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Potential of Malian Landraces in Hybrid Combination

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

The first possibility of economic hybrid seed production in sorghum has been discussed since the discovery of the genetic-cytoplasmic male-sterility. The greater advantage of hybrids to yields, compared to cultivars, has been demonstrated throughout the world. Hybrids made with local cultivars of Mali used as the male parents and were compared to their parents. Heterosis was observed in all stages of plant growth. Seedling vigour and seedling drought tolerance were emphatically better than the Malian parents. The frequency of landraces with fertility reactions was more frequent than those with maintainer reactions. Significant and positive heterotic effects were recorded for grain yield per panicle and the panicle yield components, seed number and seed weight. However, there was no scope for direct exploitation of the hybrids involving the ATx623 and Malian landrace parents. The typical Caudatum "turtle-back" seed shape was dominant in hybrid combinations with all Malian races. This seed shape renders the grain more difficult to dehull than local cultivars. The grain of hybrids made with guinea parents had a thick brown sub coat with astringent tannins, which was undesirable for food uses.

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1. INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the main cereals cultivated in Mali. It, along with pearl millet constitutes essential food sources of energy, protein, vitamins and minerals for the rural population in the country. It remains an essential culture for food security in rural areas with an area estimated of 1,204,652 hectares and an average grain yield of 1,055 kg/ha [1]. The crop is genetically adapted to the hot, dry, agro-ecologies where it would be difficult to cultivate other cereals. Sorghum is usually grown both for its grain for human food and its straw used as fodder.

Three major races of sorghum exist in the country: Guinea, Durra and Caudatum. Touré et al. [2] indicated that the race Guinea represents about 70% of the germplasm in the country, followed by the Durra (17%). It is produced under various conditions, from the arid regions of the north to high rainfall areas of the south.

The advantages of hybrid sorghum were first pointed out by Conner and Karper in 1927 [3]. The first possibilities of economic hybrid seed production in sorghum have been discussed since the discovery of the genetic male-sterility in sudangrass by Stephens in 1929 which was transferred to sorghum grain [4]. The greater advantage of hybrids to yields, compared to cultivars, has been demonstrated throughout the world [5,6]. Many studies showed that in stress conditions, the yields of both hybrids and varieties decline, but frequently the magnitude of difference, percent wise, is greater for hybrids in favourable conditions [7,8,9].

Seasonal precipitation is usually unpredictable and unreliable in most of the rain lands. Therefore, yield reductions and crop failures are predicted to occur. It is believed that superior hybrids identified under local conditions will have a rapid influence in increasing and stabilising yield levels in the rain lands. In general, F_1 sorghum hybrids, with their vigorous early growth with a fast rate, and ability to efficiently utilise limited moisture, produce higher yields under stress conditions than other varieties. The objective of this study was to monitor the potential combining ability of Malian landraces and their gene action with the introduced male sterile line.

2. MATERIALS AND METHODS

Over 800 accessions of sorghum were collected in different regions of Mali during a prospection conducted in 1979-80 by ORSTOM (Office de la Recherche Scientifique et Technique Outre-mer) and IER (Institut D'Economie Rurale du Mali). All 800 accessions representing the different sorghum races of the Malian Sorghum Collection (Guinea, Durra, and Caudatum) were crossed onto a cytoplasmic male sterile line ATx623 introduced from Texas (USA). Each of the hybrids along with the male Malian parent was evaluated systematically in 1980-81 in four main sorghum research stations (Sotuba $12^0$39', Cinzana 13°17', Samé 14°26', and Baramandougou 13°35'). A completely randomised design was used. Each entry was planted in a 2-replicated trial with 2 planting dates at each location and 15 days between planting dates. Each plot consisted of two rows, which was 5 m long and 0.75 m apart. The equivalent of 100 kg of ammonia phosphate fertiliser and 50 kg of urea per hectare was applied. Hybrids were evaluated for photoperiod sensitivity, maturity, genetic traits (presence or absence of testa, cytoplasm A1 reaction, panicle shape etc.), yield, and agronomic desirability. Photoperiod sensibility was estimated by comparing days to 50% anthesis from the two (2) planting dates at each location. The software used for the data analysis is the GenStat with Duncan's procedure for mean separation. The estimation of heterosis or vigour hybrid was calculated for each hybrid following the formula:

Mid heterosis = (F1-MP) x100

Where,

F1 = Mean performance of the hybrid,
MP = Average performance of the two (2) parents that produced the hybrid.

