Reactions of Sorghum Genotypes to Leaf, Panicle, and Grain Anthracnose (*Colletotrichum graminicola*) under Field Conditions in Mali

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Abstract

Effective field screening techniques were used to identify resistance to anthracnose [caused by *Colletotrichum graminicola* (=*C. sublineola*)] in grain sorghum at two locations (Samanko and Longorola) in Mali. The occurrence and development of anthracnose was monitored on the leaves, panicles and grains of 19 sorghum genotypes in the 1997 and 1998 rainy seasons. Foliar anthracnose severity was assessed using a 1-9 scale on individual tagged plants at regular intervals throughout the season. The area under the disease progress curve (AUDPC) was calculated for each genotype. Anthracnose severity was also evaluated on the peduncle; rachis and glumes; panicle; and grain. None of the genotypes was completely (hypersensitive) resistant to the disease, but 9 showed stable resistance to both foliar and panicle anthracnose. Nine genotypes were resistant to foliar anthracnose but moderately susceptible to panicle anthracnose. One genotype was moderately susceptible to both forms of the disease.

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is a basic staple food for human consumption in West Africa, representing 37% of total food grain production in the region (Debrah 1993). A broad range of plant pathogens limit sorghum production in West Africa (Thomas 1992). Anthracnose, caused by *Colletotrichum graminicola* (Cesati) G.W. Wilson (=*C. sublineola* Henn. in Kab. & Bubák), is an important disease in the region and worldwide (e.g., Tarr 1962; Thomas et al. 1996; Néya and Le Normand 1998). The fungus infects all above-ground portions of the host (stalk, leaf, peduncle, panicle and grain) and develops in both living and dead tissue (Tarr 1962; Ali and Warren 1992).

Disease symptoms include a foliar phase, stalk rot, and panicle and grain anthracnose. Symptoms can vary due to differences in pathogen virulence or host resistance, or changes in physiological status of the host following infection. The most common and severe form of the disease is foliar anthracnose, which can reduce the grain and fodder yield of susceptible cultivars by 50% and more (Harris et al. 1964; Harris and Sowell 1970; Ali et al. 1987).

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Anthracnose infection causes significant reduction in grain yield through reduced kernel weight and grain abortion (Thomas et al. 1996). Host-plant resistance is the most economical approach for successful management of the disease. Availability of resistance sources is a prerequisite for breeding adapted, resistant, productive sorghum cultivars. Typically, screening of sorghum for reaction to anthracnose targets the foliar manifestation of the disease. However, during a survey conducted in southern Mali from 19-20 November 1996, we observed panicle anthracnose (affecting the peduncle, rachis, glumes and grains) on local varieties in farmers' fields.

Thus, the objectives of this study were to i) evaluate selected sorghum genotypes for reaction to foliar and panicle anthracnose (taking note of disease severity on the panicle parts: peduncle, rachis & glumes and grain), and ii) identify sources of stable resistance.

Materials and Methods

The experiment was conducted at two locations in Mali during two cropping seasons (1997-1998). One trial was planted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Station in Samanko (12° 32' N latitude; 8° 7' W longitude). Samanko is situated about 25 km SW of Bamako in the Northern Guinea zone. The second trial was placed at the Institut d'Economie Rurale (IER) Station in Longorola (11° 21' N latitude; 5° 41' W longitude). Longorola is situated about 8 km N of Sikasso in the Northern Guinea zone. Sikasso is located about 380 km SW of Bamako. Test entries were selected for good levels of resistance to foliar anthracnose in the 1996 Advanced Screening Trial for Anthracnose Resistance conducted at Samanko.

Disease pressure in the anthracnose nurseries at both locations was enhanced by using infestor rows (consisting of a mixture of 3-4 anthracnose-susceptible sorghum varieties) sown adjacent to each two-row test plot. Infestor rows and test materials were inoculated by placing sorghum grains bearing mature acervuli of *C. graminicola* into the whorl of 30-day-old plants. A basal application of a compound N, P, K fertilizer (15:15:15) was applied at field preparation. Nineteen sorghum genotypes (Table 1) were evaluated in the field. The experimental lines were chosen on the basis of their field performance at Samanko in 1996. IS 21658 served as the resistant check and IS 18442 was the susceptible check. Sowing dates at Samanko were 24 June in both 1997 and 1998. At Longorola, experiments were sown on 27 June 1997 and 24 June 1998.

The experimental design was a randomized complete block with two replications at each location. Plots consisted of two rows, four m long, spaced 0.75 m apart. Within row spacing was 0.4 m. An infestor row consisting of three to four sorghum genotypes with differing maturity and a range of susceptibility to *C. graminicola* was located on each side of the experimental plots. Carbofuran (Furadan®) was applied to each hill at sowing (0.5 g) to control insects (e.g., millipedes, ants and termites). About 30 days after emergence and following rainfall, plots were thinned to 2 plants per hill. At Samanko a top dressing of 50 kg ha^{-1} of urea (46% N) was applied at 45 days after sowing (DAS). At Longorola urea was applied in two equal split applications at 30 and 45 DAS for a total of 100 kg ha^{-1}. During the cropping season fields were weeded three times with local hoes (*daba*).

Plants were observed frequently to note the first appearance of anthracnose on leaves and panicles in each experimental plot. A 1-9 scale was used to evaluate anthracnose on five plant organs: leaf; peduncle; rachis; panicle; and grain (Table 2). In this scale 1 = no disease and 9 = more than 75% anthracnose severity (Thakur et al. 1998). Notes were taken on five randomly tagged plants (in each plot) in 1996 and on ten randomly tagged plants in 1997 and 1998. Disease progress was followed on the leaves beginning at first disease appearance (four to six weeks after sowing) with notes taken at two-week intervals up to flowering and weekly intervals thereafter. These data were used to determine Area Under the Disease Progress Curve (AUDPC) calculated according to Shaner and Finney (1977). The panicles of the tagged plants were harvested within ten days after grain maturity, sun-dried and kept separate. Disease severity on the peduncle, rachis, and grain was evaluated. In addition an overall evaluation of damage to the panicle (including the peduncle, rachis, glumes, and grain).

The mean disease severity ratings for the subplots were used for the analysis of variance (GENSTAT 5, release 3.2; Rothamstead Experimental Station, Harpenden, UK). Multiple regression analysis was used to investigate the relationship among plant height (HPL) the appearance of anthracnose on the leaf (ANF) and panicle (ANP) and area under the disease progress curve (AUDPC), and anthracnose severity on the peduncle (PEA), rachis (RAA), and grain (GRA).

Results

Rainfall quantity and distribution were good at both locations (Fig.1), resulting in good crop growth and disease development. Total rainfall during the growing season (June through October) at Samanko was 732.1 mm over 49 days in 1997, and 1,013.6 mm over 66 days in 1998. For the same respective years, rainfall at Longorola was 904.2 over 61 days and 1,011.5 mm over 75 days. Longorola is a wetter (7-yr average=1,070 mm) location than Samanko (7-yr average=859 mm); an exceptional rainfall year in Samanko (1998) is similar to an average year in Longorola (1998) (Fig.1).

The sorghum genotypes studied were of short (flowering within 75 days after sowing, DAS) and medium (flowering between 76 and 90 DAS) cycle (Table 1). All were tan plant, white-grained caudatums, except for IS 14384 which was a pigmented plant, red-seeded guinea sorghum.

Anthracnose appeared early (32 DAS) on the susceptible check (IS 18442) and disease ratings were very high: 8.9 for foliar; 8.5 for peduncle; and 9 for rachis anthracnose (Table 3). Anthracnose appeared on the panicle within five days after flowering and became very severe (8.8 on the panicle, 7.5 on the grains). The disease appeared late (97 DAS and 21 days after flowering) on the resistant check (IS 21658), which was highly resistant to leaf, peduncle and rachis anthracnose (average respective scores of 1.4, 1.1, and 1.4). It was only slightly less resistant to panicle and grain anthracnose (average respective scores of 3.4 and 3.8). Anthracnose severity on the leaf is presented as the final, most severe score (Table 3).

In order to represent both severity and duration of foliar anthracnose attack, the “Area Under the Disease Progress Curve (AUDPC)” was determined. AUDPC was affected by significant ($P<0.001$) interactions between cultivar × site, cultivar × year, and year × site

(Fig.2). Susceptible (IS 18442) and moderately susceptible (CEM 34/6-4-1) materials were more severely diseased in Longorola than in Samanko whereas resistant cultivars (e.g., IS 21658 & ICSB 88019) had a similar reaction in the two locations (Fig. 2A). Susceptible IS 18442 was more heavily diseased in 1998 than in 1998 whereas the converse was true for CEM 34/6-4-1. Reaction of resistant cultivars was stable in both years (Fig. 2B). Disease pressure increased significantly in 1998 at Samanko but was constant at Longorola (Fig. 2C). Genotypes resistant to foliar anthracnose showed an AUDPC of 100 or less (Table 3). Moderately susceptible CEM 34/6-4-1 and the susceptible check IS 18442 had AUDPCs of 145 and 376, respectively.

Significant ($P<0.001$) interactions (between cultivar X site, cultivar X year, and year X site) were observed to affect grain anthracnose score (Fig. 3). Highly susceptible IS 18442 was more severely attacked in Longorola than in Samanko; the opposite was true for moderately susceptible IS 9738; and some resistant materials (e.g., IS 2834 and ICSB 88019) showed more grain anthracnose in Samanko than in Longorola (Fig. 3A). Similarly, some cultivars were more diseased in 1998 than in 1997 (e.g., IS 18442 and IS 9738), others less so (e.g., CEM 34/6-4-1 and IS 21658) and others (e.g., IS 14384 and IS 2834) manifested stable resistance (Fig. 3B).

In general, grain anthracnose was less severe in Longorola in 1998 but increased in severity in Samanko (Fig. 3C). The most resistant nine genotypes had a grain anthracnose score of <4 (Table 3). An additional nine genotypes, resistant to foliar anthracnose, were moderately susceptible to grain anthracnose (score of between 4 and 6). One entry, CEM 34/6-4-1, was moderately susceptible to both foliar and grain anthracnose.

Significant interactions ($P<0.001$) were observed between cultivar × site, cultivar × year, and year × site affecting panicle anthracnose score (Fig. 4). Highly susceptible IS 18442 was more severely attacked in Longorola than in Samanko; the opposite was true for moderately susceptible IS 9738; and some resistant materials (e.g., IS 2834 and ICSB 88019) showed more panicle anthracnose in Samanko than in Longorola (Fig. 4A). Generally, panicle anthracnose was more severe in 1998 than in 1997 but differences were less prominent in some entries (e.g., IS 14384) than others (e.g., ICSB 88019 and ICSB 41) (Fig. 4B). Between 1997 and 1998, panicle anthracnose decreased in severity in Longorola and increased in severity in Samanko (Fig. 4C). Reaction of genotypes to panicle anthracnose closely paralleled their reaction to grain anthracnose (Table 3).

Although anthracnose occurred on the peduncle and rachis of test sorghums, the severity was generally low (<3 for peduncle anthracnose and <3.5 for rachis anthracnose) (Table 3). The susceptible check was heavily attacked (scores of 8.5 and 9 for peduncle and rachis anthracnose, respectively). Moderately susceptible CEM 34/6-4-1 had scores of 3 and 5.2 for peduncle and rachis anthracnose, respectively.

Early flowering was weakly but significantly correlated with increased severity of foliar ($r=0.151$, $P<0.05$) and panicle anthracnose ($r=0.152$, $P<0.01$) (Table 4). Leaf, rachis and grain anthracnose was very weakly ($r=0.044$, 0.061, and 0.019, respectively) but significantly ($P<0.05$) correlated with increased height. Panicle anthracnose was significantly ($r=0.347$; $P<0.01$) correlated with shorter stature. Early appearance of foliar anthracnose was significantly correlated with early appearance of the disease on the peduncle ($r=0.165$; $P<0.05$), and with high levels of disease on the peduncle, rachis and panicle (r=0.435, 0.550, and 0.354; P<0.01) as well as high AUDPC (r=0.606; P<0.01). Similarly, early appearance of disease on the peduncle was significantly (P<0.01) correlated high levels of anthracnose on the panicle and rachis and with high AUDPC (r=0.290, 0.437, 0.401; P<0.01). Elevated levels of disease on the different plant organs (panicle, peduncle, rachis) were significantly (P<0.01) correlated among themselves. However, severity of grain anthracnose was not significantly correlated with AUDPC.

Nine genotypes were observed with good resistance to both foliar and panicle anthracnose (Table 3). These were: ICSB 88019; IS 2834; IS 14384; IS 21629; ICSV 901; ICSV 902; CEM 328/1-1-1-2; CEM 330/1-1-2-1; and Naga White. A further nine genotypes, although resistant to foliar anthracnose, were moderately susceptible to anthracnose on the panicle and grain. These were: ICSB 38; ICSB 39; ICSB 41; IS 3555; IS 9738; A 2267-2; CEM 326/11-5-1-1; CEM 328/2-1-1-3; and CEM 328/3-3-1-1. Genotype CEM 342/6-4-1 was moderately susceptible to all forms of the disease except peduncle anthracnose (Table 3).

Discussion

Colletotrichum graminicola is able to infect and develop on all above-ground organs of the sorghum host. This is reflected in the disease scores of susceptible IS 18442 which ranged from 7.5 (45%) on the grains to 9 (75-100%) on the rachis. Nonetheless, all test genotypes with the exception of CEM 342/6-4-1, were resistant (<10% disease) to anthracnose on the rachis and peduncle. This is attributable to their having been selected for field resistance to foliar anthracnose prior to incorporation in the trial.

Anthracnose appeared earlier on the leaves and panicles and disease developed to more severe levels on earlier genotypes (Table 4). This was true for all forms of the disease, except for grain anthracnose, suggesting that some of these genotypes may possess useful levels of genetic resistance to anthracnose of the grain.

We observed that as disease progressed up the plant, lower leaves developed severe infections and died while the fungus established itself and spread on upper plant parts. This vertical disease progression is illustrated by the data in Table 4. Significant correlations exist between severity of disease on the grain, rachis and peduncle and leaves (AUDPC) but not between AUDPC and grain.

Correlations between anthracnose on the peduncle and rachis were very high, reflecting the movement of the disease from the peduncle into the panicle. High correlations between disease on the rachis and panicle and grain anthracnose are indicative of disease progression from panicle branches and glumes onto the grains.

The use of AUDPC is an effective method to take into account both duration and severity of disease. Nine evaluations of foliar anthracnose were made during the cropping season. Resistant (<5% disease) materials had AUDPCs of £100, a moderately susceptible line of <200, and the susceptible check of >300. Disease evaluation on the panicle and its different parts were effectively made at physiological maturity. As a result, reliable selection is possible based on reaction to foliar and either grain or panicle manifestations of the disease.

Rainfall quantity and distribution is highly variable in Mali (Sivakumar et al. 1984). The anthracnose screening nursery is an effective tool for screening activities at Samanko. An increase in anthracnose severity in 1998 over 1997 was apparent, attributable in part to increasing disease pressure in the plot and in part to the elevated rainfall received in 1998. At Longorola no permanent anthracnose nursery is available and its location changes from year to year following the cotton-maize-sorghum rotation practiced in the zone. This, coupled with below-average rainfall in 1998, resulted in reduced year-to-year variability in anthracnose severity. Nonetheless, the use of infestor rows permitted successful screening to be carried out in both locations and in both years, providing reliable results.

Sorghum varieties have been identified with good levels of resistance to both foliar and panicle anthracnose which can be grown in zones to which they are well adapted (i.e., ICSB 88019; IS 2834; IS 14384; IS 21629; ICSV 901; ICSV 902; CEM 328/1-1-1-2; CEM 330/ 1-1-2-1; and Naga White) In addition, genotypes have been identified which can serve as sources of resistance in breeding programs: ICSB 88019 is resistant to both foliar and grain anthracnose; ICSB 38, ICSB 39 and ICSB 41 are good sources of resistance to foliar anthracnose although they are moderately susceptible to the disease on panicles and grain.

The two sites may provide useful locations to investigate the effect, if any, of pre-season (January-May) rainfall on inoculum availability. At Samanko in 1997 and 1998, 110 mm of rainfall was received in 15 rainfall events; at Longorola, 369 and 145 mm fell in 14 and 10 rainfall events, respectively, in 1997 and 1998. In a wetter zone it is possible that soil microflora may affect the viability of *Colletotrichum graminicola* in plant debris at and below the soil surface, influencing the availability of inoculum in the following growing season (Casela and Frederiksen 1993). This question will be investigated in the coming cropping season.

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Table 1. Plant characteristics and agronomic traits of 19 sorghum genotypes evaluated for field reaction to anthracnose in Mali 1997-98 cropping seasons.

Genotype	Origin	Race[a]	Plant type[b]	Grain color[c]	Days to 50% flowering	Plant ht. (m)
ICSB 88019	ICRISAT	C	T	W	60	1.7
IS 2834	ICRISAT	C	T	W	66	2.9
ICSV 902	ICRISAT	C	T	W	74	2.5
IS 21629	ICRISAT	C	T	W	78	3.9
ICSV 901	ICRISAT	C	T	W	74	2.1
CEM 330/1-1-2-1	CIRAD/ICRISAT	C	T	W	82	2.4
Naga White	Ghana	C	T	W	66	2.4
CEM 328/1-1-1-2	CIRAD/ICRISAT	C	T	W	75	2.8
IS 14384	ICRISAT	G	P	RB	68	3.3
ICSB 39	ICRISAT	C	T	W	71	1.5
IS 9738	ICRISAT	C	T	W	75	3.3
A 2267-2	ICRISAT	C	T	W	77	2.8
IS 3555	ICRISAT	C	T	W	74	3.7
CEM 326/11-5-1-1	CIRAD/ICRISAT	C	T	W	73	2.8
CEM 328/2-1-1-3	CIRAD/ICRISAT	C	T	W	76	3.0
ICSB 38	ICRISAT	C	T	W	71	1.6
CEM 328/3-3-1-1	CIRAD/ICRISAT	C	T	W	79	2.9
ICSB 41	ICRISAT	C	T	W	72	1.6
CEM 342/6-4-1	CIRAD/ICRISAT	C	T	W	79	2.8
IS 21658[d]	ICRISAT	C	T	W	76	3.8
IS 18442[e]	ICRISAT	C	T	W	65	2.9
SE(±)					2.8	0.19
Mean					73	2.7
CV(%)					4	7

[a]C=Caudatum; G=Guinea. [b]P=Pigmented; T=Tan. [c]W=White; RB=Red brown. [d]Anthracnose-resistant check. [e]Anthracnose-susceptible check.

Table 2. Severity scale for evaluation of anthracnose severity on sorghum.

1	=	no disease
2	=	1-5% anthracnose severity
3	=	6-10% anthracnose severity
4	=	11-20% anthracnose severity
5	=	21-30% anthracnose severity
6	=	31-40% anthracnose severity
7	=	41-50% anthracnose severity
8	=	51-75% anthracnose severity
9	=	> 75% anthracnose severity

Note: The scale is used for evaluation of disease severity on the: leaf surface; rachis; peduncle; panicle (including rachis, rachis branches, glumes and grain); and grains (damage resulting in reduction in grain size or grain abortion).

Table 3. Plant characteristics and agronomic traits of 19 sorghum genotypes evaluated for field reaction to anthracnose in Mali. Results averaged over two locations (Longorola and Samanko) and two years (1997-98).

	Days to disease appearance		Anthracnose severity on[a]					
Genotype	on leaves	on panicle	Leaves[b]	Panicle	Peduncle	Rachis	Grain	AUDPC[c]
ICSB 88019	120	80	1.2	3.3	1.2	1.3	2.5	68
IS 2834	96	94	1.2	2.6	1.2	1.2	2.7	79
ICSV 902	109	88	1.4	2.8	1.5	1.5	3	69
IS 21629	100	98	1.5	3.7	1.2	1.7	3.9	78
ICSV 901	107	97	1.6	2.9	1.6	1.8	3.3	69
CEM 330/1-1-2-1	79	96	1.6	2.9	1.5	2	3.9	93
Naga White	99	92	1.7	3.1	1.4	2	3.4	76
CEM 328/1-1-1-2	82	93	1.7	3.1	1.6	2.1	3.6	80
IS 14384	57	107	1.8	1.8	1.3	1.5	2	100
ICSB 39	87	82	1.6	5.4	1.3	2.4	5.8	86
IS 9738	98	92	1.7	4.1	2.5	3	4.7	74
A 2267-2	92	92	1.8	4	1.4	1.9	4.3	74
IS 3555	73	93	1.8	3.8	1.1	2	4.5	92
CEM 326/11-5-1-1	74	92	1.9	4.5	2.9	3	4.3	87
CEM 328/2-1-1-3	78	92	1.9	4	1.6	2.2	4.7	84
ICSB 38	83	82	2	5.4	1.1	2.5	5.8	89
CEM 328/3-3-1-1	80	90	2.1	3.9	1.4	2.4	4.4	92
ICSB 41	78	82	2.5	5.5	1.6	3.3	6	91
CEM 342/6-4-1	54	92	5.5	5.3	3	5.2	5.9	145
IS 21658[d]	97	97	1.4	3.4	1.1	1.4	3.8	81
IS 18442[e]	32	70	8.9	8.8	8.5	9	7.5	376
SE(±)	11.92	9.14	0.283	1.019	0.525	0.590	1.131	15.20
Mean	85	91	2.2	4.0	1.9	2.5	4.3	99
CV(%)	14	10	13	25	28	23	26	15

[a]On a 1-9 rating scale (From Table 2). [b]Score at the final evaluation. [c]Area under the disease progress curve. [d]Anthracnose-resistant check. [e]Anthracnose-susceptible check.

Table 4. Correlation coefficients of agronomic characters and disease severities of sorghum genotypes infected by *Colletotrichum graminicola* in Mali in 1997 and 1998.[a,b]

	DFL	HPL	APF	APP	PAN	PED	RAC	GRA
HPL	-0.035							
APF	0.074*	-0.152						
APP	0.515**	-0.031	0.165*					
PAN	-0.152**	-0.347**	-0.354**	-0.238**				
PED	-0.025**	-0.055	-0.435**	-0.290	0.492**			
RAC	-0.119**	0.061*	-0.550**	-0.437**	0.494**	0.848**		
GRA	-0.188	0.019*	-0.335	-0.470	0.550**	0.380**	0.517**	
AUDPC	-0.151*	0.044*	-0.606**	-0.401**	0.436**	0.826**	0.787**	0.382

[a]Symbols * and ** indicate departure from a zero relationship at P<0.05 and 0.01, respectively.
[b]DFL=days to flowering; HPL=plant height; APF=appearance of anthracnose on the leaf; APP=appearance of anthracnose on the panicle; PAN=anthracnose severity on the panicle; PED=anthracnose severity on the peduncle; RAC=anthracnose severity on the rachis; GRA= anthracnose severity on the grain; AUDPC=area under the disease progress curve.

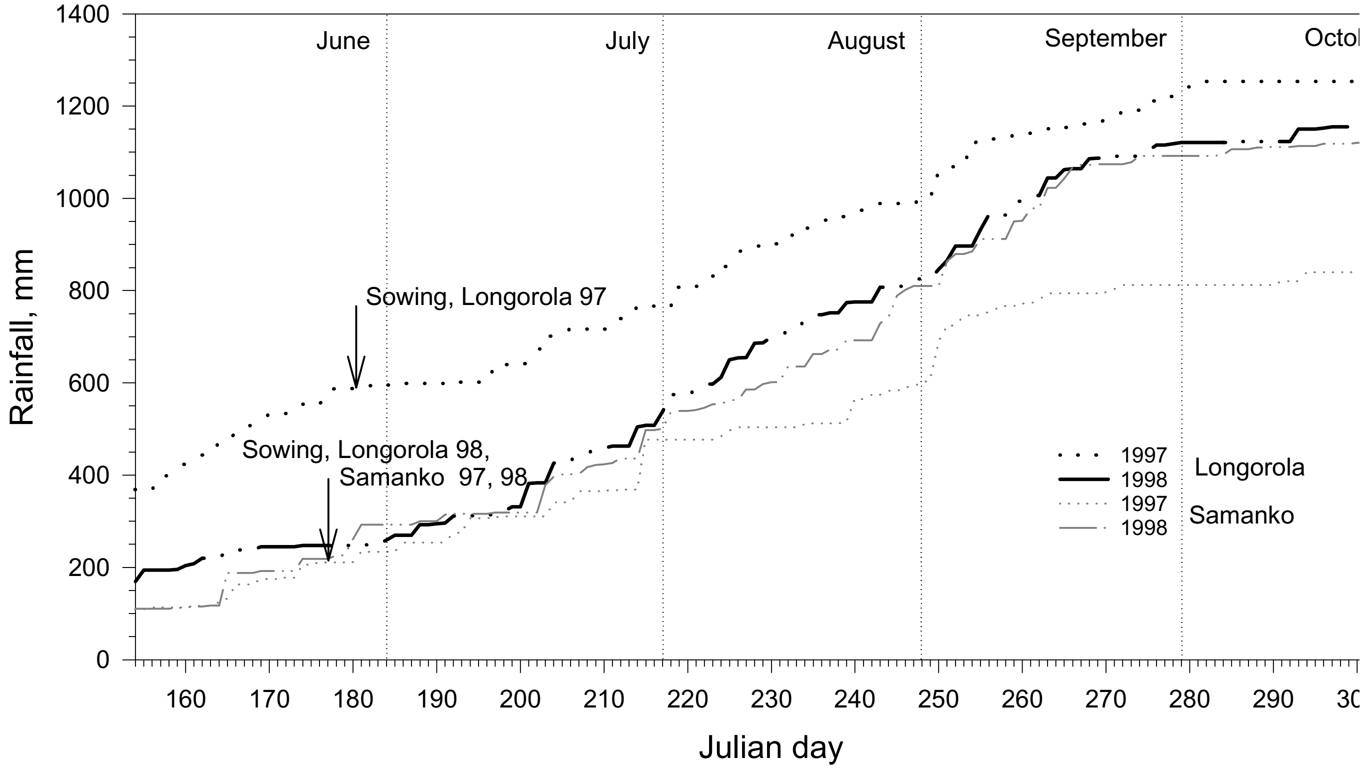

Figure 1. Cumulative rainfall at Longorola and Samanko, Mali, in the 1997 and 1998 cropping seasons. The arrows indicate dates of sowing.

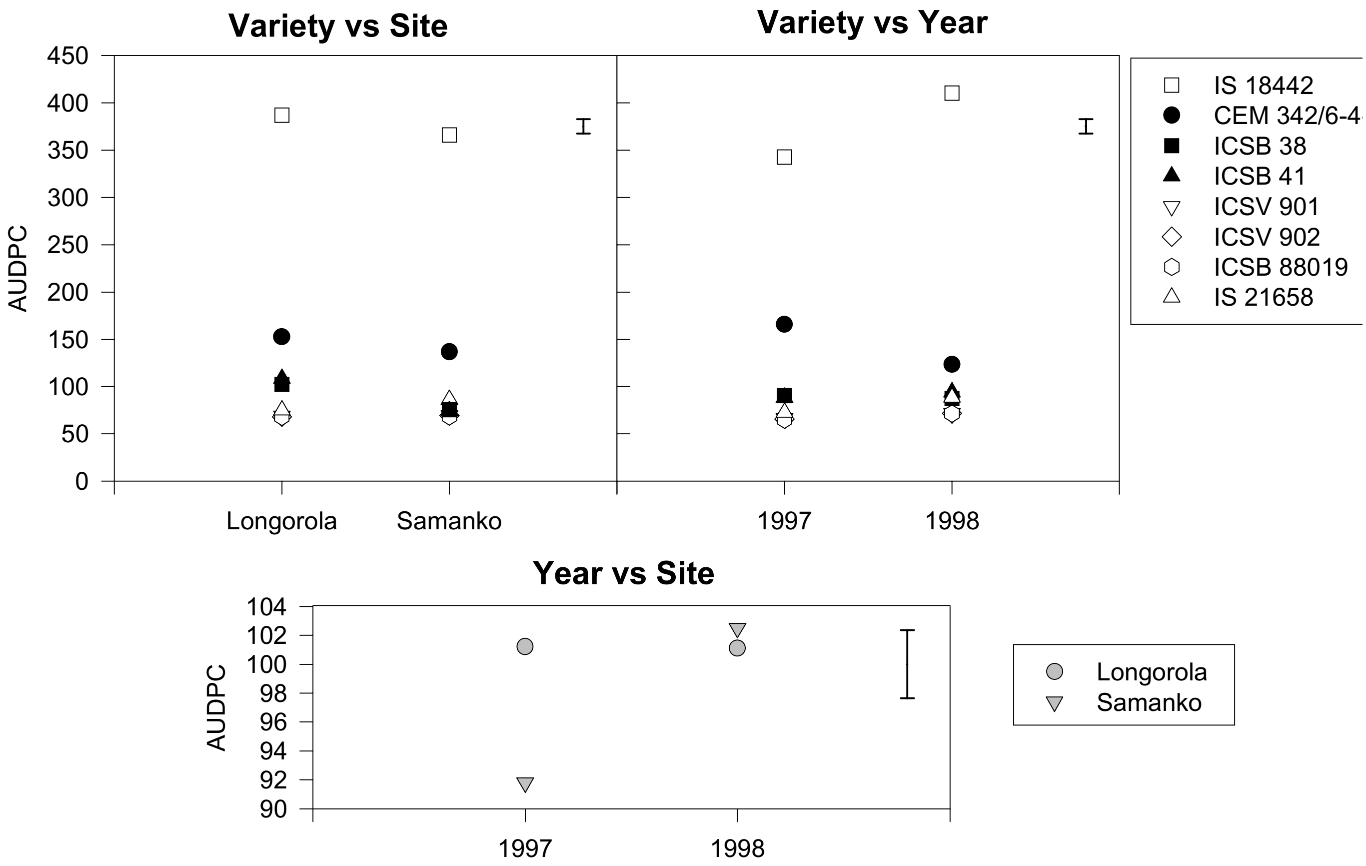

Figure 2. Effect of sorghum genotype, experimental site and year on area under the (anthracnose) disease progress curve (AUDPC). Bars represent ± 1 SE.

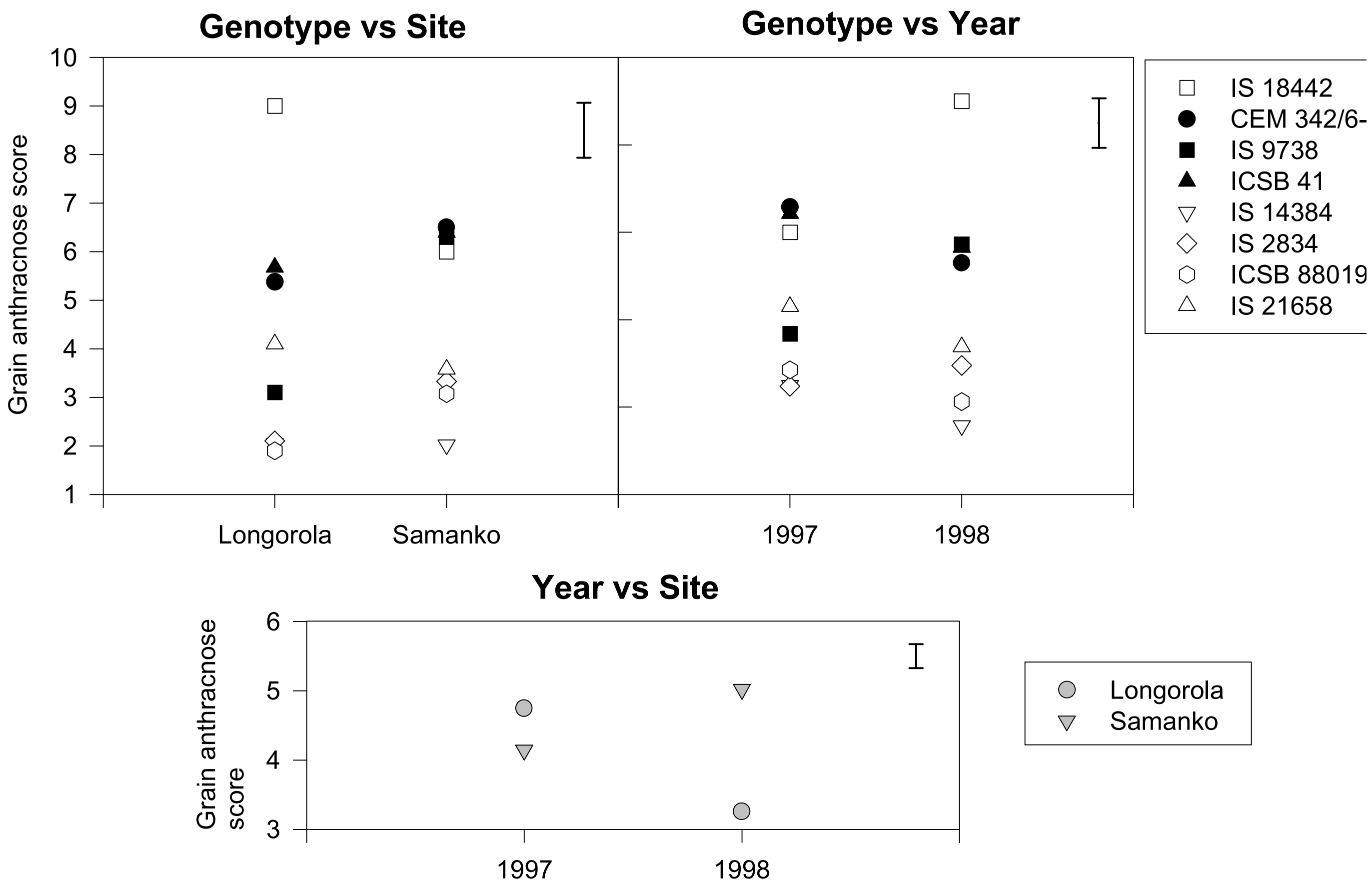

Figure 3. Effect of sorghum genotype, experimental site and year on severity of grain anthracnose. Bars represent ±± 1 SE.

