

# Agronomic Performances of Hybrid *Sorghum bicolor* [L] Moench, Guinea Races Cultivated under Limited and High-Soil Phosphorus Conditions

**Keywords:** Sorghum; Hybrids; Combining ability; Phosphorus

## Abstract

*Sorghum bicolor* [L] Moench is among the main starchy staples in Mali. However, its yield is low. Development of Guinea sorghum hybrids adapted to the Malian environment is one of the solutions to increase sorghum production and productivity. This study was carried out to: identify the combining ability of Guinea sorghum and intermediate races for grain yield, to assess the agronomic performance of hybrids in relation to local cultivars currently grown by the farmers under low and high soil phosphorus conditions; and develop the methods of hybrid seed production. Study was conducted in research stations of Samanko during the rainy season. Results revealed that the response of yield and plant growth performance to fertilization depended on the genotype. The Guinea-Caudatum/Guinea-Caudatum hybrids were the most productive in the plot with Di-Ammonium Phosphate (DAP). On the other hand, in the poor soil without DAP the Guinea-Ecotype/Guinea-Ecotype and Guinea-Ecotype/Guinea-Caudatum hybrids were the most productive. The best hybrids in terms of high yield stability in both trials were evaluated in farmers' fields in 15 villages. The hybrids: 150A/02-SB-F4DT-298, 150A/Grinkan, 12A/Lata-3-Bala, PR3009A/Lata-3-Bala and FambeA/Lata-3-Bala were identified as the farmers' preferred hybrids due to their high yield and good grain quality, and they were listed in the National Catalog. A total of 608 seed production farmers and peoples from private seed companies, farmers' associations and extension services were trained in hybrid seed production techniques. Through this study, the introduction of sorghum hybrids farming in Mali has become a reality.

## Introduction

Sorghum (*Sorghum bicolor* [L] Moench) is the fifth most important cereal crop in the world after wheat, maize, rice, and barley [1]. It is the dietary staple of more than 500 million people in more than 30 countries and is grown on 42 million hectares in 98 countries of Africa, Asia, Oceania and America [1]. Nigeria, India, USA, Mexico, Sudan, China and Argentina are its major producers. In Africa, sorghum ranks the second after maize (*Zea mays*) in terms of production and consumption with significant producing countries being Nigeria, Mauritania, Gambia, Mali, Burkina Faso, Ghana, Niger, Somalia, Chad, Tanzania and Mozambique [1]. There are 20-30 species of sorghum. Harlan JR et al. proposed a simplified classification scheme of cultivated sorghums based on morphological characteristics that most present-day breeders have come to recognize and utilize and partitioned the primary gene pool, *Sorghum bicolor* (L.) Moench into five major races: Bicolor, Guinea, Caudatum, Kafir, and Durra and ten intermediate races or all combinations of the basic races [2].



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The five basic races are:

- **Bicolor:** The most primitive cultivated sorghum, characterized by open inflorescences and long clasping glumes that enclose the usually small grain at maturity.
- **Caudatum:** Characterized by turtle-backed grains that is flat on one side and curved on the other; the panicle shape is variable and the glumes are usually much shorter than the grain.
- **Durra:** Characterized by compact inflorescences, characteristically flattened sessile spikelets, and creased lower glumes; the grain is often spherical.
- **Guinea:** Characterized by usually large, open inflorescences with branches often pendulous at maturity; the grain is typically flattened and twisted obliquely between long gaping glumes at maturity.
- **Kafir:** Characterized by relatively compact panicles that are often cylindrical in shape, elliptical sessile spikelets and tightly clasping glumes that are usually much shorter than the grain. Many subgroups can be distinguished with cultivars especially adapted to high or low rainfall regimes.

In Mali, sorghum is among the major crops along with pearl millet, rice, maize, cotton, peanut, and cowpea. Production of sorghum, however, does not meet demand of the growing population in the country. Grain sorghum yields are very low (0.8 to 1.3 tons/ha) and these yields are well below the genetic potential of sorghum, which, under favorable conditions, can yield up to 13 tons/ha [3]. Toure S indicated that three major sorghum races exist in Mali: Guinea, Durra and Caudatum [4]. The Guinea sorghums constitute

the dominant race grown by farmers and represent about 70% of sorghum races in Mali. They are well known for their high grain quality, good weathering, pest resistance, and storage qualities [5]. However, the yield potential of most cultivars is relatively low.

The sorghum production is decreasing due to several reasons including low soil fertility, high cost of input, drought, low adoption of improved cultivars and lack of sorghum hybrids.

Phosphorus (P) deficiency ranks second in importance after nitrogen (N) deficiency in sorghum-growing regions of the semi-arid tropics Africa [6]. Amelioration of phosphorus (P) deficiency by application of P fertilizers is costly for the small subsistence farmers with limited financial resources. They need to determine efficient fertilizer practices in conjunction with the development of P-efficient cultivars.