Subjective ratings were recorded by contrasting parent and hybrid from Cinzana, Baramandougou and Samé nurseries which received no appreciable rain at seedling stage and after flowering of the sorghums. Leaf stress symptoms, panicle blasting, miniature panicle size and endosperm texture softness were an indication for drought susceptibility.

Measurements were taken on the following characteristics:

1. Seedling and plant vigour – 1 to 5 taken on plot basis, 1 = vigorous, and 5 = weak.
2. Panicle shape – 1 to 3 basis, 1 = drooping, 2 = semi-drooping, and 3 = compact.
3. Seed shape – rounded, turtle-back shape (rounded = 0 and turtle-back shape = 1).
4. Grain yield per panicle – average weight in g of 5 panicles per plot (PGW).
5. 1000 seed weight - in grams (g) on a 1000-seed sample (SW).
6. Seed number per panicle (SNM) = PGW/5SW*1000.
7. Presence of testa – 1 to 2 basis, 1 = presence of brown under coat, 2 = absence.
8. Cytoplasm A1 reaction (read as seed set under selfing bags) – F_1 plants sterile, male parent = B-line, F_1 plants fertile, male parent = R-line.
9. Photoperiod sensitivity – indicated by plots from the first and second planting dates flowering.
10. Maturity – basis on early, mid-season and late sorghums.
11. Drought tolerance - rating was done on a 1-5 scale, where 1 = excellent and 5 = very poor response.

3. RESULTS AND DISCUSSION

Heterosis was observed in all stages of plant growth. Seedling vigour and seedling drought tolerance were emphatically better than the Malian parents. Similar results were obtained by Touré in 1980 [10]. Generally, plant growth was much more rapid and lush than that of parents. Patel et al. [11] and Blum et al. [12] obtained similar results showing that sorghum hybrids have a larger meristem than their parents and more rapid growth during the cell division growth process. Hybrids were tolerant to drought at all pre-floral stages of plant growth. Taye et al. [13] reported in their study that hybrids matured earlier than the adapted parents, and had higher grain yield, plant height, grain number and grain weight in all environments.

In Mali, leaf stress symptoms, panicle blasting and miniature panicle size, are the common manifestations of drought stress during panicle initiation. Selection against those traits was found to be effective. The multi- location evaluation was based heavily on those traits. Floral drought softens the endosperm texture of some varieties and hybrids. Under post floral drought conditions, the local Keninké sorghum grain became smaller than normal but maintained similar endosperm texture compared to the normal grain (Photo 2). Some varieties and hybrids maintained their grain size but became chaffy with little or no vitreous areas visible in the endosperm (Photo 1).

The extent of vitreousness depends on the amount of storage protein laid down in the endosperm. Since storage protein is one of the last components to be laid down in the grain, drought stress could block the physiological processes during the latter period of grain fill in some varieties. Most of the farmers in Mali preferred hard endosperm grain used to prepare the local dish called "To", a thick porridge. Soft endosperm grain is known to produce poor quality porridge.

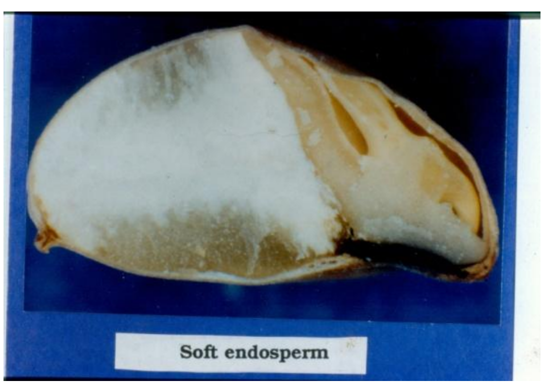

Photo 1

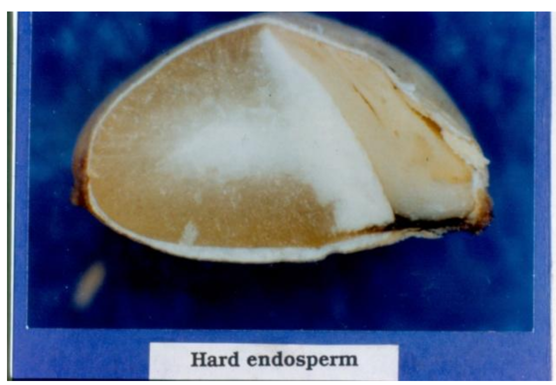

Photo 2

Photos 1 and 2. Most of the hybrids showing soft endosperm compared to local Keninke with hard endosperm
(Source A. Toure)