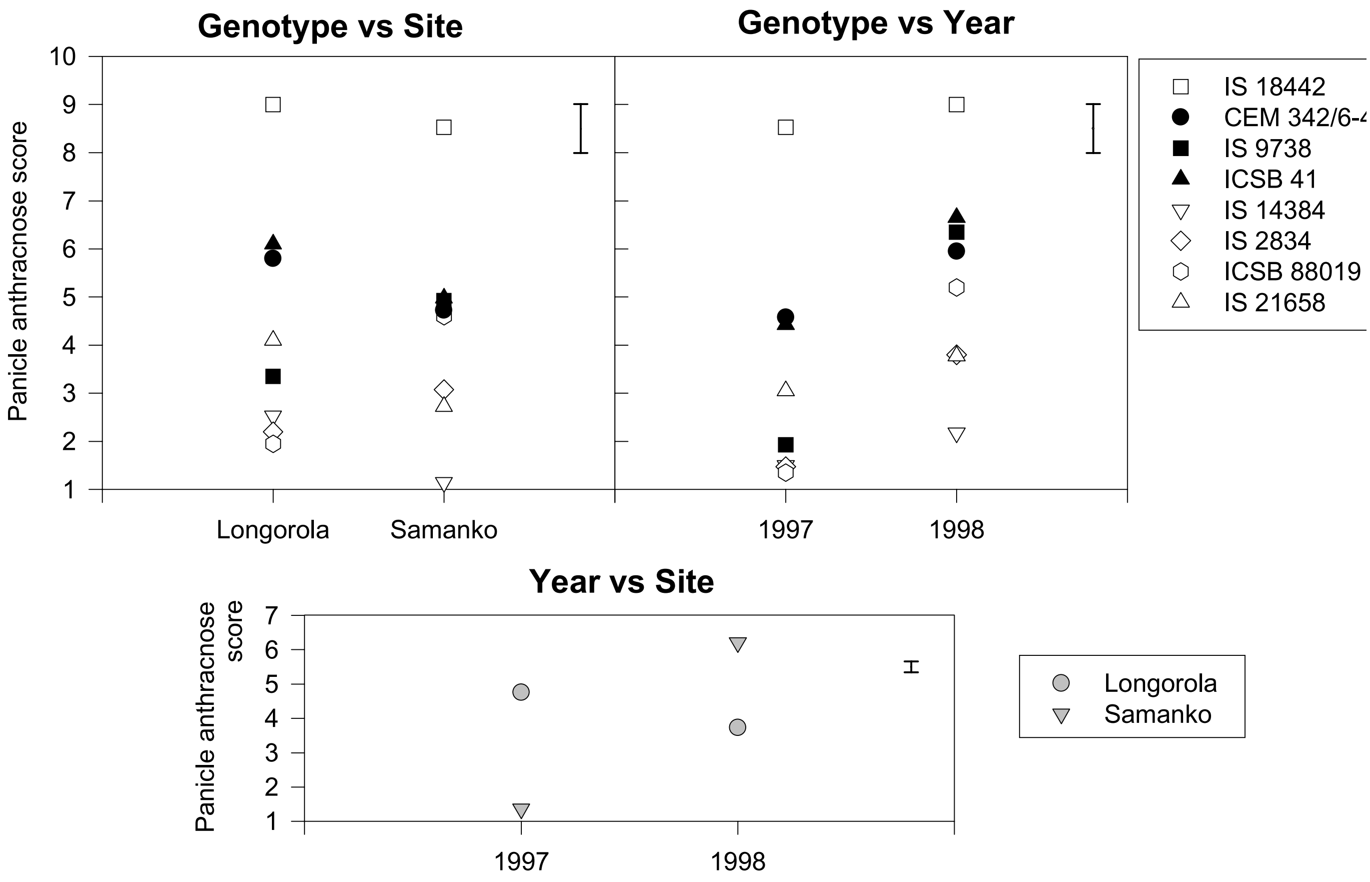

Figure 4. Effect of sorghum genotype, experimental site and year on severity of panicle anthracnose. Bars represent ±± 1 SE.

Prospects for a Pearl Millet and Sorghum Food Processing Industry in West Africa Semi-Arid Tropics

Jupiter Ndjeunga[1] and Carl H. Nelson[2]

Abstract

Relative to other cereal crops, sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*) are still the most important crops in the production systems, and the main staples for the people in the semi-arid tropics of West Africa (WASAT). During the past fifteen years, the shares of total cereal area cultivated to, and production of, the two coarse grains have declined slightly. Sorghum and pearl millet are being replaced slowly by maize, rice and wheat in average diets, especially those of urban consumers. This trend has led some to express pessimism about the ability of sorghum and pearl millet to contribute to poverty alleviation in the medium- or long-term. However, since 1984 the total cereal area planted, and production of sorghum and pearl millet have been increasing in most West African countries. And there is a slowly emerging, small-scale coarse grain food processing industry in the WASAT. There is therefore a need to reconsider the pessimistic conclusions that have been expressed about the future of sorghum and pearl millet.

Negative views of sorghum and pearl millet are based on negative growth in productivity, and limited commercialization of sorghum and pearl millet grains and processed products. This paper presents the necessary conditions for the growth of a coarse grain processing industry in the semi-arid tropics of Africa, and highlights the significant research themes that need to be explored. The adoption of supply and demand enhancing technologies in a coordinated market environment constitutes the bulk of necessary conditions for the growth of a coarse grain processing industry in the WASAT.

Introduction

The region of West Africa covers a total land area of 1.58 million km^2. With the exception of few countries (Senegal, Cote d'Ivoire and Ghana), the region is classified by the World Bank among the poorest third of the world's developing countries, with per capita incomes of US$ 320 or less. The human population, which grows at an annual rate of 2.9%, was estimated to be 185 million in 1986, and is projected to reach 284 million by the year 2000. The urbanization rate is estimated to be about 30% of the total population. It grows at a rate higher than the population growth rate, ranging from 4% in Senegal to 11.3% in Burkina Faso between 1980 and 1995 (Annex 1). Sorghum (*Sorghum bicolor*), pearl millet

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(*Pennisetum glaucum*), maize (*Zay mays*), rice (*Oryza sativa*) and fonio (*Digitaria exilis*) are the main cereal crops grown in the WASAT. They absorb 50 to 80% of total farm resources (Matlon 1987). Millet and sorghum account for 80% of total cereal production, provide more than 75% of total calorie intake, and are the main staple in diets in the WASAT.

Since 1960, area planted, production, and yields of sorghum and millet have presented some mixed patterns in WASAT, characterized by periods of area and production expansion (1960-70), decline (1970-1983) and recovery (1984-1997). The period of negative growth in both area cultivated and production is explained by repeated droughts that occurred during the years 1973 and 1983, depressing both the yield and production of pearl millet and sorghum. Since 1984, the shares of sorghum and millet in cereal area planted and total cereal grain production have declined slightly. Over the same period the total cereal area cultivated to maize and rice, and their share of total cereal production have been increasing. This trend led some scientists to argue that the demand for processed coarse grain products is limited because urban consumers have developed a strong preference for rice, which will not decline significantly, even if cheaper coarse grain alternative are made available (Reardon 1993; Fusillier 1994). The evidence for this argument is limited because the data does not provide a good understanding of the factors that explain the current, evolving supply and demand for coarse grains products in West Africa.

The data show that the total area and production of pearl millet and sorghum have been increasing since 1984. The decline in the share of area planted and production is explained by the growth in area planted and production of maize and rice. But the growth in area planted to maize and rice is constrained by agro-climatic conditions, implying that the share trends can not be projected into the future indefinitely. So pearl millet and sorghum are likely to remain significant in the WASAT cereals economy, contrary to the negative arguments about their future. A fresh view of the evidence can help identify the information and actions needed to enhance the production of pearl millet and sorghum, and overcome concerns about their declining significance in the region.

This paper uses FAO data and secondary sources of information to assess the prospects for a pearl millet and sorghum food processing industry in the WASAT. It presents the necessary conditions for the growth of a coarse grain processing industry in West Africa and highlights significant research themes that need to be investigated. The necessary conditions for the growth of a coarse grain processing industry fall into three categories: 1/ the supply of raw material (grains); 2/ the demand for the processed products and 3/ market organization. The state of knowledge in each of these categories will be reviewed below.

Raw Material Supply (Supply of Coarse Grains)

The Bio-Physical Environment - Definition of Production Zones

The semi-arid region of West Africa, roughly referred as WASAT, receives mean annual rainfall between 250 and 1100 mm. This region can be broadly sub-divided into four agro-ecological zones - the sahelian (less than 350 mm), the sahelo-sudanian (350-600 mm); the sudanian (600-800 mm) and the sudano-guinean (800-1100 mm) - with distinct agricultural systems and potential. Table 1 summarizes the major features of these agro-climatic zones. Roughly 54% of the total land area in Western Africa may be considered arid, defined as those areas where the length of growing period (LGP) is less than 90 days. Twenty percent of the land area is semi-arid (90-180 days), 16% is sub-humid (180-270 days), and 10 % is humid (180-270 days).

Climate

The four broad categories defined above are distinguished by rainfall and soil suitability parameters (Table 1). Climatic constraints are more limiting in the sahelian zones and decline in importance in the sudanian and guinean zones. The constraints include: a short uni-modal rainy season; high intra-seasonal rainfall variation, with risk of periodic critical drought at the early stages of crop growth; high evaporative demands, with peaks at the beginning and end of the rainy period; and further increases in the risk of drought stress during planting and grain filling. Moreover, high rainfall intensity may cause run-off losses of as much as 60-80 percent of precipitation, contributing to considerable risk of top soil losses through erosion (Matlon 1987).

Soils

The old and highly weathered soils of the semi-arid tropics of West Africa reinforce the climatic constraints. Soil texture varies from loamy sand in the Northern Sahel to sandy loams in the southern sudanian areas. Except for limited vertisol pockets, clay content is uniformly low (less than 20%), and the soils are structurally inert with poor water holding capacity. Due to the low clay and organic matter content (generally less than 1%), cation exchange capacities tend to be less than 5 milli-equivalents per 100 grams of soils. As a result, soils are highly fragile. In addition to low natural fertility, the low structural porosity and high bulk density reduces root penetration and water circulation. There is a tendency for compacting and hardening during the dry season, which results in early erosion run-off, severely restricting pre- and post season cultivation. This also leads to poor water infiltration (except in eolian sandy soils) due to: rapid surface crushing of soils, even after cultivation; low values of available water compared to typical Asian soils; and increasing susceptibility to erosion with continuous cultivation.

Farming Systems

Within the broad agro-climatic zones, farmers have adapted to micro-variations with highly flexible management practices. In areas, where soils tend to be droughty, such as the Sahel zone, farmers tend to grow millet and fonio, and migratory livestock rearing is predominant. In the sudano-sahelian zone, where soils are droughty, but receive more rainfall, farmers tend to grow millet, sometimes inter-cropped with cowpea, groundnut and sorghum as secondary crops. The sudanian zone is an area of transition between millet and sorghum based systems. Maize, groundnut and cotton are also cultivated. Finally, in the sudano-guinean zone, which receives rainfall between 800-1100 mm, a wide range of crops are grown, including cotton, maize, rice, rice, cowpea, groundnut and vegetables. Therefore, movement along the North-South transect, is characterized by increasing rainfall and soil depth, creating more opportunities for farmers to grow a wider range of crops.

Of the sample countries, Senegal, Niger, Mali and Burkina Faso are endowed with more than 80% of their total area in the semi-arid zones. They are referred to as Sahel countries. The other four sample countries (Nigeria, Cote d'Ivoire, Togo and Ghana), have less than 50% of their total area in the semi-arid zone. They are referred to as forest countries (Table 1). Pearl millet and sorghum, which are more drought tolerant, are predominant in the production systems of all Sahel countries. They are expected to gain more ground even in the marginal areas of the forest zones. Estimates indicate that, since 1973, there has been a southward shift of the 300 mm rainfall isohyet by 150 km. This offers a comparative advantage to drought tolerant crops, such as sorghum and pearl millet (Sivakumar 1992).

Coarse Grain Production

Farmers in the semi-arid tropics of West Africa produced about 9.6 million tons of pearl millet and 9.7 million tons of sorghum, on average, between 1995-97 (Table 2). This compares with a production level of 8.7 million tons of maize and 5.1 million tons of rice over the same period. Sorghum and pearl millet account each for about 29% of the total cereal grain production. The relative contribution of maize and rice are also important and estimated to be about 15% and 26% of the total cereal grain production. Nigeria accounts for about 70% of the total sorghum production, and more than half of the pearl millet production in West Africa. Although Niger after Nigeria comes as the second largest area allocated to millet in West Africa it accounts for only 18% of the total pearl millet produced due to low grain yield.

Except for Nigeria, every country's cereal production share has been declining. Sorghum has lost about 6% of its share from 35% to 29 %, while pearl millet's share has declined from 38 to 29% on average from 1981-83 to 1995-97. In contrast, the relative share of maize in total cereal grain production has marginally increased from 13% in 1981-83 to 15.3% in 1995-97, and the average contribution of rice in total cereal grain production has more than doubled from 14% in 1981-83 to 26% in 1995-1997. The rapid increase of rice in total cereal grain production is mainly explained by the expansion of rainfed and irrigated schemes, and higher yields compared to other cereals. The irrigated areas have more than doubled during the past fifteen years in the Sahel countries.

Within countries, the production shares of the two coarse grains have remained virtually unchanged, especially in the Sahel countries with the exception of Mali. In contrast, in forest countries, there has been a significant production decline in favor of maize production. The share of maize production has almost doubled from 17% to 31% of total cereal production (Table 3).

Although the production shares of sorghum and millet have declined, the region's total pearl millet and sorghum production has increased. Since 1984, pearl millet and sorghum production has increased at annual rates of 3.2% and 3.3% respectively. These rates are less than the production growth of maize, 7.20% and rice, 6.58% (Table 4).

There is not clear evidence that maize production is replacing sorghum or pearl millet production. While maize production has increased overall, most of the increases are in environments better suited for maize production. Maize production has more than doubled in all forest countries. Similarly, in the Sahelian countries of Burkina Faso and Mali, which are endowed with large environments better suited for maize production (800-1100 mm), a significant increase in maize production has been recorded (Table 3). Production of coarse grains is explained by the area planted and yields, among other factors. The following section examines the trend in area planted.

Coarse Grain Area Planted and Harvested

Farmers in WASAT planted over 14 million ha of pearl millet and approximately 11 million of sorghum on average between 1995-97. Maize and rice are planted on almost 7 million and 3 million ha respectively (Table 5). Nigeria, alone, accounts for 55% of the West African sorghum area. Niger and Burkina Faso also have significant sorghum area. The remaining 5 countries account for less than 15% of the West African sorghum area. Nigeria and Niger each account for about 37% of West Africa's pearl millet acreage. The remaining 6 countries account for less than 25% of the pearl millet acreage.

Over the past fifteen years all countries, except Nigeria, have been losing their regional share of area planted to all cereal crops. Nigeria's share of all cereal crops has significantly increased. For example, sorghum's share of area planted has increased from 42 to 57% of the total WASAT cereal area planted. Pearl millet's share has increased from 23 to 37%, rice area has increased from 46 to 60%, and the maize area has more than doubled, from 32% to 67% of WASAT cereal area planted.

The importance of sorghum and pearl millet within each country can be measured in terms of the proportion of total cereal grain area planted to each crop. Pearl millet accounts for the majority of cereal grain area in Senegal and Niger, 74% and 72% respectively. Sorghum accounts for 51% of the total cereal grain area in Burkina Faso followed by Nigeria (34%), Mali (31%) and Niger (27%). Both sorghum and millet account for more than 90% of the total area planted to cereal in the Sahel countries. In contrast, maize and rice are of relatively minor importance, representing less than 10% of the total cultivated cereal grain area. However the latter two crops are more important in the forest countries. For example, except for Nigeria, both maize and rice account for over 70% of the total cereal area planted compared with about 25% for both sorghum and millet. Including Nigeria, sorghum and pearl millet are important in the production systems, accounting for over 50% of the total grain area (Table 6).

Within countries, since 1984, the shares of total cereal area planted to sorghum and pearl millet have virtually remained constant in the Sahelian countries and have only have slightly decreased in the forest countries. However, in almost all countries, the area planted to sorghum and pearl millet has been increasing. In the WASAT, sorghum and millet area planted has been increasing by 3.98% and 4.20% respectively, but less than the areas planted to maize, 6.24%; and rice, 6.61% (Table 7).

There is little evidence that maize has been displacing sorghum and pearl millet at least in term of area planted. Much of the growth in maize area occurred in the predominantly forest zone. In the Sahelian countries, area growth to maize is comparable to or less than that of sorghum. In Niger, for example, the growth in area cultivated to maize has been decreasing by about 13% since 1984; whereas, sorghum and pearl millet area cultivated have increased by more than 5%. In Burkina Faso, the area cultivated to maize increased by 2.9 %, about the same as sorghum. Much of the area growth to maize in the WASAT is attributed to maize area expansion in Nigeria. The area cultivated to maize has almost doubled (13 to 27%) while Nigeria's share of the total planted area to maize in the WASAT has increased from 32 to 67% from 1981-83 to 1995-97.

Overall, the area cultivated to sorghum and pearl millet is still increasing in WASAT. There is little evidence that this area is being replaced by maize. While it may be true that the area growth in sorghum and pearl millet results from expansion on marginal lands; sorghum and millet may also be growing in areas that are no longer suitable for maize production. Further investigation is required to ascertain the directions of area growth and assess the area substitution between cereal crops. The growth in area cultivated to sorghum and millet is more than production growth suggesting that yields are depressing production. The following section examines trends in grain yields.

Coarse Grain Yields

Grain yields for pearl millet and sorghum are low by global standards and significantly less than maize or rice yields. Pearl millet yield across the sub-region averages 679 kg ha^{-1}. Nigeria has the highest grain yield (1,040 kg ha^{-1}) in the sub-region. In contrast, Niger has the lowest yield in the region, averaging 340 kg.ha^{-1}. Pearl millet yield averages less than sorghum in West Africa. Sorghum averages about 866 kg.ha^{-1}, with Nigeria achieving the highest average grain yield of about 1,107 kg ha^{-1}. In contrast in Niger, where sorghum is the second most important crop, grain yields are averaging about 190 kg ha^{-1} over the period 1995-1997 (Table 8).

Since 1984, West Africa's average yields of two major coarse grains have declined by an annual average of 1.0% for pearl millet and 0.7% for sorghum since 1984. Yield declines for the two major coarse grains may be attributed to low and erratic rainfall. In addition, limited use of improved technologies by cereal growers is a major constraint to increasing yields. Fertilizer use per ha arable land is very low. Grain yields were found to the highest in countries where more than 8 kg of mineral fertilizer is used per ha arable land (e.g., in Nigeria, Mali and Senegal). Yields are the lowest in Niger where less than 1 kg is used per ha arable land (Annex 2).

In contrast to sorghum and pearl millet, maize yields have increased moderately by 1% between 1984 and 1997; and rice yields have virtually remained constant. To remain competitive, pearl millet and sorghum yields must increase.

The Competitive Position of Sorghum and Pearl Millet

Sorghum and millet are still the most important food grains in West Africa. Since 1984, production and area planted have been increasing. However, production growth results from area expansion rather than yield. In contrast, maize production has increased as a result of both area and yield growth. Therefore, for sorghum and millet to be competitive in the system, yields must increase. The returns to the major factors of production (land and labor) for millet or sorghum must be raised to stimulate yield enhancing production practices.

Currently the returns to land and labor for pearl millet are lower than that of maize in Niger (Reardon and Hopkins 1990). In 1990, survey results in four sample villages indicated that millet returns to land averages 15500 $fcfa.ha^{-1}$ while maize returns to land averages about 31000 $fcfa.ha^{-1}$ (Annex 5). The net returns to labor for millet were estimated to be 526 $fcfa.ha^{-1}$ slightly higher than that of maize, estimated to be 497 $fcfa.ha^{-1}$. Therefore, if land becomes scarce, farmers will likely allocate more land to maize than sorghum and millet. Similarly in Mali, maize responds better to labor inputs than sorghum and millet. A man-day of work in maize production returns 46.5 kg, roughly one and half times sorghum production and two and half times millet production. Therefore when labor becomes scarce during critical periods of the year, one would expect farmers to allocate more labor to maize than sorghum and millet (Debrah 1993).

Supply enhancing technologies, including labor saving and yield stabilizing technologies, land and water management techniques, and technologies to improve productivity, such as the use of improved varieties combined with fertilizers, are well known and have been extensively studied by many scientists. Labor is usually scarce during critical periods of the year and is one of the principal constraints to cereal production (Hopkins and Reardon 1990, Debrah 1993). Labor saving technologies have the potential of alleviating the labor constraints. They include the use of herbicides and mechanization (e.g., animal traction). Yield stabilizing technologies have the potential of reducing production variability and may increase yields by enhancing crop resistance to chronic yield reducers. For example, IRAT sorghum variety IRAT204, ICRISAT millet varieties IBV8001 and IBV8004 are well adapted in Senegal, and GB8735 is well adapted in more drought prone areas of Niger, Mauritania and Chad.

Overall, total pearl millet and sorghum production and area planted are increasing. There is little evidence that these crops are being replaced by maize in terms of production and area planted. Their competitiveness is severely limited by their poor yield, which is explained by little adoption of improved technologies. Supply enhancing technologies that encompass the use of improved varieties and soil fertility restoration methods are well known. However, demand enhancing technologies that include food processing and storage are still in their infancy in West Africa. The following section reviews the current utilization and consumption of pearl millet and sorghum products and previous studies on demand for grain and processed products.

Finished Product Demand (Demand for Pearl Millet and Sorghum Processed Products)

Current Utilization and Consumption

Utilization

Worldwide, between 1992-1994, it was estimated that 42% of total sorghum produced was used for human food consumption, while 48% was used for animal feed. In contrast, 80% of the world's millet is used for food, with the remaining divided between feed, other uses and waste (ICRISAT/FAO 1997). In the WASAT, sorghum and pearl millet grains are the basic staples and are still almost entirely consumed by humans. Uses as animal feed are not yet developed. Other uses of sorghum and millet include the use of their stalks as building material or animal feed, especially during the dry season.

When consumed as food, the most common meals prepared from sorghum are: thin or stiff porridges; e.g. *ogi* in Nigeria or *tô* in Mali, Burkina and Niger; steamed cook products such as *couscous*; or beverages such as *dolo* in Burkina Faso and Mali, *pito* in Ghana and Togo, or *tchapalo* in Cote d'Ivoire. So far, sorghum products are mainly traditionally processed for family consumption. A slow and emerging industrial use is found in Mali and Burkina Faso with the processing of grains into flour, decorticated sorghum or biscuits. Sorghum flour is being experimented with as a partial substitute for wheat flour. The food technology institute of Mali, the Institut de Technologie Alimentaire (ITA) in Senegal; and the Institute of Agronomic Research in Nigeria have successfully experimented with a wide range of products where sorghum flour substitutes for about 50% of wheat flour (WCASRN& IER 1998).

There is a slow emerging industrial use of sorghum. In western Africa Nigeria is a pioneer in the industrial utilization of sorghum. Following the ban on imports of major cereal grains in January 1988, an industrial scale replacement sorghum for imported barley and malt has been initiated in the production of lager beer, stout, malt-based drinks and weaning food. Industrial demand for sorghum is currently estimated to be about 5% of the total sorghum production in Nigeria (Baidu-Forson, et al. 1995).

Pearl millet ranks first as the major staple in human consumption in the WASAT, providing the bulk of energy, proteins, vitamins and mineral requirements. It has been proven to be a high-energy nutritious food, nutritionally superior to other cereals and especially recommended for children, convalescents and the elderly. Several food preparations are made from millet, including thin and stiff porridges. A survey conducted by the West and Central African Millet Research Network (WCAMRN) on 522 consumers in four countries revealed that millet is the most preferred staple in the WASAT. Millet is consumed at breakfast, dinner and supper, followed by sorghum which is mostly consumed at supper. Rice is mostly consumed at dinner times and maize at supper. Maize was found to be consumed rarely. The main dishes derived from millet vary by country. In Burkina Faso, thin (*bouillie*) and stiff porridges (*tô* and *couscous*) are the main processed products. Ninety-two percent of respondents reported eating *tô*; 62% drinking *bouillie* and 25% eating *couscous*. In Niger, 75% reported drinking *bouillie*; 63% *pate*; 25% *tô* and 31% *gallette*. In Nigeria; 84% were reported to eat *tô*; 62% *bouillie*; 58% *fourra* and 47% *couscous*. Finally, in Senegal, 80% reported eating *couscous*; *soungouf* (64%), *sankhal* (58%) and *araw* (49%). Pearl millet products are traditionally processed mainly for family consumption (WCAMRN 1998)

The commonalty between these traditionally processed products from is that they are made from sorghum or pearl millet flour. Therefore, the supply of flour is likely to be one of the main industrial products that food processors could supply in urban markets.

Consumption

Average per capita cereal grain consumption in WASAT was estimated to be 193 kg in 1994-96 and partitioned into 26% sorghum, 26 % pearl millet, 26% maize, 17% rice, and finally 4% wheat products. Since 1984, The consumption shares of sorghum and millet have remained virtually constant in the Sahel countries. They still account for about 70% of the total cereal grain consumed, followed by rice, maize and wheat (Table 10). In contrast, in the forest countries, maize and rice account for more than 60% of per capita cereal consumption. In these countries, the shares of sorghum and millet have significantly decreased, but still account for about 30% of the per capita cereal consumption. About 60 % of the increase in maize consumption is offset by decreases in rice and wheat consumption. Large increases in per capita consumption of maize relative to other cereals are predominantly in the forest countries, driven by Nigeria. In fact, the per capita share of maize to total cereal consumption rose from 10 to 30% between 1981-83 and 1995-97 partially substituting for rice and wheat in Nigeria.

There is some evidence of a changing cereal use pattern, especially in the urban areas. Results from a household consumption survey conducted in urban Niger in 1989-1995 indicate that pearl millet is still the main staple of urban consumers, accounting for 57% of total cereal consumed, followed by rice (18%), sorghum (12%), maize (10%) and wheat (3%). However, per capita millet consumption decreased by 5% (70.4 to 67.1 kg) from 1990 to 1995. Sorghum consumption remained constant. In contrast, per capita maize consumption more than doubled from 33.4 kg to 79.4 kg, whereas rice consumption decreased from 57.9 to 25.8 kg during the same period. While pearl millet and sorghum consumption have remained virtually constant; there seems to be a shift from rice to maize consumption. Maize is supplementing, but not replacing millet. Constraints on sorghum and millet supply cause maize imported from Nigeria to be used as a substitute for making the preferred products such as: *tô*, *boule, dambou* and *semoule* (PADER/PNUD 1994).

In Urban Niger, per capita cereal consumption decreases as household size increases. Per capita cereal consumption of cereals averages 258 kg for household sizes of 1 to 2 members and decreases to 191 kg for household size of more than 15 members. There are variations by type of cereals. Per capita millet consumption decreases from 160 kg for household sizes between 1 - 2 members to 93 kg for household sizes with more than 15 members. In contrast, maize consumption follows a different pattern. Maize is consumed less by households of 1-2 members, averaging 10 kg/ person /year and is consumed more by households of more than 15 members; 24 kg/person/year (PADER/PNUD 1994).

Per capita cereal consumption also varies according the employment of the head of household. Cadres, professors, liberales, and jobless individuals eat less than 190 kg/ person/year (60% of millet and sorghum). Technicians, civil servants (personnel administratif), low skilled labor, etc eat on average 220 kg/person/year (52% of millet and sorghum). Whereas, retirees, small traders, farmers, livestock herders etc… consume on average 256 kg/person/year (87% of millet and sorghum).

Per capita cereal consumption also varies according to disposable income. Low income groups with less than 50,000 cfaf/annum/person of disposable income consume on average about 185 kg/person/year. This is less than large income groups with disposable income more than 150,000 kg/person/annum who consume about 200 kg/person/year. The highest cereal consumers are located in the middle income group with income ranging between 50,000 and 150,000 fcfa/person/annum, who consume about 230 kg/person/year. However, the share of millet and sorghum decreases with income. For the low income group, sorghum and millet account for 85% of total cereal consumed; higher than the middle income group (67%), and the large income group (47%). In contrast, maize consumption follows a reverse pattern. The low income group demands less maize (8.4 kg/year/person) than the high income group (32 kg/person/year). The same trend is recorded for rice.

In urban Niger, it was also found that per capita consumption varied according to the level of urbanization. In the capital city of Niamey, the largest urban town, the average consumption of cereal grain is estimated to be 180 kg/person/year. In the secondary urban towns, per capita consumption of cereals is estimated to be 228 kg. In the tertiary urban towns, per capita consumption is higher and estimated to be 244 kg/person/year.

Cereals are consumed more in rural than urban areas (282 kg/person/year against 217 kg/ person/year in urban area). Millet and sorghum account for almost the entire cereal grain consumed by rural inhabitants. A survey of about 100 rural consumers in 4 villages located in the sahelian and sudanian zones of Niger from 1989-90 indicates that daily cereal consumption is about 200 kg/person/year of dehulled grains. This was found to be lower in villages located in the sudanian zone than in the sahelian zone, probably because of calorie supplements generated from tuber crops. The source of calories varied by zone, and according to accessibility to the main road and markets. Ninety-eight percent of total calorie needs were supplied by household production for those located in poor accessible areas with little access to markets. In villages endowed with markets and road infrastructure, more than one third of total cereals consumed were purchased from the markets. Ninety to 98% of total calorie up-take came from pearl millet (Hopkins and Reardon 1990).

Demand for Coarse Grain and Processed Products

Few studies have specifically focused on factors determining the demand for coarse grains. Delgado and Readon (1991) investigated the determinants of the changing patterns of cereal use in West Africa and concluded that the pattern is demand driven. However, price and income did not explain the demand but rather, structural factors. Even short-run factors, such as harvest short fall or price dips, are not responsible for the changing patterns. The 1985 and 1986, bumper harvests of coarse grains in the Sahel, with the associated fall in grain prices, did not increase coarse grain consumption. Rather commercial imports of rice and wheat continue to rise.

Evidence from Mali, Senegal, and Burkina Faso (Table 11) show inelastic coarse grain own and cross-price demand elasticities. In Mali, a long-term rise of 1% in coarse grain price is associated with a 0.07% decrease in quantity demanded of coarse grains. Similarly, in Burkina Faso, a long-term rise of 1% in coarse grain price is associated with a 0.5% decrease in quantity demanded of coarse grains. Cross-price elasticities show virtually no impact of wheat and rice price on coarse grain consumption. For example, a long-term rise of 1% in wheat price in Mali is associated with a 0.01% increase in quantity demanded of coarse grains. Demand for coarse grains is also not responsive to income. A rise of 1% in income lead to a decrease of only 0.24% in coarse grain demand in Mali. The situation is, however, different for processed pearl millet and sorghum products. Micro-level evidence from Mali supports the contention that household structural and non-price factors are major determinants for the changing patterns of cereal consumption.

Sorghum and pearl millet grain is still cheaper than maize and rice (Table 12). Following currency devaluation in 1994, millet and sorghum became more competitive than maize. In Niger, maize is mainly imported from Nigeria. With currency devaluation, it became more expensive to import maize. However, this situation did not last long due to an exchange rate re-alignment between the Nigerian's Naira and the CFAF.

In contrast to grains, processed products should be more responsive to income. In Urban Mali, Boughton, et al. (1997) examined the determinants of household purchases of already processed millet, sorghum and maize, and found that the purchases of these processed products rise with the opportunity cost of women's time and household income. Processed millet and processed sorghum are similarly affected by the opportunity cost of women's time and household income.

As with grain, processed sorghum and millet are cheaper than rice, despite their high processing costs. Dibley *et al*. (1995) assessed the processing and preparation costs for rice and coarse grains in urban Mali to show that coarse grain dishes are still cheaper than rice based dishes. The main contributing factors to the higher cost of rice based dishes were the sauce, cereal and preparation costs. This result held through a wide range of rice and coarse grain prices and opportunity costs of time. The study should be applicable to urban Sahel, not just Bamako. Coarse grains need not take longer to process and prepare than rice dishes if the dehulling stage is mechanized. Pre-processed coarse grains are not competitive with household processing given present technology and the opportunity cost of women's time. Coarse grains will not be able to retain the extent of their cost advantage over rice as income and opportunity cost of labor rise without improvement in the efficiency of processing services.

This review suggests that sorghum and millet are still competitive compared to maize. Sorghum and millet grains are still cheaper than maize in the markets. Processed sorghum and millet products are still cheaper than maize and rice products. However, to remain competitive the demand for processed coarse grains must increase. In Mali, Boughton et al. (1997) concluded that to increase demand for processed coarse grains, it is necessary to: promote access to and use of abrasive-disk dehullers at the semi-whole sale level; promote improvements in the quality and cleanliness of the grains available to dehullers; institute grading by grain quality in the marketing system; and finally, increase consumer information about possible savings realized on purchases of dehulled cereals, via, for example, the Malian Market Information System (SIM).

A demand enhancing strategy requires improving product attributes, such as enhanced nutritional qualities and greater convenience in the form of decreased processing time. Demand expansion also requires that questions of consumer acceptance and product characteristics that affect storage, processing, marketing and consumption be addressed. The end-markets of sorghum and pearl millet may be diversified by introducing use as stock-feed, industrial utilization for clear beer, opaque beer, composite flour and weaning foods. Sorghum and pearl millet demand expansion will be conditional on the availability of a well functioning marketing system, and credit facilities, as well as government policies that affect imports and the purchasing power of consumers.

Market Organization

The cereals sector of most West African countries is characterized by: (i) dependence on imports; (ii) high variability of coarse grain prices; (iii) poor market organization.

Grain Trade in the WASAT - Dependence on Imports

All countries are net importers of cereals, with rice and wheat accounting for more than 95% of cereal imports (Table 13). Most of the pearl millet and sorghum are still largely consumed in the area in which they are produced. Little pearl millet and sorghum enters the market. For example, in 1997, it was estimated that only about 8% of pearl millet grain produced enters the market in Niger (Ndjeunga 1998).