The adoption of improved cultivars from sorghum breeding programs is very low, less than 5% of the cultivated area [7,8]. This is due the poor adaptation of the available cultivars to the farmers' environments, the poor food quality, poor storability of grain and the lack of information on the existence and utility of new cultivars [9].

The adoption of hybrid sorghum is also very low by Malian sorghum producers. In Mali the exploitation of hybrid sorghum began in 1979 and between 1986 and 1990 the initial hybrid materials were lost from the Malian sorghum; hence it needs to develop new parents and high yielding hybrids [10].

## Objectives

### General objective

Increase production and productivity of sorghum in Mali.

### Specific objectives

To identify the combining ability of parents of different groups of Guinea sorghum races and Guinea intermediate races for grain yield and others agronomic traits under limited and high-phosphorus conditions.

To evaluate the agronomic performance of hybrids with check in trials without phosphorus (-P) and trials with phosphorus fertilization (+P)

To develop and promote parents and hybrids of sorghum Guinea races and Guinea intermediate races in limited and high phosphorus conditions.

## Materials

### Experimental site

The Agricultural Research Station of Samanko, IER Mali is located at the West of the town of Bamako on the road of Kangaba. The climate is of Sudano Sahelian type. Coordinates are 12°54' North, 8°4' West on altitude 329 m and isohyet between 800 and 1000 mm. The soil is clay loam or sandy clay with very poor nutrients.

### Plant material

Five female parents (cms) and eleven fertile male parents developed in Mali were selected for study (Table 1). The combination of female and male parents generated 55 hybrids, including 12

Guinea-ecotype×Guinea-ecotype, 15 Guinea-Caudatum×Guinea-Caudatum and 28 Guinea-Caudatum×Guinea-ecotype (Table 2). These hybrids were planted with four sorghum lines used as checks (Table 2). One cultivar of maize (Sotubaka) was used to supplement the total number of material at 60 genotypes. The performance of this maize cultivar was not measured in the study.

## Methods

The research was conducted in 2007 and 2008 respectively at Samanko Research Station in one trial with Di-ammonium phosphate (DAP) applied and the other without phosphorus applied each year. A total of four trials were conducted (Table 3).

### Experimental design

The experimental design was alpha-lattice with three replicates [(10×6)×3] for each trial. Each genotype was sown in four rows of three meters length. The spacing between rows was 0.75 m, and between hills within a row was 0.40 m (eight hills per row). Five to six seeds of genotypes were planted in each hole and thinned to two plants per hill at three weeks after emergence to give a population density of 16 plants per row either 71,111 plants per hectare.

### The field management

- **Soil preparation:** For plowing and ridging the tractor was used, the plow was used for the butting.
- **Seed treatment:** The seeds were treated with Apron star (against seedlings and insect damage) at a dose of 10 g/4 kg of seed.
- **Fertilization:** The Di-ammonium phosphate (DAP 18-46-0) was applied to the dose of 100 kg/ha at the sowing time in the phosphorus trials in 2007 and 2008. Other two trials (without phosphorus) did not receive phosphorus in (2007 and 2008) but to supply nitrogen, these trials received 37 kg/ha nitrogen at the sowing time. And then nitrogen was also applied to all trials at 50 kg/ha at first weeding for the two years.

**Table 1:** List of plant material used in the study.

No.	Name of parent	Race (type)	Inflorescence compactness	Maturity Cycle
<b>Female parents (A lines)</b>				
1	97SB-F5DT-150A	Guinea-Caudatum	Semi-loose	Medium
2	02-SB-F5DT-12A	Guinea-Caudatum	Semi-loose	Early
3	PR-3009A	Guinea-Caudatum	Semi-loose	Early
4	FAMBE A	Guinea	Loose	Medium
5	GPN99 271-20A	Guinea	Semi-loose	Medium
<b>Male parents (B lines)</b>				
1	00-KO-F5DT-19	Guinea-Caudatum	Semi-Compact	Medium
2	MALISOR-92-1	Guinea-Caudatum	Semi-Compact	Early
3	02-SB-F4DT-298	Guinea-Caudatum	Semi-loose	Medium
4	02-SB-F5DT-189	Guinea-Caudatum	Semi-loose	Medium
5	Grinkan	Guinea-Caudatum	Semi-loose	Medium
6	LATA 3 Bala	Guinea	Semi-loose	Medium
7	CGM-19/9-1-1	Guinea	Semi-loose	Medium
8	CSM-63E	Guinea	Loose	Early
9	CSM-388	Guinea	Loose	Medium
10	SEGUETANA	Guinea	Loose	Medium
11	IS 6731	Guinea	Loose	Late

