Potential of Malian Landraces in Hybrid Combination

Aboubacar Toure1*, John F. Scheuring2, Salimata Sidibe3 and Mamourou Diourte3

1International Crops Research Institute for the Semi-Arid Tropics, Mali.
2Seed Sector, Novartis CH-4002 Basel, Switzerland.
3Institut d’Economie Rurale, Mali.

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

Article Information
DOI: 10.9734/AJRCS/2018/43288

Received 12 July 2018
Accepted 24 September 2018
Published 08 October 2018

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.

*Corresponding author: E-mail: acartoure@gmail.com;
Keywords: Sorghum; local cultivars; hybrid; heterotic effects; Mali.

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 genic 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, F₁ 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°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:

\[
\text{Mid heterosis} = (\text{F1-MP}) \times 100
\]

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) – F1 plants sterile, male parent = B-line, F1 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.

**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](image1.jpg)

![Photo 2](image2.jpg)

**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 ms,ms, genotype at the Ms, locus in the nucleus. All of the male parents had fertile cytoplasm since they all produced normal pollen. The genotype of the Ms, 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 (Ms,Ms,) was considered an R-line or “fertility restorer” line. If the plants were male sterile, the genotype of the male parent (ms,ms,) was considered a B-line or “male sterility maintainer” line. Observations of the fertility reactions of these test crosses on A1 cytoplasm showed that both maintainer and restorer genes were present in all taxonomic groups (Table 1). Those B-lines had the genotype ms,ms,. 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
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 seeding growth was excellent but was susceptible to post-floral drought and charcoal rot caused by *Macrophomina phaseolina* (Tassi) Gold.

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 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    | Ouellesebougou | 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  | Yagabougu      | 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      |

*Cycle abbreviations: 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

| Entry             | Grain weight per panicle | Seeds per panicle | 1000-grain weight | Race of Malian parent |
|-------------------|--------------------------|-------------------|-------------------|-----------------------|
|                   | Mean (g) | % Heterosis | Number (g) | % Heterosis | Mean (g) | % Heterosis |                        |
| CSM 277           | 67.50    | 142.50     | 3386      | 115         | 19.93    | 115.0       | Kéninké              |
| A623*CSM 277      | 46.50    | 142.50     | 3386      | 115         | 19.93    | 115.0       | Kéninké              |
| CSM 400           | 30       | 66.66      | 5636      | 93          | 25.28    | 25          | Kéninké              |
| A623*CSM 400      | 86.25    | 115        | 3777      | 93          | 22.83    | 11          | Kéninké              |
| CSM 432           | 15       | 768        | 768       | 19.15       | 19.51    | 115.0       | Kéninké              |
| A623*CSM 432      | 117.50   | 261        | 4972      | 191         | 23.63    | 18          | Kéninké              |
| CSM 433           | 22.50    | 833        | 2848      | 73          | 28.96    | 22          | Kéninké              |
| A623*CSM 433      | 82.50    | 127        | 5841      | 34          | 21.63    | 8           | Kéninké              |
| CSM 440           | 113.33   | 5841       | 115       | 14.18       | 19.40    | 115.0       | Kéninké              |
| A623*CSM 440      | 120.46   | 47         | 5569      | 34          | 21.63    | 8           | Kéninké              |
| CSM 463           | 23.33    | 1041       | 25       | 117          | 22.40    | 115.0       | Kéninké              |
| A623*CSM 463      | 80       | 118        | 3185      | 82          | 25.11    | 117          | Kéninké              |
| CSM 396           | 11.66    | 868        | 134       | 13.43       | 868      | 13.43       | Kéninké              |
| A623*CSM 396      | 76.66    | 148        | 4143      | 150         | 18.50    | 9           | Kéninké              |
| CSM 427           | 16.66    | 1214       | 115       | 13.72       | 115      | 13.72       | Kéninké              |
| A623*CSM 427      | 115      | 245        | 4618      | 153         | 24.90    | 45          | Kéninké              |
| CSM 134           | 28.33    | 1997       | 69        | 14.18       | 14.18    | 14.18       | Kéninké              |
| A623*CSM 134      | 45       | 14         | 2354      | 6           | 19.11    | 10          | Kéninké              |
| CSM 40            | 148.33   | 4091       | 36.25     | 36.25       | 36.25    | 36.25       | Gadiaba              |
| A623*CSM 40       | 156.66   | 58         | 5934      | 96          | 26.40    | 7           | Gadiaba              |
| CSM 46            | 90       | 2654       | 33.90     | 33.90       | 33.90    | 33.90       | Gadiaba              |
| A623*CSM 46       | 117.50   | 28         | 3394      | 33          | 34.61    | 27          | Gadiaba              |
| CSM 59            | 43.33    | 1065       | 40.65     | 40.65       | 40.65    | 40.65       | Gadiaba              |
| A623*CSM 59       | 113.33   | 3462       | 32.73     | 32.73       | 32.73    | 32.73       | Gadiaba              |
| CSM 76            | 50       | 1303       | 38.36     | 38.36       | 38.36    | 38.36       | Gadiaba              |
| A623*CSM 76       | 116.66   | 3762       | 31.01     | 31.01       | 31.01    | 31.01       | Gadiaba              |
| CSM 77            | 40       | 1066       | 37.51     | 37.51       | 37.51    | 37.51       | Gadiaba              |
| A623*CSM 77       | 86.25    | 2912       | 29.61     | 2         | 29.61    | 2           | Gadiaba              |
| B623              | 50       | 2442       | 20.47     | 20.47       | 20.47    | 20.47       | Gadiaba              |
| Mean              | 76.08    | 2988.24    | 25.57     | 25.57       | 25.57    | 25.57       | Gadiaba              |
| CV (%)            | 30       | 25         | 10        | 10          | 10       | 10          | Gadiaba              |
| Significance      | **       | NS         | **        | **          | **       | **          | Gadiaba              |
| 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 F₁ hybrids from 2 planting dates at 3 locations