Market Channels and Trading Volume

Overall, two broad types of grain marketing can be identified in West Africa. The long distance grain trade, which involves more than one country in the sub-region and is exemplified by trade in the Western sub-market (Senegal, Mali, Niger, Nigeria); and short distance trading, which is usually an internal grain marketing system. Grain trade is estimated to be roughly 15 to 20% of domestically produced coarse grains. The remaining trade is made up of imported rice and wheat flour. Short distance grain trading is usually an internal grain marketing system. The principal intermediaries for long distance trading are large-scale traders, wholesalers, and producers who sell along the border areas.

At the regional level, often countries that generate surplus grains are net exporters. In the Sahelian countries, Mali and Burkina Faso are potential grain exporters (Annex 4). Maize, millet and sorghum produced in Mali are exported to Mauritania, Senegal, Guinea and Niger by large-scale traders, and to Mauritania and Guinea by producers and wholesalers in the border towns (Debrah 1993). Apart from imported products (e.g. rice) from formal channels where data are well recorded, the trading volume of coarse grains between countries is not well known, due to the informal nature of trade. A survey of cross-border trade between Nigeria and Niger provides an illustration.

Niger is a net importer of cereal grains mainly from the border towns of Nigeria (Kano, Jibia and Maïduguri). In 1994/95, it was estimated that about 100,000 tons of cereal grains were imported from Nigeria, of which 85% was maize, 11% was millet, and 4% was sorghum. This figure could, however, double during the years following droughts. In 1993/94, it was estimated that 200,000 tons of cereal grain was imported from Nigeria. Nigeria has a significant role to play in ensuring food security in Niger. In effect, about one third of cereal domestically traded in Niger comes from Nigeria.

The cereal trade between Niger and Nigeria is led by a few large-scale traders and is organized around 4 networks (Kano-Jibia-Maradi-Niamey, Kano-Zinder-Agadez, Maiduguri-Damassak-Diffa, Jega-Argungu-Dosso). These networks are structured in a pyramidal fashion. At the top is the *Uban Guida* who is the decision-maker. The latter provides funds and bags to intermediaries (barwei and un bara) who purchase and collect grain in the local rural markets. After the grain is collected, it is distributed by intermediaries (Dilali), located in the deficit areas and towns. The latter dispatches to wholesalers and subsequently retailers. Most of this trade occurs during the months of October to February. Cereal is often traded in the form of grains.

In general, cereal grain traded in the markets is of low quality with mixed varieties and a large amount of impurities, and there is an inconsistency of grain supply. This situation can be partially explained by poor competition in the national and regional cereal grain markets. There is a high concentration of cereal trade among a few large-scale traders who exercise their monopsony power. This monopsony power results into low producer prices. This power is likely to be reinforced by the need for heavy initial capitalization to enter the large trade market. This type of market organization offers little incentive for farmers to produce and for traders to improve quality. Therefore, there is a need to establish or foster better market organizations which will allow farmers to appropriate large part of producer gains while keeping good quality (e.g marketing cooperatives).

Prices - High Variability of Coarse Grain Prices

The cereal sector is characterized by high inter- and intra-annual price variability. In general, prices are low at harvest and progressively increase prior to the planting season. In Niger for example, from October to May prices are generally low, and significantly increase during the period June to September. Moreover, prices are high during the years following drought. For example, following the drought of 1994, prices shot up. Figure 1 provides an illustration of inter- and intra-annual price variability for the years 1990-1996 in one of the largest pearl millet markets: Katako in Niger. The within-year coefficient of variation ranges from 6 to 16%. Due to high price variability and poor storage technologies, grain supply may be unreliable. High price variability may discourage grain producers, as well as investors from entering the food processing industry. Contractual schemes that could reduce this variation are likely to motivate producers, small- or medium-scale food processors. Current contractual schemes such as those occurring in the cotton or groundnut should be reviewed and lessons learned could be extended to cereal trade.

Poor Market Organization

Sorghum and millet still remain subsistence crops and little grain enters the markets. There is no linkage between the input and output markets. Lessons learned from groundnut or cotton in many West African countries show that better contractual arrangements between grain producers and grain users may stimulate the grain supply. For example, in Senegal, groundnut production is supported by inter-linked contracts between farmers, i.e. groundnut grain producers and users: the largest oil refinery: and the parastatal company: SONACOS. Farmers are provided with seed and fertilizers on credit to produce groundnuts, which are purchased by SONACOS. At harvest, credit is deducted from grain sales. The same experience is recorded in Burkina Faso for groundnut production and for cotton in Mali. In contrast, in Niger, where groundnut is also produced, there are currently no incentives for farmers to supply grain. In the early 1990s, two refineries closed down and groundnut production dropped significantly.

Technological and Information Constraints on Processing

Raw material: More than 33 pearl millet and 32 sorghum varieties have been developed and released by national agricultural research systems and international Agricultural Research Centers in the WASAT. However, very few of these varieties have reached the small-scale farmers. Inconsistent variety release policies, the poor supply of breeder seed, poor demand estimation and distribution systems and poor seed quality have constrained the supply, access, adoption, and demand for improved varieties by end-users. Unsuitability of varieties, poor linkages and institutional building as well as lack of seed laws have been hypothesized to be secondary constraints (Ndjeunga 1997). While governments should develop appropriate schemes to disseminate and enhance the adoption of these varieties; knowledge of the chemical and physical characteristics of those varieties is still limited. The suitability of varieties for making some preferred products are still less well known. Little research has been conducted on the suitability of some varieties for small- to medium-scale industrial processing. Overall, the raw material is not yet well characterized.

Equipment: Food processing is still done manually with traditional methods in West Africa. All the necessary steps to processing such as: cleaning, destoning, grading, threshing, thieving, dehulling, milling, and agglomeration are performed manually. A survey on food processing equipment in West Africa indicates that a variety of equipment is available, but not adapted to pearl millet and sorghum. There is therefore a need to adapt this equipment to sorghum and pearl millet processing (ROCAFREMI 1998). The WCAMRN has already made significant progress in adapting threshers, and developing destoners and dehulling disks. However, a lot remains to be done in optimizing the already adapted equipment or developing other adapted to pearl millet and sorghum.

Product

A number of processed products are available in the urban markets. Very little is known on the demand for those processed products or the determinants of the demand for processed products. Consumers' preference for these products are also poorly understood.

Conclusion

There are some prospects for a pearl millet and sorghum food processing industry in the WASAT. However, a number of constraints of constraints limit investments in the food processing industry. These constraints can be grouped into four broad categories: (1) the inputs, the grain; (2) the output, the processed products; (3) the processing technology; and the (4) the market.

A research agenda concerning these constraints follows:

Inputs

- Laboratory chemical and physical characterization of pearl millet and sorghum varieties for making the basic food products. This characterization should also involve their appropriateness through threshing, dehulling and milling. Economic evaluation of pearl millet and sorghum traits for making some preferred food products should be undertaken.
- Foster the adoption of appropriate technologies (e.g. improved varieties combined with soil restoration technologies and water conservation methods) that will increase the supply of grains through on-farm participatory methods.
- Improve information access to technologies by extension services, NGO, CBO, to food processors.
- Better understanding of the determinants of households' investments and consumption decisions
- Better understanding of the structure, conduct and performance of sorghum and pearl millet national and inter-regional trade

Processing technologies

- Develop or adapt proper equipment that should reduce the unit processing costs for threshing, dehulling and milling compared to current traditional practices
- Conduct feasibility studies on current traditional or improved processing technologies

Output

- Surveys on processed products likely to be preferred by consumers
- Feasibility and market tests on new products

Markets

Current pearl millet and sorghum markets are characterized by high price variability and inconsistent supply of high quality grain.

- Examine current formal contractual schemes between buyers and producers in the sub-region (e.g. on cotton and groundnut) and informal contractual schemes (forward contracts) in the sub-region in order to draw lessons useful for sorghum and millet.

- Identify contractual means to reduce the variability of output prices and ensure consistent supply of high quality grains in the market.
- Improve the information flow between processors and consumers of pearl millet and sorghum.
- Examine the socio-economic, institutional and policy constraints faced by current food processors.

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Table 1. Major characteristics of the principal agro-ecological zones of the WASAT.

		Countries (% total area)									
		Predominantly semi-arid zone					Predominantly forest zone				
Agro-climatic zone	Annual rainfall (mm)	Burkina Faso	Mali	Niger	Senegal	Ghana	Cote díIvoire	Togo	Nigeria	Total (%)	Cultivable land (%)
Sahelian	<350	0	66	79	7	0	0	0	1	40	29
Sahelo-sudanian	350-600	14	12	19	33	0	0	0	9	12	30
Sudanian	600-800	26	8	2	22	0	0	0	13	8	37
Sudano-guinean	800-1100	48	8	0	20	17	0	12	22	12	42
Guinean	1100-more	12	7	0	17	83	100	88	56	28	n.a.
Total area (000 km^2)		274	1240	1267	197	239	322	57	924	4520	
% semi-arid		88	93	100	83	17	0	12	44	72	

Source: Adapted from Matlon 1990 and ICRISAT GIS - Niamey, NIGER 1998.

Table 2. West Africa: Sorghum, pearl millet, maize and rice production, 000 tons (1981-83 and 1995-97 averages).

	Area planted (000 ha)							
	Sorghum		Pearl millet		Maize		Rice	
Country	1981-83	1995-97	1981-83	1995-97	1981-83	1995-97	1981-83	1995-97
Burkina Faso	626	1154	425	716	100	291	43	90
Mali	452	686	573	773	84	275	168	501
Niger	345	375	1306	1771	8.27	5.76	42	69
Senegal	123	126	518	565	77	85	118	195
Sahel countries	*1546*	*2341*	*2822*	*3825*	*269.27*	*656.76*	*371*	*855*
Cote díIvoire	18	21	29	61	413	569	400	929
Ghana	121	343	118	183	299	1045	58	215
Togo	81	160	48	55	149	378	14	41
Forest - Nigeria	*220*	*524*	*195*	*299*	*861*	*1992*	*472*	*1185*
Nigeria	3589	6855	2710	5512	838	6023	1257	3103
Forest countries	*3809*	*7379*	*2905*	*5811*	*1699*	*8015*	*1729*	*4288*
West Africa	5356	9721	5728	9635	1968	8670	2098	5107

Table 3. West Africa: Sorghum, pearl millet, maize and rice production, 000 tons.

	% per crop within country									
	Total cereal production (000 t.)		Sorghum		Pearl Millet		Maize		Rice	
Country	1981-83	1995-97	1981-83	1995-97	1981-83	1995-97	1981-83	1995-97	1981-83	1995-97
Burkina Faso	1200	2265	52	51	35	32	8	13	4	4
Mali	1320	2257	34.3	30.3	43.8	34.3	6.2	12.2	12.6	22.3
Niger	1705	2227	20.2	16.8	76.6	79.7	0.5	0.3	2.4	3.1
Senegal	838	939	14.2	13.6	60.6	59.7	9.7	8.9	15.5	17.4
Sahel countries	5063	7688	30.4	30.4	55.5	49.9	5.3	8.6	7.6	10.7
Cote díIvoire	867	1593	2.1	1.3	3.4	3.8	47.8	35.8	46.1	58.2
Ghana	595	1786	20.9	19.2	20.6	10.2	49	58.5	9.5	12
Togo	297	640	27.3	25.5	16.1	8.6	50.2	58.4	4.6	6.5
Forest - Nigeria	1759	4019	12.7	13.1	11.4	7.4	48.6	49.5	26.7	29.4
Nigeria	8306	21601	43.2	31.7	32.6	25.5	10.1	27.9	15.1	14.4
Forest countries	10065	25620	37.9	28.8	28.9	22.7	16.8	31.3	17.1	16.8
West Africa	15127	33607	35.0	29.2	37.9	28.9	13.0	15.3	13.9	26.0

Table 4. West Africa: Growth in total production to crops.

	Growth rate in total production (%)							
	Sorghum		Pearl millet		Maize		Rice	
Country	1970-83	1984-97	1970-83	1984-97	1970-83	1984-97	1970-83	1984-97
Burkina Faso	1.71	4.00	3.63	3.11	4.62	8.78	2.08	7.30
Mali	3.77	4.92	2.87	2.45	1.59	6.25	0.99	9.76
Niger	5.85	1.60	5.21	4.61	12.93	-4.69	1.77	1.56
Senegal	0.97	-0.21	0.79	0.06	7.81	-2.74	3.69	1.50
Cote díIvoire	1.98	0.17	0.69	3.75	5.06	1.76	1.24	5.23
Ghana	-3.21	7.67	-0.76	3.03	-4.40	4.92	-1.25	10.22
Nigeria	0.82	3.01	-2.06	3.42	-1.59	9.29	10.92	6.90
Togo	-	2.52	-11.95	-2.60	1.13	6.83	-1.77	7.31
West Africa	1.48	3.27	-0.20	3.19	0.00	7.20	5.84	6.58

Table 5. West Africa: Sorghum, pearl millet, maize and rice area (000 ha) and proportion to West Africa cultivated area to the crops (1981-83 and 1995-97 averages).

	Total cereal grain area (000 ha)							
	Sorghum		Pearl millet		Maize		Rice	
Country	1981-83	1995-97	1981-83	1995-97	1981-83	1995-97	1981-83	1995-97
Burkina Faso	1073	1522	920	1202	134	204	29	49
Mali	534	795	776	1196	81	208	162	302
Niger	1075	1978	3086	5210	12	5	21	30
Senegal	113	147	871	895	76	81	65	74
Sahel countries	2795	4442	5653	8503	303	498	277	455
Cote díIvoire	33.7	54	56	91	520	692	357	650
Ghana	213	322	168	193	382	671	72	105
Togo	103	218	67	107	181	391	23	47
Forest - Nigeria	349.7	594	291	391	1083	1754	452	802
Nigeria	2215	6188	1726	5293	684	4648	610	1876
Forest countries	2564.7	6782	2017	5684	1767	6402	1062	2678
West Africa	5385	11224	7670	14186	2070	6900	1338	3132

Table 6. West Africa: Sorghum, pearl millet, maize and rice area (000 ha) and proportion to the total cereal grain area (%) (1981-83 and 1995-97 averages)

	Total cereal grain area (000 ha)		% per crop within country							
			Sorghum		Pearl Millet		Maize		Rice	
Country	1981-83	1995-97	1981-83	1995-97	1981-83	1995-97	1981-83	1995-97	1981-83	1995-97
Burkina Faso	2167	2998	49.5	50.8	42.4	40.1	6.2	6.8	1.3	1.6
Mali	1608	2538	33.2	30.9	48.3	47.1	5	8.3	10	12.3
Niger	4201	7226	25.6	27.4	73.5	72.1	0.3	0.1	0.5	0.4
Senegal	1130	1203	9.8	12.3	77.1	74.3	6.8	6.7	5.7	6.1
Sahel countries	9106	13965	30.7	31.8	62.1	60.9	3.3	3.6	3.0	3.3
Cote díIvoire	976	1506	3.5	3.6	5.8	0.6	53.2	55.9	36.5	43.2
Ghana	833	1291	25.4	24.9	20.2	15	45.8	52	8.7	8.1
Togo	371	771	26.9	28.3	17.5	13.9	47.7	50.8	6	6
Forest - Nigeria	2180	3568	15.9	16.6	13.3	8.7	49.4	53.4	20.7	22.5
Nigeria	5279	18139	42.1	34.1	32.8	29.2	12.7	25.6	11.6	10.3
Forest countries	7459	21707	34.4	31.2	27.1	25.8	23.4	30.2	14.3	12.3
West Africa	16576	35572	32.3	31.5	46.3	39.8	12.4	19.3	8.1	8.8

Table 7. West Africa: Growth in total area planted to crops by country.

	Crop area Growth							
	Sorghum		Pearl millet		Maize		Rice	
Country	1970-83	1984-97	1970-83	1984-97	1970-83	1984-97	1970-83	1984-97
Burkina Faso	-0.1	2.93	1.17	2.19	3.33	2.9	-3.30	6.38
Mali	2.71	5.92	2.53	3.02	-2.05	6.83	-1.24	5.09
Niger	6.36	5.55	3.96	4.97	11.54	-12.57	2.37	3.04
Senegal	-1.25	0.63	-0.36	-0.65	6.20	-1.15	-1.0	0.27
Cote díIvoire	1.02	3.71	-0.33	3.07	4.45	1.41	2.33	3.09
Ghana	-0.14	3.58	-2.16	-0.44	-0.54	1.32	0.71	3.73
Nigeria	-7.02	3.75	-9.86	5.98	-6.24	9.24	7.94	9.31
Togo	-	2.87	-9.35	2.80	4.34	5.48	4.09	7.39
West Africa	-2.70	3.98	-2.22	4.20	-1.01	6.24	3.43	6.61

Table 8. Average grain yields (kg/ha) for sorghum, millet, maize and rice (1981-83 and 1995-97) averages).

	Sorghum		Pearl millet		Maize		Rice	
Country	1981-83	1995-97	1981-83	1995-97	1981-83	1995-97	1981-83	1995-97
Burkina Faso	583	755	462	595	739	1416	1567	1856
Mali	847	882	741	660	1006	1338	1052	1649
Niger	322	189	423	340	663	1106	1979	2291
Senegal	1042	856	572	629	1017	1045	1843	2164
Cote díIvoire	538	393	521	666	796	823	1127	1429
Ghana	576	1066	702	942	791	1557	809	2052
Nigeria	1620	1107	1570	1040	1331	1296	2061	1657
Togo	807	742	796	520	840	955	613	892
West Africa	1000	866	747	679	972	1257	1568	1631

Table 9. Growth rates in yields for the periods 1970-1983 and 1984-97.

	Sorghum		Pearl millet		Maize		Rice	
Country	1970-83	1984-97	1970-83	1984-97	1970-83	1984-97	1970-83	1984-97
Burkina Faso	1.81	1.07	2.46	0.92	1.29	5.88	5.38	0.92
Mali	1.06	-1.0	0.34	-0.57	3.64	-0.58	2.23	4.67
Niger	-0.51	-3.95	1.25	-0.35	1.39	7.98	-0.60	-1.48
Senegal	2.22	-0.84	1.15	0.71	1.61	-1.59	4.69	1.23
Cote díIvoire	0.96	-3.54	1.02	0.68	0.91	0.35	-1.09	2.14
Ghana	-3.07	4.09	1.40	3.47	-3.86	3.60	-1.96	6.49
Nigeria	7.84	-0.74	7.80	-2.56	4.65	0.05	2.98	-2.41
Togo	-	-0.35	-2.60	-5.40	-3.21	1.35	-5.86	-0.08
West Africa	4.18	-0.71	2.42	-1.00	1.01	0.96	2.41	-0.03

Table 10. Per capita cereal consumption (kg) and proportion to total cereal grains (%).

	Proportion											
	Per capita Cereal consumption		Percent sorghum		Percent pearl millet		Percent maize		Percent rice		Percent wheat	
Country	1981-83	1994-96	1981-83	1994-96	1981-83	1994-96	1981-83	1994-96	1981-83	1994-96	1981-83	1994-96
Burkina Faso	175	241	50.0	49.6	33.5	31.3	8.3	11.3	5.7	5.8	2.2	1.5
Mali	202	221	30.8	31.8	39.3	33.3	8.1	12.0	14.9	20.2	4.0	1.9
Niger	306	264	20.0	15.2	72.0	76.9	0.9	0.3	4.3	4.5	2.6	3.0
Senegal	229	200	11.6	8.1	37.0	36.4	6.3	7.1	35.6	36.0	9.4	12.3
Cote díIvoire	162	157	1.3	1.1	2.0	2.7	29.4	25.6	52.9	59.4	13.9	10.6
Ghana	68	119	18.1	16.9	15.2	9.1	45.0	48.4	10.7	17.7	11.0	6.9
Nigeria	135	198	34.1	29.3	26.6	23.5	10.3	29.7	17.9	14.2	11.2	3.3
Togo	131	157	22.7	22.8	13.2	8.6	41.4	53.6	9.4	9.0	11.8	5.1
West Africa	149	193	29.1	26.4	30.7	26.4	12.3	25.5	19.6	17.2	9.3	4.2

Table 11. Demand elasticities for grain from aggregate data in three sahelian countries 1966-86

	Countries		
	Mali	Senegal	Burkina Faso
% change in sorghum/millet/maize demand with respect to a 1% change in:			
Own price	-0.07	-0.11	-0.50
Wheat price	0.05	-0.03	0.02[3]
Rice price	0.24	0.13[3]	0.05
Income	-0.28[3]	-0.24	1.13[3]
Rice demand			
Own price	-1.50[3]	-0.66	-0.96
Wheat price	-0.08[3]	0.01	-0.39
Sorghum/millet/ maize price	0.75	0.13[3]	0.48[3]
Income	0.91	-0.17	1.71
Wheat demand			
Own price	-0.20	0.36	-0.51
Wheat price	-0.26[3]	0.02[3]	-0.06
Sorghum/millet/ maize price	0.47	-0.06	0.32
Income	2.44	0.51	0.73[3]

1. Cell values are compensated demand elasticities: a 1% in the variable in the left hand column is associated with the % change in demand indicated in the corresponding row, estimated by separate complete demand systems regressions by country, 21 years of annual data with source detailed in Delgado 1989. The Almost-Ideal Demand Systems (AIDS) was used and homogeneity and symmetry were imposed.
2. Burkina Faso estimated are for millet and sorghum only
3. Not statistically significant at 10%

Table 12. Relative prices of pearl millet and sorghum over maize price in three large selected cereal markets in Niger.

	Departments					
	Maradi		Katako/Niamey		Zinder	
Year	Sorghum/ maize	Pearl millet/ maize	Sorghum/ maize	Pearl millet/ maize	Sorghum/ maize	Pearl millet/ maize
1990	0.93	0.96	1.00	1.01	0.76	0.89
1991	0.82	0.87	0.99	0.97	0.81	0.89
1992	0.84	0.84	1.01	0.98	0.63	0.76
1993	0.98	0.94	1.03	1.03	0.79	0.93
1994[1]	0.95	0.96	0.99	1.07	0.84	0.98
1995	0.64	0.65	0.81	0.76	0.68	0.72
1996	0.89	0.85	0.95	0.94	0.86	0.92
1997	0.83	0.86	0.98	0.95	0.82	0.91

[1] Year of currency devaluation.
Source: OPVN/SIM 1998.

Table 13. West Africa: net imports of alternative cereal grains, averages during the three periods (000 tons)

	Sorghum		Pearl millet		Rice		Maize		Wheat		Total cereal	
Country	1981-83	1994-96	1981-83	1994-96	1981-83	1994-96	1981-83	1994-96	1981-83	1994-96	1981-83	1994-96
Burkina Faso	7.14	-1.47	0.00	-0.52	28.72	66.47	5.61	0.00	27.49	36.68	68.92	101.09
Mali	0.00	1.67	0.03	-20.00	53.96	26.43	36.13	1.00	58.13	41.93	148.47	51.03
Niger	20.80	9.52	9.02	0.00	36.80	40.00	9.06	3.27	45.55	67.52	122.30	121.31
Senegal	32.67	5.83	-1.94	0.00	342.10	443.60	6.21	16.71	120.98	203.74	500.02	669.59
Cote díIvoire	0.83	0.00	-0.10	0.99	358.09	317.64	8.02	-0.15	199.40	226.97	566.33	545.78
Ghana	20.00	1.48	0.00	-0.07	27.02	171.81	58.17	1.05	82.80	141.91	187.98	337.17
Nigeria	8.86	-20.00	10.0	0.00	579.92	316.67	212.28	5.33	1129.26	699.81	1947.07	999.97
Togo	1.05	0.00	0.00	0.03	20.63	1.74	1.35	2.30	42.93	32.46	65.96	52.52
West Africa	91.36	-19.57	17.19	-2.98	1447.23	1400.35	341.83	24.19	1705.5	1451.0	3670.5	2878.46

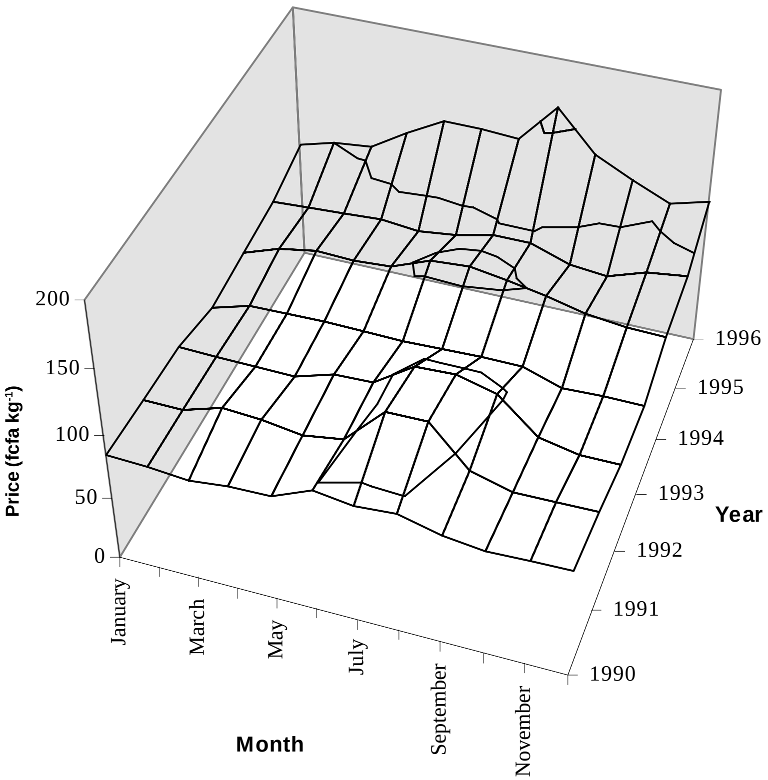

Figure 1. Inter- and intra-annual trends in nominal pearl millet consumer prices in one of the largest cereal market, Katako, Niamey, Niger.

Annex 1. Basic and macro-economic indicators in 8 West African countries.

Indicators	Burkina Faso	Mali	Niger	Senegal	Nigeria	Ghana	Cote díIvoire	Togo
	Countries							
	With a high predominant Sahel Zone				With a high predominant Forest zone			
Surface area (000 km^2)	274	1240	1267	197	924	239	322	57
Arable land (000 km^2)	33.90	46.06	49.94	22.45	303.71	28.00	29.00	20.70
Population (mil. Inhabitants -1995)	10.4	9.8	9.0	8.5	111.3	17.1	14.4	4.1
Population growth rate (1990-95)	2.8	2.9	3.3	2.7	2.9	2.8	3.1	3.0
GNP per capita (1995 dollars)	230	250	220	600	260	390	660	310
Average annual growth rate GDP 1990-1995 (%)	2.6	2.5	0.5	1.9	1.6	4.3	0.7	-3.4
Trade as a percent GDP in 1995	45	38	30	69	81	59	76	65
Aid as a percent of GNP in 1994	23.5	24.5	25	17.2	0.6	8.5	24.8	13.8
Agricultural labor force as a percent of total labor force in 1990	92	93	91	76	43	60	60	66
Crop land (% total land area-1994)	13	2	3	12	36	19	12	45
Adult literacy (% - 1995)	81	69	86	67	43	na	60	48
Urban population (% total population in 1995)	27	27	23	42	39	36	44	31
Agriculture value added in 1995 (% GDP)	34	46	39	20	28	46	31	38
Average annual growth rate in agricultural GDP in 1990-95 (%)	4.6	3.1	na	1.3	2.3	2.4	0.3	3.3

Source: World Development Report 1997 and FAO 1998.

Annex 2. Plant nutrient use (kg) per hectare of arable land by country (1984 - 1996).

Year	Countries							
	Burkina Faso	Côte d'Ivoire	Ghana	Mali	Nigeria	Níger	Senegal	Togo
1984	3.9	18.0	3.7	25.0	9.8	0.7	7.8	3.5
1985	4.1	17.4	5.2	9.7	10.2	1.0	8.8	4.9
1986	5.4	12.2	3.2	7.2	9.1	0.6	9.0	5.6
1987	5.8	13.6	4.4	7.7	10.1	0.8	9.0	5.4
1988	4.3	17.0	4.9	6.5	10.7	0.5	11.1	6.1
1989	5.8	16.1	3.3	8.7	12.9	0.8	5.4	5.9
1990	6.0	14.7	4.8	7.4	13.6	0.6	5.1	5.6
1991	5.7	17.8	2.9	7.3	14.4	0.1	6.6	5.7
1992	6.1	22.2	3.6	10.5	16.7	0.4	7.3	5.9
1993	6.1	18.6	2.7	10.2	16.8	0.4	10.7	4.8
1994	6.7	22.4	4.3	8.4	9.8	1.4	8.5	5.5
1995	7.2	22.1	4.3	8.4	6.0	2.0	7.1	7.9
1996	7.1	24.1	4.6	6.9	4.4	2.2	6.7	8.5
Average	5.7	18.2	4.0	9.5	11.1	0.9	7.9	5.8

Source: FAO data 1998.

Annex 3. Summary statistics of grain yields and cash returns by fertility options in Banizoumbou and Karabedji - Niger; 1996-1997.

	Treatment					
	Control	SSP	PRT	PRT&SSP	15-15-15	SSP&CAN
Statistic	Banizoumbou - Pearl millet grain Yield (kg/ha)					
Mean	331	568	423	527	681	801
Standard deviation	196	317	289	357	342	364
Minimum	56	97	35	86	220	187
Maximum	827	1373	1293	1460	1633	1507
Average yield gains over the control	0	237	92	196	350	470
	Banizoumbou - Cash returns (cfaf/ha)					
Mean	31547	32267	37833	46363	38958	38416
Standard deviation	25284	40348	38118	45568	43318	46327
Minimum	-5716	-32229	-15757	-12648	-28877	-46681
Maximum	95091	134472	150472	167428	159052	128879
Average cash returns gains over the control	0	720	6286	15816	7411	6869
	Karabedji - Pearl millet grain yield (kg/ha)					
Mean	432	656	499	692	738	783
Standard deviation	255	281	268	262	285	305
Minimum	103	95	167	112	328	236
Maximum	1436	1749	1945	1639	1359	1392
Average yield	0	224	67	260	306	351
Average yield gains over the control						

Continued

Annex 3 continued

	Treatment					
	Control	SSP	PRT	PRT&SSP	15-15-15	SSP&CAN
Karabedji - Cash returns (cfaf/ha)						
Mean	47294	49089	50842	74872	53700	46757
Standard deviation	32596	39702	34246	38231	42026	46371
Minimum	1992	-35502	5891	-11856	-14513	-40164
Maximum	176088	184480	237188	191235	136367	122952
Average cash returns gains over the control	0	1795	3548	27578	6506	-538

The local pearl millet variety was used in the trials. SSP: Super Single Phosphate applied at 13 kg $P.ha^{-1}$ broadcast PRT: Tahoua Rock Phosphate applied at 13 kg P. ha^{-1} broadcast PRT & SSP: Tahoua Rock Phosphate applied at 13 kg P. ha^{-1} and 4 kg of $P.ha^{-1}$ of SSP hill placed 15-15-15: Commercial NPK applied at 13 kg of $P.ha^{-1}$ broadcast SSP & CAN: Super Single Phosphate applied at 13 kg $P.ha^{-1}$ and 30 kg of N from Calcium Ammonium Phosphate broadcast

Source: Ndjeunga and Bationo (1998, p.).

Annex 4. Per capita cereal grain surplus/deficits in few countries in WASAT (1987-1997).

Year	Countries			
	Burkina Faso	Mali	Niger	Senegal
1987/88	-33	-37	-56	-14
1988/89	-13	-13	3	-17
1989/90	10	61	-5	0
1990/91	-34	9	-36	2
1991/92	34	1	12	-20
1992/93	34	3	-2	-22
1993/94	29	10	-57	-14
1994/95	19	2	-7	-14
1995/96	-2	7	-12	-30
1996/97	-1	-9	16	-12
1997/98	-18	-11	-29	-34
1998/99	14	11	44	5
Per capita average yearly surplus/deficit (kg)	3.25	2.83	-10.75	-14.17
Per capita official cereal consumption (kg)	190	204	242	185

Source: CILSS/DIAPER, AGRYMET Niamey, Niger. 1998.

Annex 5. Net returns to land and labor (principal crop only) by region and by crop enterprise 1990 (hcfa.ha^{-1}).

Region	Net return to	Millet/ cereal	Millet/ pulse	Sorghum	Maize/ sorghum	Maize/ rice	Maize	Rice	Fonio	Peanut	Wanzou
		Sudano-sahelian zone									
Northern Boboye	Land	10838	8569	7583	15290	ñ	ñ	ñ	ñ	22887	48156
		(0.73)	(0.62)	(-)	(1.21)					(1.07)	(0.56)
	Labor	258	312	157	209	ñ	ñ	ñ	ñ	17	324
		(0.54)	(0.65)	(-)	(0.57)					(0.98)	(0.76)
Southern Boboye	Land	17638	9256	-4572	ñ	ñ	38764	28503	ñ	35330	57798
		(0.83)	(1.78)	(-8.64)			(0.86)	(-)		(0.84)	(0.98)
	Labor	734	280	-59	ñ	ñ	795	416	ñ	196	426
		(0.63)	(3.34)	(-11.9)			(0.22)	(-)		(0.98)	(1.35)
		Sudano-guinean zone									
Dallol Mauri	Land	10901	8180	6943	22606	8725	20073	47780	7362	17005	21224
		(1.24)	(0.91)	(1.50)	(-)	(1.33)	(0.24)	(0.60)	(1.40)	(0.90)	(0.54)
	Labor	348	350	136	323	1063	173	1269	246	178	260
		(1.29)	(1.29)	(1.38)	(-)	(1.88)	(0.49)	(0.40)	(1.37)	(0.95)	(0.55)
Gaya Plateau	Land	11749	12226	9223	28183	ñ	21597	ñ	13574	7620	23554
		(0.54)	(0.56)	(0.59)	(0.92)		(0.91)		(0.63)	(1.01)	(1.49)
	Labor	384	402	305	449	ñ	249	ñ	415	144	149
		(0.64)	(0.84)	(0.30)	(1.74)		(0.80)		(0.73)	(1.02)	(0.63)
Gaya River	Land	25446	23936	26141	20136	43628	66795	58102	ñ	365	-1772
		(0.58)	(0.44)	(0.80)	(0.86)	(1.00)	(0.53)	(1.05)		(63.24)	(-)
	Labor	806	595	628	336	336	1361	324	ñ	-60	-25
		(0.86)	(0.69)	(0.82)	(0.85)	(0.97)	(0.64)	(0.60)		(-4.91)	(-)

Continued

Annex 5 continued

Region	Net return to	Millet/ cereal	Millet/ pulse	Sorghum	Maize/ sorghum	Maize/ rice	Maize	Rice	Fonio	Peanut	Wanzou
Total sample	Land	15517	12185	14911	22220	26177	30854	47975	10541	18754	32932
		(0.85)	(0.99)	(1.58)	(0.89)	(1.34)	(0.86)	(0.70)	(0.93)	(1.20)	(1.19)
	Labor	526	380	369	361	700	497	877	333	154	269
		(0.94)	(1.45)	(1.40)	(1.29)	(1.98)	(1.02)	(0.70)	(0.98)	(1.18)	(1.22)
	Sample size	90	95	18	39	8	15	7	43	74	61

Number in parentheses represent coefficient of variations.
Source: IFPRI/INRAN survey 1990.

