SORGHUM AND MILLET BREEDING IN WEST AFRICA IN PRACTICE

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Sorghum and millet are very important cereals in the semi-arid areas of the tropics and subtropics including Africa. Generally, the area of sorghum and millet in Africa has steadily increased over the years but the average yield trends are downwards. Paramount among the yield reducing factors are predominant cultivation of inherently low yielding varieties, poor soil fertility, drought, Striga, pests and diseases. Exploitation of host-plant resistance through genetic enhancement has always been the first approach or forms the basis of an integrated control package in addressing these constraints. The relative limited processing, utilization and marketing of sorghum and millet also present a disincentive to farmers in adopting improved technologies for greater impact. The various National Agricultural Research Systems (NARS) either separately or in collaboration with the international research centres like ICRISAT, INTSORMIL and the regional sorghum and millet networks have drawn up research strategies to address the constraints facing the production, processing and utilization of sorghum and millet. Though a lot of research on sorghum and millet breeding has been done and documented within and without the continent of Africa there is still a lot to be done looking at the current persistent constraints. This paper attempts to highlight the strategies and achievement of sorghum and millet breeding on the continent so far, identify the existing gaps and define the future approach for greater impact.

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) and the millets (*Pennisetum glaucum* (L.) R. Br.), are essential to diets of poor people in the semi-arid tropics where droughts cause frequent failures of other crops. They are most important in West Africa, taking about 70% of total cereal production[2]. Of the 700 million ha planted to cereals in the world, 45 million are planted to sorghum and about 80% of this is grown in developing countries[3]. Approximately 70 million metric tons of sorghum grain is produced annually as a dietary staple for some 500 million people in 30 countries. Pearl millet is planted on about 28 million ha, mainly in Africa and India, to produce 10 million tons of grain per year for 70 million people. Pearl millet is particularly adapted to Sahelian West Africa where landraces have evolved in different ecological niches. Four countries in the Sahel of Africa with a population of 38 million depend on pearl millet for over 1,000 calories per person per day[3].

The yields of sorghum and millet may be low under the area's environmental conditions but they are relatively the most dependable. In the last 35 years the area harvested to sorghum in Africa has nearly doubled, but yields averaging 800 kg/ha have not increased (Table I). A similar trend exists for all millets in Africa where the area planted has increased by 50% but yields, averaging 620 kg/ha and showing more fluctuation than sorghum, have changed little[2]. A projection of sorghum production into the future also indicates trade deficit for West Africa and developing counties (Table II). As a result of these phenomena, the various National Agricultural Research Systems (NARS), ICRISAT and INTSORMIL, have directed their research thrusts towards the yield reducing factors such as genetically low yielding landraces, drought, Striga, pests and diseases. Research on grain quality has been on the evaluation of the physical and functional properties of the grains with very little effort on improving their nutritional values though both crops are mainly used as food. This paper therefore seeks to review the sorghum and millet breeding strategies in West Africa, highlights the achievements so far and outline future trends of research in relation to the current gaps.

HISTORY OF SORGHUM AND MILLET RESEARCH IN WEST AFRICA

The first research on sorghum and millet started in 1931 using an experiment station created in 1921 at Bambey, Senegal[11]. In 1938, Bambey became the headquarters of agricultural research in French Sudan with a regional vocation of the Sahelo-Sudanian zone of West Africa from Senegal to Niger including countries of the coast from Guinea to Benin. In 1950, the French West Africa government established the Agricultural Research Centre of Bambey (CRA), which was transferred to the Republic of Senegal in 1960. Before 1951 and until 1960 CRA was the only organization mandated for sorghum improvement in most West Africa countries. The main sorghum breeding objective was the improvement of local cultivars through mass selection. In the 1960's, after independence, most West African countries established their own National Agricultural Research Institutes (NARIs). In addition

Table I Sorghum area, yield and production by region[1]