**Table 2:** List of sorghum hybrids and checks (controls) used in the study.

No.	Hybrid	No.	Hybrid
	Guinea-Caudatum /Guinea-Caudatum		Guinea-Caudatum /Guinea-Ecotype
1	12A/00-KO-F5DT-19	1	12A/CSM-388
2	12A/MALISOR-92-1	2	12A/CSM-63E
3	12A/02-SB-F4DT-298	3	12A/12A/IS 6731
4	12A/Grinkan	4	12A/SEGUETANA
5	12A/12A/02-SB-F5DT-189	5	150A/CSM-388
6	150A/00-KO-F5DT-19	6	150A/CSM-63E
7	150A/MALISOR-92-1	7	150A/IS 6731
8	150A/02-SB-F4DT-298	8	150A/SEGUETANA
9	150A/Grinkan	9	PR3009A/CSM-388
10	150A/02-SB-F5DT-189	10	PR3009A/CSM-63E
11	PR3009A/00-KO-F5DT-19	11	PR3009A/IS 6731
12	PR3009A/MALISOR-92-1	12	PR3009A/SEGUETANA
13	PR3009A/02-SB-F4DT-298	13	12A/CGM-19/9-1-1
14	PR3009A/Grinkan	14	12A/Lata 3 Bala
15	PR3009A/02-SB-F5DT-189	15	150A/CGM-19/9-1-1
<b>Guinea-Ecotype/Guinea-Ecotype</b>		16	150A/Lata 3 Bala
1	FambeA/CSM-388	17	PR3009A/PR3009A/CGM-19/9-1-1
2	FambeA/CSM-63E	18	PR3009A/Lata 3 Bala
3	FambeA/IS 6731	19	FambeA/00-KO-F5DT-19
4	FambeA/SEGUETANA	20	FambeA/MALISOR-92-1
5	GPNA/CSM-388	21	FambeA/02-SB-F4DT-298
6	GPNA/CSM-63E	22	FambeA/Grinkan
7	GPNA/IS 6731	23	FambeA/02-SB-F5DT-189
8	GPNA/SEGUETANA	24	GPNA/00-KO-F5DT-19
9	FambeA/CGM-19/9-1-1	25	GPNA/MALISOR-92-1
10	FambeA/Lata 3 Bala	26	GPNA/02-SB-F4DT-298
11	GPNA/CGM-19/9-1-1	27	GPNA/Grinkan
12	GPNA/LATA 3 Bala	28	GPNA/02-SB-F5DT-189
<b>List of check (control)</b>			
<b>No.</b>	<b>Sorghum line</b>		
1	00-KO-F5DT-19		
2	MALISOR-92-1		
3	CSM-388		
4	Tieblé		

**Table 3:** List of trials, site and data sowing.

Trial	Site	Date of sowing
SK-DAP-07	Samanko	July 18, 2007
SK-SDAP-07	Samanko	July 17, 2007
SK-DAP-08	Samanko	July 01, 2008
SK-SDAP-08	Samanko	July 07, 2008

SK-DAP-07: Samanko with DAP 2007; SK-SDAP-07: Samanko without DAP 2007; SK DAP-08: Samanko with DAP 2008; SK-SDAP-08: Samanko without DAP 2008

**Data collection**

- **Plant height:** The plant height was recorded by measuring the distance from ground level to the tip of the panicle at physiological maturity and expressed in centimeters.
- **Days to 50% heading:** It was recorded as number of days from the date of sowing to the date when half (50%) of the plants in the plot have visible heads.
- **Grain yield (kg/ha):** The grain yield was computed as:

$$GY = GYP / PA$$

where,

GY = Grain yield (kg/ha)

GYP = Grain yield per plot (kg)

PA = Plot Area (ha)

**Data analysis**

The analysis of the various parameters was carried out using the GenStat twelfth edition (12.1.0.3278). Analysis of the variance was performed using the regression method.

**Combining Ability Analysis of hybrids' parents**

The ANOVA of General Combining Ability (GCA) and Specific Combining Ability (SCA) were estimated for each environment using the regression method.

- **Model for each environment:**

$$Y = (R) + (R / B) + (M) + (F) + (M * F)$$

Where,

Y = Regression model

R = Number of Repetitions

R/B = Repetitions and Blocks

M = Males

F = Females

M \* F = Males and Females interaction

In order to assess the effect of the Genotype\*Environment interaction on combining ability, a combined analysis was performed using the regression method.

- **Model for across environments**

$$Y = E + (E / R / B) + (M) + (F) + (E * M) + (E * F) + (M * F) + (E * M * F)$$

Where,

Y = Regression model

E = Environment

E/R/B = Environment, Repetitions and Blocks

M = Males

F = Females

E \* M = Environment-Males interaction

E \* F = Interaction-Environment Females

M \* F = Male-Female Interaction

E \* M \* F = Environment-Male-Female interaction

- **Estimation of GCA and SCA effects**

GCA was computed as:

$$GCA_j = X_j - \mu$$

and

$$GCA_m = X_m - \mu$$

Where,

$X_f$  and  $X_m$  = Mean of female and male respectively

$GCA_f$  and  $GCA_m$  = General combining ability of female and male respectively.  $\mu$  = Overall mean of crosses in the trial.

