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ADAPTATION OF BIO-FORTIFIED SORGHUM HYBRIDS (sorghum bicolor) TO DROUGHT RESILIENCE IN MALI

Alfousseiny M Maiga[1,2*], Abdoulaye G. Diallo[1], Cheich oumar Dembele[1] and Yacouba Kane[1]

[1]Research assistant at Institute of Rural Economy /Regional Centre of Applied Research of Sotuba, Sorghum Program BP: 258 Bamako;

[2]West Africa Centre for Crop Improvement (WACCI), College of Basic and Applied Sciences, University of Ghana, Legon

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ABSTRACT

Sorghum is a staple food in Mali, yet grain yields are low and do not contain high lysine, threonine, iron and zinc content. Drought is the most significant cause of crop yield loss, especially in water limited areas where most of the world's poorest farmers live. Development of drought tolerant bio-fortified sorghum hybrids will enhance food production and the livelihood of farmers in these areas. To assess the adaptation, yield potential, and to identify the traits contributing directly and indirectly to drought resilience, a study was conducted in two locations. Thus, a total of 49 F1 hybrids were developed and used in this study along with three commercial hybrids. Ten (10) bio fortified hybrids were identified with grain yield ranging from 3774 to 5068 kg ha-1 with an average heading date of 74-83 days. The new bio-fortified sorghum hybrids in this study yielded three times as much as the local varieties, which yielded 1 to 1.5 tons. The index of varietal sensitivity varied 253.43 to 81.12 %. For drought resilience, a significant correlation was identified with index of varietal sensitivity through mibrid, stay green and leaf senescence. A positive and negative correlation among grain yield, stay green and mibrid were observed. This study identified bio fortified sorghum hybrids with high grain yield and tolerant to drought stresses. These ten hybrids are worthy to be utilized in participatory trials for their registration in the seed catalog.

Keywords: Sorghum, Bio fortified, resilience, Drought.

1. INTRODUCTION

In Mali, sorghum (*Sorghum bicolor* (L.) Moench) is widely grown, ranked the 3th position after corn and rice [1] and it plays a key role as food security for rural and urban people. Mali is among the top producers of sorghum in West Africa with 1,219,620 hectares of cultivated area and total average yield of 1.50 t. ha^{-1} [2]. The crop has gained much popularity especially in the Sahelian area of West Africa where the grain is harvested for consumption, the straw is used for roofing and as stake for yam. Unfortunately, the crop is faced with several biotic and abiotic stresses resulting in its low productivity in SSA.

Malnutrition is one of the major causes of morbidity and mortality among children under five in Mali. It remains a chronic problem and particularly affects Koulikoro, Sikasso, Mopti and Ségou regions with a prevalence of more than 30% as illustrated by (UPUBU, 2014, SAP, 2015). UPUBU, 2014 emphasized that, the prevalence of global acute malnutrition is between 10% and 14% in the regions of Kayes (11.3%), Mopti (11.6%), Koulikoro (13.8%), Segou (14.0%), District of Bamako (14.2%) and Timbuktu (14.8%).

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[3] believed that, the rapid growth of demography and intensive agriculture on marginal lands, sorghum will become more and more important. Due to its various uses, yield stability, adaptability and drought resistance to a wide range of climates, sorghum has retained its importance and reliability. Therefore, improving this crop will have a significant impact on the socio-economic status of people living in semi-arid zones.

Considerable efforts have been made to improve this low level of productivity and proteins content. Thus, since the 1970s, breeding programs in different countries in West Africa have focused on improving the guinea race of sorghum for increased productivity level. In Mali, a systematic evaluation of more than 1300 accessions of sorghum collected were carried out at different stations and sub - stations of agronomic research [4]. The exploitation of these collections made it possible to identify the agronomic and organoleptic characteristics of the cultivars or tolerance to various abiotic and biotic constraints [5]. Among abiotic stresses, drought and heat have been considered as the main threats to food security and sustainability of production systems leading to more than 60% Sorghum yield reduction in SSA [6]. Predictions indicated a shifting in rainfall amounts and patterns and a rising in temperature up to 1.2 °C by 2035 and 2100 that could be causes of great threats to food and nutrition security of many smallholders in West Africa whose economies are highly dependent on the crops [7]. The best approaches to significantly improve sorghum output while maintaining its adaptability and desiring characteristics is the development of F_1 hybrids with characteristics of the Guinea type, the most dominant in Mali. Indeed, scientific findings have highlighted the advantage of hybrids over open pollinated varieties in sorghum. Although in sorghum grain, efforts were made to expand the protein content. Strategies of nutrient elements for various cereals, involve improved agronomic practices, breeding for high nutrient yielding varieties as indicated by [8 and 9]. Although, in sorghum grain, scientists have been trying to expand the protein content, just few lines were reported with “high lysine content” IS11167 and IS11758 as shown by [10] and P721 Q was induced by chemical mutagenesis, which is a mutant of phenotype opaque.