Panicle shape was intermediate between the parents. The female parent, a Caudatum-Zerazera, had a long upright panicle with numerous short branches. Hybridisation of lax panicle Keninké (Gambicum and Guineense types in the Snowden classification) and Kendé (Margaritiferum in the Snowden classification) (Photo 5) with the Caudatum-Zerazera resulted in upright semi-open panicles with the same numbers of seeds branches as the Guineense parent but with increased seed numbers (Photos 3 & 4). The lax and semi- opened panicle are preferred by farmers because these types of panicles do not serve as a habitat for insects and the development of grain molds.

As reported by Touré [10] the dense panicle of Gadiaba (Durra) and Hegari (Caudatum) parents produced long and dense panicle hybrids combination with The ATx623 parent.

The female parent of hybrid had cytoplasmic male sterility, which was conditioned by both a sterile cytoplasm and the $\underline{ms_cms_c}$ genotype at the $\underline{Ms_c}$ locus in the nucleus. All of the male parents had fertile cytoplasm since they all produced normal pollen. The genotype of the $\underline{Ms_c}$ locus of the male parents could be revealed by the male fertility of the plants from crosses to a cytoplasmic male sterile parent. If the hybrid plants were male fertile, the genotype of the male parent ($\underline{Ms_cMs_c}$) was considered an R-line or "fertility restorer" line. If the plants were male sterile, the genotype of the male parent ($\underline{ms_cms_c}$) was considered a B-line or "male sterility maintainer" line. Observations of the fertility reactions of these test crosses on A_1 cytoplasm showed that both maintainer and restorer genes were present in all taxonomic groups (Table 1). Those B-lines had the genotype $\underline{ms_cms_c}$. The frequency of landraces with fertility reactions was more frequent than those with maintainer reactions. No obvious geographic pattern was observed for the distribution of fertility reaction as reported by Touré and Scheuring [14]. However, the information on the distribution of fertility reaction in the local germplasm held in the development of female and male hybrid parents.

Heterosis could be exploited in Malian sorghums. That exploitation will be approached from a number of angles: the sterilisation and the dwarfing of Malian B-lines, the use of an array of different female parents in combination with the best Malian parents, pedigree recovery of Malian R-lines by introduced R-lines, recovery of R-lines with Malian grain characteristics from recurrent selection in breeding populations.

Significant and positive heterotic effects were recorded for grain yield per panicle (261-28%) and the panicle yield components namely, seed number (191-6%) and seed weight (45-2%) (Table 2). A similar study was conducted by Rini et al. [15] showed that hybrids had high mid-parent heterosis for grain yield/plant with 72-62-% higher yield compared to the average of the two parents. However, there was no scope for

Photo 3. Intermediate erected panicle shape of hybrids

Photo 4. Intermediate semi-compact panicle shape of hybrids

Photo 5. Lax panicle of the local Keninke parent

(Source A. Toure)

direct exploitation of hybrids involving the ATx623 and Malian variety parents. The typical Caudatum turtle-back seed shape was dominant in hybrid combinations with all Malian races. The seed shape renders the grain more difficult to dehull than Guinea (Keninké) grain, which was oval, rounded and symmetrical. The hybrid grain made with Guinea parents had a thick brown sub coat with astringent tannins, which was undesirable for food uses. The hybrids with Gadiaba male parents did not have a sub coat, and their seedling growth was excellent but was susceptible to post-floral drought and charcoal rot caused by *Macrophomina phaseolina (Tassi) Goid*.

There were two independent genes B1 and B2 which condition the presence or absence of the coloured testa in the grain (undercoat) since there was a need to be at least one dominant allele at both loci for the testa to be apparent. Two white seeded, testa-free parents of contrasting allele type B1B1b2b2 and b1b1B2B2 produced a heterozygous hybrid B1b1B2b2 with testa colour in the grain. All hybrids from ATx623 x Keninké and Kendé crosses had coloured testa in the grain. Yet, ATx623 and all of the Keninké and Kendé parents used did not have an undercoat. The study assumed that the Keninké and Kendé sorghums of Mali had the genotype B1B1b2b2 since the genotype of ATx623 was b1b1B2B2. While the Keninké and Kendé hybrids had a coloured undercoat, they also maintained a white pericarp. If the spreader gene (S) was present in the dominant form, the testa colour of dominant gene B1_B2_ would have been spread throughout the pericarp. When the homozygous recessive gene (ss) is present the testa colour of dominant alleles B1_B2_ occurs only in the testa layer. This means that the brown colour appears in the pericarp if genes B1_B2 are present. The hybrids of Keninke and Kendé showed a presence of testa colour which did not spread throughout the pericarp. Thus, they were homozygous ss at the testa colour spreader alleles. The identification of B1 and B2 genes responsible for the presence of testa, condensed tannins in grains that are not preferred by farmers because tannins are widely recognised to reduce the caloric availability. However, the information on the presence or B1 and B2 genes in the local germplasm will help to breed cultivars without testa.