Contributions du PROCELOS dans la lutte pour la sécurité alimentaire au Sahel

Mamadou Diouf[1]

Résumé

Le thème de l'atelier semble matérialiser une volonté de contribuer plus concrètement à l'atteinte de la sécurité alimentaire au-delà de l'autosuffisance alimentaire en se préoccupant davantage de la destination finale de la production. Cette approche, assurément novatrice, fait du consommateur et du transformateur, au même titre que le producteur, des acteurs et bénéficiaires des performances de la filière.

Les animateurs du ROCARS ont certainement compris que les objectifs visés par le réseau ne seront pleinement atteints que lorsque les attentes des segments situés aussi bien en amont qu'en aval de filière de la production agricole seront satisfaites.

La démarche ainsi employée est certainement un des meilleurs moyens de valoriser les efforts et résultats de la recherche agronomique qui doit rester en éveil permanent pour maintenir et accroître les performances des variétés créées. A cet égard, les récoltes doivent de plus en plus être perçues par les producteurs comme des matières premières et non des produits finis.

La promotion du sorgho par la transformation en vue d'en accroître l'utilisation, la consommation humaine en particulier, constitue ainsi un large domaine favorable à un partenariat dynamique ROCARS-PROCELOS/CILSS.

Ce partenariat se justifie par la nécessité de partager les acquis de chacune de nos structures pour en assurer une meilleure capitalisation. Dans ce cadre, les résultats acquis constituent, pour le PROCELOS, sa contribution à la lutte pour l'autosuffisance alimentaire ou plutôt, la sécurité alimentaire.

Introduction

Le PROCELOS est une des composantes du Programme majeur politique de sécurité alimentaire (PMPSA). Son objet a évolué, passant de “promotion des céréales locales” à “promotion des produits locaux” pour devenir “Promotion des PME de transformation des produits agro-alimentaires”, tout en conservant l'acronyme PROCELOS.

A ce titre le PROCELOS constitue la structure à travers laquelle le CILSS apporte son soutien en vue d'une meilleure valorisation et transformation des produits agro-alimentaires locaux. Ainsi le PROCELOS vise essentiellement à promouvoir les actions suivantes:

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1. Promotion des céréales locales (PROCELOS), 03 BP 7049 Ouagadougou, Burkina Faso.

- promotion de la consommation
- amélioration de la connaissance du secteur
- transfert et promotion de technologies appropriées
- appui au développement de produits de type nouveau à base de céréales, fruits, légumes, produits de l'élevage et de la pêche, mieux adaptés à la consommation urbaine
- sensibilisation sur la valeur nutritive et la qualité des produits en général

Ainsi le CILSS, n'a pas encouragé le contingentement ou la restriction des importations, cela ne semblant pas durable. Il a plutôt cherché à contribuer à la réalisation de conditions permettant aux opérateurs économiques d'offrir des produits locaux concurrentiels, adaptés aux goûts et au pouvoir d'achat des consommateurs.

L'option pour cette approche depuis les années 1980 a été dictée par les règles du commerce international et les tendances de la solidarité internationale d'une part, l'urbanisation rapide et la recherche de diversification et de modernisation des modes de consommation d'autre part.

Dès lors, le choix d'agir sur le levier de la transformation a été fait. A cet effet, l'objectif stratégique fixé était "l'augmentation significative de la place des produits locaux dans les modes de consommation des populations sahéliennes" alors que l'objectif opérationnel des trois dernières années était "l'augmentation de certains produits transformés concurrentiels".

Dans ce cadre, les résultats suivants étaient attendus des interventions du PROCELOS:

- faire mieux connaître tout en rendant plus attrayant certains produits agro-alimentaires transformés (PAAT)
- améliorer l'environnement socio-économique, juridique et réglementaire du secteur de la transformation agro-alimentaire
- aider les opérateurs économiques du secteur à mieux s'organiser pour être plus performants en vue de satisfaire la demande et prendre en charge la promotion du secteur et la défense de leurs intérêts.
- améliorer la qualité de l'offre en PAAT

Les réalisations principales du PROCELOS

Pour l'essentiel, les activités sont exécutées au niveau national, par les organes nationaux que sont les relais nationaux (RNP) et les Bureaux-Conseil (BC), la coordination régionale veillant à la cohérence et assurant le suivi et l'appui ainsi que la circulation de l'information entre les organes nationaux.

Le PROCELOS se voulant être un facilitateur, a beaucoup travaillé avec certains acteurs, développé des synergies avec d'autres dans la réalisation de ses programmes d'activité et mené seul certaines actions.

De façon succincte, la contribution du PROCELOS dans la lutte pour la sécurité alimentaire au Sahel a abouti aux actions concrètes suivantes:

- mieux faire connaître les PAAT mis au point par des chercheurs et autres acteurs. Ainsi, les semoules, farines et autres produits tels que le couscous et les aliments pour enfants, globalement compétitifs, sont mieux présentés et plus attrayants. Ces produits sont présents dans les grandes surfaces modernes, les boutiques de quartiers voire des pharmacies. Même des exportations sont faites vers des pays dits du Nord.

- développer le marché des PAAT (nette augmentation des ventes entraînant même parfois certaines difficultés pour les fournisseurs à satisfaire la demande).
- diffuser et vulgariser des recettes culinaires à travers, entre autres, des livrets, émissions, démonstrations, séances de dégustation. Ces actions ont eu un impact réel sur la consommation. Il convient de signaler qu'à sa demande, plusieurs recettes ont été communiquées à la FAO en vue de leur diffusion dans le cadre de son programme Information Network on Post Harvest Operations (INPHO).
- des réflexions menées pour mieux appréhender les problèmes de l'emballage et identifier des solutions à court et moyen termes dont la mise en œuvre est en cours dans certains pays. Par ailleurs, des pistes de solutions à long terme sont explorées dans la sous-région.
- faire un état des lieux de l'environnement institutionnel et socio-économique préalable à l'implantation du projet dans les pays. Dans quelques-uns d'entre eux, une actualisation a été faite et des propositions d'amélioration en préparation.
- la création d'organisations professionnelles de transformateurs, avec l'appui des organes nationaux, dans différentes filières(céréales, fruits et légumes, produits de la pêche).
- l'accroissement du professionnalisme des acteurs avec l'assistance des bureaux
- conseil mis à leur disposition par le PROCELOS dans chaque pays.
- la publication de bulletins agro-alimentaires nationaux périodiques donnant des informations sur des sujets concernant aussi bien les transformateurs que les autres acteurs de la Sécurité alimentaire.
- une plus grande conscience de l'importance de la qualité (sensibilisation et information sur l'état de la situation) et des efforts réels d'amélioration de la qualité des PAAT.

Les contributions ou actions ainsi décrites vont dans le sens de l'amélioration de l'approvisionnement et la distribution alimentaires des centres urbains en rendant les produits plus commodes et plus stables. Quand on sait que transformer c'est également conserver, on perçoit que transformer est une autre manière de réduire les pertes post-récoltes, ce qui est favorable à la disponibilité alimentaire.

La promotion du secteur de la transformation est également une manière d'accroître les revenus des populations rurales dont les débouchés de leurs récoltes s'élargissent en se diversifiant pour nourrir les villes.

Conclusions et recommandations

Bien qu'amoindri par les importations commerciales et l'aide alimentaire, le déficit alimentaire au Sahel reste globalement préoccupant, car, grâce aux lois du commerce international, il a considérablement contribué à modifier les habitudes alimentaires et le mode de vie des populations surtout dans les centres urbains. Par conséquent, les problèmes de sécurité alimentaire vont de plus en plus se poser avec acuité dans les villes tandis que les modes de consommation dans les zones rurales vont par voie de fait subir également l'influence ou la tendance des habitudes alimentaires adoptées par les centres urbains.

Il est dès lors impératif que la valorisation des productions locales soit accrue en vue de permettre une plus grande acception et consommation des produits alimentaires locaux. Il nous semble que c'est là l'un des meilleurs moyens de stimuler la production et partant une plus grande disponibilité des produits locaux. Il importe par ailleurs qu'au niveau de la recherche un effort particulier soit mis afin de tenir compte chaque fois des besoins d'utilisation/transformation des produits locaux avant toute prise de décision d'amélioration génétique ou de création de nouvelles variétés. L'utilisation devrait correspondre à des besoins spécifiquement identifiés, voire exprimés directement par les utilisateurs potentiels.

En conséquence, le rôle et la place de la transformation agro-alimentaire devraient être revus dans le sens de leur accroissement afin qu'elle exerce davantage et mieux son incidence positive sur l'amélioration globale de la sécurité alimentaire.

Le PROCELOS a la ferme conviction que la bataille de la sécurité alimentaire ne pourra être gagnée de façon durable qu'avec les productions locales, tant il est vrai que l'on gagne rarement une guerre avec les armes des autres.

Amélioration des techniques traditionnelles de production de tchapalo en Côte d'Ivoire

Koffi Augustin Yao et Moussa Ouattara[1]

Résumé

Le sorgho est une des céréales produites en Côte d'Ivoire; sa production annuelle est estimée à plus de 30.000 tonnes. En dehors des plats traditionnels (tô, couscous, bouillie, galette, etc.), l'utilisation de cette céréale se limite généralement à la fabrication d'une bière locale appelée «tchapalo» ou dolo. La consommation du « tchapalo » augmente de jour en jour, mais les méthodes traditionnelles de préparation n'ont guère évolué et sont peu aseptiques, ce qui limite la durée de vie à 48 heures ou à 72 heures dans le meilleur des cas.

Afin de remédier à cette situation, cette étude a été conduite pour préparer le tchapalo dans de meilleures conditions hygiéniques, par l'utilisation de cuves améliorées assurant la fermentation en anaérobiose et permettant la vente sans contact des mains avec la boisson pendant au moins 7 jours. De nouvelles étapes comme l'immobilisation, la clarification, la pasteurisation et le conditionnement introduites dans le diagramme de production, permettent une conservation de longue durée (8 mois et plus).

Introduction

Le sorgho occupe la 5ème place dans la production mondiale des céréales. Avec 4 % de cette production, il se classe après le blé 29 %, le riz 28 %, le maïs 23 % et l'orge 10 %. En Afrique, le sorgho occupe la 2ème place après le maïs (Chantereau et al. 1991). En Côte d'Ivoire, le sorgho forme avec le mil et le fonio un groupe de céréales dont la production est essentiellement confinée dans le Nord du pays. A l'heure actuelle, la production actuelle est estimée à 30.000 tonnes pour 40.000 ha de superficies cultivées (Assamoi 1996).

Traditionnellement, le sorgho entre dans la confection des plats cuisinés sous forme de tô, de couscous, de bouillie ou de galettes. Dans les zones non ou faiblement islamisées, le tchapalo est une bière traditionnelle préparée à partir du sorgho, du mil ou du maïs. La production du tchapalo est la principale voie de transformation du sorgho en Côte d'Ivoire. Cette boisson faiblement alcoolisée est un produit très apprécié de grande consommation.

La fabrication locale du tchapalo est une activité essentiellement féminine caractérisée par des conditions d'hygiène plus ou moins déplorables; la durée de vie de cette boisson en général n'excède pas 48 heures et il en résulte des pertes pour les femmes qui s'adonnent à cette activité pour subvenir à leurs besoins économiques. Yao et al (1995) ont montré que le

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tchapalo préparé dans des conditions d'hygiène acceptables, stabilisées et conditionnées peut être conservé pendant plusieurs jours en gardant toutes ses qualités. Cette étude vise à l'amélioration de la technique traditionnelle de préparation du tchapalo en vue de mettre à la disposition des consommateurs une boisson plus saine avec une durée de vie prolongée sur plusieurs jours tout en optimisant aussi la production.

Matériels et méthodes

Matériels

Pour cette étude, la matière première utilisée pour la fabrication du tchapalo est le sorgho. L'agent de floculation utilisé est une liane (Grevia Flavescens) ou des tiges de gombo ou l'écorce de baobab.

Les appareils utilisés sont: un ébulliomètre, un pH-mètre, un réfractomètre et un pasteurisateur. Quant aux autres matériels, il s'agit de feuille de polyéthylène, de sac de jute, de claie de séchage, de bac de trempage, de cuve d'extraction, de cuiseur, de cuve de fermentation équipée de robinet et de toile de filtration.

Les produits chimiques utilisés sont:

- solution d'acide chlorhydrique (HCl) 0,1 N
- solution d'hydroxyde de sodium (NaOH) 0,1 N
- phénolphtaléine
- levure
- bentonite

Méthode

Maltage

Les grains de sorgho sont lavés trois fois puis trempés dans l'eau pendant 10 à 12 heures; ils sont retirés, lavés et étalés au soleil sur des feuilles de polyéthylène et recouverts de sacs de jute, qui sont maintenus humide par aspersion d'eau 2 à 3 fois par jour pendant trois jours, ce qui entraîne la germination. Les grains germés sont ensuite séchés au soleil sur des claies de 1 mètre de hauteur pour arrêter la croissance des germes et favoriser le changement de couleur et le développement du goût et de l'arôme caractéristique.

Brassage

Les grains germés et séchés sont broyés puis macérés dans l'eau froide en présence d'extrait d'agent de floculation obtenu par trempage d'écorce de liane (Grevia flavescens), de tiges de gombo ou d'écorce de baobab. Le tout est vigoureusement remué pour obtenir un mélange homogène qu'on laisse décanter pendant 5 heures. Après la décantation, le surnageant est recueilli et mis dans des fûts; le résidu est porté à ébullition pendant 10 à 15 minutes et après tamisage, le jus est récupéré, mélangé au surnageant et le tout est stocké pendant au moins 12 heures pour provoquer l'acidification et la saccharification. Cette solution est filtrée puis portée à ébullition pendant 3 à 4 heures pour évaporer et augmenter la teneur en sucre qui peut atteindre 17° « Brix » à la fin de l'opération. La concentration en sucre est ensuite ramenée à 14° « Brix » par dilution. Le moût sucré ainsi obtenu est mis dans des cuves de fermentation munies d'un robinet et d'un tuyau pour l'évacuation des gaz produits pendant la fermentation. Après refroidissement à la température ambiante, le moût est ensemencé avec la levure obtenue par séchage des dépôts du tchapalo fabriqué antérieurement. La vente du tchapalo commence après 12 heures de fermentation.

Immobilisation-clarification-filtration

L'immobilisation consiste à chauffer le tchapalo à 50° C pendant 20 minutes pour permettre une bonne décantation. La clarification a été faite en mélangeant de la bentonite préalablement mouillée au tchapalo et le tout est largement remué. On la laisse ensuite se décanter pendant 30 minutes et le surnageant est filtré sur une toile.

Stabilisation et conditionnement

La stabilisation est faite par pasteurisation à 60° C pendant 30 minutes. Pour cela, le tchapalo est mis dans une casserole avec couvercle et chauffé à feu doux, en évitant toute ébullition hâtive pouvant altérer le goût, l'arôme et la teneur en alcool. A l'aide d'un thermomètre, on contrôle la température. Les bouteilles sont soigneusement lavées, rincées et plongées dans de l'eau chaude. Le remplissage se fait à chaud immédiatement quand le temps de pasteurisation est atteint. Les bouteilles remplies et fermées sont mises dans l'eau froide pour un refroidissement rapide.

Le moût sucré clarifié, filtré puis pasteurisé et conditionné donne une boisson au goût agréable (cf diagramme de production du tchapalo).

Résultats et discussion

L'étude de l'amélioration des techniques traditionnelles de préparation du tchapalo a été faite au laboratoire et dans les stations de fabrication du tchapalo traditionnel. L'amélioration porte sur les nouvelles étapes introduites pour obtenir un produit de meilleure qualité et conservable sur une longue période. Ces étapes sont:

- la fermentation en anaérobiose;
- l'immobilisation,
- la clarification et la filtration;
- la stabilisation et le conditionnement.

La fermentation en anaérobiose a été faite dans les cuves améliorées munies de robinet de service et de tuyau pour l'évacuation des gaz. Cette technique qui remplace la fermentation dans les cuves ouvertes permet d'obtenir un produit dont les caractéristiques restent constantes pendant au moins 7 jours. En effet, avec les anciennes cuves ouvertes, le tchapalo avait une durée de vie de 48 heures en moyenne ce qui posait beaucoup de contraintes aux fabricants, car il fallait écouler la production le plus rapidement possible au risque de voir les qualités de la boisson se détériorer entraînant ainsi des pertes. Avec les nouvelles cuves, le contact des mains avec le produit est éliminé ce qui améliore les conditions d'hygiène pendant la commercialisation du tchapalo vendu en vrac.

L'immobilisation, nouvelle étape introduite se justifie par le fait que le tchapalo est obtenu après 12 heures de fermentation, en général de 18 heures à 6 heures du matin. Les levures continuent de fermenter activement le moût dont la teneur en sucres fermentescibles n'est pas épuisée; il se produit un mouvement continu de remontée et de descente des particules dans le liquide. Il n'est donc pas possible de le décanter efficacement et d'obtenir une bonne filtration. Le chauffage à 50° C pendant 20 minutes réduit l'activité des levures et facilite la clarification et la décantation.

La clarification du tchapalo avec la bentonite est satisfaisante. Nous avons déterminé qu'il faut 11g de bentonite pour clarifier 1 litre de tchapalo. Dans ces conditions, la quantité de bentonite à utiliser doit être rehydratée avec 2,3 fois son poids avec du tchapalo avant de le mélanger à la boisson à clarifier. Dans certains produits comme le vin, la bière et les jus de fruits, la formation de troubles, de dépôts et la détérioration due aux oxydations diverses constituent de sérieux problèmes. Certaines substances phénoliques naturelles sont souvent impliquées. Les protéines et les substances peptidiques contribuent avec les polyphenols à la formation de troubles (Lindsay 1976). La clarification avec la bentonite améliore la filtration et donne du tchapalo qui reste limpide et brillant.

Les échantillons de tchapalo stabilisés, conditionnés et conservés pendant 1 mois, 6 mois et 8 mois ont été analysés pour vérifier la stabilité de certains paramètres tels que le taux d'alcool, le pH, l'acidité et la teneur en sucre. Ces analyses ont montré que la teneur en sucre reste stable dans tous les cas étudiés, alors qu'on observe une variation du taux d'alcool entre le tchapalo traditionnel et le tchapalo stabilisé. Cette différence serait probablement due à l'évaporation pendant le traitement thermique. On observe aussi une augmentation du pH donc une baisse de l'acidité pendant la conservation de longue durée . Ces observations pourraient s'expliquer par le fait que pendant la conservation de longue durée du tchapalo stabilisé, certaines réactions chimiques dues au réarrangement des composés en présence peuvent avoir lieu et suivre une évolution favorable à l'amélioration du goût de cette boisson comme dans le cas des vins.

Le moût sucré clarifié, stabilisé et conditionné donne une boisson sans alcool au goût très agréable, qui peut être conservée pendant 8 mois. La conservation du moût sucré peut être une solution pour la conservation du tchapalo traditionnel car il peut être fractionné et fermenté selon la demande pour réduire les pertes.

Conclusion

L'exécution du projet « P3 ROCARS » 1996 et 1997 sur la diversification de la transformation et de l'utilisation du sorgho nous a permis d'améliorer sensiblement la production du tchapalo. La fermentation dans les cuves munies de robinets et de tuyaux d'évacuation des gaz, permet d'obtenir un produit dans de meilleures conditions hygiéniques et augmente la durée de vie du tchapalo de 2 à 7 jours au moins, dans les conditions habituelles de commercialisation. Les nouvelles étapes introduites dans la chaîne de fabrication conduisent à un produit plus stable que le tchapalo traditionnel et conservable pendant plus de 8 mois.

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Transfer of the Utilization of Sorghum Composite Flour for Bread and Confectioneries to End-users in Kaduna State, Nigeria

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Abstract

The technology of wheat/sorghum composite flour was transfered to bakeries and confectioneries for adoption in Zaria and Kaduna towns. Acceptable bread and snacks (cake, buns and doughnut) were produced commercially with sorghum substitution for wheat of up to 20% and 30%, respectively. Over 70% of the test population accepted the products. Economic analysis showed that commercial production of bread and snacks from wheat/composite flour is profitable. The adoption and eventual utilization of this technology however depends largely on the right Government policy on importation of wheat flour.

Introduction

Baked products constitute a significant component of the diet in Nigeria. These products (bread, biscuits, doughnuts, buns etc.) are produced mainly from wheat flour, which is largely imported, hence drawing on a significant portion of the scarce and meagre foreign exchange earnings of the country.

The Institute for Agricultural Research (IAR), Zaria, in collaboration with West and Central Africa Sorghum Research Network (WCASRN) initiated a project on the development of technology for production of acceptable sorghum/wheat composite bread and confectioneries. This project primarily sought to diversify the utilization of sorghum while cutting down on production costs (wheat flour) in bread making and confectioneries.

Earlier reports by Aluko and Olugbemi (1989) and Olugbemi (1993) showed that acceptable bread was produced when wheat flour was substituted with 30% sorghum flour. Onyenekwe and Olugbemi (1995) also reported that acceptable bread could be produced when up to 20% of the wheat is substituted with sorghum flour. The bread however tended to crumble. Substitution of wheat flour up to 80% and 40% gave acceptable cookies and biscuits, and, cake and doughnut, respectively (Onyenekwe 1995). Consumers' organoleptic evaluation showed that the appearance, taste, and smell of the wheat/sorghum

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composite bread were more acceptable than the texture. Protein content of the wheat/ sorghum bread was lower than that of 100% wheat bread, however.

Because of potentially high gains that wheat/sorghum composite flour holds for the bakery industry, WCASRN in conjunction with IAR, decided to transfer this technology to end-users with the view to determining its acceptability and consequently its adoption by the bakery industry.

Materials and Methods

Selection of Bakeries and Confectioneries

Four commercial bakeries and two confectioneries were selected for the project. The bakeries consisted of three medium-scale in Zaria and one large-scale in Kaduna. The two confectioneries included one large-scale in Kaduna and one small-scale in Zaria. The scale of the bakery/confectionery was determined by the number of bags of flour utilized per day. Bakeries utilizing 1-4 bags/day were considered small scale; 5-10 bags/day medium scale and more than 10 bags/day, large scale. This categorization was arrived at from interviews conducted with the bakeries.

Formulation of wheat/sorghum flour. To produce the composite flour, sorghum (var-farafara) grains were first cleaned of stones and dirt, dehulled with a plate mill, washed and sun dried. The dried grains were milled in a local plate mill, sieved (about 120-mesh size). Thereafter, the Composite flour was made as follows: 1) bread - 80% wheat: 20% sorghum; 2) snacks - 70% wheat: 30% sorghum. One anti-collapsing tablet was ground and mixed with each 50-kg bag of composite flour.

One bag of composite flour was given to each bakery in the first instance to acquaint them of the technology of bread production from composite flour. The confectioneries were given about half a bag. More flour was supplied as was necessary. Marketing of products was done with the assistance of Food Science Programme because the bakeries/ confectioneries were reluctant to market the products through their established marketing channels for fear of loosing their customers who might notice a change in their product.

Questionnaires were administered to determine consumers' response on the products (organoleptic tests) and reaction of the bakeries/confectioneries on the suitability of the use of sorghum composite flour for baking. Profitability of using wheat/sorghum composite flour was determined using costs and return analysis.

Pilot Production

Bread and three confectionery products (cakes, doughnut and buns) were produced on pilot scale in the Food Science and Technology, Laboratory of IAR, following the outline by Obilana et al (1985), and Aluko and Olugbemi (1989). Organoleptic tests were conducted on the products. The same products were then produced by the bakeries and confectioneries.

Results and Discussion

Organoleptic Evaluation

The results showed that bread of acceptable quality was produced from wheat flour substituted with 20% sorghum flour. The organoleptic assessment among consumers in Kaduna and Zaria towns is presented in Table 1. Appearance, taste and smell of the bread were well rated. Even though the smell was highly rated (67%), there was a tint of raw sorghum smell in the bread. Texture was lowly rated due to the coarse nature of the sorghum flour, which was not as fine as the wheat flour. Generally, about 78% of the test population accepted and were prepared to buy the bread if produced on a regular basis compared to 22% who would decline to eat bread produced from composite flour. Similar results were obtained by Aluko and Olugbemi (1989) and Olugbemi (1993) where 70% of the test population rated the overall quality of bread produced from 70:30% wheat/sorghum composite flour, as either very good or good. Shelf life varied between 2-3 days compared to 4-5 days of bread from pure wheat flour.

Acceptability of snacks was higher than for bread. The four principal organoleptic parameters were rated very high (>60%) for the three snacks (Table 2). This result is corroborated by the results of Onyenekwe (1995) who reported the production of acceptable cakes and doughnuts with 40% substitution of wheat flour.

Profitability of Using Wheat/Sorghum Composite Flour.

The profitability of wheat/sorghum composite bread and snacks was assessed by comparing the cost of production and returns from bread/snacks from 100% wheat flour with that from composite flour. The result of the analysis shown in Table 3 indicate that the production of bread in both cases were profitable. However, producing bread from 100% wheat flour has a higher profit of up to 34% per kg of flour (i.e. ₦25.86 compared to ₦17.0). The difference is contributed mainly to the fact that a fewer number of bread loaves are produced from the composite flour (90 vs 100) compared to pure wheat flour. However, the difference in profit margin could be reduced if the sorghum grain was purchased at harvest time. For instance, buying sorghum at 1200Naira/100 kg bag at harvest in 1998 reduced the difference in profit margin to 18% (Table 4). This finding was similar to results obtained in 1991 and 1992 in Zaria (Olugbemi 1993).

Production of snacks from sorghum composite flour was also shown to be profitable. The result of the economic analysis for different products is shown in Table 5. The number of snacks produced from 100% wheat flour were the same as those produced from composite flour.

Problems Encountered during Baking

It was observed by the bakeries that the bread from the composite flour proofs well, but tended to collapse as it is fed in to the oven thereby decreasing the size. Bread was not as spongy and therefore breaks more easily than bread from pure wheat. A third problem is the fineness of the flour. The composite flour was not as fine as that of pure wheat flour.

Prospects

The future of composite flour in the baking industry in Nigeria is quite promising. The success of this product, however, will largely depend on the Government policy in favor of concerned research and agro-industries in that sector. For instance, by reducing the level of importation of wheat flour, the use of sorghum and other local grains will be encouraged. In addition, making funds and other necessities available for research to solve impending problems relative to palatability, appearance, and shelf life of those composite-flour-based products could further enhance their acceptability among the consumers. Moreover, reducing taxes for those industries concerned could result in increased productivity with substantial gains in profits and employment for the national economy. It was observed that some bakeries are already utilizing sorghum and other cereal grains for bread making. Thus, countries with serious food problems and scarce foreign exchange will find this technology very useful in meeting their food requirement while improving the overall performance of their economy.

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Table 1: Organoleptic evaluation of wheat/sorghum composite flour bread.

	Assessment Response (%)			
Parameter	Appearance	Texture	Taste	Smell
Very good	12	3	7	0
Good	57	49	62	67
Fair	23	41	31	25
Poor	16	14	5	9

Table 2. Organoleptic assessment of wheat/sorghum composite flour snacks (cake, buns and doughnut).

	Assessment Response (%)			
Parameter	Appearance	Texture	Taste	Smell
Very good	22	33	33	0
Good	67	67	78	89
Fair	11	22	23	0
Poor	0	0	0	0

Table 3. Comparative costs and returns from bread produced from pure wheat and composite flour in Kaduna State, Nigeria, 1998.

	100% Wheat Flour	Composite Flour
Quantity of wheat flour	50kg	40kg
Quantity of sorghum flour	0kg	10kg
Cost of wheat flour	₦2,017.00	₦1,613.00
Cost of sorghum flour	₦0.00	₦447.00
Cost of ingredients	₦690.00	₦690.00
Total cost	₦2,707.00	₦2,750.00
Loaves of bread produced	100	90
Revenue from bread produced	₦4,000.00	₦3,600.00
Gross profit	₦1,293.00	₦850.00
Profit/kg flour	₦25.86	₦17.00

NB. 1. Cost of production does not include fixed costs; 2. $1 = ₦85.00

Table 4. Comparative cost and returns from bread produced from pure wheat and composite flour if the sorghum was bought at harvest time in Kaduna State, Nigeria, 1998.

	100% Wheat Flour	Composite Flour
Quantity of wheat flour	50kg	40kg
Quantity of sorghum flour	0kg	10kg
Cost of wheat flour	2,030.00	1,624.00
Cost of sorghum flour	0.00	266.00
Cost of ingredients	535.00	535.00
Total cost (x)	2,565.00	2,425.00
Loaves of bread produced	100.00	90.00
Revenue from bread (y)	N4,000.00	N3,600.00
Gross profit (x - y)	N1,435.00	N1,175.00
Profit/kg flour	N28.70	N23.50

NB. 1. Cost of production does not include fixed costs.
2. $1 = ₦85.00

Table 5. Comparative cost and returns from snacks produced from pure wheat and composite flour in Kaduna State, Nigeria, 1998.

Confectionery	100% Wheat fFour			Composite Flour		
	Cake	Buns	D/nut	Cake	Buns	D/nut
Quantity of wheat flour (g)	50	50	50	40	40	40
Quantity of sorghum flour (g)	0	0	0	10	10	10
Cost of wheat flour(₦)	2,050	2,050	2,050	1640	1640	1640
Cost of sorghum flour (₦)	0	0	0	447	447	447
Cost of ingredients (₦)	20,000	22,750	8,813	20,000	22,750	8,813
Total cost (x)	22,050	24,800	10,863	22,087	24,837	10,900
Number of product	3,000	2,500	938	3,000	2,500	938
Revenue from product (y)	60,000	50,000	18,750	60,000	50,000	18,750
Gross profit	N37,950	25,200	7,888	3,913	25,163	7,850

NB. 1. Cost of production does not include fixed costs.
2. $1 = ₦85.00
3. D/nut = Doughnut.

Farmers' Participatory Selection of Sorghum and Pearl Millet Varieties in Nigeria

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Abstract

To develop useful varieties, especially under rain-fed agriculture conditions, it is important to involve farmers in the entire variety development process both at on-station and on-farm levels. While it is mainly the NARS that will interact directly with their farmers/clients, ICRISAT should encourage, facilitate, and often participate collaboratively with the NARS in these activities both at on-farm and on-station levels.. The purpose of this paper is to review the reasons for non-adoption of station-based research, key points for the success of on-farm farmers' participatory research, and the status of farmers' on-farm/on-station participatory selection of sorghum and pearl millet varieties in Nigeria. During 1998, SOSAT-C 88 (matures in 90 days) was preferred by majority of the farmers in northern Nigeria. GB 8735 (matures in 70 days) was preferred in drier parts of northern Nigeria. Two pearl millet varieties [SOSAT-C88, and LCIC 9702 (improved over GB 8735 by 20%)] have been identified for on-farm testing in 11 states of northern Nigeria during 1999. Two sorghum varieties (ICSV 111, and ICSV 400) released in 1997 in Nigeria are being extensively tested under on-farm conditions to accelerate the adoption of these varieties. Both sorghum and pearl millet farmers are invited at research stations to select the plants/ progenies of their choice within variable populations and progenies to develop new varieties. Key points for the success of on-farm research and the reasons for non-adoption of varieties developed through station-based research are examined.

Introduction

Technology development, testing, dissemination, and adoption constitute a continuum. In agriculture, the process begins with developing an understanding of the target production system, and a detailed diagnosis of problems, constraints, and opportunities that exist within the system. This is followed by the design and development of technologies expected to improve the productivity, efficiency and/or long-term sustainability of the production system. These technologies are then tested, and if they prove to be both effective and practical, they move into the dissemination stage. The primary objective of this integrated

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and continuous process, is to benefit the clients of research, who are ultimately, for ICRISAT and NARS, the resource-poor farmers of the semi-arid tropics (SAT) (Heinrich and Gupta 1996).

The scientists concerned with technology transfer must also be concerned with the process of technology development itself and subsequent testing, to ensure that research products are effective, and that they meet the needs and interests of the clients. To ensure the ultimate acceptance of research products by clients, it is important that the clients be involved in all phases of the process.

In West Africa, crop or livestock production are organized within the context of the farm household, which is both a production unit and a consumption unit. On-farm research strategies should include appropriate technology that will enhance farmers' welfare. This will affect his commitment to all the process of implementation.

Most countries in Africa require on-farm testing of varieties before formal release. This is a reasonable requirement and this provides a rationale for on-farm farmers' participatory trials. However, an on-farm trial program can also provide a very important impetus in overcoming the inertia of the system and speeding up process of variety release, seed production, and dissemination. When a variety performs well on-farm and proves popular with farmers, this has several important effects:

First, it gives the breeder a great deal of confidence when presenting the varieties to the release committee. Breeders are sometimes reluctant to present varieties to release committees, but once a variety has proved popular with farmers as the experience in Southern African would indicate this reluctance rapidly disappears.