| Entry                   | Date of 50% flowering at Sotuba | Date of 50% flowering at Cinzana | Date of 50% flowering at Baramandougou | Difference of days between flowering dates |
|-------------------------|----------------------------------|----------------------------------|----------------------------------------|------------------------------------------|
|                         | 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 1                                   |
| A623*CSM 4              | 14/9 15/9                        | 26/9 28/9                       | 14/10 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                       | 14/10 15/10                            | 1 0 0                                   |
| CSM 9                   | 19/9 20/9                        | 28/9 29/9                       | 18/9 29/9                              | 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                     | 5/10 5/10                               | 3 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                       | - -                                    | -                                       |
| A623*CSM 174            | 10/9 14/9                        | 23/9 26/9                       | 26/9                                  | 4 3 0                                   |
| CSM 193                 | 12/9 17/9                        | 23/9 23/9                       | 5/10 25/9                              | 3 6 0                                   |
| A623*CSM 193            | 11/9 13/9                        | 23/9 25/9                       | 14/10 26/9                             | 3 6 0                                   |
| CSM 258                 | 23/9 29/9                        | 25/9 5/10                       | - -                                    | -                                       |
| A623*CSM 258            | 13/9 16/9                        | 27/9 27/9                       | 14/10 5/10                             | 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 20/9                               | 1 5 2                                   |
| 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 25/9                       | 14/10 14/10                             | 3 2 0                                   |
| A623*CSM 434            | 15/9 16/9                        | 20/9 23/9                       | 14/10                                  | 1 3 0                                   |
| CSM 437                 | 21/9 23/9                        | 4/9 10/10                       | 30/9 -                                  | 2 0 2                                   |
| A623*CSM 437            | 14/9 15/9                        | 23/9 29/9                       | - -                                    | 1 6 2                                   |
| B623                    | 6/8 18/9                         | 30/8 2/9                        | 2/9                                    | 12 21 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**
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.