The female parent, ATx623 was strictly photoperiod insensitive and flowered 70-74 days after the planting date. The photoperiod sensitivity of Malian varieties was indicated by plots from the first and second planting dates flowering (Table 3). The hybrids of photoperiod sensitive Malian parents were also strictly photoperiod sensitive. A photoperiod sensitive hybrid performance of insensitive x sensitive parental cross indicated the dominant gene action of photoperiod sensitivity. This model fitted well with the one described by Quinby and Karper [16]. The crossing of a photoperiod sensitive variety with a neutral variety gives a photoperiod sensitive product with a reduction of the threshold for floral induction [17]. The results obtained from this study concurred with previous studies that photoperiod sensitivity can be easily detected and can be used to breed for comparing flowering date from contrasting planting dates. The flowering of the ecotypes occurred in the 25 days which preceded the average date by the end of the rain season and floral initiation started and finished during the time to which the day is shorter than the night. This study showed a delay of 3 weeks in sowing, and the ecotypes lose 10 to 96% of their seeds with an average of 66% [18]. The sorghum varieties obtained by selection in recent years brought progress especially regarding productivity in favourable conditions. To meet the needs and constraints of farmers in Sudano-Sahelian zone, it is now necessary to incorporate agronomic characteristics of local varieties, including their sensitivity to the photoperiod sensibility which provides a large adaptability in the face of climate change.

There was an array of maturity genes available in Malian sorghums. The action of photoperiod sensitivity genes was to be distinguished from maturity genes before a clear understanding of their respective inheritances and interactions. Most of the photoperiod insensitive x sensitive the hybrids described above were 10 to 30 days earlier than the Malian parent, but, were still photoperiod sensitive. Heterosis was expressed at the early flowering stage by more tillers and reduced plant height. For example, in 1966, Kambal and Wegster [19] reported a 20% increase in average grain yield of hybrids, and 2.5 days hastening of flowering when compared to the parental mean. Similar results were also obtained by Kirby and Atkins [20], Sodani and Chaturvedi [21], Penga et al. [22] and Yanga et al. [6]. But there was one hybrid, ATx623 x CSM193 which had essentially the same maturity and photoperiod sensitivity as the CSM 193 parent. It was clear that CSM193 differed genetically from the other photoperiod sensitive parents in the study.

Five hybrids combinations resulted in the crosses, which redden at flowering and completely dried up before normal grain maturity (See parents Table 4). The physiological leaf reddening could be due to epistatic gene action. The entry CSM 576 was a normal Kendé from Samé (Kayes), yet the hybrid with ATx623 was 29 cm tall and male sterile.

Table 1. Some of cytoplasmic male sterility maintainer lines (B-lines) in the Malian Sorghum collection