Secondly, if the popularity among farmers is documented, this provides a strong impetus for release. If for example, a breeder can demonstrate to the release committee that a new variety performs well in terms of yield on-farm and also that 90% of farmers who grew the full set of varieties selected this one as their first preference, this is a strong supporting rationale for release.

A third point is that there is often a considerable inertia to overcome in bulking and distributing seed of newly released varieties. However, if a variety proves popular with farmers, this often creates pressure that can help in overcoming the inertia. What happens is that farmers, extension personnel, and NGOs who are in contact with the breeder are also usually in contact with seed producers, and so the pressure works itself back up through the system. While on-farm trials should never be confused with demonstrations, they can none-the-less provide a very effective start to the technology dissemination process.

The above discussion can be highlighted with an example. In Tanzania, on-farm trials with both sorghum and pearl millet were initiated in the 1993/94 season. One of the new pearl millet varieties, TSPM 91018 (later released under the name Okoa) was so popular that it was released after only 1 year of on-farm testing, though the testing continued in the second year to verify the results. They were the first releases in Tanzania approximately after 20 years. (Heinrich and Gupta 1996).

To develop useful technologies for farmers, especially those involved in rainfed agriculture, it is important involving farmers in the entire technology development process. The starting point is to gain an understanding of the farming system and to identify key research opportunities that are likely to give a substantial pay-off in the near future (Norman et al. 1994). Farmer participation in all aspects of technology development is important to ensure the acceptance and utilization of research products. While it is mainly the NARS that will interact directly with their farmers/clients, ICRISAT should encourage, facilitate, and often participate collaboratively with the NARS in these activities both at on-farm and on-station levels. Farmer participation in the process needs to be greatly increased, and while ICRISAT cannot do this directly, it can nonetheless make a major contribution by encouraging and assisting to develop farmer participation at the national level.

In a breeding program, it is suggested that the farmers be involved in selection of plants/progenies in segregating materials (such as F2, F3, F4 etc.), and breeding products such as open-pollinated varieties and hybrids (Witcombe et al. 1996). Generally number of entries in early stage of breeding is large and such materials are evaluated on 1 to 3 research stations. Farmers from target areas should be invited at least at grain filling stage to assist breeders in selection of plants/progenies of farmers' choice. This will also help breeders to understand farmers' preferred traits in different areas. Few selected varieties should be extensively evaluated under on-farm conditions and should be recommended for release only if they become popular among participating farmers in on-farm trials.

The purpose of this paper is to review the reasons for non-adoption of station-based research, key points for the success of on-farm farmers' participatory research, and the status of farmers' participatory on-farm/on-station selection of sorghum and pearl millet varieties in Nigeria.

Reasons for Non-Adoption of Station-Based Research

The agricultural research in West Africa is usually carried out under on-station conditions and sometimes evaluated as on-farm trials without participation of farmers. Farmers have seldom adopted such technologies (except a few). The on-station research environment is often characterized by favorable natural circumstances, availability of inputs, little concern with cost or risk and generally a single objective of increasing output per unit area. Reasons for the non-adoption of on-station based technologies are given below:

- The natural circumstances (soils, topography, climate) facing small scale farmers in specific situations vary from one location to another and are generally different from those on research stations.
- The institutional support services (such as extension, NGOs, input suppliers etc.) needed to supply inputs and provide technical support to farmers are either nonexistent or unreliable.
- The cost and risks of using new technologies are too high for small scale farmers relative to the benefit they could expect.
- Small scale farmers have multiple objectives stemming from household consumption, minimal risk taking and maximum return expectations to heterogeneous resources such as family labor, whose opportunity cost varies at different times in the season according to individuals.

- Farmers' circumstances are determined by both physical and social factors. The household farming systems tend to be complex. This complexity is particularly evident in tropical areas with long growing seasons where inter-cropping and multiple cropping are practiced.
- Technologies, which increase productivity per unit of land, are not the only ones that can be beneficial to farmers. Technologies that do not increase area yields but make more efficient use of time or cash are often equally acceptable. Technologies which save family labor are particularly attractive (e.g. variety of sorghum or pearl millet that thresh easily; early maturing varieties) to small household farm unit.

Key Points for the Success of On-farm Farmers' Participatory Research

The planning and implementation of on-farm farmers' participatory trials are usually more complex than for on-station trials. This primarily can be attributed not only to the logistical difficulties (e.g., having numerous trial sites, numerous implementers, and delivering inputs to a large number of locations in a timely manner), but also because of other factors, such as the need for careful site and farmer selection, usual statistical designs and data analysis issues, and a lesser degree of control over non-experimental variables. The key points given below should be considered while planning on-farm research:

IARC-NARS Partnership

It is important for IARC based scientists to keep in mind that on-farm trials must be conducted with, and largely by, the national agricultural research systems (NARS). This is particularly true, considering that only the NARS, not IARCs, have the mandate for research and technology development in any given country. In addition, NARS are partners of IARCs, assisting in the provision of information that helps to target upstream research, utilizing and adapting products of IARC research, releasing and disseminating technologies to farmers within their national boundaries. They are directly responsible for the application of research findings at the national and local levels. IARCs should not conduct on-farm research in the absence of their NARS partners. Moreover, it should recognized that the NARS are usually better equipped than IARCs in handling the logistics involved in conducting on-farm trials. On-farm trials often require a network of collaborators across a wide area in the country. It is expensive for one organization to take on the full responsibility of designing and implementing on-farm trials, collecting and analyzing the data. It is much more efficient to develop collaborative programs that involve personnel and resources that are already in place (e.g., Farming Systems Teams, Extension Personnel, and NGOs). This type of collaboration reduces cost considerably (Heinrich and Gupta 1996).

Trial Implementation

The trials are largely implemented by extension personnel and farmers, except for a few cases where NGOs are involved. Research personnel assist with provision of inputs (seed, data collection field books, fertilizer where required, etc.) as well as data collection, analysis and reporting. To maintain a good collaborative spirit, it is important that extension personnel are provided with the results of the trials so that they know what their efforts have achieved and so that they can share appropriate findings with participating farmers.

Degree and Value of Farmers'/Partners' Participation

Generally, farmers participation in the process of on-farm research not only enrich and speed up information gathering but also result in large scale adoption of products of research. As work by ICLARM, CIAT and other organizations have shown, farmers' discussions around technological ideas presented by researchers may save much research time. For instance, such discussions can help research by contributing new ideas or eliminating options, which would have been totally unpractical for farmers. On-farm trials represent an opportunity for obtaining farmers' input at virtually no extra cost, whether or not obtaining that was part of the objectives set in these trials. Thus, for all on-farm trials, systematic collection of farmers' input (perceptions, preferences, ideas, etc.) should be an integral part of the process. This might involve a minimal effort, such as simply including one page questionnaire at the back of the trial field books, or a more detailed one, including field days and group interviews with farmers. On-farm trials also provide a unique opportunity for interaction and discussion of field problems and possibilities among all partners in the technology development and dissemination process. Partners might include researchers, farmers, extension personnel, NGOs, agribusiness representatives, policy makers, and others.

NGOs' Participation

In many countries, NGOs are actively working with farmers to improve their livelihood. NGOs are excellent partners as they normally work at grassroots level. In Nigeria, we actively participated with two NGOs [Sasakawa Global 2000 (SG 2000), and Sokoto Agricultural Community Development Project/IFAD (SACDP)] in five states of Nigeria during 1998. In addition to SG 2000 and SACDP, we are establishing contacts with other NGOs, such as WOFAN (Women Farmers Association of Nigeria), Leventis Foundation (supporting Agriculture School, Panda for training to farmers), and Small and Large Scale Farmers Association (SALSFA).

Joint Planning

A program that involves several organizations and large number of personnel will only succeed if all participants understand and support the program, and fulfill their different roles. Joint planning develops support among the collaborators, since all are then involved in developing the program. It becomes their program. In addition, joint planning ensures that the plans are practical for all the implementers (including farmers). During the planning meetings, all implementers have the opportunity to suggest alternatives to any proposed activities that will be difficult or impossible for them to complete. Thus, the final action plan will be practical and feasible. Planning meetings should therefore involve all personnel who are expected to participate in the on-farm trials program. These might include IARC personnel, national program scientists (mixed discipline), extension personnel (supervisors and village level officers), NGO staff, farmers and anyone else potentially involved.

Training Workshops

During joint planning, on-farm trials are developed and agreed by all the potential partners. Thereafter, locations (villages), farmers and sites are jointly selected for each trial by collaborators. Researchers in consultation with other partners develop the detailed work plans. Training should be provided to participating farmers and extension officers and the trial details should be provided to them. These training workshops are normally for one day in each location. After the workshops, the inputs can be provided to farmers so that they can plant the trial at right time. For example, ICRISAT provided pre-season training to 35 community development agents in collaboration with SACDP/IFAD on 12-13 April 1999 at Sokoto, Nigeria.

Trial Design with Clear Objectives

A situation occurred where the objective was to test a set of varieties on-farm. Based on discussion among partners, the trials were designed such that each participating farmer was given seed of only one variety. In a number of cases, the farmers did not even sow their variety next to a test plot on the same day. Thus, the relative performance of the set of varieties could not be evaluated.

The plot size should be so that the farm operations in the on-farm trial can be carried out as planned, and the valid conclusions can be drawn. Farmers can provide the land and also appreciate the value of new technology. In one case, plot sizes were set at 0.2 ha per plot, at the request of extension personnel. Sowing of individual replications was spread over a week, making the trials invalid. Some flexibility has to be allowed on-farm to deal with the farmer needs and contingencies, but basic treatment parameters must be properly implemented to produce valid trial conclusions.

Joint Field Visit by Partners

These are vital for identifying and addressing any implementation problems that occur during the season, and monitoring data collection procedures. The frequent interaction with farmers is very important to ensure full participation of farmers who are their primary clients. Concerned partners should support joint field visits to the trials by IARC and national scientists, extension staff, and NGO personnel. On the job training can be provided to farmers and extension agents during field visits.

Data Analysis and Reporting

Assistance should be provided to partners through training workshops in the design and analysis of on-farm trials. In addition, wherever necessary, support should be provided to

NARS in developing reports both for on-farm trials activities and general reports that cover both on-station and on-farm variety trial results, especially when these are meant for presentation to national variety release committees. Farmers' preference data relating to varieties is very useful (for adoption) and adds strength to the conclusion.

Confusing On-farm Trials with Demonstrations

It is common for station-based researchers to view any on-farm activity as extension or demonstration plots. In fact, it is not uncommon for researchers to refer to on-farm trials as demonstration trials. This is wrong of course. A trial is a comparison of different treatments (as with different varieties in a variety trial), or a test of hypothesis. In either case, it is an experiment where the outcome is not known, and new knowledge is being sought. On the other hand, in a demonstration, the outcome is already known. Known facts are being demonstrated for the purpose of passing known information on to end-users, such as farmers. A typical demonstration example for instance would consist of demonstrating that application of phosphate will increase grain yields on phosphate deficient soils, where other factors are not limiting. It also sometimes results in a lack of systematic data collection since researchers somehow feel they are doing demonstrations and that therefore data collection is not very important. This confusion can be avoided by the clear definition of trial objectives, and planning trial layouts and data collection procedures to meet those objectives. It also requires that station-based researchers recognize the validity and necessity of on-farm trials.

Seed Production

ICRISAT has encouraged national program breeders to take responsibility for ensuring that seed of newly released varieties is multiplied and made available to farmers through other national organizations (such as seed companies). In Nigeria, farmer-based seed production programs is encouraged, as seed companies are not able to produce sufficient seed of sorghum and millet varieties to meet the growing needs of farmers.

Status of Farmers' Participatory On-farm/ On-station Selection of Sorghum and Pearl Millet Varieties in Nigeria

Sorghum

On-Farm Farmers' Participatory Selection of Sorghum Varieties

During 1996, sorghum on-farm trials were conducted in three villages of each Kano, Jigawa and Katsina states in the Sudan savanna ecological zone. Three varieties of sorghum (ICSV

111, ICSV 400, and ICSV 247) were evaluated. Farmers were free to determine the plot size permitted by the quantity of seeds and single superphosphate applied at 30 kg P2O5 per ha. No agronomic packages were specified apart from the seeds, and farmers managed their plots in accordance with usual practices. Enumerators were stationed in each village to take records. Breeders, agronomists, crop protectionists and socio-economists inspected the fields and made observations. The salient results are presented in the following paragraphs:

Based on mean over all the nine villages, all the three improved sorghum varieties out yielded local variety. Among improved varieties, ICSV 111 produced highest grain yield (1.3 t ha^{-1}) followed by ICSV 400 (1.21 t ha^{-1}), ICSV 247 (1.12 t ha^{-1}), and farmers' local (0.91 t ha^{-1}). All the improved varieties performed better in northern locations (80 to 86% more than local) than at southern locations (1 to 17% more than local). In Jigawa State, all the improved varieties gave 50% or more grain yield than farmers' local did.

During 1998, in collaboration with SG 2000, two sorghum varieties (ICSV 111, ICSV 400), and one hybrid ICSH 89002 NG were evaluated by 21, 20, and 4 farmers respectively in four states of northern Nigeria. The hybrid was most preferred by farmers.

Seven farmers evaluated the same three cultivars in Sokoto State in collaboration with Sokoto Agricultural Community Development Project (SACDP). The hybrid, ICSH 89002 NG was highly preferred by farmers. ICSV 400 and ICSV 111 were equally preferred. These cultivars were released in Nigeria in 1997 and are under on-farm test since 1991.These cultivars matures in 110 to 120 days and suitable to areas between 500 to 700 mm rainfall. On-farm testing can accelerate the adoption of these cultivars in the regions of their adaptation. In drier areas of Katsina State, K A Elemo (IARAgronomist) evaluated ICSV 111 in several farmers fields during 1997 and 1998. It appears as ICSV 111 is preferred by farmers in Katsina state because of its earliness, good grain and food quality.

During 1999, Agricultural Development Programs (ADPs) in collaboration with Institute for Agricultural Research (IAR), ICRISAT, Sasakawa Global 2000 (SG 2000), SACDP, and farmers will be evaluating ICSV 111 and ICSV 400 in over 100 on-farm trials in 10 states of Nigeria.

On-station Farmers' Participatory Breeding and Selection of Sorghum Varieties

The segregating populations/progenies are grown at research stations and farmers are involved in selection at every stage of development. The current activities in sorghum are described below.

Two varieties (ICSV 111, and ICSV 400) are under on-farm test since 1991 and the adoption rate has been low except in few areas. The results of 1996 and 1998 showed that these varieties are suitable to only drier areas such as Katsina and Jigawa states. The majority of the farmers in Nigeria grow late maturing sorghum varieties inter-cropped with early maturing pearl millet varieties, and legumes Striga is a serious problem in Nigeria. Following activities have been initiated to develop farmers' preferred-varieties in different agro-ecological zones:

Development of varieties - elite x local crosses. Six F2 populations (involving ICSV 400, ICSV 903 NG, KSV 8, SK 5912, and Blanc de Karimama parents) were planted at Bagauda on June 8 1998 with 400 plants per population. Ten farmers were invited on October 29 1998 to select plants of their choice. They selected 217 F3Æs, which were planted on January 21 1999 at Kadawa for generation advance. The derived F4 progenies will be subjected to farmers' participatory selection at three research stations during the 1999 main season.

Development of *Striga* resistant varieties. Three hundred and sixty F3 progenies (derived from 10 crosses) were planted at Bagauda on June 15 1998. One hundred plants from 62 progenies were selected These 100 F4Æs were planted at Minjibir on January 21 1999 for generation advance. The derived F5 progenies will be subjected to farmers' participatory selection at three research stations during 1999 main season.

Pearl Millet

On-farm Farmers' Participatory Selection of Pearl Millet Varieties

During 1996, IAR/ICRISAT scientists in three villages of each Kano, Jigawa and Katsina states in the Sudan Savanna ecological zone conducted pearl millet on-farm trials. One variety of pearl millet (GB 8735) was evaluated along with farmers' control. Farmers were free to determine the plot size permitted by the quantity of seeds and single superphosphate supplied at 30 kg P2O5 per ha. No agronomic packages were specified apart from the seeds, and farmers managed their plots in accordance with usual practices.

Pearl millet variety - GB 8735 was distributed to 34 farmers in Kano (12), Jigawa (15) and Katsina (7) states. GB 8735 produced 1.22 t grain ha^{-1}, whereas farmers' local produced only 0.90 t ha^{-1}. As in the case of sorghum, the grain yield of GB 8735 increased from southern (30% more than local) to northern locations (41% more than local). GB 8735 became popular among farmers because of its extra earliness (compared to any of the farmers' varieties), large and bright seeds. Its' taste, food quality and quantity were highly appreciated.

During 1998, three millet varieties (SOSAT-C88, GB 8735, and ICMV-IS 89305) were evaluated by 12 farmers in Sokoto state in collaboration with SACDP, and Lake Chad Research Institute (LCRI). Farmers selected SOSAT-C88 for good grain yield and early maturity. In dry areas, farmers selected GB 8735 for extra earliness (matures in 75 days). Farmers did not choose ICMV-IS 89305, as they did not find any advantage over their local variety.

In collaboration with SG 2000, and LCRI, a total of 12 farmers in four states evaluated SOSAT-C88, GB 8735, and Ex Borno in 1998. Estimated adoption rate of SOSAT-C88 was from 60 to 70% in all the four states. GB 8735 was most preferred in Gombe state (estimated adoption rate 50 to 60%), and least preferred in Kano state (estimated adoption rate 10 to 20%).

In collaboration with LCRI and extension, 50 farmers evaluated GB 8735, IKMP 1, SOSAT-C 88, and ICMV-IS 89305 in 10 states of northern Nigeria in 1998. The majority of the farmers preferred SOSAT-C 88 and GB 8735. For example, Rista Y. Yakubu, Director of Technical Services in Gombe state remarked thatGB 8735 was planted in all the Local Government Areas (LGAs) of Gombe state during 1998, and that this variety was well received by the farmers because of its earliness. He further observed that farmers have given several names to GB 8735 in local languages meaning- “my saviour”, “helper”, “drives away hunger”, “first to mature”, “sustains orphans”, and “it has come to us””.

In the last few years, farmers mentioned that poor traits in GB 8735 included among other things its small panicle length. In response to need, we have developed LCIC 9702 to replace GB 8735. Both mature in 70 to 75 days, similar in morphology, but LCIC 9702 has bigger panicles and produce 20% more grain than GB 8735.

During 1999, two millet varieties (SOSAT-C88 and LCIC 9702) will be evaluated in 11 states in Nigeria by over 100 farmers in pearl millet based on-farm trial. Farmers will evaluate these varieties along with control under their own farming practices. There will be 8 replications in each village, and 12 to 15 villages are expected to conduct the trial. The purpose of this trial is to identify adaptation zones for SOSAT-C88 and LCIC 9702 in northern Nigeria.

Farmers’ participatory breeding and selection. Under this activity, we are creating genetic variability, such as composite populations and provide the seed material to farmers for selection of plants of their choice (under close supervision of research staff) following gridded mass selection. Scientists will understand the farmers’ needs and their selection criteria. Base on farmers’ preferences, specific cultivars can be developed to suit the needs of their cropping systems.

The seed of four composites (early, medium, and late maturing, and dwarf) was supplied to eight farmers (in Gargai, and Bichi area). Each farmer planted one composite in 0.2 ha plot. Farmers were trained in grid mass selection through continuous interaction. Farmers harvested 10% plants of their choice following grid mass selection. Early maturing composite was most preferred by the farmers. Late maturing composite was rejected because of poor seed setting. Three composites (early, medium, and dwarf) were retained for improvement through farmers’ participatory selection. Another composite population (Maiwa 98) was developed in 1998 for participatory selection from 1999. The selections from Maiwa 98 are likely to be grown in areas where photosensitive millets are grown.

On-station Farmers’ Participatory Breeding and Selection of Pearl Millet Varieties

Nineteen F2 populations were created in 1997 by crossing improved seven land races with three elite varieties. After F2 evaluation, the F2 seed from similar crosses was bulked to produce three variable populations. LCIC 9904 produced by bulking F2 seed derived from five crosses between GB 8735 and five land races. LCIC 9905 was produced by bulking F2 seed derived from five crosses between SOSAT-C88 and five land races. Similarly, LCIC 9906 was produced by bulking F2 seed derived from crosses between NC d2 and seven land races. These populations will be grown in isolations at research stations, and at soft dough stage, farmers will be invited to select plants. The seed will be bulked from selected plants to repeat the cycle of selection.

Enhance Capacity of NARS and Farmers in Seed Production

ICRISAT encouraged Nigerian NARS scientists to produce breeder seed of sorghum and millet varieties. ICRISAT provided breeder seed to IAR (ICSV 111, ICSV 400), and LCRI for seed production; and visited their seed multiplication plots. LCRI produced seed of GB 8735 (1.1 t), SOSAT-C88 (1.5 t), ICMV-IS 89305 (70 kg), and ICSV 111 (150 kg).

Farmer-based seed production, in collaboration with NGOs, such as SACDP, and SG 2000, ADPs, and Research Institutes (IAR and LCRI) was initiated in 1998. Thirty-four farmers involved in the seed production of pearl millet (SOSAT-C88, and GB 8735), and sorghum (ICSV 111, and ICSV 400) varieties. We involved senior extension officials, and research staff as progressive farmers in farmer-based seed production programs. Directors of ADPs, other extension officials, and scientists/technicians as progressive farmers have produced at least 20 t of seed combined of pearl millet and sorghum varieties.

During 1999, over 100 farmers are expected to produce seed of sorghum and millet varieties in all the ten sorghum/millet growing states in Nigeria. ICRISAT/LCRI/IAR will provide the breeder seed to farmers through ADPs/NGOs, monitor the seed production, and provide training to farmers/extension agents in seed production.

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Understanding Farmers' Seed Management as a Basis for Participatory Breeding

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Abstract

The farmers' seed system includes various aspects such as the nature, development, maintenance, exchange of varieties, as well as the farmers' strategies using his/her portfolio of varieties. Characterization of the following four themes will provide a thorough understanding of the farmers' seed management strategies: a) the farmers' germplasm base, b) the farmers' production and storage of seed, c) the exchange, movement and availability of seed at the farmers level, and d) the information exchange regarding varieties. This paper explores what information would be needed for each theme, and the expected benefits of that information to effectively conduct participatory breeding activities.

Introduction

The participation of farmers in the process of agricultural research is now widely accepted as essential for achieving impact. This is especially true in zones with great environmental diversity and complex farming systems, such as the sorghum production systems of Western and Central Africa. The prominence of participatory approaches in the WCASRN strategic plan affirms the commitment of the Network to enhancing farmer participation in the research and development process. This emphasis on farmers' participation acknowledges that it is essential for

- developing solutions that respond to the requirements and felt needs of farmers in their current and evolving farming systems
- the effectiveness of current research approaches and the impact that they will achieve, and
- supporting and strengthening the farmers' own activities in developing, obtaining, producing and maintaining varieties of sorghum

The opportunities for farmers' participation in the breeding process are extremely diverse. Farmers can contribute in a variety of ways to each stage in the breeding process (Fig. 1). The degree of farmers' participation ranges from simply providing land for researcher designed and managed trials to farmers taking the lead in decision making, and

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the design and implementation of activities. The diversity of possibilities is further heightened by the sometimes striking differences in needs and skills between different villages, and between farmers in the same village. Thus a highly complex matrix of possibilities for participatory breeding emerges.

With so many possibilities, how can researchers and farmers assess the full range of needs and opportunities and identify the priority topics for which participatory activities are feasible and most required? The answer that is emerging in our minds, is that working with farmers on the basis of their seed management systems will provide the framework that is needed to effectively carry out participatory breeding in sorghum.

Farmers' Seed Management System

The farmers' seed management system can be characterized by the following four major domains:

- Farmers' germplasm base: The varieties farmers currently grow and their strategies for using genetic diversity
- Farmers' seed production and storage methods
- The dynamics of farmers' seed exchange, movement, and availability
- Exchange of information regarding varieties

Each of these four domains will be examined to determine what information is pertinent and required to understand the nature and dynamics of that domain. And by defining that body of information, the ways in which each will facilitate effective participatory breeding becomes apparent.

Farmers' Germplasm Base

A good starting point for any new breeding program is to thoroughly characterize the varieties currently being grown by farmers and the systems that they form a part of. Both researchers and farmers, using their own sets of criteria, will provide these descriptions. This characterization will undoubtedly shed light on the varietal traits that farmers value, and what kind of trade-offs they are willing to make.

Understanding of the sorghum production system(s) will be gained with such questions as: How are these varieties being grown, under what conditions? What strategies are farmers pursuing in maintaining and using the range of varieties that they have? How do these differ among farmers, for example, between better-off and less advantaged farmers, between men and women, and between farmers with more market oriented versus subsistence oriented goals.

The primary contributions of this first domain to the various stages of a participatory breeding program are expected to be:

- Establishing goals that best address the farmers' variety needs, and determining which production systems are to be targeted, and what specific types of adaptation are required.
- Identifying varieties with highly desired traits or trait combinations that can serve as parent material for generating new variability.

- More appropriate design of selection protocols and identification of testing conditions that best correspond to the priority goals and traits desired by farmers.

The Sorghum Germplasm Base in Mali

Certainly at a country level, it is undeniable that Mali is the home of tremendous diversity of sorghum germplasm. There are over 1300 sorghum accessions that have been collected in Mali to date. These represent four of the five major races of sorghum, Guinea, Durra, Bicolor, and Caudatum.

At a regional and village level great diversity is also found. A preliminary survey of 19 random farmers from 16 different villages around Kolokani revealed that 26 different varieties were grown, with individual farmers growing on average three different varieties. Farmers from a single village of Katibougou, described a total of 15 different varieties grown in their village.

The farmers' descriptions of these varieties also provide insights into their production systems, and to the adaptation and usefulness of each variety in their system. For example, among the varieties grown in Katibougou, "Ngengeble" was preferred for production on good soils, "Folomba" was better adapted to less productive conditions and would be sown after "Ngengeble", and "Sakoyka", which was adapted to very poor soils, would eventually replace "Folomba". The description by one farmer from Kolokani of the strengths and weakness of the six varieties that he grows gives additional insights into how farmers' portfolio of diverse sorghum varieties may contribute to food security and maximizing the use of available human and natural resources (Table 1).

These examples of the use of many, contrasting varieties within a single village or even by an individual farmer points to the importance of varietal diversity in sorghum production systems in Mali. Clearly, a research and development model of promoting a single best one or two varieties is not appropriate for these systems.

Farmers' Seed Production and Storage

Sorghum farmers certainly have knowledge and skills regarding seed production and storage, as the current diversity of varieties is a testament to their success in creating and maintaining these varieties. For breeders and development personnel to work more effectively with farmers on the production and storage of seed, it would be helpful to have information on the following:

- How do farmers select seed? What selection criteria do they use? Under what conditions is selection done?
- Which farmers are respected as experts for selecting good seed?
- How effective are the farmers' methods of seed storage?

Answers to these questions would be important for identifying who to work with on participatory seed production and breeding activities. They would clarify the opportunities for farmers' involvement in selecting within segregating materials, as well as help to define what roles and responsibilities breeders and farmers could take for most effectively conducting selection.

A better understanding of farmers' varietal trait preferences would enhance effective setting of goals for variety development work. Knowledge of the bottlenecks and constraints for seed preservation would enable identification of potential interventions to strengthen local seed systems.

Seed Exchange, Movement, and Availability

Books on plant breeding typically end the breeding process with the production of the new variety. However, disappointments with the low adoption of new varieties, and the importance of seed security for agricultural productivity makes research involvement in the steps beyond varietal development of great interest. Information that would be essential for involvement in this area would include:

- Is seed availability a constraint, and if so for whom? And what are the underlining causes of this problem?
- What are the social rules and social factors that promote or limit seed exchange?
- Who are the important seed providers?
- How do farmers evaluate new varieties that they have just obtained?

Discussing with farmers in Mali about the sorghum varieties they are currently growing revealed that most farmers say that one or more of the varieties now being grown were acquired within the last five years. Farmers have often associated these changes with responses to altered rainfall patterns. If it is really true that farmers have successfully disseminated and adopted new varieties on such a large scale, how can research and development become more a part of this process?

Information Exchange

Understanding current ways that farmers' obtain information about new varieties would provide a basis for identifying opportunities enhancing the effectiveness of that information flow. Some helpful questions in this regard would be:

- How do farmers find out about new varieties?
- What information do farmers want about new varieties?
- Who are the important providers of information about varieties?
- What communication technologies or media, traditional or emerging electronic forms, would be effective for transmitting information about varieties?

Strengths of Understanding Farmers' Seed Management Systems

The approach of understanding farmers' seed management systems will ensure a complete analysis of all aspects of the breeding cycle, with every stage in the breeding process being addressed (Fig. 2). This approach also appears to be powerful, with information gained from one domain being useful for many different stages of the breeding process (Fig. 2). Thus a solid basis for effectively conducting variety development and dissemination will be obtained.

The participatory nature of this work will also provide direct advantages. The close contact with farmers can offer farmers immediate access to information and ideas for their own experimentation. By working at the farmers' level the research and development activities formulated will certainly be addressing real needs in the farmers production systems.

The complexity of the farmers production systems, the diverse physical and social context, leads to a bewildering array of needs and opportunities for working with farmers. The information and understandings gained through this approach will prove very helpful, if not essential, in identifying the most promising opportunities for working together. It should also clarify where and how farmers participation is essential, and help define the roles and responsibilities that breeders and farmers can most effectively assume.

Future Work and Conclusions

This paper provides a conceptual framework for understanding farmers' seed management systems. The implementation of this work will require development of methodologies appropriate for addressing each of the domains identified. Examples of this would be; communication tools that effectively elicit the information desired, ways of organizing farmers' participation, and decision support for identifying the highest priority activities.

There is also need for developing partnerships between farmer organizations, development agents and researchers. Only through partnerships is it possible to assure the complementation of knowledge, contacts and resources, to achieve the critical mass necessary. Also, partnerships with development organizations and farmers organizations are essential to ensure that benefits reach beyond the immediate participants. Having the opportunity for scaling-up and sharing information and experience with non-participants, and determining ways to implement this would be an important part of this work.

The prospects offered by this approach are exciting. The usefulness of this approach for conducting participatory breeding activities is convincing. Furthermore, the understanding gained and the methodologies developed through this work should also be of relevance to other WCASRN activities such as participatory approaches to integrated management of *Striga*, diseases and pests and to marketing and transformation. The progress that the Network makes in this approach, and the impact achieved, could prove to be a model for other crops that, like sorghum in WCA, are rich in genetic diversity, contributing to complex production systems in which farmers knowledge and strategies are highly evolved and dynamic.

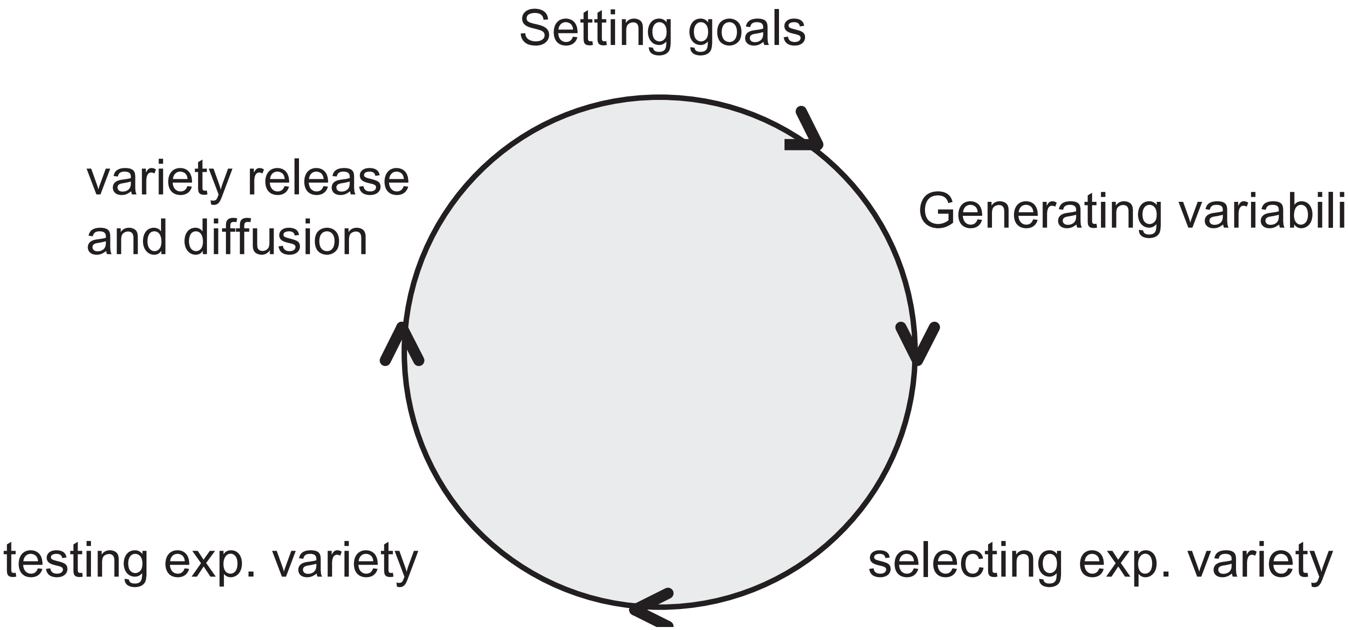

Figure 1. The stages of the breeding cycle.

Figure 2. Contributions to specific breeding stages expected by working with farmers on the basis of their seed management system.