	Area (million ha)			Yield (t/ha)		
	1979-81	**1989-91**	**1992-94**	**1979-81**	**1989-91**	**1992-94**
Developing countries	38.60	38.30	40.00	1.14	1.04	1.11
Africa	13.40	18.30	21.80	0.89	0.75	0.78
Northern Africa	3.29	4.07	5.95	0.90	0.67	0.69
Sudan	3.05	3.90	5.77	0.74	0.53	0.58
Western Africa	**5.70**	**10.00**	**11.30**	**0.89**	**0.76**	**0.82**
Burkina Faso	1.05	1.32	1.40	0.59	0.75	0.89
Mali	0.43	0.77	0.95	0.78	0.87	0.77
Niger	0.82	2.04	2.26	0.42	0.19	0.18
Nigeria	2.70	4.90	5.70	1.22	0.98	1.07
Eastern Africa	3.23	2.95	3.08	0.95	0.88	0.89
Southern Africa	0.17	0.22	0.19	0.50	0.37	0.39
Far East	19.85	15.95	14.51	0.95	1.03	1.19
China	2.83	1.55	1.36	2.49	3.31	4.12
India	16.36	13.79	12.55	0.70	0.78	0.89
South Africa	0.38	0.22	0.18	1.43	1.58	2.05
United States	5.27	4.06	4.05	3.63	3.69	4.32

Table II Projected sorghum production, demand and trade ('000 tonnes), 1992-94 to 2005

Regions	**Actual (1992-94 average)**					**Projected (2005)**				
	Production	**Total use**	**Food use**	**Feed use**	**Trade gap[1]**	**Production**	**Total use**	**Food use**	**Feed use**	**Trade gap[1]**
Developing countries	44,239	46,679	26,371	14,762	-2440	53,251	58,327	30,343	21,550	-5,076
Africa	17,075	16,889	12,660	1,197	186	23,764	21,946	17,633	2,390	1,818
Northern Africa	4,099	3,761	2,579	758	338	5,925	5,665	3,556	1,568	260
Western Africa	**9,256**	**9,361**	**6,944**	**341**	**-105**	**12,861**	**13,245**	**9,843**	**662**	**-384**
Central Africa	894	925	779	7	-31	1,100	1,120	945	13	-20
Eastern Africa	2,753	2,747	2,276	87	6	3,780	3,784	3,172	142	-4
Southern Africa	73	94	82	4	-21	98		131		116
Asia	17,975	18,089	13,244	2,973	-114	18,035	19,674	12,172	5,815	-1639
Near East	639	959	459	471	-320	1,007	1,343	648	658	-336
Far East	17,337	17,129	12,785	2,502	208	17,028	18,031	11,524	5,157	-1005
South America	4,234	3,347	36	3,088	797	5,104	4,645	38	4,223	459
Developed countries	19,659	16,805	318	15,807	2854	20,569	15,359	370	14,281	5210
World	63,898	63,484	26,689	30,569	414	73,820	73,820	30,713	35,831	134

1. Production minus utilization

Source: FAO/ICRISAT, 1996[13]

to the improvement of local cultivars, NARs initiated breeding programmes through hybridization, introduction of exotic material, and exploration of hybrid vigour.

BREEDING PROCEDURES

Sorghum and millet germplasm collection and conservation

Collections have become an important component of several breeding programmes at both the national and international levels since advances in the development of new and acceptable crop varieties and hybrids are to a greater extent dependent on the diversity of resource materials at the breeder's disposal. The original major sorghum collection site in West Africa was in Nigeria, and that collection was sent to India for inclusion in the Rockefeller Collection in the early 1960's[9]. Although a wide array of sorghums is present in West Africa, there is a unique area in central and southern Mali, Burkina Faso, and a portion of Senegal where the true guinea types are grown almost exclusively. In the northern, dry regions of Mali, Niger, Mauritania, and northern Nigeria, durras are the predominant race. In the higher-rainfall areas of West Africa, south of the zone of guinea cultivars, there are more caudatums and caudatum derivatives. The collection of millet germplasm was also at tandem with that of sorghum. Though characterization of morphological and agronomic variability among these accessions of sorghum and millet was carried out including gene mapping[7, 8], very little was documented on nutritional qualities.

Sorghum conversion

Sorghum conversion programme continues to be one of the major sources of new germplasm for many of the sorghum breeding programmes throughout the world. Several converted materials from most breeding programmes around the world, such as ICRISAT and INTSORMIL, United States have been introduced into West Africa through collaborative projects with the various NARS. A few examples of widely used photoperiod-insensitive sorghums include Sureno, a grain mould-resistant line; SRN39, a Striga-resistant line; Malisor 84-7, a head bug-resistant and CS 3541, Macia, and CS 3541 derivatives for high yield and adaptation.

