, created the need for crop diversification and use of alternate crop varieties that could withstand the drought. Within an 11-year period (1983-84 to

1994-95) the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP), which is responsible for genetic enhancement of sorghum and pearl millet in the southern Africa region, together with NARS in Botswana, Namibia, Zambia, and Zimbabwe, collected local germplasm (a total of 3,000 sorghum and 2,500 pearl millet accessions) from the region, and introduced 23,000 exotic sorghum and pearl millet germplasms. The exotic accessions consisted of both indigenous and enhanced germplasm. These were distributed and tested across the whole southern Africa region, and utilized in several ways by each NARS for its genetic enhancement research.

This massive germplasm movement created a favorable base for generation of impact at both intermediate (scientist) and farmer levels.

Availability of Improved Varieties and Hybrids

Through a series of national and regional breeding nurseries, crossing blocks, off-season winter nurseries, and preliminary screening, a total of 96,391 enhanced germplasm, breeding lines, and populations of both sorghum and pearl millet were developed by the NARS (which are strong in breeding research) in collaboration with SADC/ICRISAT SMIP during 1984-85 to 1994-95 (Table 8). Compared to the period 1975-76 to 1982-83 before the inception of SMIP, this is a 460% combined achievement in germplasm enhancement in Botswana, Namibia, Zambia, and Zimbabwe.

From these enhanced genetic stocks, collaborative research efforts in multi-locational, multi-year, and multi-disciplinary testing have resulted in the release of 32 improved sorghum and pearl millet varieties and hybrids in eight southern Africa countries in the era of SMIP. Of these, 20 are in Botswana (4), Namibia (1), Zambia (10), and Zimbabwe (5). Only eight (40%) of these cultivars (two sorghum in Botswana, one pearl millet in Namibia, three sorghums in Zambia, and one sorghum and one pearl millet in Zimbabwe) have resulted in impact on farmers' fields.

On-farm Testing and Farmer Preference Evaluation

In collaboration with our National Agricultural Research and Extension System (NARES) partners, the regional SMIP initiated the transfer of technologies to farmers' fields in 1992. The initial countries involved in on-farm testing in 1992-93 were Zimbabwe, Namibia, and Malawi. During the 1993-94 season, on-farm trials on sorghum and pearl millet were conducted in seven of the 12 SADC countries. In Zambia, this activity was done by the NARS on its own since 1989. New improved genotypes and production technologies (IPM on *Striga* and armoured cricket only) were demonstrated on farmers' fields.

The research outcomes of on-farm tests and farmer preference evaluations led to release of new varieties and hybrids in the SADC countries. "Farmer pressure" was especially influential in leading to cultivar releases in Botswana (for sorghum), Namibia (for millet), and most recently Tanzania in November 1995 (for sorghum). It is worthwhile to note that early maturity and grain quality were the two main traits that influenced choice of cultivars and preference for release.

Emergency Seed Production of 1992

The 1991-92 drought in southern Africa was widely described as "the worst in living memory"; total rainfall in the region of 12 countries ranged from 0.0-350mm, coupled with early cessation and poor distribution of the total rainfall (less than 200mm in most countries). In early 1992, when the magnitude of the drought became apparent, planners quickly assessed the requirements for drought recovery and sustainable intervention during the following 1992-93 cropping season. This unique situation fostered the popularity of sorghum and pearl millet among farmers and in government circles. In response, production of sorghum and pearl millet seeds of the available improved cultivars was carried out under irrigation in the dry winter off-season of 1992.

This project, funded by United States for International Development (USAID) and the Canadian International Development Agency (CIDA), resulted in production of 493 mt of SV 2, 250 mt of kuyuma, both white sorghum varieties, 161 mt of pearl millet (PMV 2 and Okashana 1), and 40 mt of kaufela millet variety. Almost all the seed produced for distribution in Zimbabwe, Zambia, and Namibia reached small farmers.