ACKNOWLEDGEMENT

Authors wish to thank colleagues of Sotuba Agronomic Research Station especially whose from the National Sorghum Improvement Program. This work was financially supported by Rural Economy Institute of Mali (IER) and ICRISAT/Mali.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. FAO. Food and agricultural organization of the United Nations 1996. Production Yearbook. FAO, Rome; 2014.
2. Touré AK, Traoré A, Bengaly JF, Scheuring DT, Rosenow, Rooney LW. The potential of local cultivars in sorghum improvement in Mali. African Crop Science Journal. 1998;6(1):1-7.
3. Conner AB, Karper RE. Hybrid vigor in sorghum. Texas Agri. Exp. Sta. Bul. 1927; 359.
4. Stephens JC. Male sterility in sorghum: Its possible utilization in production of hybrid seed. Amer. Soc. Agron. 1937; 29:690-696.
5. Frederick R. Miller, Yilma Kebede. Genetic Contributions to yield gains in Sorghum, 1950 to 1980. In genetic contributions to yield gains of five major crop plants. CSSA Special Publication. 1984;7:1-14. ISBN: 978-0-89118-586-4.
6. Woonho Yanga, Shaobing Peng, Rebecca C. Lazab, Romeo M. Vipersasb, Maribel L. Dionisio-Sesec. Grain yield and yield attributes of new plant type and hybrid rice. Crop Sci. 2006;47(4):1393-1400.
7. Janick J. “Exploitation of heterosis: Uniformity and stability,” in The Genetics and exploitation of heterosis in Crops, J. G. Coors and S. Pandey, Eds., 1999;319-333, ASA-CSSA-SSSA, Madison, Wis, USA.
8. Andrew K. Borrell, Graeme L. Hammerb, Robert G. Henzella. Does maintaining green leaf area in Sorghum improve yield under Drought? II. Dry Matter Production
and Yield. Crop Sci. 2000;40(4):1037-1048.

9. Nouri Maman, Stephen C. Mason, Drew J. Lyon, Prabhakar Dhungana. Yield components of pearl millet and grain sorghum across environments in the central great plains. Crop Sci. 2004;44(6):2138-2145.

10. Touré A. Etude de l'effet hétérosis chez les sorghos au Mali. Mémoire de fin d'étude. Ingénieur d'agriculture. Institut Polytechnique Rual de Katiougbou, Mali; 1980.

11. Patel MH, Desai KB, Kukadia MU. Note on the manifestation of heterosis in sorghum. Indian J. Agric. Sci. 1982;52:856-857.

12. Blum A, Jordan WR, Arkin GF. Sorghum root morphogenesis and growth. II. Manifestation of heterosis. Crop Sci. 1977;17:153-157.

13. Taye T, Midaye, Emma S. Mace, Ian D. Godwin, David R. Jordan. Heterosis in locally adapted sorghum genotypes and potential of hybrids for increased productivity in contrasting environments in Ethiopia. The Crop Journal. 2016;4(6):479-489.

14. Touré AB, Scheuring JF. Présence de gênes mainteneurs de l'androstérilité cytoplasmique parmi les variétés locales de sorgho au Mali. Agronomie Tropicale. 1982;37:362-365.

15. Erin Pusipta Rini, Trikoesoemaningtyas, Desta Wirnas, Didy Sopandie, Tesfaye T. Tesso. Heterosis of sorghum hybrid developed from local and introduced lines. Int. J. Agr. Agri. Res. 2016;8(3):1-9.

16. Quinby JR, Karper RE. The Inheritance of three genes that influence time of floral initiation and maturity date in Milo. J. Amer. Soc. Agron. 1945;37:916-936.

17. Traore K, Touré A, Niangado O, Scheuring JF. Caractérisation et méthodes de criblement des variétés de sorgho S. guineense photopériodiques du Mali. Bulletin de la Recherche Agronomique du Benin. 1998;22:43-53.

18. Gapili Naoura, Romaric K. Nanema, Sawadogo Mahamadou, Jean-Didier Zongo. Study of the photoperiodism of ecotypes of sorghum of Burkina FASO. In International Journal of Innovation and Applied Studies. 2016;13(4):2028-9324.

19. Kambal AE, Webster OJ. Manifestation of hybrid vigor in grain sorghum and relation among the components of yield, weight per bushel and height. Crop Sci. 1966;6:513-515.

20. Kirby JS, Atkins RE. Heterosis response for vegetative and mature plant characters in grain sorghum, Sorghum bicolor (L.) Moench. Crop Sci. 1968;8:335-339.

21. Sodani SN, Chaturvedi SN. Heterosis for grain yield and its components in sorghum. Indian J. Hered. 1978;10:21-30.

22. Penga S, Cassmanb KG, Virmanic SS, Sheehya J, Khushc GS. Yield potential trends of tropical rice since the release of IR8 and the challenge of increasing rice yield potential. Crop Sci. 1999;39(6):1552-1559.

© 2018 Toure et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.