SCA was computed as:

$$SCA_{ij} = X_i - E_j = SCA_{ij} = Cross_{(ij)}\text{mean} - GCA_{female_i} + GCA_{male_j} = \mu$$

Where,

$X_i$  = Observed mean value of the cross

$E_j$  = Expected mean value of the cross based on the 2 GCAs of its parents

ij = crosses, ij= 1...n

## Results and Discussions

### Combining ability analysis for grain yield of parents and their $F_1$ hybrids in different environments

Analyses of variance (ANOVA) for different environments showed significant or highly significant differences (at  $P=0.05$  and  $P=0.01$ ) of GCA female and male parents in all environments except for SK-DAP-07 environment for female parents ( $P=0.47$ ) (Table 4).

Significant to highly significant differences (at  $P=0.05$  and  $P=0.01$ ) were observed between hybrids for SCA in two environments (SK-DAP-07 and SK-SDAP-07) (Table 4). However, there were not significant differences among hybrids for SCA in the two environments: SK-DAP-08 and SK-SDAP-08 (Table 4).

The ratio GCA/SCA values were greater and positive in all environments except SK-DAP-07 for the female parents (Table 4).

### GCA effects of male parents for grain yield under low and high-soil phosphorus conditions in Samanko station (2007 and 2008)

The GCA effects of the male parents under low and high-soil phosphorus environments are presented in Table 5. Under low soil phosphorus environment in 2007, two male parents LATA 3 Bala and 00-KO-F5DT-19 showed high and positive GCA for grain yield with gain +327 and +173 kg on yield. These parents produced the highest yield in hybrid combination. In the same condition in 2008 five genotypes: CGM-19/9-1-1, Lata 3 Bala, 02-SB-F4DT-298, Grinkan and 00-KO-F5DT-19 showed high and positive GCA effects for grain yield (Table 5). Under high-soil phosphorus environment in 2007, the

**Table 4:** Analyses of variance (ANOVA) of combining ability (GCA & SCA) of parents and their  $F_1$  hybrids for grain yield in different environments.

Environ ment	GCA Male			GCA Female			Male×Female (SCA)			Ratio GCA/ SCA	
	vc	vr	F pr	vc	Vr	F pr	vc	vr	F pr	Male	Female
SK-DAP-07	666.67	2.03	0.05	-61.00	0.91	0.47	391.33	1.61	0.05	1.70	-0.16
SK-DAP-08	7369.67	5.97	0.00	12314.33	9.30	0.00	535.00	1.36	0.10	13.78	23.02
SK-SDAP-07	557.40	2.35	0.02	1624.75	4.94	0.00	420.45	2.02	0.01	1.33	3.86
SK-SDAP-08	4955.67	8.91	0.00	3848.67	7.14	0.00	229.33	1.37	0.10	21.61	16.78

Vc: Variance component; vr: Variance ratio; Fpr : F. Probability

male parents LATA 3 Bala, CSM-63E and Grinkan, with +357, +167 and +122 increased yield over low phosphorus plots, had positive and high GCA effects. In 2008 in high-soil phosphorus environments, five male parents MALISOR-92-1 (+520), Grinkan (+458), 00-KO-F5DT-19 (+386), Lata 3 Bala (+194) and 02-SB-F4DT-298 (+136) exhibited positive and high GCA and produced higher yield in hybrid combinations.

Under both low and high-soil phosphorus conditions in 2007 and 2008, the parents LATA 3 Bala and Grinkan had positive GCA effects and produced high yielding hybrids in hybrid combination (Table 5).

### GCA effects of female parents for grain yield under low and high-soil phosphorus conditions in Samanko station (2007 and 2008)

Under P-limited environment in 2007 and 2008, the female parent FambeA (+210 and +290) had positive GCA and produced hybrids with high yield (Table 6).

Under high-P conditions in 2007, the parent FambeA exhibited positive GCA (+127), whereas in 2008 the parent 150A had high and positive GCA (+550) and produced best combinations for grain yield under high-soil phosphorus conditions.

### SCA effects of male crossed with female parents for grain yield under low and high-soil phosphorus conditions in 2007 and 2008

Estimates of specific combining ability effects (SCA) and mean data of genotypes for grain yield (kg/ha), are presented in Appendix 1.

**Table 5:** GCA effects of male parent for grain yield under low and high-soil phosphorus conditions in Samanko station (2007 and 2008).