Drought is the most significant cause of crop yield loss [11], especially in water limited areas where most of the world’s poorest farmers live. Up to 45% of the world’s agricultural lands, where 38% of the world’s population resides, are subjected to continuous or frequent drought [12]. Development of drought tolerant crops will enhance food production and the livelihood of farmers in these areas. Moreover, as the world population continues to grow and water resources for crop production decline, development of drought tolerant cultivars and water use efficient crops is becoming a major strategic priority.

Several sorghum genotypes have been identified that exhibit the stay-green characteristic including B35 (BTx642), KS19, SC56, and E36-1 [13.14.15.16] . The most common source of stay green trait has historically been the sorghum line B35, a member of the durra race. This genotype has been particularly useful as a source of stay green trait in public and commercial breeding programs in Australia [17].

Research has been conducted in Mali targeting tolerance to drought in sorghum, but no research has been conducted into tolerance to Sorghum drought bio fortified hybrids. To the best of my knowledge, no research using new technologies to develop new hybrids of sorghum bio fortified tolerant to post flowering drought has been conducted so far.

The aim of the present study was to identify bio fortified sorghum hybrids with high grain yield and tolerant to drought stresses and then to Identify the best bio-fortified sorghum hybrids through participatory farmer evaluation.

2. METHOD

2.1 Study Area

The study was carried out in the Regional Center for Agronomic Research (CRRA) of Sotuba, and Sub-station of Kolombada IER, Mali, located respectively in the district of Bamako and region of Koulikoro.

- Regional Center for Agronomic Research (CRRA) of Sotuba: The Regional Center for Agronomic Research (CRRA) of Sotuba, IER Mali, is located in the district of Bamako and on the left bank of the Niger river about 7 km from downtown Bamako and covers an area of approximately 265 ha (Figure 1). The climate is Sudano-Sahelian type. Coordinates are latitude $12^0$38', longitude 7056' and an altitude of 320 m with rainfall varying from 800 to more than 1000 mm. The soil is of the clay loam or clay sandy type.

  During 2021, the average rainfall observed was 1017 mm. The rainfall amounts collected during the months of May, August, September and October were above the average of the last ten years except June and July.

- Regional Center for Agronomic Research (CRRA) of Kolombada: Regional Center for Agronomic Research (CRRA) of Kolombada is located in the Koulikoro Region (commune of Fana) and about 12 km from Fana and covers an area of approximately 37 ha (Figure 1). Its geographic coordinates are: latitude 12041', longitude 7059' and an altitude of 310 m. The climate is Sudano-Sahelian type with an annual rainfall varying from 600 to 900 mm. The soil is sandy loam type.

  During 2021, the average rainfall observed was 597 mm. The rainfall amounts collected during the months were above the average of the last ten years except July.

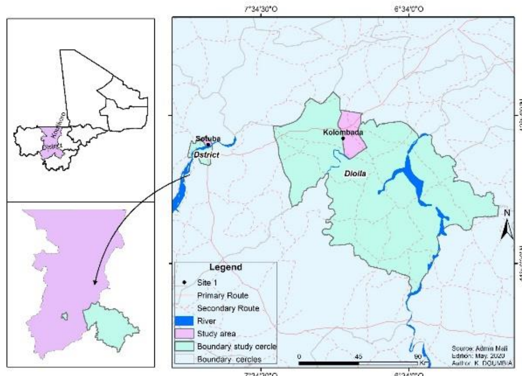

Figure 1 : Maps showing agro ecological zones.
(Source: [18])

2.2 Plant Material

The plant material consisted of Forty-nine (49) new bio-fortified hybrids resulting from crosses between seven female parents (5A, 7A, 9A, 11A, 13A,15A and 17A) and 10 male parents containing high organic (lysine and threonine) and inorganic (iron and zinc) content (Touré *et* *al.*, 2017, Maiga *et al.*, 2021) (Table 1). The 49 hybrids were compared to to three released hybrids (Sassilon, Fadda and Sewa). The trial was conducted during a rainy season at three zones. The parents have a diversity of agronomic traits such as plant cycle, yield, zinc, iron, lysine and threonine content (Table 1).