Hybrid Production

Between 60's and the mid 80's sorghum hybrids were introduced into Niger, Mali, Nigeria and Burkina Faso. The West African Sorghum Hybrids Adaptation Trial (WASHAT) from ICRISAT was also initiated in the mid-1980 and was conducted in about 17 countries in West Africa[11]. Virtually everywhere that sorghum hybrids have been compared to improved and landrace varieties, there has been a yield advantage, commonly in the order of 20 to 60% (Table III) [6]. As growing conditions become stressed, the yields of both decline, but the yield differences between hybrids and varieties become proportionately larger, favouring the hybrids. Out of the 17 sorghum growing countries in West and Central Africa, only Nigeria and Niger have formally released sorghum hybrids[11]. In 1986, exploratory research on pearl millet hybrids was initiated at the ICRISAT Sahelian Centre in Niamey, Niger. Efforts were devoted to the development of inbred variety hybrids (IVH), because of lack of adapted male sterile lines. Extensive evaluation of IVHs and open-pollinated varieties also showed that the former had around 10% yield advantage.

Population improvement

Sorghum breeding programmes have used population improvement for a variety of traits, such as drought tolerance, yield potential, wide adaptation, improved quality, and pest resistance[11]. The goal of most population improvement programmes is to accumulate favourable alleles for the traits of interest while maintaining as much genetic diversity as possible. Most sorghum population improvement programmes utilised genetic male sterility to facilitate the hybridization necessary to generate populations for the next generation. The method of selection in population improvement programmes in sorghum ranges from mass selecting to family-based selection. Significant improvements in yield have been reported using this methodology, but the transfer of the gains made through population improvement to hybrid releases has been challenging[11]. At least, eight countries within the West African sub-region had received such populations developed at ICRISAT, Mali for evaluation and selection of source materials for further breeding work.

Breeding for abiotic stress

Both crops are usually grown under stress conditions (particularly moisture and temperature) in semi-arid environments. Drought resistance in sorghum and millet is a complex trait affected by a number of interacting plant and environmental factors. For sorghum, two distinct types of stress response have been identified which are related to the stage of growth at which the stress occurs[9, 10]. Several drought-resistant breeding lines developed at the Texas A&M University have been introduced into West Africa and screened by various NARS. The main strategy generally adopted in West Africa involves breeding for early maturity to avoid terminal drought in particular. Though most cereal breeders acknowledge the benefits of herterosis in providing superior performance of hybrids when grown under stress conditions, they have been reluctant to adopt sorghum and millet hybrids. The belief is that hybrids are adapted to and, therefore, profitable only under high yielding favourable environments, where modern production practices are employed and production inputs are available

Breeding for biotic factors

Sorghum and millet are attacked by an array of pathogens that cause significant economic losses. This has led to substantial research in the area of host plant resistance to identify genes for resistance for the most damaging diseases[4]. The four most economically damaging disease groups for sorghum include grain mould, stalk rots, anthracnose, and sooty stripe. The most important diseases on pearl millet are downy mildew, smut and ergot for which a lot of resistance sources have been identified and utilised. Similarly, sorghum and millet are also attacked by an array of insects that inflict significant economic losses in West Africa. For most of these insect pests and many others, sources of resistance have been identified and the

Table III Comparative performance of sorghum hybrids, improved varieties, and land race cultivars

Country	**Years of Testing**	**Number of Trials**	**No, of entries** Hybrid	**Var.**	**Local**	**Yield kg/ha-1** Hybrid	**Var.**	**Local**	**% Increase over** Var.	**Local**
Zambia	1989-90		3	3		3977	3238		22.8	
	1990-91		3	3		4162	3091		34.6	
	1991-92		3	3		2741	1928		42.2	
Sudan	1985-irr		1	1		5189	3010		72.3	
	1985-dry		1	1		2968	1543		92.3	
	1986	2	1	1		4152	2700		53.7	
		2	1	1		2670	2483		7.5	
		2	1	1		3891	3113		24.9	
		9	6	1		4573	3109		47.0	
Niger	1988-irr		90	33	2	2582	1779	1605	45	61
	1988-dry		90	33	2	1799	1081	1204	66	49
West and Central Africa*	**1986 - 1995**	**87**	**10-34**	**1**		**2970**	**1770**		**67.7**	
Burkina Faso						2258-	2795-	1345	-19	67
Farako Ba		1	21	2	1	4241	3236		31	
Kamboinse		1	21	2	1	945-	0-			185
						1904	679	331	180	
Ouahigouya		1	21	2	1	687-	1031-	271	-33	154
						2302	1490		54	

*Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Mali, Niger, Nigeria, Senegal and Togo.