Male Parent	SK-SDAP-07	SK-SDAP-08	SK-DAP-07	SK-DAP-08
00-KO-F5DT-19	173*	171*	-168	386*
MALISOR-92-1	-131	-205	28	520**
02-SB-F4DT-298	49	295*	-112	136
Grinkan	41	229*	122	458**
02-SB-F5DT-189	-262	-543	-320	-264
CGM-19/9-1-1	-35	385**	124	-54
LATA 3 Bala	327*	305**	357*	194
CSM-388	-11	-109	-10	-688
CSM-63E	-7	28	167*	-306
IS 6731	-71	-357	2	-420
SEGUETANA	-119	-303	-121	-130
Lsd	210	220	306	348

Lsd: Least significant difference; \*: Significant at the 0.01 probability level; \*\*: Significant at the 0.05 probability level

**Table 6:** GCA effects of female parents for grain yield under low and high-soil phosphorus conditions in Samanko station (2007 and 2008).

Female parent	SK-SDP-07	SK-SDP-08	SK-DAP-07	SK-DAP-08
12A	-107	-35	-33 ns	-49
150A	-15	103*	-43 ns	550**
FambeA	210**	281**	127 ns	-99
GPNA	-39	-213	-85 ns	-302
PR3009A	-49	-135	34 ns	-99
Lsd	132	150	208	232

Lsd: Least significant difference; \*: Significant at the 0.01 probability level; \*\*: Significant at the 0.05 probability level; ns: Not significant

Under P-limited environment in 2007, the genotypes FambeA/00-KO-F5DT-19 (1520 kg/ha), and 12A/LATA 3 Bala (1370 kg/ha) were the highest yielding hybrids. These two hybrids also had high and positive values for SCA with +450 and +249, respectively (Appendix 1). The best check in this environment was CSM 388 with grain yield 770 kg/ha (Appendix 1).

The hybrids 150A/CSM-388 and GPNA/Grinkan had high and positive value of SCA with +367 and +293, respectively but they did not produce high grain yield.

In this study, yields were very low for all combinations. The mean grain yield for Guinea-Caudatum/Guinea-Caudatum was 489 kg/ha, for Guinea-Ecotype/Guinea-Ecotype was 646 kg/ha and for Guinea-Caudatum/Guinea-Ecotype 809 kg/ha (Figure 1). Under low-P environment in 2008, the hybrids from group Guinea-Caudatum/Guinea-Caudatum: 150A/02-SB-F4DT-298 (2570 kg/ha), 150A/Grinkan (2390 kg/kg) and 12A/00-KO-F5DT-19 (2250 kg/ha) had high and positive values for SCA and high yield. The hybrids from group Guinea-Ecotype/Guinea-Ecotype: FambeA/CGM-19/9-1-1 and FambeA/LATA 3 Bala produced high yield with 2520 kg/ha and 2300 kg/ha respectively. The Guinea-Caudatum/Guinea-Ecotype combination: 12A/CGM-19/9-1-1, FambeA/Grinkan and FambeA/00-KO-F5DT-19 exhibited high grain yield and positive value for SCA (Appendix 1). In SK SDAP 08 environment, the Guinea-Caudatum/Guinea-Ecotype combination had the highest mean grain yield with 1862 kg/ha, followed by Guinea-Ecotype/Guinea-Ecotype with 1823 kg/ha (Figure 1). The best check, under low-P environment in 2008, was also CSM 388 with yield 1630 kg/ha (Appendix 1).

Under high-P environment in 2007, two hybrids PR3009A/MALISOR-92-1 and PR3009A/Grinkan of group Guinea-Caudatum/Guinea-Caudatum had higher yield and positive values for SCA (Appendix 1). Among group Guinea-Ecotype/Guinea-Ecotype: FambeA/CSM-63E (3310 kg/ha) and GPNA/CGM-19/9-1-1 (3220 kg/ha) were the best hybrids with high and positive values for SCA. And hybrids: 12A/LATA 3 Bala (3480 kg/ha) PR3009A/LATA 3 Bala (3430 kg/ha), 12A/CGM-19/9-1-1 (3350 kg/ha), FambeA/Grinkan (3290 kg/ha), 12A/CSM-63E (3260 kg/ha), GPNA/02-SB-F5DT-189 (3240 kg/ha), 150A/IS 6731 (3190 kg/ha), and FambeA/MALISOR-92-1 (3170 kg/ha) had higher yield and positive SCA. In this environment (SK-DAP-07), all combinations yielded well but it should be noted that the Guinea-Caudatum/Guinea-Ecotype

combination had the best average yield and the highest number of hybrids (eight) with superior yield (Figure 1). The genotype CSM 388 was the best check under high-P environment in 2007 with 2540 kg/ha (Appendix 1).