This project provided the first opportunity for a large number of small farmers in semi-arid regions of Zimbabwe, Namibia, and Mozambique to plant improved sorghum and pearl millet cultivars. (Much had already been done in Zambia by the NARS before this project.) Seeds offered through the project contributed about 35% of the sorghum and pearl millet harvested by small farmers in Zimbabwe and at least 15% of the pearl millet grain harvested in Namibia (ICRISAT 1993). More important, the emergency seed project stimulated and promoted the adoption of new improved cultivars, thus enhancing their impacts at the farmer level, and offered a continuing stream of benefits to some of the poorest farmers in each of the target countries.

Collaboration Among All Partners

SMIP has collaborated effectively with all relevant partners, especially with the weaker NARS in the National Agricultural Research and Extension Systems (NARES), including NGOs in each country, at each stage of technology development, technology testing, and technology transfer, for the generation and assessment of impact due to genetic enhancement. Success has been due to:

- collaborative work planning for research activities including identification of responsibilities, expected outputs, and associated budgets.
- joint travel to research test locations for evaluation of cultivar trials.
- joint data analyses, reporting and publications.
- backup supply of breeder seed and facilitation of seed production in-country.
- national and regional training in seed production and on-farm research.
- experiment station and on-farm field visits by farmers, farmer

groups, seed producers, and non-governmental organizations (NGOs) interested in technology transfer and exchange of improved varieties of sorghum and pearl millet.

Long-Term and Committed Donor Support

The funding support by committed donors to long-term (15 years) research on genetic improvement of sorghum and pearl millet, coupled with the maintenance of a critical mass of research and development scientists provided from such donor funds, has significantly enhanced the development of improved cultivars. Specific support has been given by USAID, BMZ (Bundersministerium fur Wirtschaftliche Zusammenarbeit und Entwicklung)/GTZ (Dentsche Gesellschaft fur Technische Zusammenarbeit), CIDA (Canadian International Development Agency), to SADC/ICRISAT SMIP, and by SIDA (Swedish International Development Agency) to Zambia.

Commitment of Breeders to Champion Their Own Course and Their Confidence in the Improved Technologies

The success of transfer of any technology depends on how good the technology is. A good technology sells itself, and confidence in the technology by the developers and adopters enhances its impact. However, any technology needs a promoter who will champion the push.

The scientists, officers, and agents of the NARS in Botswana, Namibia, Zambia, and Zimbabwe, in collaboration with breeders in SMIP, have developed very good improved varieties and hybrids of sorghum and pearl millet. The improved cultivars have been jointly evaluated for several years on-station (4-8 years) and on-farm (2-4 years) in several locations (2-8 locations) of the target four countries. They have been exposed to farmers through effective demonstrations. Farmers have liked them and preferred them to indigenous cultivars, especially for early maturity and good grain quality for food and malting. At any or all of these stages, the breeders have been in the forefront encouraging the push into farmers fields and working with other scientists, agents, extension officers, NGOs, and seed industry.This commitment and belief in the improved cultivars' performance has been the basis for impact.

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Table 1. Events and overlapping sets of activities that would generate impact in genetic improvement.

Event	Activities	Collaborators
Technology generation	Germplasm movement *exotic introductions *indigenous collections *distribution Germplasm utilization *crossing block *trait management *initial selections *variety development *population and lines development	Breeder Genetic resources scientist Farmers Breeder Entomologist Pathologist
Technology testing	On-station trials *multi-locational effects *year effects On-farm evaluation and verification Farmer preference tests Laboratory grain and food quality screening	Breeder Technology exchange specialist/agronomist Extension specialist Food technologist/scientist Farmers
Technology transfer and exchange	Cultivar releases *line and population releases *breeder seed multiplication and production *training in genetic improvement and breeder seed production Linkages Monitoring adoption Assessing impact	Breeder Seed Producers Technology exchange specialist Extension specialist Economist Farmers

Table 2. Sorghum varieties released in Botswana as a result of collaborative technology development and testing between NARS and ICRISAT, 1984-1995.