Domain: Farmers' Germplasm Base

- Goal Setting
  Identify farmers' variety needs
  Determine target environments and production systems

- Generate Variability
  Farmers provide and chose source materials for initiating breeding

- Varietal Selection and Testing
  Selection criteria that best correspond to farmers needs
  Testing conditions that correspond to the target environment

Domain: Seed Production and Storage

- Varietal Selection and Testing
  Knowledge of how farmers can be involved
  Identification of which farmers to involve
  Definition of roles of breeders and farmers

- Goal Setting and Diffusion
  Identification of bottlenecks for preservation
  Knowledge of varietal traits of greatest importance

Domain: Seed Exchange, Movement and Availability

- Goal Setting
  Knowledge of varietal variability patterns

- Varietal Testing
  Farmers' skills improved

- Diffusion
  Ways to strengthen local seed production and storage identified
  Local institutions for seed production and storage supported or created
  Estimates of farmers demand for seed
  Knowledge of which farmers and institutions to work with

Domain: Information Exchange

- Diffusion
  Information content of messages increased
  Spread of information enhanced
  Key communicators associated with varietal testing activities, with more immediate communication of information

Table 1. Description by one farmer (Moustapha Diarra) of the strengths and weakness of the six sorghum varieties he currently grows.

Variety	Strengths	Weaknesses
Kenikeba	Large panicle, good storage, good processing qualities	Long growth duration, drought susceptibility
Tiemarifing	Productive, medium growth duration	Slightly susceptible to drought
Badjouloudjan	Productive, medium growth duration	Slightly susceptible to drought
Nitélini	Short growth duration, harvest during hunger period, production assured	Poor grain storage
Dagassigui	Short growth duration, harvest during hunger period, production assured	Poor grain storage
Gadiabani	Later date of sowing, harvest during hunger period, productive, drought resistant, production assured	Poor grain storage

The Experience of Winrock International with Seed Multiplication in West Africa through On-farm Seed Project and On-farm Productivity Enhancement Program

Alphonse Faye and Pierre Antoine[1]

Introduction

The focus of seed production in Senegal has primarily been on groundnut, which is the traditional main cash crop. In contrast, other crops have received limited attention and funding. As a consequence of the "Economic Recovery Program", a new agricultural policy calling for a reduced role of the government in the seed production systems was developed. Owing to this new policy requirement, the role of the Directorate of Seed Production and Control (DPCS) should accordingly be limited to quality control only. Although privatisation is needed in the area of agricultural input marketing, it remains to be seen whether the private sector alone has what it takes to replace the government that had hitherto played this role. The net implication here is that farmers increasingly must take a greater responsibility in assuring for their own input supply, including seeds.

One major drawback in the seed systems for food crops has been the high cost involved in the distribution and marketing of seeds at local level. Another drawback can also be attributed to the limited testing of improved varieties under farmer's conditions in order to assess their compatibility with the existing production systems along with the necessary recommended practices.

Thus, successful identification and production of appropriate seed varieties requires appropriate research and extension. However, farmers themselves can multiply any seed variety or varieties, once they have the necessary material to work with. In fact, seed production can be a small-scale rural enterprise for income generation.

Winrock International through its "OFPEP" program in particular aims at meeting the farmer demands for seed by helping them to improve their practices in terms of seed selection, production and storage. The rationale for this program stemmed from the fact that in some world leading institutions on agricultural seeds, such as Mississippi State University (MSU), still pertinent today, despite 30 years of emphasis on national seed programs and industry investment in seed production and supply programs. Although seed industry development has been important and the assistance received well managed, the national seed institutions still need time in developing ways that would make traditional

1. Winrock International, BP 16278 Dakar, Senegal.

seed production and distribution systems more effective and convincing enough before farmers are willing to adopt and incorporate improved seeds into their traditional seed production and exchange systems.

Inappropriate methods of selection and storage of seeds tend to diminish the potential benefits of improved seed varieties, impede the introduction of non- traditional crops and restrict the range of crops planted. In light of the mounting pressures for increased food supplies and the need to generate income, viable alternatives to such problems need to be found.

Program Development and Support

The program has provided assistance to the seed related programs of PVOs and U.S. Peace Corps in Senegal and the Gambia. Such assistance in particular consisted of adapting the technical assistance to the needs expressed by small farmers. For both Senegal and the Gambia, support and commitment to the Seed program came from several sources. In the Gambia, Winrock International often used a cost-sharing approach in order to collaborate with many NGOs that were involved in seed production activities. The Program made available field data to the Seed Technology Unit in Sapu and the unit in turn provided all the required technical assistance to program. USAID/Banjul also provided support for seed research in the Gambia.

The Government of Senegal is committed in providing support to seed research and production. Likewise, Winrock International has helped national research and production programs by introducing and disseminating new technologies and appropriate varieties through the extension services of PVOs, NGOs and Peace Corps Volunteers that work to implement seed improvement at the village level. In addition, Winrock International has significantly contributed to the design phase of Peace Corps Rice Initiative as well as World Vision International and Christian Children Funds agricultural programs.

Winrock International’s assistance to PVOs, NGOs, and Peace Corps consisted of helping these organisations to strengthen their activities through training and technical assistance. Thanks to the resources made available by the project, the OFPEP’ s staff were able to provide the necessary linkages between regional and local groups on the one hand, and between national agricultural research institutions (such as ISRA in Senegal and Seed Technology Unit in the Gambia) and international consortia on the other. Such consortia in particular included programs, such as the Collaborative Research Support Programs (CRSP) and INTSORMIL.

The Winrock International Seed Program Approach

The approach used by Winrock International has two major characteristics which may be described as follows: (1) it is a collaborative program in which all activities are implemented through PVOs and Peace Corps units, and (2) it is participatory and requires that traditional seed production techniques and problems be examined first with farmers before any activity is undertaken. The long-term goal of the Winrock International seed program aims at developing "a model or models on-farm seed production systems, which in turn can be replicated or adapted to meet local needs in other areas". Such approach may be analysed from several standpoints:

Replicability

Because of the diversity of interests among PVOs, the Winrock International seed program tries to adapt its services to meet the needs of each organisation. This has proven to be an effective way of assisting PVO field personnel in the area of seed technology. This approach, however, should be flexible enough, so that both the training and technical assistance being provided can meet each PVO's unique needs and requirements. The Winrock International seed program has developed basic training packages in seed production and in rice agronomy, which can be modified to fit the needs of any particular audience. In some cases, the Winrock International seed program can even provide, if requested by the PVO, appropriate technical assistance in crop production and extension activities rather than in seed production

Innovativeness and Leadership Development

Most seed programs in developing countries usually target the large scale farmers' group as their beneficiaries at the expense of the small scale farmers. In contrast, the Winrock International seed program aims at making the small scale farmers' group its main target and beneficiary.. The program essentially is implemented at the "grassroots level", where PVO field staff and volunteers living in villages provide the linkage between Winrock International and the target farmers. Through this participatory approach, Winrock International encourages the establishment of lead farmers in each village or community based organisations (CBO).

Policy Implications

A critical factor in any project is to be able to comply with the national policy of the host country where it is operating. In this regard, Winrock International seed program has been consistent with existing government policy in both Senegal and the Gambia. For instance in Senegal, the existing agricultural policy aims at reducing the role of government in the supply of agricultural inputs while contributing to promote the development of private sector related enterprises. In light of this policy, Winrock International seed program tries to play a complementary role by developing models of on-farm seed production systems through the promotion of village level seed production (Christophersen et al, 1998). The adoption of improved millet seeds in particular constitutes one of the most interesting examples of how Winrock International is helping villagers to respond to USAID/Senegal presence in their areas while and catalysing the synergies between improved NRM and the new decentralisation and private sector SOs".

From Seed Demonstration Plots to On-farm Seed Multiplication

Unlike the majority of seed production programs in developing countries, which usually focus on developing national seed programs, Winrock International in contrast prefers putting an emphasis on the introduction at village level of improved varieties through demonstration plots and field days

In most cases, this collaborative approach could go beyond the simple stage of a collaborative relationship and reach the point where CBOs created by farmers are sponsored by the PVOs. This normally complies with one of the Windrock International major output goals, which anticipates that “some communities will support local system or seed production and distribution either through co-operatives or by individuals who establish private firms”.

A study carried out in 1993 in Northern Senegal in collaboration with World Vision confirmed indeed the development of a marketing system for cowpea and millet seeds produced on local grounds by farmers.

Through surveys, the study in particular showed that sales of seed were taking place at different levels among farmers within villages, and between villages and the markets.

It should be noted that World Vision International did not record the quantities produced through multiplication, but rather monitored the quantities that were being purchased to be sold as certified seeds. This probably implies that part of the seed produced even though not recorded may have ended up being sold with various containers through the markets and villages. This raises the question as to how such a product can be distinguished as a quality product from the one that is usually being sold on the market place.

The answer to this question probably will depend on the impact being made by the demonstration of seed varieties on concerned farmers from the target villages and surrounding localities. Word of mouth advertising and recognition of “bush-consultants” as appropriate sources of information usually can also generate sales. For demonstration purposes, , “bush consultants” can for instance carry out germination tests in small metal basins in their house to show to potential buyers. The information gathered from our field surveys revealed in particular that farmers both from the target and surrounding villages usually preferred going to the “bush consultant” for the purchase of their seed needs. In addition, it was observed that those farmers going to the “bush consultant” were not only making purchases for themselves, but in some instances had also seed purchase orders which they agreed to carry out on behalf of peers who stayed in the village..

Project Beneficiaries

Winrock International has provided training, technical assistance and other related services to the PVOs and Peace Corps. Such assistance in particular was useful for the field personnel in those organisations for properly carrying out their respective program activities in Senegal and the Gambia. Thus, the project beneficiaries included both the PVOs and small farmers of the two countries

Those PVO beneficiaries include:

Save the Children Federation (Scf), The Gambia

SCF carries various program activities, which include health, food production and education.. Approximately 30 % of SCF's resources are devoted to agricultural activities. These resources in particular are being used to provide appropriate assistance to 10,000 women farmers from 24 villages in order to increase their food production. Activities being supported in these villages include gardening, growing of new rice varieties and seed multiplication. Since 1988, Winrock International "OFSP" project has been assisting SCF in a number of ways which include: (1) training field staff farmers in seed production, post harvest handling, and rice production, (2) providing technical assistance in rice agronomy, (3) assisting in the planning of seed multiplication and demonstration activities. SCF rice activities initially involved 25 contract growers for producing rice seed in 10 villages. As of 1991, there were 117 contract growers in 20 village producing seed on 21 hectares.

Freedom from Hunger Campaign (Ffhc), The Gambia

FFHC works with women rice growers in 32 villages from the Lower River, North Bank, and Mac Carthy Island North Divisions in the Gambia. FFHC's efforts have primarily been concerned with rice production in swamps, and rain-fed -lowland areas, respectively. These efforts in particular have been focussing on introduction of new rice technologies, promotion of water harvest techniques control of salt water intrusion, and strengthening of village level institutions. Winrock International assistance to FFHC included training of field personnel on rice growing techniques, monitoring of seed multiplication fields and demonstration plots, and collaborative testing of a prototype rice seeder.

World Vision International, Senegal (W.V.I)

World Vision International has an integrated development program at Louga and Thies in Senegal. This program in particular is concerned with the improvement of water, agriculture and health conditions for a population of 150,000 from over 320 villages Agriculture in these northern regions of Senegal is increasingly becoming marginal, owing to limited rainfall (250-300 mm per year), widespread deforestation, and gradual decline in soil fertility. Initially, Winrock International, through "OFSP" and "OFPEP", provided training to twenty five W.V.I staff members and forty farmers commonly known as "bush consultants" or lead farmers. Currently, W.V is carrying out seed multiplication activities for millet and cowpea with 60 "bush consultants" in 57 villages.

Christian Children's Fund (Ccf), Senegal

Winrock International and CCF collaboration integrates efforts to improve farmer's access to good seeds with activities aimed at increasing soil fertility and management at the farm level. This collaboration essentially relies on six community-based organisations, which are financed by a system of Children's sponsorship. These CBOs are playing an important role in the adoption and diffusion of technologies being made available by "OFPEP". OFPEP in particular represents the real link for activities, such as training of farmers, implementation of demonstration plots, and monitoring of seed activities. The experience in Senegal seems to suggest that easy access to seed is a critical factor in entrancing seed use. Indeed, once farmers are convinced of the quality of improved seed varieties, seed supplies should t be available locally. Only a decentralised system of seed production and marketing can address such needs, especially in a situation where farmers were scatered in 41 villages and 6 CBOs. Through the CBOs, Winrock International trained 6 seed extension specialists and 73 seed growers. As a result, every CBO's staff member now is able to monitor the production of millet seeds as well as ensure the marketing of the products.

Conclusion

Thanks to its good collaboration with various PVOs and NGOs, Winrock International was able to foster the development of models of on-farm seed production systems that benefited all parties involved. Many farmers for instance have now an easier access to improved seed varieties produced locally by the PVOs and NGOs. In turn, both the PVOs and NGOs are benefiting from the seed program that is providing appropriate technical assistance to farmers. ISRA's technologies are being extended to farmers, and valuable feedback obtained from the farmers is useful for future technology development.

Nevertheless, it would have been difficult to produce these activities without the necessary training, technical assistance and such a facilitating role played by Winrock International. The PVO and NGO managers have a major role to play during the implementation of activities at grassroots' level. Such role in particular includes, among other things, management of personnel and budgets, logistical support, linkages with their respective headquarters. Time constraints and lack of internal expertise in certain areas, such as training or other related technical know-how may limit, however, the role that can be played by these managers. Under such circumstances, Winrock International has the capability to provide the required seed technology services in order to meet the specific needs of the NGO programs, which in turn are meant to benefit the farmers.

Another point that is worth noting is the fact that it is now fairly easy to identify most small scale farmers who can produce quality seeds of various crop varieties in both Senegal and the Gambia.

Provided proper incentives and adequate marketing opportunities are made available, these farmers can become "contract seed farmers" and thus constitute the first step toward the development of a viable private seed sector in both Senegal and the Gambia.

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Impact économique de la recherche et de la vulgarisation des variétés ameliorées de sorgho: le cas de la Région des Savanes au Togo

Kossi M. Sedzro[1]

Introduction

Le sorgho et le mil sont à la base de l'alimentation des populations du Nord Togo et particulièrement de celles de la Région des Savanes (DRDR/S, 1989; DESA,1984-1993). Cette région produit à elle seule près de 32% de la production annuelle de sorgho, la deuxième céréale nationale qui après le maïs occupe 38% de la superficie totale annuelle. La production régionale annuelle a varié de 21 000 tonnes à 61 000 tonnes entre 1982 et 1994. La même région produit 90% de mil sur près de 86% des superficies totales nationales (DESA 1982-1994). Le sorgho et le mil sont presque toujours cultivés en association. Selon les rapports de l'Institut National des Cultures Vivrières (INCV), de la Direction Régionale du Développement Rural des Savanes (DRDR/S) et de la Société Togolaise du Coton (SOTOCO) qui sont les plus importantes structures actuelles d'encadrement de la production agricole dans la région, les paysans de la région ont toujours cultivé et cultivent encore des variétés traditionnelles de mil. Il n'y a pas eu une seule variété améliorée de mil vulgarisée.

Par contre, la situation n'est pas la même avec le sorgho. Vers la fin des années 70 et dès le début des années 80 (1979/1980), plusieurs variétés améliorées de sorgho ont été introduites des pays voisins (Benin, Burkina Faso, Ghana, Sénégal) pour des essais d'adaptation. Celles qui se sont révélées les plus adaptées à l'écologie, ont été vulgarisées. Il s'agit en particulier des variétés améliorées "Framida", "Naga White", "Kadag" et "517". Mais en dehors de la variété 517 très voisine de la variété locale "Tchouleli" (ou "Tchanlouli"), les autres variétés ont connu peu de succès auprès des paysans à cause de leurs qualités culinaires et organoleptiques (aptitude à la préparation de la bière locale et de la pate) peu appréciées les consommateurs. Un rapport de la recherche d'accompagnement vivrière entreprise par SOTOCO en collaboration avec l'IRAT du Burkina Faso en 1984 souligne que bien que les variétés locales avaient un faible rendement, elles répondaient mieux au goût des consommateurs et étaient préférées par rapport aux variétés introduites(BAH et al. 1990).

La variété 517 sélectionnée au Burkina Faso par l'Institut de Recherche Agronomique Tropicale (IRAT) a été vulgarisée et plus adoptée et cultivée par les paysans vers le début des années 1980 (1982/1983).

1. Institut Togolais de Recherche Agronomique, BP 2318 Lomé, Togo.

A la suite de la mauvaise récolte de sorgho en 1987/1988 dans la Région des Savanes, les Autorités ont envoyé au début de 1988 une mission dans les pays sahéliens en quête de variétés qui seraient plus adaptées aux conditions de culture caractérisées par des saisons de pluie de plus en plus courtes ou irrégulières. Les essais d'adaptation ont été mis en place dès le retour de la mission. Mais face à l'urgence des besoins de production de cette denrée à la base de l'alimentation dans le Région des Savanes, les paysans n'ont pas voulu attendre les résultats des essais d'adaptation. Ils ont introduit eux-mêmes les variétés plus précoces et plus productives Naga White et Kadag trouvées auprès de leurs collègues paysans du Ghana. A partir de 1989, les deux variétés ("NagaWhite" et "Kadag") introduites par les paysans ont progressivement remplacé la 517 qu'elles ont pratiquement éliminée des parcelles des paysans dès le début des années 1990.

Les deux variétés ont été préférées à la variété 517 et autres variétés traditionnelles de la région pour deux raisons essentielles:

- leur cycle est plus court. Il est de 90 jours pour Naga White et de 120 jours pour "Kadag" contre 140 à 150 jours pour les variétés locales "Dimoni" ou Tchouleli et,
- leurs rendements plus élevés. Ils varient de 1,5 t à 2,5 t ha^{-1} contre 0,8 t à 1,5 t ha^{-1} pour les variétés traditionnelles (M'PO et al., 1995/1996).

A cause du raccourcissement des saisons de pluie, "Naga White" et "Kadag" sont plus cultivés dans le Nord-Ouest de la région où les conditions de production (fertilité du sol et pluviométrie) sont plus sévères. Les deux variétés semblent progresser vers d'autres localités. Selon les estimations, les superficies annuelles actuellement occupées par les deux variétés ("Jerry" et "Kadag") dans certaines zones de culture atteindraient ou dépasseraient 40% de la superficie totale annuelle cultivée en sorgho dans la région. Le raccourcissement de plus en plus constaté de la saison des pluies est l'une des principales causes de la régression ou de la stagnation des superficies cultivées en sorgho et mil dans la région (M'PO et al.1995).

Les deux variétés ("Naga White" et "Kadag") ne se conservent pas bien pendant le stockage et risquent de ne pas s'adapter à la zone sud de la Région des Savanes où la saison des pluies est un peu plus longue que dans le Nord-Ouest. Nous partageons le point de vue de Chantereau (1995) selon lequel les producteurs de sorgho de la région sont encore demandeurs de variétés plus adaptées aux différentes écologies pour accroître leur production.

Pour répondre à ce besoin, le programme sorgho et mil de l'Institut National des Cultures Vivrières a sélectionné des variétés améliorées en tenant compte des conditions agroclimatiques de la Région des Savanes et du goût des consommateurs (INCV 1996). Ces variétés (SORVATO1, SORVATO7 SORVATO10, SORVATO28, SORVATO33) sont en phase de prévulgarisation en milieu paysan depuis 1996 et la réaction des paysans face à ces variétés n'est pas encore totalement connue.

Des études antérieures se sont surtout intéressé aux systèmes de production et aux stratégies de production agricole des paysans de la région. Pour venir en appui aux sélectionneurs de sorgho en ce qui concerne les caractéristiques des variétés à sélectionner en fonction du désir des producteurs et éclairer davantage les décideurs et d'autres partenaires du développement agricole de la Région des Savanes et des zones de conditions agro-socioéconomiques similaires, il apparaît utile de mener d'autres études. Ces recherches sont nécessaires pour connaître les principaux facteurs agronomiques et socioéconomiques qui déterminent les paysans à adopter une variété ou non, le taux d'adoption des variétés améliorées de sorgho utilisées actuellement dans le système cultural de la région, la perception des paysans par rapport à ces variétés et pour déterminer l'impact socioéconomique de la recherche, de la vulgarisation et l'adoption des variétés améliorées de sorgho.

Objectifs de recherche

Notre objectif principal est de déterminer l'impact socioéconomique des variétés améliorées de sorgho dans la Région des Savanes au Togo. Cet objectif global comprend les objectifs spécifiques suivants qui visent à déterminer:

a) le taux d'adoption des variétés améliorées de sorgho qui sont actuellement cultivées par les paysans;
b) l'appréciation des variétés améliorées actuellement cultivées dans la région par les paysans;
c) les gains sociaux nets dus à l'adoption des variétés améliorées de sorgho

Brève présentation de la région des savanes

Généralités géographiques

Située à l'extrême nord du Togo, la Région des Savanes est l'une des cinq régions administratives du pays. Elle est limitée au nord par le Burkina Faso, à l'ouest par le Ghana, à l'est par le Bénin et au sud par la Région de la Kara. Elle compte près de 12% de la population nationale repartie sur près de 15% (8 533 km) du territoire national. La température annuelle varie de 21 à 40 C. Le climat comprend une saison des pluies de mai à septembre et une saison sèche qui va d'octobre à Avril pendant laquelle souffle le vent de l'harmattan. La pluviométrie annuelle qui varie de 700 mm à 1100 mm va en diminuant du sud vers le nord-ouest. La savane arborée et la savane herbacée constituent l'essentiel de la végétation.

La région des Savanes compte quatre préfectures qui sont celles de Tone, de l'Oti, de Tandjoaré et de Kpendjal. La capitale régionale est Dapaong située à 630 km au nord de Lomé la capitale.

Aperçu sur le secteur agricole de la région

L'activité principale dans la région est la production agricole et concerne les cultures, l'élevage et la pêche. Le sorgho et le mil sont les principales cultures et sont à la base de l'alimentation des populations. Viennent ensuite le riz cultivé dans les bas-fonds puis le niébé, l'igname, le voandzou, l'arachide. Le maïs récemment introduit dans la région connaît un important développement. Les tomates et les gombos sont les légumes traditionnels. Le manguier est le principal fruitier. Le coton, le kapok, le néré et l'arachide sont les principales produits procurant des revenus monétaires. Les associations de cultures comprennent surtout les combinaisons sorgho-mil, mil-sorgho-haricot, mil à long cycle-mil à cycle court, mil-maïs, et arachide sorgho.

L'on pratique l'élevage de bovins, de petits ruminants, de volailles et de porcins. Malgré les efforts des populations de la Région des Savanes, le secteur agricole continue à se heurter à deux sortes de contraintes principales auxquelles des solutions doivent être trouvées. Il s'agit de la pauvreté des sols et l'incertitude des pluies et de leur répartition dans le temps et dans l'espace. Un facteur encourageant cependant est le développement relatif de l'utilisation de la traction animale.

Bref historique de la recherche agricole au Togo

Avant la deuxième guerre mondiale, la recherche agricole se limitait à quelques expérimentations conduites par des chercheurs français basés à Dakar. Mais la recherche agronomique proprement dite n'a commencé au Togo qu'après 1940 avec l'installation de plusieurs antennes d'instituts de recherche français. L'IRHO (Institut de Recherche pour les Huiles et Oléagineux) et l'ORSTOM (Office de Recherche Scientifique et Technique Outre-Mer) ont élaboré et démarré des programmes nationaux de recherche en 1942. En 1949 l'IRCT (Institut de Recherche du Coton et des Textiles Exotiques) a installé une station de recherche pour le coton à Kolokopé. En 1952 naissait l'IRTO (Institut de Recherche Scientique du Togo) qui a mené des recherches dans les domaines des sciences du sol, de la nutrition et de la sociologie.

Après l'indépendance en 1960 la collaboration avec les instituts français a continué à travers de nouveaux instituts tels que l'IRAT (Institut de Recherche Agronomique Tropicale en 1961) et l'IFCC (Institut Francais du café et du cacao en 1967). Mais les activités de recherche française ont été plus étroitement intégrées aux structures nationales de recherche agricole. Dans le souci de regrouper tous les instituts de recherches agricoles, la Direction Nationale de la Recherche Agronomique a été crée en 1991. Elle comprend aujourd'hui l'Institut Zootechnique et Vétérinaire (INZV) l'Institut de la Nutrition et de la Technologie Alimentaire (INTA) l'Institut National des Sols (INS), la Direction de la Météorologie Nationale (DMN), l'IRCT, l'IRCC (déjà indiqués) et l'Institut National des Cultures Vivrières (INCV) qui se charge des activités d'amélioration du sorgho à travers son programme Sorgho et Mil.

Bref historique de la recherche et de la vulgarisation sur le sorgho au Togo

Durant les années 1970, des essais d'adaptation ou de comportement ont été réalisés par la mission IRAT au Togo à partir des variétés introduites des pays voisins. Par exemple les variétés 51-59 et SH 60 ont été introduites du Sénégal, S8, Nomgomsoba, Belko, 217, Gnofing, Zalla, E 35-1, Framida et 517 du Burkina Faso, Ghana1 du Ghana, C 4-2, C-4-5, L 81 etc du Bénin. Plusieurs de ces variétés se sont revélées intéressantes mais leur qualité organoleptique n'a pas été appréciée par les paysans.

De 1982 à 1989 les recherches ont concerné surtout l'amélioration des variétés locales. Des travaux de prospection et de collecte des écotypes locaux ont été entrepris par la recherche d'accompagnement IRAT-SOTOCO, par SAFGRAD (Semi-Arid Food Grain Research and Development) et la Direction de la Recherche Agronomique. Une sélection massale ainsi réalisée a permis d'identifer une dizaine de variétés intéressantes qui ont été reparties à travers le pays suivant leur origine. Mais très vite ces variétés n'ont pas connu de succès auprès des paysans à cause de leur cycle trop long par rapport à la saison des pluies qui de plus en plus devenait courte avec des pluies de plus en plus mal reparties dans le temps.

Depuis 1989 l'amélioration du sorgho est prise en charge par le Programme Sorgho et Mil de l'INCV.

L'objectif des travaux de sélection de ce programme est la création de variétés adaptées aux principales zones agroécologiques du Togo ayant des rendements supérieurs à ceux des variétés traditionnelles, de taille plus courte et de qualités organoleptiques proches de celles des variétés traditionnelles. Les variétés obtenues de ces travaux sont prometteuses et sont mises en prévulgarisation depuis 1996 mais la réaction des paysans face à ces variétés n'est pas encore totalement connue.

Parallèlement aux travaux de sélection nationale, la collaboration avec le Réseau Ouest et Centre Africain de Recherche sur le Sorgho (ROCARS) se poursuit. Les meilleures variétés obtenues dans les pays membres ont été introduites dans le cadre des essais variétaux d'adaptation. Dans ce cadre, par exemple les variétés E35-1, Framida, ICSV 1002 et Sepon 82 ont été testées par le Projet de Developpement et SAFGRAD -Togo dans les régions où l'on produit du sorgho dans le pays. Mais ces variétés n'ont pas été adoptées par les paysans soit parce qu'elles n'ont pas donné un rendement meilleur ou n'ont pas un goût meilleur par rapport aux variétés traditionnelles. Le problème de variétés adaptées aux différentes conditions agroécologiques de la région n'est que partiellement résolu.

Méthodologie

Cadre théorique d'analyse: le surplus économique

L'approche du surplus économique a été utilisée par plusieurs chercheurs (Ahmed, Mohamed M. et al. 1994, S.Ouedraogo; et al. 1995; M.G. Fisher et al. 1995; Dalton, T. 1996) pour évaluer l'impact économique de la recherche et de la vulgarisation agricole. Elle permet de déterminer la rentabilité en termes de gain social total des investissements consacrés à la recherche et à la vulgarisation agricole d'une nouvelle technologie. Pour ce faire, les concepts de l'offre et de la demande et de l'équilibre permettent de transformer les données agronomiques en valeurs économiques.

Cette approche part du concept que le surplus du consommateur est la différence entre le prix que le consommateur paye effectivement pour chaque unité d'un bien sur le marché et le prix qu'il serait disposé à payer pour chaque unité supplémentaire jusqu'à concurrence de la quantité totale achetée. Par similitude, le surplus du producteur est la différence entre le prix auquel il vent son produit sur le marché et le prix auquel il est disposé à vendre chaque unité supplémentaire du produit jusqu'à concurrence de la quantité totale vendue.

Le surplus du consommateur et le surplus du producteur constituent le surplus économique qui peut se définir comme la somme d'argent que les consommateurs auraient payé pour chaque unité consommée moins la somme que les producteurs auraient payé pour chaque unité produite avant d'atteindre le point d'équilibre entre le prix et la quantité sur le marché (W. A. Masters et al. 1996). L'idée qui sous-tend l'évaluation de l'impact économique de la recherche est de comparer la situation sans recherche à celle avec recherche agricole.

Un niveau de production de plus en plus élevé implique un niveau d'utilisation de plus en plus élevé d'intrants donc un coût de production de plus en plus élevé. L'influence des coûts de production sur le niveau de la production définit la fonction Ps = Fs(Qs) appelée la courbe de l'offre, où Ps est le prix du produit offert et Qs la quantité de la production. La pente positive de la courbe indique qu'on ne peut accroître le niveau de la production sans accroître le niveau du prix à payer à moins d'apporter un changement (une réduction) dans le coût des intrants ou en utilisant une variété plus productive par exemple.

Par ailleurs, la demande augmente quand le prix offert à la consommation baisse. Cette relation est définie par la fonction Pd = F(Qd), où Pd est le prix du consommateur et Qd la quantité demandée.

Les courbes d'offre et de demande peuvent prendre diverses formes. Mais elles peuvent être assimilées à des lignes droites.

L'impact de la recherche est la mesure du changement intervenu dans le surplus économique au bénéfice de la société. Pour les producteurs, l'impact bénéfique de la recherche est la réduction du coût de production et pour les consommateurs c'est la réduction des prix à la consommation et une quantité plus grande de produits disponibles pour la consommation. Mathématiquement les gains sociaux se calcule grâce aux formules suivantes:

Changement dans la production dû à la nouvelle technologie

j = (dY x t)/Y

où

j = changement proportionnel dans la production induit par la nouvelle technologie,

dY indique la différence de rendement entre l'ancienne et la nouvelle technologie,

Y = le rendement moyen(kg/ha)

t = le taux d'adoption de la nouvelle technologie

Différence de coût des inputs utilisés due à l'adoption de la nouvelle technologie

$c = (dC \times t)/Y \times P$
où c = coût d'adoption de la nouvelle technologie en proportion du prix du produit,
dC = différence du coût des intrants entre l'ancienne et la nouvelle technologie (fcfa/ha),
P = prix moyen réel offert au producteur (fcfa/kg),

Changement net (k) intervenu dans le coût de production en termes de proportion de prix du produit

$k = (j/\in) - c$
avec $\in$ = élasticité de l'offre.

Changement intervenu dans la quantité d'équilibre produite à la suite de l'adoption de la nouvelle technologie

$dQ = (Q \times \in \times e \times k)/(\in + e)$
où
dQ = changement dans la quantité d'équilibre produite
Q = Production totale de sorgho (en kg)
e = élasticité de la demande.

Gain Social (GS) obtenu en f cfa dû à l'adoption de la nouvelle technologie

$GS = (k \times P \times Q) - 1/2(k \times P \times dQ)$

Gain Social Net (GSN) obtenu en f cfa dû à l'adoption de la nouvelle technologie

$GSN = GS - R - V$
où
R = Coût total de la recherche,
V = Coût total de la vulgarisation

L'adoption et l'utilisation d'une variété plus performante mise au point par la recherche augmente la productivité et permet donc de réduire les coûts de production. Ce qui entraîne un déplacement parallèle de la courbe d'offre et donc une variation du surplus économique. Toute variation dans le surplus économique est une mesure des gains sociaux tirés de la recherche.

Choix des sites et échantillonnage

Les enquêtes préliminaires nous ont permis de constater que:

- toute la région des savanes dans l'ensemble a été plus ou moins touchée par la vulgarisation ou l'introduction d'au moins une variété améliorée de sorgho,

- la plupart des paysans de la région ont la possibilité (accessibilité) de se procurer et cultiver une variété améliorée de sorgho s'ils le désirent,
- l'importance de l'utilisation des variétés améliorées de sorgho varie suivant les localités dans la même région.

Nous avons donc limité notre zone d'étude à toute la région des savanes pour deux raisons principales:

- premièrement, c'est la plus grande région productrice de sorgho du pays. Près du tiers (32%) de la production nationale de sorgho provient de cette région (DESA 1982/1994),
- deuxièmement, des efforts y ont été faits par les services de vulgarisation pour diffuser les meilleures variétés de sorgho, dans la région, efforts renforcés par les paysans eux-mêmes pour accéder aux meilleures variétés accessibles provenant des pays voisins,

Pour parvenir à une meilleure estimation de la diffusion ou de l'adoption des variétés améliorées de sorgho à travers la région, trois sites en accord avec les services de vulgarisation agricole ont été retenus comme suit:

Le premier est celui où l'action de vulgarisation ou d'adoption des variétés améliorées de sorgho a été la plus forte durant les dix dernières années. Ce site concerne surtout la zone dite «zone FED» et inclut dans le cadre de notre étude les villages de Cinkassé, Korbongou, Pana Tiérou, Tami, Nanergou, Naki-Ouest, Nano et Lotogou.

Le deuxième site est celui où l'action de vulgarisation et d'adoption des variétés améliorées ont été moyennement fortes. Dans le cas de notre investigation, ce site englobe les villages de Bombouaka, Tandjoaré, Nagbeni, Barkoissi et les villages situés aux alentours de ces villages tels que Galangachi, Bantierk et Bogou.

Enfin le troisième site est la zone où la vulgarisation et l'adoption des variétés améliorées ont été faibles et où les agriculteurs bien qu'ayant la possibilité de se procurer des semences améliorées sur le marché, semblent préférer les variétés traditionnelles. Ce site comprend aussi bien les parties au nord qu'au sud de Mango et englobe les villages tels que Mogou, Gando, Sadori et Koumongou.