Under high-P environment in 2008, five combinations: 150A/00-KO-F5DT-19 150A/00-KO-F5DT-19, 150A/MALISOR-92-1, PR3009A/Grinkan, 150A/02-SB-F4DT-298 and 12A/MALISOR-92-1 from Guinea-Caudatum/Guinea-Caudatum showed high yield and SCA values (Appendix 1). In group Guinea-Ecotype/Guinea-Ecotype only GPNA/SEGUTANA had high yield and SCA value; just like in Guinea-Caudatum/Guinea-Ecotype group only 150A/LATA 3 Bala showed best yield and high SCA value.

The group Guinea-Caudatum/Guinea-Caudatum had the highest average yield in this environment (Figure 1).

In SK-DAP-08 trial in 2008, the best check was the genotype 00-KO-F5DT-19 with 3250 kg/ha (Appendix 1).

**The performance of genotypes for plant height and 50% heading across low and high-soil phosphorus conditions (2007-2008)**

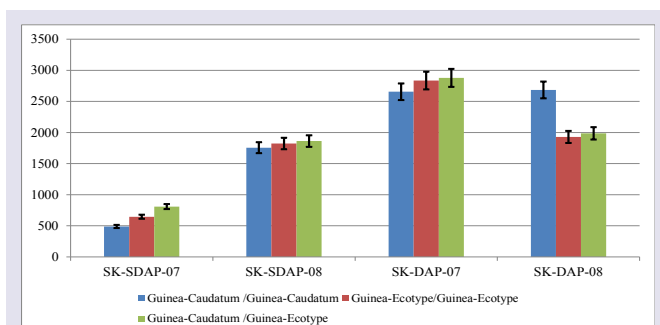
**Mean squares of plant height and 50% heading in the four environments:** The analyses of variance were highly significantly different or significantly different at P=0.01 at P=0.05 and for plant height and 50% heading at all four environments, suggesting that, the performance of genotypes was different in the environments for these traits (Table 7).

**Performance of genotypes for 50% heading under low and high-soil phosphorus conditions**

The 50% heading under low and high-soil phosphorus conditions are presented in Appendix 2.

Under low soil phosphorus environment in 2007, the mean of number of days from the date of sowing to the 50% heading was 81; the minimum was noted with FambeA/CSM-63E (74 days). In the same condition in 2008, the mean of number of days was 85 days and the minimum number was by the same genotype FambeA/CSM-63E (79 days).

Under high soil phosphorus environment in 2007, the mean of number of days from the date of sowing to the 50% heading was 71 days; the minimum days was seen with PR3009A/02-SB-F5DT-189 (63 days), whereas, in the same environment in 2008, the mean was 81 days and the earliest genotype was PR3009A/02-SB-F5DT-189 (63 days). The high soil phosphorus conditions reached 50% heading before that of those in low soil phosphorus conditions, but the difference observed was not highly significant.



**Figure 1:** Average yield of hybrids combinations low and high-P environments (2007 and 2008).

**Table 7:** ANOVA of plant height and 50% heading across low and high-soil phosphorus conditions.

Environment	Plant height					50% heading				
	ms	vr	F pr.	se	cv (%)	ms	vr	F pr.	se	cv (%)
SK-DAP-07	16.897	7.34	<0.001	1.514	0.56	14436	40.37	<0.001	18.95	5.69
SK-DAP-08	59.17	4.15	<0.001	2.868	1.40	20360	19.52	<0.050	17.86	6.81
SK-SDAP-07	39.388	6.36	<0.001	2.647	0.89	5422.3	7.73	<0.001	28.19	12.81
SK-SDAP-08	43.628	26.54	<0.001	0.969	0.47	10684.5	15.93	<0.001	19.68	10.43

ms: Mean squares; vr: Variance ratio; Fpr: F. Probability; se: Standard error; cv: Coefficient of variance

The group Guinea-Caudatum/Guinea-Caudatum was later maturing than other two groups in low-P conditions but, in high P conditions, it was earlier maturing than other two groups (Figure 2).

**Performance of genotypes for plant height under low and high-soil phosphorus conditions**

The plant height under low and high-soil phosphorus conditions are presented in Appendix 2.

Under low-P, the mean plant height was 207 cm and 255 cm, respectively, for SK-SDAP-07 and SK-SDAP-08 environments. The hybrid 150A/MALISOR-92-1 had the minimum high in these environments, 94 cm in SK-SDAP-07 and 159 cm in SK-SDAP-08 (Appendix 2).

Under high soil Phosphorus conditions, the mean plant height was 338 cm and 358 cm respectively, in SK-DAP-07 and SK-DAP-08 environments. The genotype 12A/02-SB-F4DT-298 showed minimum plant height with 209 cm in SK-DAP-07 environment and in SK-DAP-08 environment, the genotype 150A/02-SB-F4DT-298 showed minimum plant height (203 cm). The plant height was higher under high soil phosphorus conditions than under low P conditions. The group of ecotype Guinea-Caudatum/Guinea-Caudatum had the shortest plant height at all four study environments followed by the group the Guinea-Caudatum/Guinea-Ecotype (Figure 3). The highest plant height was seen for the group Guinea-Ecotype /Guinea-Ecotype at all study environments (Figure 3).