Variety name (ICRISAT/NARS acronym)	ICRISAT germplasm used (Yes/No)	Year of release	Year of first significant diffusion	Area of expected coverage (% of total)	Area of current coverage (% of total)	Remarks
1.Phofu (SDS 3220)	Yes	1994	1995	40 000-50 000 ha (45-56%)	22 000 ha (25%)	White-seeded. Has staygreen trait. Dual purpose for food grain and stover.
2.Mahube (SDS 2583)	Yes	1994	1995	20 000 ha (22%)	900 ha (1%)	Red-seeded for malting and animal feed. Tannin-free.
3.BSH1 (SDSH 48)	Yes	1994	1995	10 000-15 000 ha (11-17%)	130 ha (0.2%)	White-seeded with excellent flour quality. Mainly for food.
4.Mmabaitse (BOT 79)	No	1994	-	-	-	White-seeded with brown specks.

Table 3. Pearl millet varieties released in Namibia as a result of collaborative technology development and testing between NARS and ICRISAT, 1984-1995.

Variety name (ICRISAT acronym)	ICRISAT germplasm used (Yes/No)	Year of release	Year of first significant diffusion	Area of expected coverage (% of total)	Area of current coverage (% of total)	Remarks
Okahana 1 (ICMV 88908)	Yes	1990	1991	93 000 ha (56%)	47 000 ha - 1994 (14%) 74 000 ha - 1995 (45%)	Recommended for the north central region of Namibia

Table 4. Sorghum varieties released in Zambia as a result of NARS efforts in technology development and testing with some collaboration with ICRISAT, 1984-1995.

Variety name (ICRISAT/NARS acronym)	ICRISAT germplasm used (Yes/No)	Year of release	Year of first significant diffusion	Area of expected coverage (% of total)	Area of current coverage (% of total)	Remarks
WSH 287	Yes	1987	-	-	-	Dropped
Sima (IS 23520 derivative)	No	1989	1990	7 000 ha (18%)	5 000 ha (13%)	White-seeded for food
Kuyuma (MR4/4606T11; WSV 387)	No	1989	1990	10 000 ha (25%)	5 000 ha (13%)	White- seeded for food
MMSH 375	No	1992	1991	5 000 ha (13%)	n.a.*	Brown-seeded for malting
MMSH 413	Yes	1992	1991	10 000 ha (25%)	n.a.*	Brown-seeded for malting
ZSV 12	No	1995	n.a.*	n.a.*	n.a.*	Pigmented white grain
FSH 22	No	1995	n.a.*	n.a.*	n.a.*	Forage sorghum hybrid

*n.a. = not available

Table 4a. Pearl millet varieties released in Zambia as a result of NARS efforts in technology development and testing with some collaboration from ICRISAT.

Variety name (ICRISAT/NARS acronym)	ICRISAT germplasm used (Yes/No)	Year of release	Year of first significant diffusion	Area of expected coverage (% of total)	Area of current coverage (% of total)	Remarks
Kaufela (ICMV 82132)	Yes	1989	1990	20 000 ha (38%)	10 000 ha (19%)	Recommended for the southern province
Lubasi (LBC)	Yes	1991	1992	324,00 (62%)	20000 ha (62%)	Recommended for the western province

Table 5. Sorghum and pearl millet varieties released in Zimbabwe as a result of collaborative technology development and testing between NARS and ICRISAT, 1984-1995.