Après avoir déterminé le taux d'adoption par site, nous avons fait la moyenne pour ces trois sites et déterminé le taux d'adoption moyen des variétés améliorées de sorgho au niveau de la région. Pour ce faire, une quarantaine de paysans (chefs d'exploitation) a été choisie au hasard par site à partir de la base de sondage des paysans chefs d'exploitation déjà constituée par la Direction des Enquêtes et Statistiques Agricoles (DESA). Ce qui représente en tout 120 chefs d'exploitation à enquêter pour les trois sites.

Collecte des données

Pour la collecte des données, des enquêteurs de niveau BEPC et parlant les langues du milieu (moba, tchokossi) ont été recrutés et formés. Ceux-ci ont travaillé sous la supervision du chercheur principal. La collecte des données a couvert essentiellement la période qui a duré de juin à novembre 1996.

Les données permettant de calculer les superficies couvertes par les variétés améliorées de sorgho et les rendements sont collectées grâce aux fiches de questionnaire en interrogeant directement les chefs d'exploitation et en mesurant les superficies et les rendements par la méthode des carrés de rendement.

Les données collectées

Superficies, quantités et prix de la production

La DESA dispose par préfecture et par région et pour tout le pays des données sur les superficies, les quantités et les prix (ruraux) de sorgho produit chaque année. La Direction de la Statistique Générale, entre autres relève les prix sur les marchés des centres urbains.

Les données permettant de calculer les superficies couvertes par les variétés améliorées de sorgho et les rendements sont collectées grâce aux fiches de questionnaire en interrogeant directement les chefs d'exploitation et mesurant les superficies et les rendements.

Les rendements

Les données sur les rendements des diverses variétés (améliorées et traditionnelles) de sorgho en station et en milieu paysan sont obtenues auprès des stations de recherche, des services d'encadrement agricole et la DESA.

Quantités et prix des intrants

Nos enquêtes auprès des chefs d'exploitation, des stations de recherche et des services de vulgarisation nous ont permis d'obtenir les données sur les quantités de semences de chaque type utilisées pendant chaque campagne agricole. Les quantités d'engrais et autres intrants utilisés pour les variétés améliorées ou non de sorgho et leurs prix ont été relevés en interrogeant les paysans.

Elasticité de l'offre et de la demande

Pour la collecte des paramètres économiques comme l'élasticité de l'offre et de la demande, nous nous sommes référés à des sources spécialisées (services des enquêtes Budget-Consommation, documentations).

Le coût de la recherche et de la vulgarisation

Pour les informations sur les coûts, nous collaborons avec les services nationaux de recherche et de vulgarisation pour déterminer les budget alloués et la part consacrée au sorgho. Mais surtout nous nous appuyons sur les conseils de ROCARS pour estimer les coûts de recherche surtout quand les variétés améliorées utilisées par les paysans ont été sélectionnées ailleurs par les Centres Internationaux de Recherche Agricoles et non par la recherche agricole nationale.

Résultats obtenus et discussions

Taux d'adoption et perception des paysans

La détermination de l'impact économique des variétés améliorées de sorgho dans la Région des Savanes suppose une adoption de ces variétés par les producteurs de la région. L'observation des deux tableaux qui suivent nous renseigne sur le taux d'adoption des variétés améliorées de sorgho en termes de nombre de chefs d'exploitation (CE) utilisant ces variétés et en termes de superficie couverte par ces variétés dans la région.

En comparant les deux types de taux d'adoption, l'on observe que plus de la moitié de paysans (57%) sur l'ensemble des trois sites cultivent des variétés améliorées de sorgho mais qu'en termes de superficie, moins de la moitié (38%) des superficies consacrées au sorgho porte des variétés améliorées. Cela veut dire que bien qu'un nombre important de paysans cultivent des variétés améliorées de sorgho, les superficies consacrées aux variétés traditionnelles sont encore plus importantes dans l'ensemble de la Région des Savanes.

Les raisons évoquées par les CE pour justifier l'adoption ou le rejet des variétés améliorées de sorgho varient suivant les paysans mais les principales raisons recueillies auprès des paysans adopteurs (Cf. Tableau 3) sont: le cycle (les variétés améliorées sont de cycle plus court et sont préférées pour cela), le rendement (qui est plus élevé chez les variétés améliorées) et les besoins d'autoconsommation. Cette dernière raison peut être assimilée aux deux premières (cycle et rendement).

Les deux tableaux qui suivent présentent l'impression des paysans sur les variétés améliorées par rapport aux variétés traditionnelles. Les critères de comparaison généralement retenus par les paysans de la zone d'étude sont le rendement, le cycle, le goût à la consommation (pâte et bière locale «tchakpalo»), la résistance aux maladies et insectes, la facilité du battage et l'aptitude à la conservation. Il convient, toutefois, de noter que ce dernier critère n'a pas pu être pris en compte dans cette analyse.

Gains sociaux de la recherche et de l'adoption des variétés améliorées de sorgho

Pour un coût total réel de 89 353 913,53 fcfa dû à la recherche et à la vulgarisation des variétés améliorées de sorgho de 1979 à 1986 dans la région des savanes au Togo, le taux interne de rentabilité atteint 64,60%, une valeur actualisée nette de 18 833 775 fcfa pour une période d'adoption de près de 15 ans (1982 à 1996). Pour la même période le gain social total net s'élève à plus de 5,8 milliards d fcfa (voir en annexe le détail des calculs).

Dans l'évaluation de la rentabilité économique, les coûts d'apport d'engrais et de fumier ont été imputés à la seule production de sorgho pour lequel l'agriculteur souvent apporte l'engrais. Dans la réalité cet apport de fumure profite aussi aux autres cultures autres que le sorgho dans les systèmes culturaux (sorgho-mil, mil-sorgho-haricot, mil à long cycle-mil à cycle court, mil-maïs, et arachide-sorgho) observés dans la région. Ce qui permet à l'exploitant d'augmenter son rendement et donc certainement son revenu. Dans ce cas le gain social net obtenu au niveau de la région est certainement plus important que celui calculé si l'on tient compte de tous les cultures du système cultural sur l'exploitation**.**

Conclusions

La plupart des variétés améliorées introduites dans les années 1980 n'ont pas été adoptées par les agriculteurs de la région des savanes soit parce que ne répondant pas au goût des consommateurs ou soit parce qu'elles ne sont pas adaptées aux conditions agro-écologiques. Seule la variété introduite "517" sélectionnée par l'IRAT/Burkina a été adoptée en 1982/1983. Mais son cycle relativement long (135 jours) n'a pu s'adapter aux saisons des pluies devenant de plus en plus courtes dans la région. Par conséquent, elle a été progressivement remplacée depuis le milieu des années 1980 avant d'être pratiquement éliminée des parcelles des paysans en 1989/1990. Deux nouvelles variétés de cycle court et moyen (90 et 120 jours) "Jerry" et "Kadag" introduites des pays voisins (Ghana et Burkina) par les paysans ont depuis pris sa place.

De ces deux variétés, "Jerry" est actuellement de loin la plus cultivée à cause de son cycle court (90 jours) et de son rendement (1,5 t -2,5 t ha^{-1}) relativement élevé par rapport aux variétés traditionnelles (1t à 1,5 t ha^{-1}). Mais il se conserve mal pendant le stockage et s'adapte difficilement aux conditions de saison de pluies relativement longue. C'est pourquoi le Programme National Sorgho et Mil a inscrit parmi ses priorités la sélection de variétés qui seraient plus adaptées aux diverses conditions agro-écologiques ainsi qu'aux exigences de consommation de la région.

Les principaux critères de sélection observés par les paysans de la région pour adopter une variété de sorgho semblent être le cycle, le rendement et le goût à la consommation.

Pour une période d'adoption de près de 15 ans (1982 à 1996), l'utilisation des deux principales variétés cultivées dans la région des savanes ("Jerry" et "Kadag"), le gain social total net obtenu s'élève à plus de 5,8 milliards de fcfa pour un coût total de sélection et de vulgarisation total de 89 354 000 francs cfa.

Le taux interne de rentabilité atteint 63,60% et la valeur actualisée nette atteint 18 833 775 fcfa (cf. calcul en annexe).

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Tableau 1. Principales variétés traditionnelles cultivées par région.

Variétés	Cycle (jours)	Rendement (t/ha)	Hauteur (m)	Couleur (grain)	Région de culture	Faiblesses
Dimoni	140	1,0	4,5	rouge	Savanes	Tige trop haute,
Tchouleli	135-140	1,2-1,5	4,5	blanc		cycle long
						rende-ment faible
Tchina Miri	160-165	1,5	5,0-5,5	blanc	Kara et	Tige trop haute,
Idji Imama	160-165	1,5-2,0	5,0-5,5	rouge	Centrale	cycle long,rende-
Boulé	160	1,5-2,0	5,0-5,5	blanc		ment faible
Sada Pébo	140-150	1,5-2,0	4,5-5,5	rouge	Plateaux	Tige trop haute,
Mélé Kessembé	140-150	1,1-2,0	4,5-5,5	rouge		cycle long,rende
Djoni-Yéré	140-150	1,5-2,0	4,5-5,5	blanc		-ment faible

Source: Programme Sorgho et Mil/INCV,1993

Tableau 2. Variétés sélectionnées introduites au Togo.

Variétés	Cycle (jours)	Rendement (t/ha)	Hauteur (m)	Couleur grain	Origine	Faiblesses
Framida	90-100	2,5-4,0	2-2,5	brun-rouge	ICRISAT	Très sensible aux charançons
E35-1	90	2,0-3,0	2,0	blanc-crème	ICRISAT	Sensible aux moisissures
517	135	1,5-2,0	4,5	blanc	IRAT/BF	Cycle long, tige haute
Sepon 82	105	3,0-5,0	2,0	blanc-crème	INRAN/ Niger	Sensible aux moisissures grain sucré
Blanc de Karimama	140	1,5-2,0	3,75	blanc	Benin	Cycle long, rendement faible
Jerry	90	1,5-2,5	2-2,5	blanc	Ghana	sensible aux charançons
Kadag	120	1,0-1,5	2-2,5	rouge	Ghana/BF	sensible aux charançons

Source: Programme Sorgho et Mil/INCV, 1993 & 1996

Tableau 3. Principales variétés de sorgho sélectionnées par le Programme Sorgho et Mil de l'INCV.

Variétés (jours)	Cycle (m)	Hauteurs moyen en	Rendement des grains milieu paysan (t/ha)	Couleur culture	Région de	Force/Faiblesse
SORVATO1	95-105	2-3	1,5-2,0	blanc	R.Savanes	Sensible aux moisissures
SORVATO7	95-105	2-3	1,5-2,0	blanc	« «	Bon aspect hysique des grains
SORVATO 10	95-105	2-3	2,0-2,5	blanc	« «	En obervation
SORVATO 28	95-105	2-3	2,5 3,0	rouge	« «	Bon pour pate et Tchakpa
SORVATO 33	95-105	2-3	2,0-2,5	blanc	« «	En observation

Source: Programme Sorgho et Mil/INCV, 1997

Tableau 4. Adoption des variétés améliorées de sorgho en termes de nombre de paysans.

Sites	Ceux qui sont informés et peuvent se procurer les variétés modernes	Ceux qui sont informés mais non pas utilisé les variétés modernes	Ceux qui n'ont pas adopté les variétés modernes	Ceux qui ont adopté les variétés modernes	Effectifs des chefs d'exploi-tation	Taux d'adop-tion (%)
Site I	39	1	2	38	40	95
Site II	37	4	11	30	41	73
Site III	32	7	38	1	39	2,6
Total	108	12	51	69	120	(57 = 69/120)

Source: Données de l'enquête, 1996.

Tableau 5. Adoption des variétés améliorées de sorgho en termes de nombre de paysans et de superficie.

Sites	Adoption en termes de nombre de paysans CE (%)	Adoption en termes de superficie (%)
Site I	95	74
Site II	73	33
Site III	2,6	9
Moyenne	57	38

Source: Données de l'enquête
CE = Chef d'Exploitation

Tableau 6. Principales raisons de l'adoption des variétés améliorées de sorgho sur l'ensemble des trois sites.

Raisons Principales	Effectif des CE utilisant une V.A.	Pourcentage
Rendement	16	23
Commercialisation	3	4
Cycle	19	28
Autoconsommation	23	33
Bier locale (Tchakpalo)	8	12
Total	69	100
(Na/Nt)	(69/120)	(57)

Source: Données de l'enquête
CE = Chef d'Exploitation; V.A. = Variété Améliorée
Na = Nombre de CE ayant adopté les variétés améliorées
Nt = Nombre total de CE enquêtés
Les principales raisons de non-adoption des variétés améliorées recueillies auprès des CE (cf. Tableau no 4 ci-après) sont liées au goût, à la sensibilité aux attaques de maladies et d'insectes et à la faible aptitude à la conservation après la récolte.

Tableau 7. Principales raisons de non adoption des variétés améliorées de sorgho.

Raisons	Nombre de CE n'utilisant pas les variétés améliorées	Pourcentage
Je ne trouve pas d'autres variétés meilleures que les V. T. pour le goût,résistance et conservation après récolte	21	41
Les variétés traditionnelles font meilleure pate et meilleure bier («tchakpalo»)	30	59
(Nna/Nt)	(51/120)	(42,5)

Source: Données de l'enquête
CE = Chef d'Exploitation
V.A. = Variété Améliorée
V.T. = Variété Traditionnelle
Na = Nombre de CE n'ayant pas adopté les variétés améliorées
Nt = Nombre total de CE enquêtés

Tableau 8. Impressions des paysans sur l'ensemble des variétés améliorées (V.A.) de sorgho par rapport aux variétés traditionnelles (V.T.) exprimées en pourcentage de l'effectif des paysans (CE) enquêtés par site.

Impressions	Sites	Rendement	Cycle	Goût (pâte et bier)	Résistance Aux malad. et insect.	Battage
Les V.A. sont meilleures	Site I	56	25	29	29	58,5
	Site II	90	857,5	7,5	15	37,5
	Site III	25,6	30,7	12,8	25,6	10
Les V.T. sont meilleures	Site I	26,8	17,5	63	56	9
	Site II	2,5	10	80	72,5	15
	Site III	25,6	18	41	28	18
Il n'y a pas de différence	Site I	12	7,3	4,8	7,3	19,5
	Site II	2,5	0	0	0	40
	Site III	0	2,5	5	0	25,6
Je ne peux me prononcer	Site I	4,8	15	9,7	7,3	12
	Site II	5	5	12,5	15	5
	Site III	46	43,5	41	46	46
Effectif total	Site I	41	41	41	41	41
	Site II	40	40	40	40	40
	Site III	39	39	39	39	39

Source: Données de l'enquête
CE = Chef d'Exploitation ;V.A. = Variété Améliorée
V.T. = Variété Traditionnelle

Tableau 9. Impressions des paysans (CE) sur l'ensemble des variétés améliorées (V.A.) de sorgho par rapport aux variétés traditionnelles (V.T.) exprimées en pourcentage de l'effectif total de l'échantillon.

Impressions	Rendement	Cycle	Goût (pâte et bier)	Résistance aux maladies et insectes	Battage
Les V.A. sont meilleures	57,5	59	16	23	36
Les V.T. sont meilleures	18,5	16	61	52	14
Il n' y a pas de différence	5	4	3	2,5	29
Je ne peux me prononcer	19	21	20	22,5	21
Total	100	100	100	100	100
Nombre de paysans enquêtés	120	120	120	120	120

Source: Données de l'enquête
CE = Chef d'Exploitation
V.A. = Variété Améliorée
V.T. = Variété Traditionnelle

Annexe I-Superficies et Productions de sorgho dans la Région des Savanes au Togo.

Années	Superficies totales en ha (S)	Productions totales (Q)	Rendements moyens en tonne/ha (Rm)	Superficies sous variétés améliorées en ha	Taux d'adoption (t)
1979	55000	30000	0,545	0	0
1980	55000	30000	0,545	0	0
1981	55000	30000	0,545	0	0
1982	55500	30380	0,547	1110	0,02
1983	55400	24600	0,444	2493	0,05
1984	66800	36300	0,543	4676	0,07
1985	72000	43300	0,601	6840	0,10
1986	45000	33900	0,753	5400	0,12
1987	47800	21400	0,448	6692	0,14
1988	74900	26600	0,355	12733	0,17
1989	74900	60880	0,813	14600	0,19
1990	80700	30450	0,377	17750	0,22
1991	83200	42660	0,513	19660	0,24
1992	60800	46110	0,758	15800	0,26
1993	89900	41110	0,960	26070	0,29
1994	69100	27000	0,830	21420	0,31
1995	69000	35700	0,680	24840	0,36
1996	83000	41400	0,499	31540	0,38

Sources: -Direction des Enquêtes et Statistiques Agricoles pour les données des colonnes 2 et 3 -Les données des colonnes 4 à 6 proviennent de nos enquêtes sur le terrain et de nos calculs.

Annexe II-Les données agronomiques.

Années	Rendements moyens du sorgho en t ha^{-1} (Rm)	Rendements moyens des deux variétés améliorées* de sorgho en t ha^{-1}	Gain de rendement en t ha^{-1} (dR)
1979	0,545	0	0
1980	0,545	0	0
1981	0,545	0	0
1982	0,547	0,76	0,21
1983	0,444	0,62	0,17
1984	0,543	0,76	0,21
1985	0,601	0,76	0,15
1986	0,753	0,76	0,007
1987	0,448	0,65	0,20
1988	0,355	0,65	0,29
1989	0,813	0,85	0,03
1990	0,377	0,85	0,47
1991	0,513	0,85	0,33
1992	0,758	1,02	0,26
1993	0,960	1,05	0,09
1994	0,830	1,02	0,19
1995	0,680	0,98	0,30
1996	0,499	0,98	0,48

* Il s'agit des variétés améliorées Jerry (Naga White) et Kadag

Sources: -Les rendements sont calculés à partir des données de la Direction des Enquêtes et Statistiques Agricoles.

Les rendements des deux variétés améliorées proviennent de nos enquêtes sur le terrain.

Annex III-Les Prix.

Années	Prix du sorgho en cfa t^{-1} (P)	Indice des prix à la consommation	Prix réels du sorgho en fcfa t^{-1}	Elasticité de l'offre	Elasticité de la demande
1979	47000	0,39	119898	0,8	0,4
1980	62000	0,41	151220	0,8	0,4
1981	73000	0,52	140385	0,8	0,4
1982	77000	0,58	132759	0,8	0,4
1983	81000	0,62	130645	0,8	0,4
1984	87000	0,64	135938	0,8	0,4
1985	68000	0,70	97143	0,8	0,4
1986	62000	0,75	82667	0,8	0,4
1987	57000	0,76	75000	0,8	0,4
1988	90000	0,78	115385	0,8	0,4
1989	71000	0,78	91026	0,8	0,4
1990	54000	0,79	68354	0,8	0,4
1991	78000	0,81	96296	0,8	0,4
1992	92000	0,82	112195	0,8	0,4
1993	68000	0,83	81928	0,8	0,4
1994	68000	0,88	77273	0,8	0,4
1995	123000	0,94	130851	0,8	0,4
1996	160000	1	160000	0,8	0,4

Sources: -Les informations sur les prix proviennent de la Direction des Enquêtes et Statistiques Agricoles
proviennent de nos enquêtes et calculs.

Annex IV-Les Coûts d'adoption.

Années	Coût de semences en fcfa ha^{-1}	Coût des engrais en fcfa ha^{-1}	Coût de la main d'oeuvre d'épandage des engrais et fumier en fcfa ha^{-1}	Coût nominal total d' adoption en fcfa ha^{-1}	Coût réel d'adoption En fcfa ha^{-1} (dc)
1979	0	0	0	0	0
1980	0	0	0	0	0
1981	0	0	0	0	0
1982	500	0	0	500	862
1983	500	0	0	500	806
1984	500	0	0	500	781
1985	500	0	0	500	714
1986	500	0	0	500	667
1987	2000	1000	1500	4500	5921
1988	2000	1000	1500	4500	5769
1989	2000	1000	1500	4500	5769
1990	4000	3000	2000	9000	11392
1991	4000	3000	2000	9000	11111
1992	4000	3000	2000	9000	10975
1993	4000	3000	2000	9000	10843
1994	4000	3000	2000	9000	10227
1995	5000	4000	3000	12000	12765
1996	5000	4000	3000	12000	12000

Sources du précédent tableau:
-Les données sur le coût des semences proviennent de la Direction des Enquêtes et Statistiques Agricoles et sont ajustées par nos enquêtes sur le terrain -Les données sur le prix des engrais proviennent du Service National Engrais et Moyens de Production.
-Le prix de la main d'oeuvre provient de nos enquêtes sur le terrain.
La fumier de ferme produit par les animaux de la ferme n'a pas été évalué sauf sa main d'oeuvre de collecte et d'épandage.

Annex V-Paramètres économiques.

Années	Augmentation proportionnelle de la production j = dR*t/Rm	Augmentation proportionnelle du coût d'adoption c = dc*t/Rm*P	Paramètre k k =(j/E)-c	Augmentation de l'offre dQ = QeEk/(E+e)
1979	0	0	0	0
1980	0	0	0	0
1981	0	0	0	0
1982	0,008	0	0,004	28,46
1983	0,018	0,001	0,022	143,50
1984	0,028	0,001	0,012	113,83
1985	0,025	0,001	0,003	29,89
1986	0,001	0,001	0,001	8,73
1987	0,063	0,025	0,098	558,18
1988	0,141	0,024	0,272	1931,63
1989	0,009	0,015	0,011	179,40
1990	0,276	0,097	0,102	824,96
1991	0,155	0,053	0,158	1800,10
1992	0,090	0,034	0,079	971,13
1993	0,027	0,040	0,006	-68,30
1994	0,071	0,049	0,123	886,10
1995	0,0159	0,052	0,147	1400,40
1996	0,367	0,057	0,402	4433,80

Sources: Les calculs de l'auteur

Annex VI-Coût de la recherche et de la vulgarisation.

Années	Coût de la recherche d'adaptation	Coût de la vulgarisation	Coût nominal total
1979	6 300 000	0	6 300 000
1980	6 300 000	0	6 300 000
1981	6 000 000	0	6 000 000
1982	6 000 000	1 800 000	7 800 000
1983	6 000 000	1 800 000	7 800 000
1984	4 500 000	1 800 000	6 300 000
1985	4 500 000	1 500 000	6 000 000
1986	0	1 500 000	1 500 000
1987	0	0	0
1988	0	0	0
1989	0	0	0
1990	0	0	0
1991	0	0	0
1992	0	0	0
1993	0	0	0
1994	0	0	0
1995	0	0	0
1996	0	0	0

Source: Les données sur les coûts de recherche d'adaptations et de vulgarisation proviennent d'une estimation des informations obtenues à partir des documents comptables de la Direction Régional du Développement Rural(Région des Savanes), de la Direction de la Société Togolaise de Coton (Région des Savanes) et du Programme Sorgho et Mil de la Direction de l'Institut National des Cultures Vivrières.

VII-Bénéfice net de la recherche et de la vulgarisation.

1)Années	Gain social brut (Fcfa) GSB = kPQ-0,5*kPdQ	Coût réel total de recherche et vulgarisation (Fcfa)	Gain social net (Fcfa)
1979	0	16 071 429	-16 071 428
1980	0	15 365 854	-15 365 854
1981	0	11 538 462	-11 538 462
1982	14 160 994	13 448 276	712 718
1983	70 096 572	12 580 645	57 515 927
1984	57 937 529	9 843 750	48 093 779
1985	10 884 099	8 450 704	2 433 395
1986	2 705 051	2 054 795	650 257
1987	15 491 423	0	154 941 423
1988	805 453 128	0	805 453 128
1989	61 147 082	0	61 147 082
1990	208 597 058	0	208 597 058
1991	636 322 571	0	636 322 571
1992	404 280 933	0	404 280 933
1993	-21 000 654	0	-21 000 654
1994	252 553 918	0	252 553 918
1995	673 683 251	0	673 683 251
1996	2 517 826 504	0	2 517 826 504
Total		89 353 914	5 760 235 548

Source: Calculs de l'auteur

VIII-Principaux résultats et analyses de sensibilité. Gains sociaux obtenus de la recherche et de l'adoption des variétés améliorées de sorgho.

Indicateurs	Valeurs
TIR	63,60
VAN	18 833 775
GSN	5 760 235 548

Si les coûts de recherche et d'adoption augmentent.

	Taux de croissance des coûts			
Indicateurs	25%	50%	75%	100%
TIR	57,56	53,01	49,41	46,46
VAN	12 155 153	5 476 530	-1 202 092	-7880715
GSN	5 737 897	5 715 558 591	5 693 220 113	5 670 881 635

Si les coûts d'adoption augmentent.

	Taux de croissance des coûts			
Indicateurs	25%	50%	75%	100%
TIR	62,52	61,34	60,08	58,73
VAN	16 718 983	14 598 364	12 471 916	10 339 640
GSN	5 363 210 756	4 964 759 230	4 564 880 972	4 163 575 980

Source: Calculs de l'auteur

New Sorghum and Millet Cultivar Introduction in Sub-Saharan Africa: Impacts and Policy Implications

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Summary

In spite of substantial introduction of new sorghum and millet cultivars in semiarid sub-Saharan Africa, there has been minimum aggregate impact on yields. Large yield increases occurred only in areas where inorganic fertilizers and improved water retention or irrigation were combined with new cultivars. Given the low soil fertility and irregular rainfall in semiarid regions, both increased water availability and adequate levels of essential nutrients are necessary for substantial yield increases. The cultivar-alone-strategy is unlikely to have a significant sustainable yield effect and therefore to reduce poverty in semiarid Sub-Saharan Africa.

Introduction

Poverty alleviation has been a principal objective of technology development strategies for crops with drought resistance in Sub-Saharan Africa, specifically sorghum, millet, peanut, and cowpea . Poverty is concentrated in rural areas[4] and a high proportion of the population (25%) of Sub-Saharan Africa lives in semiarid regions (Sanders, Shapiro and Ramaswamy 1996, p. xix). Since sorghum and millet are the principal staples of the poor, sustainable improvement in their productivity would contribute to alleviation.

Farming in drought areas has been characterized as a subsistence activity with farmers producing many products primarily for their own consumption and using few purchased inputs. With climatic and price variations, poor soils, insect and disease problems, agriculture is risky there (Anderson and Dillon 1992). Moreover, rather than focusing on profitability and risk reduction in agriculture, public policy has been to search for technologies involving minimal expenditures by farmers and no foreign exchange. Hence, the emphasis in new technology introduction has been on new cultivars and the increased utilization of on-farm and within region resources. Unfortunately, this new cultivar emphasis has not been as successful in the marginal resource areas where sorghum and millet are concentrated as for the principal food crops (rice, wheat, and maize) in the better endowed regions (Byerlee 1996, p. 701).

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The concern of this paper is to evaluate the success of new technology introduction for sorghum and millet in Sub-Saharan Africa and then to make some policy recommendations to accelerate technology diffusion. The paper specifically aims at addressing the following questions or issues. First, have new cultivars been introduced and, if so, what are the returns to these research investments? Secondly, what are the effects of the new cultivars and associated technologies on aggregate yield levels? The next three sections respond to these questions drawing upon the field studies in various countries. In analyzing aggregate effects we identify two predominant systems of technology introduction. Then, two sections consider the origin of present public policy and alternative approaches to facilitate the transformation of the agricultural sector. Finally, the conclusions attempt some general policy inferences.

Cultivar Introduction In Sub-Saharan Africa

Despite lagging behind many other commodity-based research programs, such as maize and cotton, sorghum and pearl millet research in Sub-Saharan Africa has been successful in diffusing a large number of new cultivars onto farmers' fields.

The last two decades of research have resulted in the release of over 40 sorghum cultivars in 23 countries and 16 millet cultivars in 12 countries (Miller et al. 1996; Rohrbach 1996). In West Africa, new sorghum cultivars include S-35 in Cameroon and Chad; ICSV 400 (Malisor) in Mali; ICSV 1049 and 1002 in Burkina; Framida in northern Ghana, Togo, Cote d'Ivoire and Burkina; and Sepon 82 in Niger. New millet cultivars include IBMV 8001 and IBMV 8004 in Senegal, and Toroniou C-1 in Mali (Table 1).

In East and Central Africa, the famous Serena and Seredo were released in Uganda in the '50s and '60s with their high tannin and bird resistance. In Kenya, Rwanda and Burundi, new sorghum cultivars have been introduced for confectionery products and for the brewing industry. In Ethiopia, several new cultivars, including Gambella 1107, which then became E-35-1 in Burkina Faso, have become available (Sanders, Bezuneh, and Schroeder 1994, p. 14). In Sudan, several new cultivars were released, the most successful of which is Hageen Dura-1 (HD-1), the country's first commercial sorghum hybrid. In southern Africa, the ICRISAT Sorghum and Millet Improvement Program (SMIP) developed a wide range of improved cultivars. So far, 18 sorghum and 9 pearl millet cultivars have been released in 9 southern African countries (Rohrbach 1996). In South Africa a wide range of high-yielding hybrids are available, of which NK 283, a medium to long-maturing hybrid, is widely grown by commercial farmers on 50-70 percent of the sorghum area[5].

Among the large number of new cultivars, seven success stories of diffusion were documented[6] (Table 2). Outside of South Africa and Sudan, most of the new cultivars are open-pollinated and early maturing. Thus, drought escape was a principal factor in the breeders' strategy to overcome the moisture constraint in the semiarid environments. During the last 30 years in the Sahel rainfall has been one standard deviation below the long-term normal (Fig. 1). In southern Africa, there were several major droughts in the '80s and '90s.

Since there were substantial drought problems in the '80s, the earliness of these cultivars has been much appreciated. However, short-seasoned cultivars are generally adopted by farmers as part of a portfolio strategy with other longer-season cultivars to take advantage of the years when rainfall is adequate or good. Thus, we can expect only small-scale or partial adoption of early maturing cultivars.

Earliness gives drought escape but reduces the potential of the plant to respond to better growing conditions since the plant will not be in the field long enough to take advantage of these conditions (Shapiro et al. 1993). An illustrative example of the disadvantage of earliness is S-35. S-35 was selected from ICRISAT material in northern Nigeria and then made available in regional trials to Cameroon. In 1984, widespread trials on farmers' fields were implemented. In this major drought year, the yields of the early S-35 doubled the local and other new cultivar yields (Kamuanga and Fobasso 1992, p. 22; Johnson 1987, p. 657). Trials continued another three years but in those normal and good rainfall years after 1984, there was no yield advantage to S-35. For a portfolio addition to protect against dry years, S-35 was very popular. After its release in 1986, farmers in northern Cameroon began rapidly introducing S-35 into their mix of cultivars of different season lengths. It was thus a disaster-avoidance strategy but has not led to increased input use or substantial yield gains, except in low rainfall years.

The diffusion of short-maturing cultivars was very successful in low-rainfall years and regions. Unfortunately, farmers in these regions are hesitant to use fertilizers due to the risk of fertilizer response in years with water stress. Without fertilization, yield increases from introduction of the new cultivars were small. In on-farm trials in Zimbabwe in 1992/93 and 1993/94, the yield gains of SV 2 and PMV 2 over local varieties were only 18 and 14%, respectively (Ahmed 1996). In the Gezira, the yield of HD-1 without fertilization and improved agronomy had no advantage over traditional sorghum cultivars (Ahmed and Sanders 1992).

For a substantial yield increase, it is necessary to use fertilizer. Inorganic fertilizers can be combined with rotations and manure but the deficits of nitrogen and phosphorus are generally so severe that some inorganic fertilizers will be required. In Zimbabwe and Namibia, governments have been promoting both improved cultivars and inorganic fertilizers. However, inorganic fertilizer use on sorghum and millet is still minimal in these countries.

Field surveys in several countries have indicated that diffusion of these improved sorghum and millet cultivars is delayed by the slow evolution of the seed industry. The lack of sufficient high-quality seeds was cited as the major constraint to adoption of improved cultivars by 60%, 66% and 45% of the non-adopters of PMV 2, SV 2 and the new sorghum cultivars in Zambia, respectively. In Sudan, the public sector seed producers were unable to respond to the rapidly increasing demand for HD-1 seeds (Ahmed and Sanders 1992). In the early '90s, approximately one-third of Gezira farmers complained about their inability to obtain HD-1 seeds and/or inorganic fertilizers (Nichola 1994).

In south African countries, most improved sorghum and pearl millet seeds are distributed through government drought relief agencies and NGOs. Trade in seed is limited and the private sector has shown little interest in selling open-pollinated varieties to small-scale farmers. Rather than distributing sorghum and millet seed through outlets in rural areas, seed companies find it less risky and more profitable to sell in bulk to government agencies and NGOs. In contrast, private seed and other input markets are well-established in South Africa, and the private seed sector is reentering the production of hybrid sorghum seeds in the Sudan.

Although the seed market for small grains is limited[7], government programs have played an important role in promoting new sorghum and millet cultivars and accelerating adoption. If farmers depend upon NGO and government handouts of seeds, the development of private marketing institutions will be hindered unless sufficiently high prices are charged so that a private company can make a profit. In the seed industry, a price ratio of 8:1 to 10:1 is generally the rule of thumb for a sufficient difference between seed and grain prices for a private seed producer to have a sufficient margin to make the necessary investments.

Returns to Research

All these new cultivars were selected from germplasm made available by ICRISAT to the national programs (except PMV 2). The internal rates of return were calculated for the costs[8] and benefits to the country. The low research costs for the national systems and short lag time contributed substantially to the returns even though yield gains were small and diffusion levels only moderate. The national programs had the advantage that they could borrow technology especially new cultivars from other institutions outside the country.

The estimated internal rates of return (IRR) for research expenditures on cultivar development and diffusion were generally low, except for HD-1 and PMV 2 (Table 3). The measure for HD-1 is much higher, 36%, due to the larger yield gains achieved under irrigation and fertilizer application. The high IRR estimates for PMV 2 are due to the low research costs in development since PMV 2 was only a small part of a larger portfolio of ICRISAT's program in Zimbabwe.