**Discussion**

The objective of the present study was to determine the combining abilities of parents of different groups of guinea sorghum races and guinea intermediate races for grain yield and other agronomic traits

under limited and high-phosphorus conditions. Analyses of variance for different environments showed significant or highly significant differences (at P=0.05 and P=0.01) of GCA for female and male parents at all environments except for SK-DAP-07 for female parents (P=0.47).

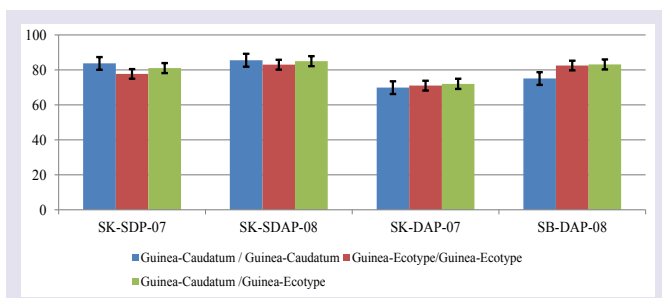
There were high significant differences between hybrids (SCA) for yield and others agronomic traits in trials without phosphorus (-P) and trials with phosphorus fertilization (+P) in 2007 and 2008. The lowest yields were observed under phosphorus limited environments, however, under high phosphorus environments, the yields of genotypes were higher in 2007 and 2008 trials. Yield reduction in trials without phosphorus (-P) compared to the trials with phosphorus (+P) has been reported by several authors [11-15]. Sandaña PA et al. also reported that the Low P trials generally exhibited reduced grain yields, relative to the corresponding high P trials [16].

In trials without phosphorus (-P), the maximum for Guinea-Caudatum/Guinea-Caudatum hybrids had low yield compared to the Guinea-Caudatum/Guinea-Ecotype and Guinea-Ecotype/Guinea-Ecotype. Whereas under +P environments, the latter were the most productive. This result agrees with those obtained by other authors [17,18]. The Guinea races (type local) respond poorly to intensification in contrast to improved Guinea-Caudatum races, which explains the low level of productivity of Guinea-Caudatum/Guinea-Ecotype hybrids on poor soil. Toure A et al. reported that the Guinea sorghums are well known or for their high grain quality, good weathering, pest resistance, and storage qualities. However, the yield potential of most cultivars is relatively low and they do not respond well to mineral fertilizer [5].

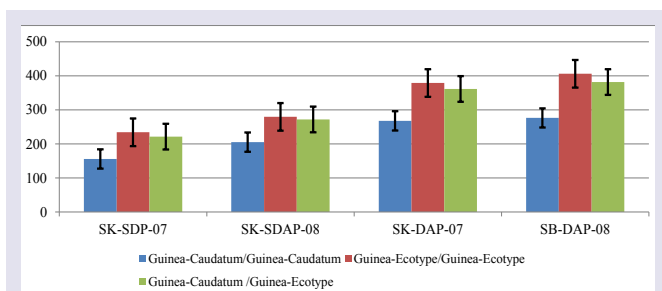
The study noted early heading of genotypes under high-phosphorus environments in 2007 and 2008, however, under P-limited environments, the heading was delayed. This result agrees with those obtained by Lamond RE et al. who reported that the effects of phosphorus deficiency on plant growth delayed maturity, reduced quality of forage, fruit, vegetable, and grain crops, and decreased disease resistance [19]. In addition, Sahrawat KL et al. reported that the deficiency of phosphorus is known to reduce plant height and delay plant growth in sorghum [12].

The Guinea-Caudatum/Guinea-Caudatum hybrids were later maturing than Guinea-Caudatum/Guinea-Ecotype and Guinea-Ecotype/Guinea-Ecotype hybrids combinations in low-P conditions but, in high P conditions, they were earlier maturing than other two combinations. This is in line with the research of several authors who reported that the Guinea-Caudatum respond well to mineral fertilizer.

A difference in plant height in trials without phosphorus and in trials with phosphorus in 2007 and 2008 was seen. The tallest genotypes were obtained under +P environments while those under -P conditions were the shortest. Camacho R et al. reported similar results and reported that lack of phosphorus substantially reduced plant height [20]. It should be noted that the yield reduction, heading delay, and reduced height in -P compared to +P have been reported for several crops : Fageria NK et al. on rice cultivar [21]; Atlin GN et al., on oat [22]; Sahrawat KL et al. on sorghum [13]; Wissuwa M



**Figure 2:** Mean of 50% heading under low and high-soil phosphorus conditions (2007 and 2008).



**Figure 3:** Mean of plant height under low and high-soil phosphorus conditions (2007 and 2008).

et al. on rice [23] and Manske GG et al. on wheat [24]. This suggests that our environmental selection based on yield differences, height reduction, and heading delay was appropriate.