Entry	Cycle*	Race	Origin village	Region
CSM 50	M	Gadiaba	Boro	Kolokani
CSM 280	P	Gadiaba	Diondanko	Kita
CSM 9	P	Kendé	Massala	Bamako
CSM 30	P	Kendé	Sirakorola	Bamako
CSM 289	P	Kendé	Toukoutou	Kita
CSM 296	P	Kendé	Kassaro	Kita
CSM 470	M	Kendé	-	-
CSM 590	P	Kendé	Dag-Dag	Kayes
CSM 661	P	Kendé	Sirakoroba	Kolokani
CSM 662	P	Kendé	Sirakoroba	Kolokani
CSM 664	P	Kendé	Dialakoroba	Bamako
CSM 666	P	Kendé	Ouellessebougou	Bamako
CSM 669	P	Kendé	Solo	Bougouni
CSM 672	P	Kendé	Toba	Bougouni
CSM 673	P	Kendé	Toba	Bougouni
CSM 374	P	Kendé	Boumoukou	Bougouni
CSM 4	P	Kéninké	Massala	Bamako
CSM 7	P	Kéninké	Massala	Bamako
CSM 8	P	Kéninké	Massala	Bamako
CSM 42	M	Kéninké	Toubakouro	Kolokani
CSM 43	M	Kéninké	Toubakouro	Kolokani
CSM 79	M	Kéninké	Tougouni	Bamako
CSM 137	M	Kéninké	Diankouté	Niono
CSM 154	M	Kéninké	Diéma	Niono
CSM 159	M	Kéninké	Youri	Niono
CSM 192	M	Kéninké	Mandeha	Niono
CSM 193	P	Kéninké	Kirane	Niono
CSM 205	M	Kéninké	Samé	Kayes
CSM 207	E	Kéninké	Ambidedi	Kayes
CSM 216	M	Kéninké	Sadiola	Kayes
CSM 225	M	Kéninké	Aourou	Kayes
CSM 226	P	Kéninké	Aourou	Kayes
CSM 279	P	Kéninké	Dindanko	Kita
CSM 391	P	Kéninké	Beni	San
CSM 428	M	Kéninké	Tibi	Ségou
CSM 435	P	Kéninké	Tibi	Ségou
CSM 465	M	Kéninké	Tibi	Ségou
CSM 468	M	Kéninké	Tibi	Ségou
CSM 579	P	Kéninké	Ambidedi	Kayes
CSM 657	P	Kéninké	Yagabougou	Kolokani
CSM 659	P	Kéninké	Missira	Kolokani
CSM 663	P	Kéninké	Sonitieni	Bamako
CSM 725	P	Kéninké	Malobala	Koutiala
CSM 762	P	Kéninké	Boula	Douentza

**Cycles are abbreviated: P = photoperiod sensitive, M = mid-season, E = early*

Table 2. Heterosis for grain weight per panicle, seeds number par panicle and 1000-grain weight in selected ATx623 x Malian variety hybrids

	Grain weight per panicle		Seeds per panicle		1000-grain weight		
Entry	**Mean (g)**	**% Heterosis**	**Number**	**% Heterosis**	**Mean (g)**	**% Heterosis**	**Race of Malian parent**
CSM 277	67.50		3386		19.93		Kéninké
A623*CSM 277	142.50	143	5636	93	25.28	25	
CSM 400	30		1466		20.46		Kéninké
A623*CSM 400	86.25	115	3777	93	22.83	11	
CSM 432	15		768		19.51		Kéninké
A623*CSM 432	117.50	261	4972	191	23.63	18	
CSM433	22.50		833		27.01		Kéninké
A623*CSM 433	82.50	127	2848	73	28.96	22	
CSM 440	113.33		5841		19.40		Kéninké
A623*CSM 440	120.46	47	5569	34	21.63	8	
CSM463	23.33		1041		22.40		Kéninké
A623*CSM 463	80	118	3185	82	25.11	17	
CSM 396	11.66		868		13.43		Kendé
A623*CSM 396	76.66	148	4143	150	18.50	9	
CSM 427	16.66		1214		13.72		Kendé
A623*CSM 427	115	245	4618	153	24.90	45	
CSM 134	28.33		1997		14.18		Kendé
A623*CSM 134	45	14	2354	6	19.11	10	
CSM 40	148.33		4091		36.25		Gadiaba
A623*CSM 40	156.66	58	5934	96	26.40	7	
CSM 46	90		2654		33.90		Gadiaba
A623*CSM 46	117.50	28	3394	33	34.61	27	
CSM 59	43.33		1065		40.65		Gadiaba
A623*CSM 59	113.33	142	3462	97	32.73	7	
CSM 76	50		1303		38.36		Gadiaba
A623*CSM 76	116.66	133	3762	101	31.01	5	
CSM 77	40		1066		37.51		Gadiaba
A623*CSM 77	86.25	91	2912	66	29.61	2	
B623	50		2442		20.47		
Mean	76.08		2988.24		25.57		
CV (%)	30		25		10		
Significance	**		NS		**		
LSD	4.676		-		0.029		

*CV: Coefficient of variation; ** Significance at 0.05*
LSD: Least significant differences; NS: No significance

Table 3. Flowering dates of photoperiod sensitive Malian male parents and their F_1 hybrids from 2 planting dates at 3 locations