Table 1: Material list of hybrids parents used to develop the bio-fortified hybrids with their main traits

N	Lines	cycle	yield	lysine	Threonine	Iron	zinc
			Parents Males				
1	016-BE-BC1F6-1105	68	1880	1.03	3.13	6.82	1.24
2	016-BE-BC1F6-1048	71	2730	2.33	2.26	5.4	5.98
3	016-BE-BC1F6-73	82	3333	1.19	2.31	4.67	0.21
4	016-BE-BC1F6-CT-2016	82	2300	2.33	2.26	5.4	5.98
5	016- SB -BC1F6-1105	83	923	1.78	3.18	4.28	3.96
6	016- SB -BC1F6-1090	81	2800	1.97	3.33	6.16	7.06
7	016- SB -BC1F6-1068	86	2080	1.62	5.53	3.2	0.82
8	016- KO -BC1F6-1086	84	2210	1.25	2.45	3.19	4.15
			Parents females				
9	5A	65	2533	11.56	15.66	0.06	0.13
10	7A	63	2615	13.39	16.99	0.05	0.14
11	9A	70	3015	8.43	10.08	0.04	0.13
12	11A	73	2871	12.32	14.86	0.03	0.16
13	13A	68	2987	8.59	9.86	0.06	0.17
14	15A	66	2657	14.31	20.81	0.03	0.13
15	17A	67	2985	9.14	11.41	0.04	0.14
			Checks				
16	Sassilon	78	4000				
17	Fadda	80	2500				
18	Sewa	78	2500				

2.3 Experimental Design and Agronomic Practices

The experimental design used was an Alpha lattice with two replications. The elementary plot was 2 rows of 3m. Seeding was carried out at 0.75m intervals between the sowing rows and 0.30m between the hills. The distance between the two blocs was 1.5 m and 2 m between replications. Thinning was done at 2 plants per hill. The cereal complex (N (17)-P2O5(17)-K2O (17)- kg $^{-1ha}$) was used as fertilizer at the rate of 100 kg -$^{1\ ha}$ or approximately 45 g per elementary plot, 15 days after sowing. Urea was then applied 45 days after sowing at the rate of 50 kg -^{1ha} or about 23 g per elementary plot. The in-row spreading method was used for both these fertilizer inputs.

The hybrids obtained from the two parents were in line by testers.

2.4 Data Collection

Data were collected as described in table 2.

Parameters	Abreviations	Description	Unit
Seedling vigor	SV	It expresses the physical energy with which the seedlings emerge from the earth (height and number of leaves) 14-15 days after sowing.	Score (5=Excellent, 1= Very Bad)
Heading time	HT	From sowing until 50% of the plants in the plot to reach heading time.	Date
Plant height	PH	Distance from ground to top of panicle	Cm
Stay green at Maturity	SGM	It is the number of green leaves at physiological maturity on 3 plants. It allows to determine the average number of green leaves.	Number
Midrib	M	It consists in observing the central Midrib	scale: 1= dry, 2 = wet and 3= brown.
Leaf senescence	LS	Death of leaves and stalk at grain maturity	Scale : 1 Very slightly senescent and 9 Completely senescent (leaves and stalk dead)
Number of harvested hills	NHH	Counting of Number of harvested hills per plot	Number
Panicle harvested number	PHN	Counting of Panicle harvested number per plot	Number
Panicle weight	PW	Panicle weight per plot	g/plot
Grain Weight	GW	Grain weight per plot	g/plot
Grain of quality (Endosperm texture)	GQ	It is a visual appreciation after having broken the seed into two parts. Data were taken according to the following scores	Scores: 1(Completely corneous; 2 (Mostly corneous); 5 (Intermediate); 7(Mostly starchy) and 9 (Completely starchy).
Remark		Problems or specific additional observations (leaf diseases, insect damage)	By a specialist

2.5 Statistical Analysis

The data collected on the 12 variables was entered and verified with an Excel version 2017 spreadsheet. The analysis of variance was carried out using the software GenStat twelfth edition (12.1.0.3278) in order to discern the variability (s) linked to the plant material studied. The analysis of variance for the various parameters was performed using the following model described by Kempthorne (Kempthorne, 1957). Genotypes were considered fixed effects, while replicates and localities were considered random effects.

$$Yijk = \mu + Li + R_{ij} + G_k + (LG)_{ik} + E_{ijk} \quad (1)$$

Yijk = Measured variable of the j^{th} repetition in the i^{th} site of the ij^{th} entry

μ = Overall mean

L_i = Effect of the i^{th} sity

R_{ij} = Effect of the j^{th} repetition in the i^{th} sity

G_k = Effect of the k^{th} designation (parent, check and hybrids)

$(LG)_{ik}$ = Effect of the interaction of the k^{th} designation in the i^{th} sity

E_{ijk} = Residual effects

Associations between traits were described using Pearson correlation analysis.