Variety name (ICRISAT/NARS acronym	ICRISAT germplasm used (Yes/No)	Year of release	Year of first significant diffusion	Area of expected coverage (% of total)	Area of current coverage (% of total)	Remarks
Sorghum						
1. SV1 (ICSV 112)	Yes	1987	-	500 ha (4%)	500 ha (4%)	White -seeded for food Out of production
2. SV2 (A6460)	Yes	1987	1992	60 000 ha (54%)	40 000 ha (36%)	White -seeded for food
3. ZWSH 1	No	1992	-	-	-	White-seeded with brown specks. Never produced.
Pearl Millet						
1. PMV 1 (RMP 1)	Yes	1987	n.a.*	500 ha (2%)	n.a.*	Recommended for zones 4 and 5
2. PMV 2 (SDMV 89004)	Yes	1992	1993	100 000 ha (41%)	35 000 ha (14%)	Recommended for zones 4 and 5

*n.a. = not available

Table 6. Cultivars released in the four case study countries of Southern Africa showing the trend of achievements of the national and regional breeding programs in genetic improvement and impact generated in the respective countries.

Country	Number of cultivars released prior to 1983			Number of cultivars released in the period 1984-1995			Grand Total
	Sorghum	Pearl Millet	Total	Sorghum	Pearl Millet	Total	
Botswana	7(4)*	1	8(5)*	4	-	4	12(9)*
Namibia	-	-	-	-	1	1	1
Zambia	2(0)	-	2(0)	7	3**	10	12(10)
Zimbabwe	2	-	2	3	2	5	7
Total	11(6)	1	12(7)	14	6	20	32(27)

* number of the cultivars produced are shown in parentheses for sorghum.
** not included in the impact for Zambia.

Table 7. Economic indices of impact generated by and assessed for genetic enhancement of sorghum (SV2) and pearl millet (Okashana 1) in Zimbabwe and Namibia, respectively, 1992-93*.

Economic index	Zimbabwe for SV2	Namibia for Okashana 1
Diffusion estimates (%)	29.0[a] 30.0[b]	9.5[a] 17.0[b]
Average area planted (Ha) per household	0.73 (0.58)[c]	-
Calculated benefits accruing to improved cultivars (U.S. dollars)	1.29M	0.35M
Net benefits (U.S. dollars)**	0.22 M	0.04M
Internal rate of return (%) without fertilizer	25.8	13.3

* Modified from Anandajayasekeram et al (1995).
[a] Based on seed sales.
[b] Based on survey data.
[c] Average area planted for local farmer variety relative to SV2.
**Net benefits after research and transfer of germplasm costs have been deducted.

Table 8. Movement and sources of sorghum and pearl millet germplasm* and breeding lines from genetic enhancement programs into Botswana, Namibia, Zambia and Zimbabwe, 1975-76 to 1982-83 and 1984-85 to 1994-95.

	1975-76 - 1982-83			1984-85 - 1994-95					
	from ICRISAT			ICRISAT		SMIP			
Country	Sorghum	Pearl Millet	Total	Sorghum	Pearl Millet	Sorghum	Pearl Millet	Total	Grand total
Botswana	6594	310	6904	890	13	5067	2684	8654	15558
Namibia	-	-	-	-	28	41	3143	3212	3212
Zambia	4695	822	5517	6811	3362	11467	717	22357	27874
Zimbabwe	4505	292	4797	22504	8092	6752	24820	62168	66965
Total	15794	1424	17218	30205	11495	23327	31364	96391	113609

*The germplasm include re-introductions of indigenous germplasm collected in the SADC region and exotic accessions introduced from the rest of the world.

Table 9. Summary yield (t ha^{-1}) and maturity (days to 50% heading) data of four sorghum cultivars and controls released in Botswana.

	Grain yield t ha^{-1}				
	On-experiment station		On-farm		
Cultivar	Average	Range	Average	Range	Maturity
Phofu	3.25	1.18-4.69	0.73	0.45-1.01	69
Mahube	1.22	0.69-2.01	0.59	0.43-0.75	58
BSH1	3.83	1.21-7.00	-	*	72
Mmabaitse	1.93	0.50-2.84	-	*	70
Control/Farmer variety	2.34	0.72-4.00	0.51	0.46-0.55	86
S.E.±	0.547	0.38-0.88		n.a.	
C.V.%	29.74	18.0-50.0		n.a.	