Table IV Priorities for sorghum breeding

	India	China	Nigeria	Sudan	Tanzania	Russia	USA		Rank[a]
Drought (+ CR[b])	8			10	8	9	10	45	1*
Striga	6		9	8	7	5		30	2
Smuts		10		5		10	7	27	3
Malting etc		7	6		7		4	24	5
Grain mould	7		10				6	23	6*
Grain hardness			7		10		4	21	7*
Stem borer		9	3	4	5			21	7*
Green bug/aphid		8				3	9	20	9*
Cold	9					8		17	10
Shoot-fly	10			3	4			16	11*
Midge				3	4		8	15	12*
Forage			4			6	1	11	13
Leaf blight	6					4		10	14
Heat stress				9				9	15*
Headbug			8					8	16*
Height				6				6	17
Downy mildew							5	5	18*
Stover quality			5						18*
Chinchbug							3	3	20*
Seed quality							2	2	21

Note: a * = traits suitable for molecular marker breeding
b CR= charcoal rot

genetics of the resistance determined. The exploitation of host plant resistance has identified genes for resistance to the most damaging pests. For sorghum, these include head bug, sorghum midge, stem borers and shoot fly. Significant among millet the insects include, shoot fly, head caterpillars and stem bores.

Grain quality improvement

About 97% of all sorghum and millet breeding efforts have been geared towards improving the grain yields with very little attention to the grain quality. Taking a look at Table IV, which is an outcome of an international conference on using molecular markers in sorghum and millet breeding for developing countries, one gets the impression that grain quality is not important. There is currently no motivation to put much emphasis on selection based on nutritional quality in breeding sorghum and millet. This is logical since there is always a production deficit that places research emphasis on increasing yield at the expense of improving nutritional qualities. Besides, grain quality criteria are determined by end users. Sorghum and pearl millet in West Africa are grown mainly for food, and only occasionally used for brewing. The grain quality criteria for millet are less well-defined than for sorghums[1]. For millet, usually grey to yellowish white plumb grain is widely accepted, though in part of West and Central Africa, light brown or creamy white grains are preferred. The research and development efforts on cereal technology of sorghum and millet grains have lagged behind that of other major cereals. The research on utilization of these cereals must be increased if we are to provide acceptable value-added and nutritious products to an increasingly urbanised population. Some encouraging research is in progress in several West African laboratories, and these must be enhanced. These laboratories should inform the workshop as to the effects of all these processing on the protein quality of the products.

CONCLUSIONS

Since 1931, research on sorghum and millet started in West Africa, all efforts have been on improving the yields of these crops with little attempt on nutritional quality improvement. It is evident that several thousand accessions of sorghum and millet have been collected and characterized agro-morphologically. There is the need for future germplasm characterisation that combines both the classical phenotypical characterisation and biotechnological tools, to ensure a more complete and informative characterisation that reveals the true genetic diversity of the accessions in terms of nutritional qualities.

Though natural and induced high-lysine mutants in sorghum have been identified, these have not been adapted to the West African sub-region. Breeding for quality and resistance traits, may be accelerated by better methods of gene identification and transfer that will almost certainly involve biotechnology. But the ability of biotechnology to help improve very complex traits such as yield potential still is uncertain for both technical and economic reasons. In any case, improvements are needed in existing breeding methods to extract and transfer new genetic variability that will contribute to combining ability and high nutritional values for sorghum and millet.

Some facts are worth emphasizing at this point: i) that sorghum and millet are the most important cereals in West Africa, providing about 70% of the total cereal production, ii) that sorghum and millet are essential to the diets of poor people in the semi-arid tropics including West Africa where drought causes frequent failure of other crops, iii) that there are regional deficits of production of these two cereals in relation to their demand/utilisation and iv) that protein levels of sorghum and millet are generally low and deficient in essential amino acids like lysine and tryptophan.

These facts present more than enough justification for research to embark upon developing high quality-protein sorghum and millet varieties adapted to the West African sub-region and other semi-arid zones. The importance of high-lysine maize developed in Ghana and currently utilized in the whole of West Africa and some parts of East Africa cannot be over-emphasized.

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