**Promotion of Best Hybrids Identified in Limited and High Phosphorus Environments**

**Experimentation in farmers’ fields:** From 2009 to 2012, around twenty hybrids (among the three combinations) identified with high yield stability in both trials without and with phosphorus fertilization were evaluated in the farmer’s fields in 15 villages of Bougouni and Kati prefectures (Table 8). The local cultivars grow by farmers were used as checks.

The objective of the experimentation was to identify the best and the farmers’ preference hybrids in different sites.

After experimentations in 15 villages of Bougouni and Kati prefectures, five hybrids were identified (two Guinea-Caudatum/ Guinea-Caudatum, two Guinea-Caudatum /Guinea-Ecotypes and one Guinea-Ecotype/Guinea-Ecotype) as farmers’ preferred hybrids with high yield and good grain quality compared with local cultivars used as checks (Table 9). These new hybrids were added to in to the National Catalog in 2013.

**Hybrid seed production technique:** To promote sorghum hybrids, 608 people, composed of seed farmers, private seed companies, farmers’ associations and extension services, were trained in hybrid seed production techniques, thus increasing the availability of hybrid seed to the producers (Plate 1 and 2) (Table 10). Indeed, in 2011 and 2012, 19,658 tons of hybrid seeds was produced and

**Table 8:** List of villages involved in Bougouni and Kati prefectures.

No.	Village	Prefecture
1	Banankoro	Bougouni
2	Bougouni	Bougouni
3	Bèko	Bougouni
4	Djambala	Bougouni
5	Faraba	Bougouni
6	Kokélé	Bougouni
7	Laban	Bougouni
8	Madina	Bougouni
9	N'Tjilla	Bougouni
10	Niako	Bougouni
11	Ouré	Bougouni
12	Sola Buguda	Bougouni
13	Bossofala	Kati
14	Dio	Kati
15	Kambila	Kati

**Table 9:** List of hybrids identified as suitable for farmers.

Local name	Pedigree	Hybrid combination
Sewa	150A/02-SB-F4DT-298	Guinea-Caudatum/Guinea-Caudatum
Grinkanyerewolo	150A/Grinkan	Guinea-Caudatum/Guinea-Caudatum
Fadda	12A/Lata 3 Bala	Guinea-Caudatum/Guinea-Ecotypes
Omba	PR3009A/Lata 3 Bala	Guinea-Caudatum/Guinea-Ecotypes
Pablo	FambeA/Lata 3 Bala	Guinea-Ecotype/Guinea-Ecotype

traded in Mali by the various actors. Thus, it can be assumed that the introduction of sorghum hybrids in a farming environment has become a reality in Mali.

**Conclusion**

The performance of hybrids and their parents was different in two environments, without and with phosphorus fertilization, for yield, 50% heading and plant hight. Yield reduction, delay of heading, and reduction of the plant height was seen in trials without phosphorus supply (-P) compared to trials with phosphorus supply (+P). Five hybrids 150A/02-SB-F4DT-298 (Sewa), 150A/Grinkan (Grinkanyerewolo), 12A/Lata 3 Bala (Fadda), PR3009A/Lata 3 Bala (Omba), FambeA/Lata 3 Bala (Pablo) and three parents: Lata 3 Bala (male), 150A and FambeA (females), were suitable for farmers in

**Table 10:** List of locations, actors and number of persons trained in hybrid seed production techniques from 2010 to 2012.

Year	Location	Actor	Men	Women	Total
2010	Siby, Dioila, Samanko	Cooprosem, ULPC, Fasokaba, Comptoir 2000	45	4	49
2011	Yanfolila, Bougouni, Dioila, Kita, Siby	EUCORD, Fasokaba, Nakoshi, Comptoir 2000, OP, Service technique	249	79	328
2012	Kati, Kita, Beleco, Siby, Doila, Koutiala et Yanfolila	USCPMD,OP, Service technique, EUCORD, ACF, CRPROSEM, ULPC, AMEDD, MOBIOM, AMASSA	199	32	231
Total			493	115	608



**Plate 1:** Workshop in hybrid seed production techniques at Yanfolila in 2011.



**Plate 2:** Farmers in practice of seed production techniques at Faraba in 2010.

sorghum production in Mali. These new hybrids were added to the National Catalog. The farmers were well-trained in sorghum hybrid seed production techniques and acquired good skills in hybrid seed production techniques.

Thus, the introduction of sorghum hybrids in a farming environment has become a reality in Mali.

However, further studies should be carried out in order to consolidate the results obtained.

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