Even though the total area in HD-1 was only 35,000 ha in 1996, or 17% of the sorghum area in the Gezira project, the IRR is the highest (Table 3). Substantial yield increases resulted from the improved agronomic environment, which accompanied adoption of HD-1. Besides irrigation, this included increasing levels of inorganic fertilizers and improved management practices.

The returns to the other sorghum cultivars were smaller but not negligible. These IRR estimates consider the impacts of the new cultivars alone. If fertilization had been introduced, the impacts of the new cultivars would have been increased. The IRRs for SV-2 would increase to 39% and PMV 2 to 58% with moderate fertilization (Ahmed 1996). In on farm-trials, the yield gains of these new cultivars with moderate fertilization over traditional cultivars without fertilization were 82% and 80%.

Sorghum and pearl millet production in Sub-Saharan Africa follows two distinct development paths with respect to adoption of improved technology: an intensive path and an extensive path. The observed intensive development path utilizes hybrids and inorganic fertilizers under irrigation or with water-harvesting technology. This system characterizes sorghum production in the irrigated Gezira of Sudan and semiarid regions of South Africa.

The extensive system, on the other hand, uses a mixture of traditional and improved, early maturing cultivars, with little or no purchased inputs under rainfed conditions and generally without effective water conservation. This system dominates the small-scale farming that produces most of the sorghum and pearl millet in the remaining parts of sub-Saharan Africa.

Generally in Sub-Saharan Africa, new sorghum cultivars were adopted as a risk-avoidance strategy without improved agronomy, neither fertilization nor water retention technology. In Zambia, none of the small-scale farmers had ever used fertilizer on sorghum (Chisi et al. 1997). Less than 2% of the farmers surveyed in southern Zimbabwe used fertilizer with the new varieties (Ahmed 1996). These minimal gains are not surprising given the low fertility levels, especially for nitrogen and phosphorus, characteristic of many of the soils of Sub-Saharan Africa (Buresh, Sanchez, and Calhoun 1997; Crosson and Anderson 1994; p. 23) and indicate the failure of an extensive development strategy in Sub-Saharan Africa[9].

Evaluating the Aggregate Impact

Since 1985, sorghum area in sub-Saharan Africa has expanded considerably, reaching a record high of over 23 million hectares in 1997 (Fig. 2) with production increasing at 2.9% a year. Unfortunately, average yields have been declining at 0.8 percent a year[10] (Fig. 2). With population growing at an annual rate of 2.8%, sorghum production per capita growth is negligible (0.1%).

Only in the two cases of sorghum in the Sudan and South Africa are aggregate yield increases clearly visible. Figure 3 compares sorghum yields on the main irrigation project of the Gezira (approximately 50% of the irrigated area) with those in the mechanized drylands, the main sorghum production area the Sudan. From 1985-1996, irrigated yields increased by 3%, whereas on the mechanized drylands they declined by 0.3% per year.

In contrast to the intensive system of sorghum production in Gezira, sorghum in the mechanized vertisols of Sudan is produced extensively without fertilization or water-retention technologies, but new cultivars are widely adopted. Among the sorghum cultivars grown, many were introduced in the early ‘70s as combinable high-yielding cultivars (for example, Dabar 1 and Gadam Elhamam 47; see Nichola and Sanders 1996). In the ‘90s, with emphasis on Striga resistance, three new cultivars were introduced (SRN 39, IS 9830 and M 90393) with some diffusion being reported (Rohrbach 1996). Nevertheless, even with these new cultivars there were apparently no aggregate yield effects on these vertisols.

Sorghum production in South Africa is another example where high-yielding hybrids were combined with inorganic fertilizers and water-retention technologies. 50 to 60% of the South African sorghum area is in NK 283, a mid to late maturing hybrid (Dr. W.G. Wensel, Agricultural Research Council, Grain Crops Institute, Potchefstroom, communication).

On the sandy soils of the semiarid regions of South Africa, larger sorghum producers store water in the soil by controlling the weeds in the off season and cultivating to absorb more water. A sub-surface crust one to two meters down holds the water and makes it accessible to the sorghum. With the utilization of this water conservation technique, the South Africans then do not need to select for earliness for drought escape[11].

Sorghum yields averaged 1.8 t ha^{-1} in South Africa since 1980 despite the six drought years after 1980 and the 1991-92 drought. This contrasts with the 0.8 t ha^{-1} in the rest of Sub-Saharan Africa (Fig. 4). Sorghum yields in South Africa show substantial variation with weather but they are substantially higher than those of the three countries with rapid introduction of the new sorghum cultivars (Fig. 5). In the two cases cited where new cultivars were combined with inorganic fertilizers and either irrigation or water harvesting techniques, the aggregate impacts are very clear.

The success of the intensive production pattern of sorghum in Sudan and South Africa is similar to the success of cotton in Francophone Africa and maize technologies in the Sudano-Guinean zone of the Sahel (see Sanders, Shapiro and Ramaswamy 1996; pp. 54-58). In these regions, new cultivar introductions were combined with crop-management improvements, including increases in fertilization, density, and pest control. This maize technology introduction has resulted in rapid increases in maize yields[12] amounting to 1.2 to 4.9% annual growth rates in Mali, Ghana, and Burkina Faso (Fig. 6). From the mid-'60s, cotton yields in Burkina Faso increased from less than 200 kg ha^{-1} at an annual growth rate of 5.6% to more than 1 t ha^{-1} in the 1990s (Fig. 7). Similarly, over 60% of the threefold increases of sorghum yields in the United States in 30 years were due to improved agronomy practices, especially fertilization, the use of herbicides, and water control (Miller and Kebede 1984, pp. 6, 11).

Our principal explanation for the limited aggregate gains for sorghum and millet is the over-reliance on a cultivar alone strategy in the harsh environments where sorghum and millet are produced[13]. In these agroecological zones, both water stress and inadequate soil fertility are generally encountered. Higher input use to simultaneously overcome these two constraints is necessary to obtain significant yield effects from new cultivars of sorghum and millet. Fuller tests of this hypothesis about increasing yields in various semiarid regions in West Africa and the Sudan are undertaken in Sanders, Shapiro and Ramaswamy (1996, Chs. 3-6).

Technology Introduction and Economic Policies

Historically, one major difficulty in constraining the growth of the agricultural sector in West Africa has been the poor choice of economic policies by governments. These policies were oriented toward urban residents and directly and indirectly taxed the agricultural sector. One principal indirect tax has been overvalued exchange rates leading to artificially low prices for cereal imports. This was an excellent strategy for keeping down cereal prices paid by urban consumers but served as a disincentive to farmers for investing in inputs or on-farm investments. To offset the depressing effect of cheap food policies, governments frequently relied on subsidies for inputs until these were eliminated by the structural adjustment programs of the '80s. With low expected profitability of cereal production, it is a rational strategy for farmers to retreat to subsistence cropping (as farmers did in the U.S. during the Depression), marketing little, and purchasing very few inputs. This environment has to be changed and cereal production made more profitable for farmers to be interested in purchasing higher levels of inputs.

In the Sahel (and the rest of the French economic community), one public policy variation was a currency pegged to the French Franc. The CFA became substantially overvalued only after 1986 (IMF 1994). However, creation of a drought mentality has led to periodic appeals for food aid whenever cereal prices increase. Food price policy needs to separate between reducing malnutrition by increasing incomes of the poor and improving farmers' incomes so that they will invest in inputs and soil improvements. An overemphasis on maintaining low food prices ensures that agriculture will not be profitable and farmers will move back to subsistence. Clearly, the combination of keeping down cereal prices and the production risks of semi-arid regions have reduced the incentives for improving cereal productivity in the Sahel.

With structural adjustment, this anti-agricultural orientation of economic policy is changing since one principal objective of these programs is to make agriculture more profitable. The recent policy reforms and the higher sorghum prices appear to have accelerated the diffusion processes of HD-1 in the Sudan, SV-2 in Zimbabwe, and Okashana I in Namibia. But in the Sahel, the drought mentality persists among public policymakers. As a consequence the first response of public policymakers to increased cereal prices is to look for cereal aid shipments from donors. The need for agriculture to be profitable in order for farmers to increase expenditures on inputs and on-farm investments ought to be more firmly established in Sub-Saharan Africa.

Contrary to the widely held hypothesis, trade and exchange rate reforms, associated with the structural adjustment, do not make the poor worse off. Rather, their principal effect is to diminish the rents obtained by the urban middle class, according to a 10 country study (Sahn, Dorosh and Younger 1996; p. 719). For the urban middle class, including the very influential government employees, real incomes were reduced with structural adjustment. Hence, the continuation of structural-adjustment policies requires resisting the traditional power holders in these societies and has depended upon outside pressures from donors (see Sachs 1989, pp. 275-284).

Role of the Public Sector

The release of early maturing cultivars was seen by many as a low cost strategy to effect marginal improvements in sorghum and millet yields. However, after nearly two decades of sorghum and millet research in Sub-Saharan Africa, there is no evidence of any aggregate yield improvement (Figs. 4 and 5). Given the harshness of the semiarid regions, both increased water availability and higher principal soil nutrient levels apparently will be necessary in order to increase yields substantially.

There is much discussion of substituting for soluble inorganic fertilizers with organic fertilizers, rotations, rock phosphate and several other more exotic or region-specific alternatives. However, cereal yields have nowhere been substantially increased without moderate levels of inorganic fertilizers. These other soil fertility measures need to be thought of as complements to rather than substitutes for inorganic fertilizers (Quiñones, Borlaug, and Dowswell 1997). It is unlikely that sub-Saharan Africa will make scientific breakthroughs in soil fertility or change the basic economics of these would be substitutes. Without combining new cultivars with increased water and inorganic fertilizers, national yields will remain low or decline. Then research programs will only have limited impacts on farmers' incomes, nutrition, and food security.

The combined technology of inorganic fertilizers, increased water availability, and new cultivars is expected to substantially increase yields and improve farmers' incomes and nutrition. Organic fertilizers will frequently need to complement the inorganic ones. Sustainable increases in output will depend upon the improved functioning of input and output markets and on policies to increase farmers' incentives to make the necessary investments. Farmers need to be able to obtain improved seed, fertilizer, and credit, and to profit from selling surpluses. Policy measures that reduce the prices paid by farmers for the inputs used or increase the prices received by farmers for the resulting outputs will strengthen farmer incentives to adopt these innovations (Crosson and Anderson 1995, pp. 28).

At the initial stage, public sector involvement in delivery of quality seed and inorganic fertilizer often is required to provide the inputs required to accelerate adoption. The public sector has been involved in seed distribution in many countries, even though the focus was on drought assistance rather than new cultivars. Governments need now to improve the distribution channels for quality seed and fertilizer. Over time and as the adoption process proceeds, these activities will be taken over by the private sector (for a Sudanese case study see Sanders, Shapiro, and Ramaswamy 1996, pp.114-134).

The demand for cereals tends to be inelastic. If production increases rapidly with technological change, then prices decline substantially and reduce the incentive to adopt the technology. The prices of basic staples often collapse in good rainfall years as in the Sudan the year after the drought of 1984. This price collapse temporarily halted the adoption of HD 1 (Ahmed and Sanders 1991). For both types of price decline resulting from good weather and technological change, governments need to promote alternative uses of basic cereal staples.

There are many uses of most basic food staples. Market development, as for the use of domestic cereals in bread and beer, can serve an intermediate function until domestic incomes rise sufficiently to begin the rapid dietary change to animal products and therefore the shift to the use of cereals as feed. As technological change lowers the marginal cost of production and structural adjustment programs reduce the price distortions favoring cereal imports, the traditional cereals (sorghum and millet) will be able to compete favorably with food imports in the domestic market.

The important point here is the need for governmental concern with farm incomes and not just with maintaining low food prices for urban consumers. The niche crops will make a few farmers wealthy. But there are many options for expanding demand for traditional food crops, and a large sector of farmers already know how to grow them.

If sorghum and millet are not sufficiently profitable crops because markets do not expand or governments continue to provide poor policy support, then farmers will either not use inputs or will use them on smaller areas with sorghum and millet. In this case regional and international research priorities will need to shift from the traditional cereals since adoption of cultivars alone is insufficient to improve yields. A poverty alleviation policy of introducing cultivars alone or with some soil fertility measures but without inorganic fertilizer will not be sustainable as soil nutrient mining continues.

During the last two decades, increases in sorghum and millet output in Sub-Saharan Africa to feed the growing population were possible only through rapid area expansion because yields were low and declining. In the long-run, the current area expansion will be reversed by successful implementation of the combined technology. Over time, as the benefits of combining moderate levels of inorganic fertilizers, water retention and improved cultivars become apparent, farmers will gradually increase the level of input use by reinvesting part of the additional gains. As this intensification process continues, the area in traditional cereals will diminish and farmers will shift to higher value or cash crops in the long-run.

Conclusions

In sub-Saharan Africa, the returns to research programs for sorghum and millet have been low to moderate where only new cultivars were introduced. Everywhere in the world, including Sub-Saharan Africa, that yields have been successfully increased in semiarid regions, more water and inorganic fertilizers have been required . The breeding effort has been outstanding and needs to continue, but we need to make things easier for the breeders with an emphasis on improving the production environment and increasing the profitability of traditional cereal production. Short-term yield increases that are not sustainable due to increasing soil fertility deficits will not have long-term effects on poverty reduction.

An important issue for this region is whether low input strategies have been prompted by the poor resource base and riskiness of these agricultural systems or by the overemphasis in public policy on maintaining low food prices to the detriment of the modernization process in agriculture. To transform the agricultural sector in semiarid regions, farming needs to be profitable and risk reduction feasible, thereby encouraging farmers to purchase more inputs and increase land productivity.

The major emerging constraint, once the diffusion process of new cultivars and associated technologies has begun, is the ability of input markets (seeds, fertilizer, and credit) to respond to rapidly increasing demands. Attention to the evolution of new uses in the product markets should also accelerate diffusion by moderating the between season price collapses and partially offsetting the long-run price decline resulting from successful technology introduction.

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Notes

[4] In 1990 48% of the population of Sub-Saharan Africa or 218 million people were living in poverty (World Bank, 1992, p. 30). Sorghum and millet contribute to the food security of many of the world's poorest, most food-insecure, agroecological zones (FAO/ICRISAT, 1996).

[5] These South African cultivars include medium- and medium- to long-maturing (PAN 8564, NS 5511, SNK 3003, SNK 3939, and SNK 3860), and short- and medium- to short-maturing hybrids (PAN 8446, PHB 9467, and Buster).

[6] Only seven success stories were documented here because most of these new cultivars were only recently released. Documentation and *ex-post* impact assessment can be undertaken when the cultivar is widely accepted and grown by farmers.

[7] Exceptions need to be made for the production of hybrid seeds by two public sector agencies in the Sudan. The private sector companies have been returning in the '90s (Sanders, Shapiro, and Ramaswamy, 1996, pp. 121-129). In South Africa both private companies and agricultural cooperatives are very active in seed distribution.

[8] Note that the principal for identifying costs is to include all expenditures necessary for national adaptation and diffusion within the country. This does not include the costs of the international research system for the development of the cultivar before it arrived in the country. In the studies reviewed here, direct ICRISAT research expenditure in the particular country, including scientists' travel, national and ICRISAT scientists' time spent in the country, plus material and equipment provided by ICRISAT were included. If these costs had not been incurred by the international center, they would have had to be made by the national system. Costs also include the costs of the national systems in testing and adapting and the costs of the extension service in the diffusion. Farmers' additional costs are also taken into account in the analysis.

[9] Sorghum yields in Sub-Saharan Africa were actually declining over the past two decades. They fell by 1% during the 1980s and declined by 1% annually between 1979 and 1994 (FAO and ICRISAT 1996). Between 1980 and 1997, yields were falling at an annual rate of 0.8%, area was expanding at a 3.7% rate, with production increasing at a rate of 3% per year (FAO 1998).

[10] Similarly, millet area was expanding at an annual rate of 4.1%, and production at 3.3% while yields were declining at 0.7% a year between 1980 and 1997 (FAO, 1998).

[11] With high fertilization and irrigation on these sandy soils, sorghum yields of 7 t/ha have been achieved (J.C. Pretorius, personal communication).

[12] Clearly, there are problems with aggregate data in Sub-Saharan Africa, especially for crops that are principally used for home consumption. However, if these aggregate yield effects can be estimated and are significant in a number of countries for maize, we should be able to evaluate them for sorghum and millet.

[13] Our conclusions of no aggregate gains in sorghum and pearl millet yields, except where fertilization and irrigation or water harvesting were practiced, are consistent with the assertion of the 1994 report of the Technical Advisory Committee (TAC) on CGIAR commitments to West Africa. Here, it is stated that there has been no impact in West Africa from ICRISAT efforts to introduce sorghum and millet technologies and the report

considers it unlikely that there will be effects in the future (CGIAR 1995; p. 2). Nevertheless, many new cultivars have been released recently and large future impacts are possible if complementary technologies are introduced. Further investments in the evolution of input and output markets will be necessary to increase the profitability of these intensive technolog

Table 1. NARS-ICRISAT sorghum and millet cultivars in the Sahel.

Cultivar[1]	Country	Area of adoption	Source[2]
S-35 (S)	Cameroon Chad Northern Nigeria	33 and 27 % of sorghum area in Cameroon and Chad, respectively	Yapi et al. 1997
Framida (S)	Ghana Togo Côte d'Ivoire	Firm data not currently available	
GB 8735 (M)	Chad	30,000 ha	Breeders' estimate
ITMV 8001	Chad	10,000-20,000 ha	Breeders' estimate
IBMV 8001			
IBMV 8004 (M)	Senegal	10,000-30,000 ha	Breeders' estimate
ICSV 400 (S)	Nigeria	4,800 ha	For Guinness brewery
ICSV 400 (S)	Mali	20-30% adoption	ICRISAT field study in the region survey
ICSV 1049			
ICSV 1002 (S)	Burkina Faso	firm data not currently available	Breeders' estimate
ICSH 89002 NG	Nigeria	10 tons of seed sold (1992-95)	Estimate obtained from Premier Seed Co. (Hybrid sorghum)
SEPON 82 (S)	Niger	Firm data not currently available	Diffusion study in progress
Toroniou C-1 (M)	Mali	Diffused near the Cinzana station	Breeders' estimate

[1] For ICRISAT releases, the code for sorghum (S) or millet (M) is the third letter. For others, sorghum (S) and millet (M) are identified in parenthesis.
[2] Estimates of economists and breeders in ICRISAT-WCA are based on their field data or interviews with national scientists. Estimates for cultivars ICSV 400 and ICSH 89002 NG were obtained from the companies listed.
Source: Miller et al. (1996).

Table 2. Selected characteristics of the successful new sorghum and millet cultivar introductions.

Cultivar[a]	Country	Year of release	Current adoption[b]
HD-1 (S)	Sudan	1983	17% (1993)
S-35 (S)	Cameroon	1986	33% (1996)
	Chad	1989	27% (1996)
SV 2 (S)	Zimbabwe	1987	36% (1995)
Zambian cultivars[c] (S)	Zambia	1987-1993	35% (1996)
PMV 2 (M)	Zimbabwe	1991	26% (1995)
Okashana 1 (M)	Namibia	1990	35% (1993)
NK 283	South Africa	Unknown	50-70% (1998)

[a] Sorghum and millet are, respectively, identified by the letters S and M in parentheses.
[b] Latest available information with the year in parentheses.
[C] Include two hybrids and three open-pollinated cultivars, of which Kuyuma and Sima (released in 1989) and MMSH-928 (released in 1993) are the most widely adopted.
Source: Anandajayasekeram, et al., 1995; Ahmed and Sanders, 1992; Sanders et al., 1994; Ahmed, 1996; Yapi et al., 1997; and Chisi et al., 1997.

Table 3. Estimated rates of return to sorghum and millet cultivars in Sub-Saharan Africa.

Cultivar	Internal rate of return
HD-1	36% (low fertilization)
S-35	2%
SV 2	18%
Zambian cultivars[b]	12%
PMV 2	31%
Okashana 1	13%

Sources: Anandajayasekeram, et al. 1995; Ahmed and Sanders 1992; Sanders 1994; Ahmed 1996; Chisi et al., 1997.

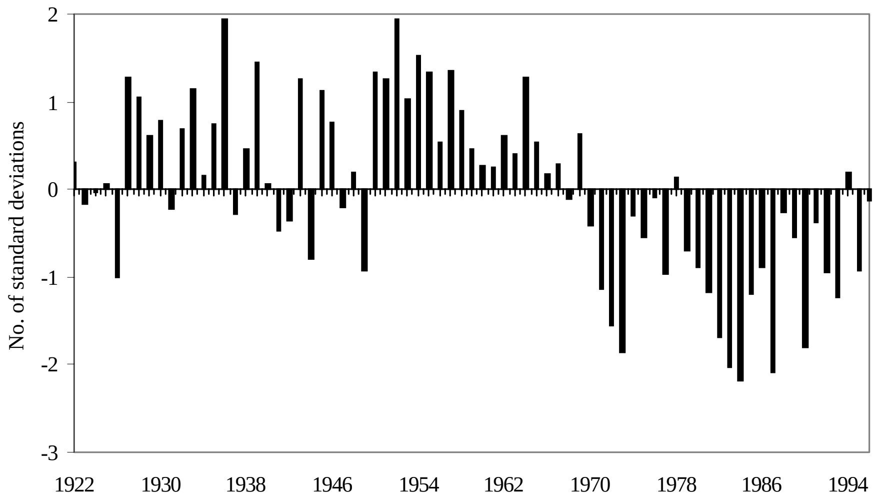

Figure 1: Rainfall in the Sahel 1922-1996.

Note: This figure graphs the number of standard deviations from average long-term rainfall in the Sahel for each year. The base long-term mean was calculated from rainfall over the period 1922-1996.

Source: Updated from USAID/FEWS (1994, p.1). Reprinted with permission of USAID/FEWS.

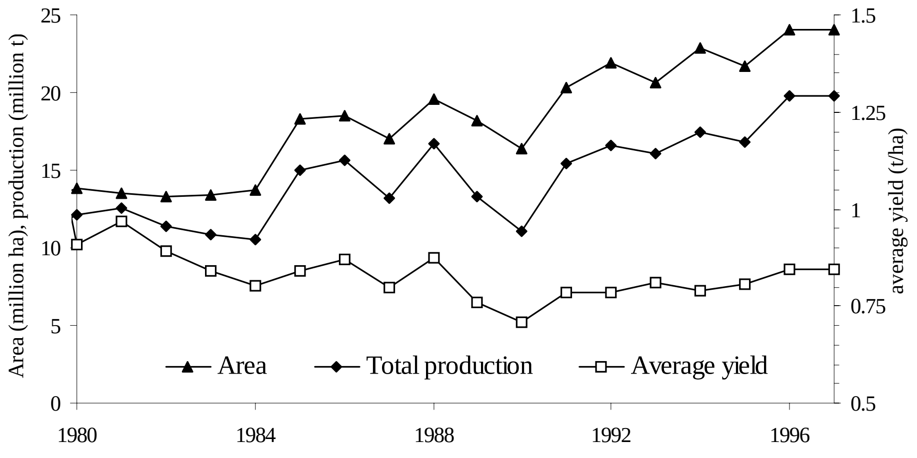

Figure 2: Sorghum area, production and average yield in Sub-Saharan Africa 1980-97.

Note: From 1980 to 1997, the annual rate of growth of sorghum area in Sub-Saharan Africa was 3.7%, production 2.9% and yield -0.8%.
Source: FAO 1998.

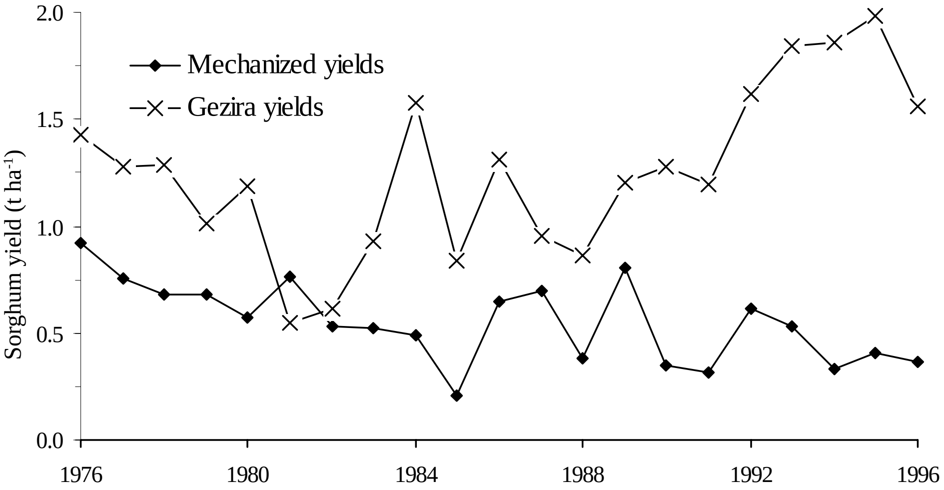

Figure 3. Sorghum yields in the irrigated Gezira and the mechanized sector of Sudan (1976-96).

Note: From 1985 to 1996, the annual rate of growth of yield in the Gezira was 3% and in the mechanized zone was -0.3%.
Source: Sanders et al. 1996; Nichola and Sanders 1996.

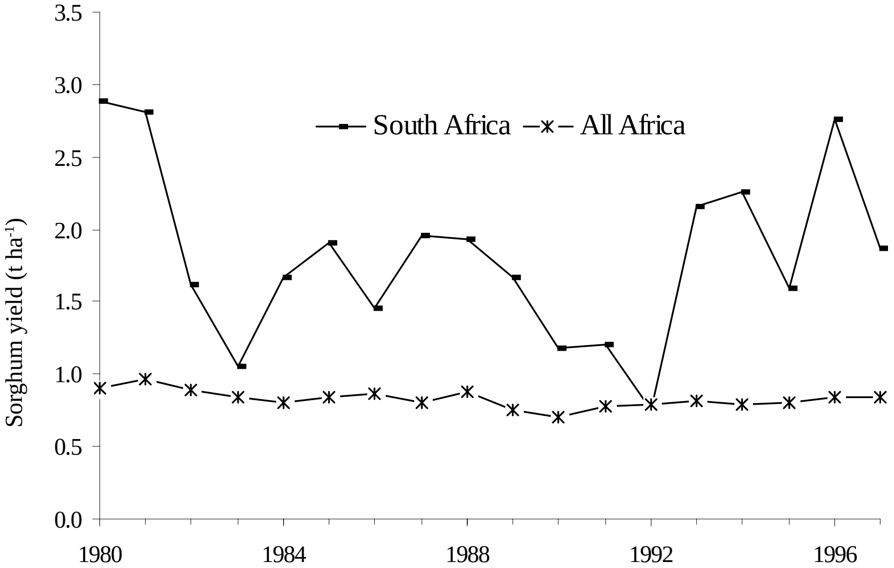

Figure 4. Comparison of sorghum yields in South Africa and all Sub-Saharan Africa.

Source: Data from FAO 1998.

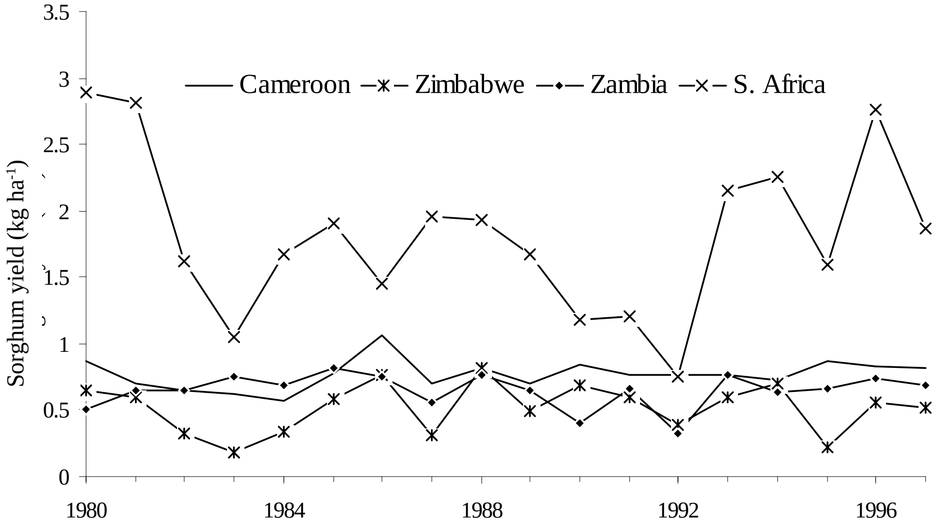

Figure 5. Sorghum yields in Cameroon, Zimbabwe, Zambia, and South Africa
Source: Data from FAO 1998.

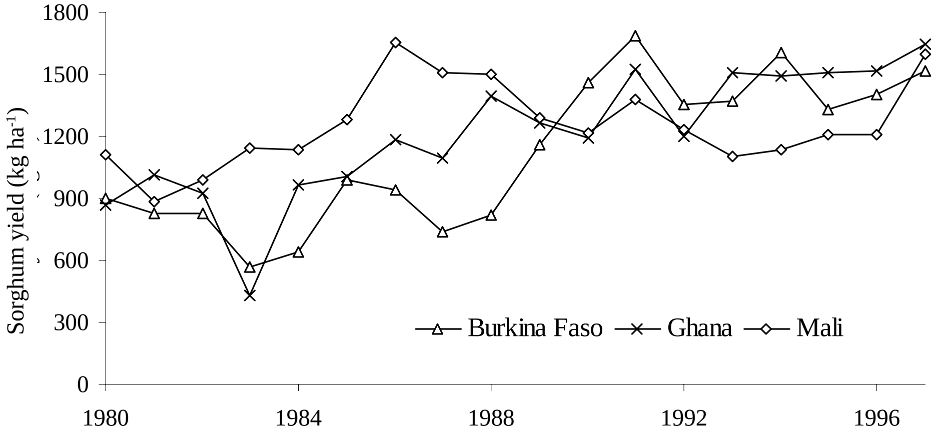

Figure 6. Maize yields in Burkina Faso, Ghana, and Mali 1980-1997

Note: Growth rates (per annum) for the period 1980-97 were: Ghana, 4.5%; Burkina Faso, 4.9%; and Mali, 1.2%.
Source: Data from FAO 1998.

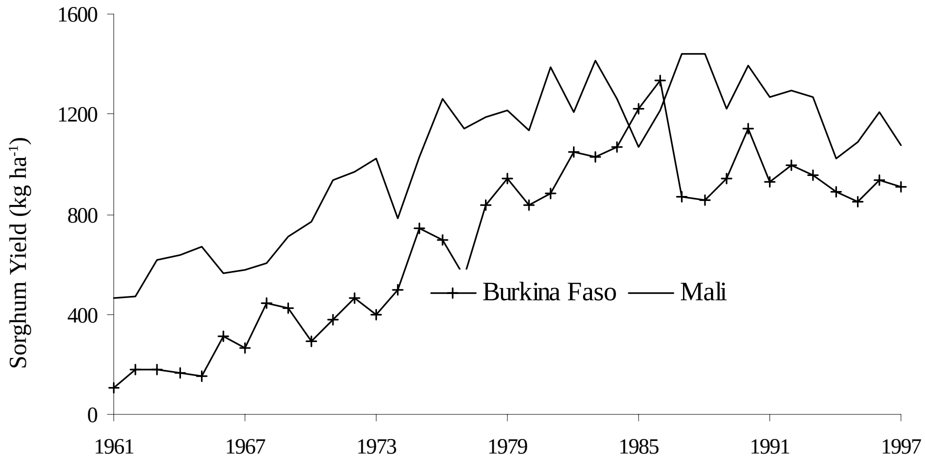

Figure 7. Cotton yields in Burkina Faso and Mali 1961-1997.

Note: Growth rates (per annum) for the period 1961-97 were: Burkina Faso, 5.6%, and Mali, 2.6%.

Source: Data from FAO 1998.

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About ROCARS

Sorghum is one of the most important cereal crops in the semi-arid countries of West and Central Africa (WCA). The first Regional Sorghum Research Network was created in 1984 and became operational in 1986 for a 5-year term, with financial support from the United States Agency for International Development (USAID) through the Semi-Arid Food Grain Research and Development (SAFGRAD). In 1990, a joint initiative by the Institut du Sahel (INSAH) and the Special Program on African Agricultural Research (SPAAR) to develop a NARS-driven system for regional cooperation led to the creation of a regional sorghum "pole" by member countries of the Comité permanent inter-Etats de lutte contre la sécheresse dans le Sahel (CILSS) in 1992. In 1995, the membership of the pole was expanded, and the pole concept was replaced with that of a collaborative research network—the West and Central Africa Sorghum Research Network (WCASRN), often referred to by its French acronymn ROCARS (Réseau ouest et centrafricain de recherche sur le sorgho).

The overall objective of ROCARS is to improve the production, productivity, and use of sorghum, to contribute to greater food security, and to enhance the economic and social well-being of the people of the sorghum-producing countries of WCA. ROCARS member countries are Benin, Burkina Faso, Cameroon, Cape Verde, Central African Republic, Chad, Côte d'Ivoire, The Gambia, Ghana, Guinea-Bissau, Guinea-Conakry, Mali, Mauritania, Niger, Nigeria, Sierra Leone, Senegal, and Togo. Since its creation in 1984, ROCARS has been funded by USAID. The Network Office is based at the Bamako (Mali) location of ICRISAT, which provides logistical and technical support to the Network.

About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, apolitical, international organization for science-based agricultural development. Established in 1972, ICRISAT is one of 16 Future Harvest Centers, supported by more than 50 governments, foundations, and development banks, through membership in the Consultative Group on International Agricultural Research (CGIAR). The mission of ICRISAT is to help developing countries apply science to increase crop productivity and food security, reduce poverty, and protect the environment.

ICRISAT focuses on the farming systems of the semi-arid tropical areas of the developing world, where erratic rainfall, low soil fertility, and extreme poverty are formidable constraints to agricultural development. ICRISAT's vision is 'Science with a Human Face', tailoring research to address and resolve real human needs: to reduce poverty, hunger, and environmental degradation — across the semi-arid tropics of the world.

WCASRN/ROCARS

West and Central Africa Sorghum Research Network

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