*Not tested on-farm. BSH1 is an F_1 hybrid. Mmabaitse was not included in on-farm trials.
n.a. = Not available

Table 10. Summary yield (t ha^{-1}) and maturity (days to 50% bloom) data for Okashana-1, the cultivar released in Namibia.

	Grain yield t ha^{-1}				
	On-experiment station		On-farm*		
Cultivar	Average	Range	Average	Range	Maturity
Okashana-1	2.45	0.69-5.25	1.65	1.28-1.73	55
Controls (farmers local)	2.37	0.83-5.46	1.14	1.06-1.24	65
S.E.±	0.269	0.147-0.428	0.076		
C.V.%	30.50	16.0-42.7	38.4		

*Yield data averaged over 5 on-station sites and 21 on-farm environments during 1992-93 season.

Table 11. Summary yield (t ha^{-1}) and maturity (days to 50% heading) data of five sorghum and two pearl millet cultivars with controls released in Zambia.

	Grain yield t ha^{-1}				
	On-experiment station		On-farm*		
Cultivar	Average	Range	Average	Range	Maturity
Sorghum					
WSH 287	3.31	1.03-4.43	n.a.	n.a.	78
Sima	3.29	2.87-3.50	n.a.	n.a.	86
Kuyuma	3.36	3.05-3.77	n.a.	n.a.	78
MMSH375	3.81	2.52-5.67	n.a.	n.a.	79
MMSH 413	4.37	3.20-6.11	n.a.	n.a.	74
Controls/farmer variety	3.33	2.33-5.50	n.a.	n.a.	77
L.S.D.	1.38	0.39-2.79			
C.V.%	32	10-63			
Pearl Millet**					
Lubasi	2.38	0.94-3.82	n.a.	n.a.	62
Kaufela	2.04	0.89-3.33	n.a.	n.a.	60
Controls/farmer variety	1.48	0.32-2.70	n.a.	n.a.	70
L.S.D.	0.76	0.44-1.30	-	-	-
C.V.%	27	12-61	-	-	-

* On-farm data are not available (n.a.)
** Pearl millet data averaged over 10 sites for two seasons.

Table 12. Summary yield (t ha^{-1}) and maturity (days to 50% heading) data of three sorghum and two pearl millet cultivars and controls released in Zimbabwe.

	Grain yield t ha^{-1}				
	On-experiment station*		On-farm**		
Cultivar	Average	Range	Average	Range	Maturity
Sorghum[1]					
SV1	4.06	2.58-6.33	-	-	75
SV2	3.38	2.41-3.79	2.15	1.22-3.15	63
ZWSH1	4.91	3.36-6.45	2.37	0.94-4.05	72
Controls/farmer variety)	2.73	2.29-3.78	1.56	0.45-3.44	76
S.E.±	0.380	0.10-0.74	0.292	0.25-0.68	-
C.V.%	29.71	17.0-48.3	32.88	16.1-67.3	-
Pearl Millet[2]					
PMV-1	2.27	1.64-2.69	1.70	0.67-3.07	60
PMV-2	2.81	2.22-3.23	2.28	1.22-3.17	54
Controls (farmers)	2.10	0.52-2.44	1.07	0.24-1.86	70
S.E.±	0.288	0.11-0.41	0.256	0.10-0.63	-
C.V.%	22.57	13.17-29.34	20.35	8.39-38.33	-

*,1 No. of sites in sorghum experiment station trials are 30 for four years, for SV1 and SV2, and 14 sites for two years for ZWSH1.
**,1 No. of sites in sorghum on farm trials are 15 for two years for all three released cultivars.
**,*2 Pearl millet maturity averaged over 25 on-station sites over 4 years, and 10 on-farm environments over 2 years.