	Date of 50% flowering at Sotuba		Date of 50% flowering at Cinzana		Date of 50% flowering at Baramandougou		Difference of days between flowering dates		
Entry	**1st planting**	**2nd planting**	**1st planting**	**2nd planting**	**1st planting**	**2nd planting**	**SB**	**CZ**	**BR**
CSM 4	28/9	28/9	9/10	10/10	14/10	-	0	1	-
A623*CSM 4	14/9	15/9	26/9	28/9	24/9	15/10	1	2	9
CSM 8	28/9	29/9	7/10	8/10	14/10	-	1	1	-
A623*CSM 8	14/9	15/9	26/9	26/9	26/9	26/9	1	0	0
CSM 9	19/9	20/9	28/9	29/9	18/9	29/9	1	1	11
A623*CSM 9	4/9	6/9	15/9	17/9	16/9	25/9	2	2	9
CSM 30	19/9	20/9	28/9	29/9	6/10	6/10	1	1	0
A623*CSM 30	28/8	30/8	8/9	10/9	20/9	28/9	2	2	8
CSM 102	28/9	30/9	10/10	10/10	-	-	2	2	0
A623*CSM 102	26/8	4/9	10/9	12/9	25/9	25/9	9	2	0
CSM 174	20/9	23/9	5/10	5/10	-	-	3	0	-
A623*CSM 174	10/9	14/9	23/9	26/9	26/9	-	4	3	-
CSM 193	12/9	17/9	23/9	23/9	6/10	6/10	5	0	0
A623*CSM 193	11/9	13/9	23/9	25/9	26/9	1/10	2	2	4
CSM 258	23/9	29/9	25/9	5/10	-	14/10	3	6	-
A623*CSM 258	13/9	16/9	27/9	27/9	24/9	7/10	3	0	13
CSM 279	12/9	13/9	20/9	22/9	24/9	24/9	1	2	0
A623*CSM 279	10/9	11/9	15/9	17/9	26/9	26/9	1	2	0
CSM 420	16/9	17/9	19/9	24/9	20/9	-	1	5	-
A623*CSM 420	9/9	14/9	23/9	25/9	19/9	20/9	5	2	1
CSM 434	19/9	21/9	27/9	29/9	14/10	14/10	3	2	0
A623*CSM 434	15/9	16/9	20/9	23/9	14/10	-	1	3	-
CSM 437	21/9	23/9	4/9	4/10	30/9	-	2	0	-
A623*CSM 437	14/9	15/9	23/9	29/9	-	-	1	6	-
B623	6/8	18/9	30/8	2/9	2/9	-	12	21	-

Sotuba (SB) 1st planting date 22/5
2nd planting date 8/6
Cinzana (CZ) 1st planting date 20/6
2nd planting date 4/7
Baramandougou 1st planting date 10/6
2nd planting date 14/7

Table 4. Male parents of F_1 hybrids with ATx623 which display physiological leaf redding at flowering

Entry	Race	Origin village	Region
CSM 412	Kéninké	Sekoura	Bankass
CSM 427	Kendé	Niono	Niono
CSM 435	Kéninké	Konobougou	Segou
CSM 725	Kéninké	Molobala	Koutiala
CSM 762	Kéninké	Boula	Douentza

4. CONCLUSION

The seedling and plant vigour, the pre- floral drought tolerance, and the clear yield advantage of hybrids made with Malian male parents convinced that heterosis could be exploited in Malian sorghums. However, there was no scope for direct exploitation of hybrids involving the ATx623 and Malian variety parents. The typical Caudatum turtle-back seed shape was dominant in hybrid combinations with all Malian races. This seed shape rendered the grain more difficult to dehull than local cultivars. The thresh ability of the hybrids panicles was also very poor. The hybrid grains made with Guinea parents had thick brown sub coat with astringent tannins, which were undesirable for food uses. The development of acceptable hybrids using local germplasm could be addressed through various approaches. Hybrids based on introduced male-sterile lines and landrace pollinators might be pursued through modification of hybrid parents to rectify traits determined by relatively few genes such as seed sub coat and pericarp thickness. However, development of hybrids with Guinea grain shape and grain quality would likely require the development of Guinea grain shape male-sterile lines. The sterilisation and dwarfing of Malian B-lines, the use of an array of different female parents in combination with the best Malian parents, pedigree recovery of Malian R-lines by introduced R-lines, recovery of R-lines with Malian grain characteristics from recurrent selection in breeding populations could open up a new range of possibilities for developing hybrids for the country.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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