Preference by gender was calculated by the following formula:

$$\text{Pref / gender \%: } ((1xNB+0.5xNJ+0xNR)/(NB+NJ+NR)) *100 \quad (2)$$

Pref%: Preference by sex

NB: Number of white

NJ: Number of yellow

NR: Number of red

The index of variety sensitivity (IVS) was determined by the formula of FISCHER and MAURER (1978):

$$IVS = Rs / Rt *100 \quad (3)$$

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where Rs is the grain yield under drought conditions, Rt, the grain yield under non water-limiting conditions (control)

3. RESULTS

3.1 Agronomic Performance of Bio-fortified F1 Hybrids Compared to Checks

With respect to designation, sites and designation. Site, analysis of variance (Table 3) showed a highly significant difference between treatments for all traits except designation. Site for plant height, which was not significant (Table 3).

Table 3: Mean squares for all studied traits over four sites

	Source	d.f.	SS	MS	VR	F pr.
Grain yield	DESIGNATION	51	176275880	3456390	5.66	<.001
	SITE	1	46181644	46181644	75.61	<.001
	DESIGNATION.SITE	51	69145915	1355802	2.22	<.001
Plant height	DESIGNATION	51	204498.3	4009.8	4.24	<.001
	SITE	1	34996.2	34996.2	37.04	<.001
	DESIGNATION.SITE	51	52452	1028.5	1.09	0.353
Cycle	DESIGNATION	51	4802.014	94.157	11.88	<.001
	SITE	1	236.942	236.942	29.89	<.001
	DESIGNATION.SITE	51	549.506	10.775	1.36	0.095
Midrib	DESIGNATION	51	40.8846	0.8017	1.57	0.055
	SITE	1	32.546	0.7016	1.07	0.035
	DESIGNATION.SITE	51	15.8846	0.5017	2.03	0.015
Saty green	DESIGNATION	51	10.1256	0.125	1.12	0.025
	SITE	1	12.5212	0.7018	1.13	0.011
	DESIGNATION.SITE	51	15.9846	0.5117	2.13	0.001
leaf senescence	DESIGNATION	51	21.1346	0.5017	1.52	0.015
	SITE	1	12.5468	0.8016	1.37	0.035
	DESIGNATION.SITE	51	25.8946	0.5017	2.03	0.015
Index of variety sensibility	DESIGNATION	51	12.8846	0.815	1.57	0.058
	SITE	1	12.546	0.1016	1.07	0.025
	DESIGNATION.SITE	51	15.8846	0.7017	2.03	0.015

d.d.l: Degree of freedom, F pr : Significance, m.s: Mean of squares, s.s: Sum of squares, v.r: Ratio of variation,

- **Grain yield**

At Kolombada, grain yield ranged from 707 to 5395 kg/ha with an overall average of 2145 kg/ha (Table 4). The hybrids IER-TSR- 021-MLT-MD-FH-8 (5395 kg/ha), IER-TSR- 021-MLT-MD-FH-10 (3820 kg/ha), IER-TSR- 021-MLT-MD-FH-13 (3795 kg/ha), IER-TSR- 021-MLT-MD-FH-26 (3773 kg/ha) IER-TSR- 021-MLT-MD-FH-19 (3237kg/ha), IER-TSR- 021-MLT-MD-FH-49 (3222kg/ha) and IER-TSR- 021-MLT-MD-FH-11(3012kg/ha) were more productive than all other treatments. In fact, the control was more productive than some of the new hybrids (IER-TSR- 021-MLT-MD-FH-20 and IER-TSR- 021-MLT-MD-FH-37 (Table 4).

Grain yield at Sotuba ranged from 808 kg/ha to 6121 kg/ha (Table 4). The average observed was 3088 kg/ha. The most productive hybrids were IER-TSR- 021-MLT-MD-FH-10 (4576 kg), and IER-TSR- 021-MLT-MD-FH-11 (4589 kg), IER-TSR- 021-MLT-MD-FH-12 (5515 kg) , IER-TSR- 021-MLT-MD-FH-13 (4996 kg) , IER-TSR- 021-MLT-MD-FH-15 (5266 kg), IER-TSR-021-MLT-MD-FH-16 (4320 kg), IER-TSR- 021-MLT-MD-FH-17 (4054 kg), IER-TSR- 021-MLT-MD-FH-19 (6121 kg) IER-TSR- 021-MLT-MD-FH-34 (4296 kg), IER-TSR- 021-MLT-MD-FH-35 (4613 kg) , IER-TSR- 021-MLT-MD-FH-36 (5020 kg) and IER-TSR- 021-MLT-MD-FH-8 (4741 kg) (Table 4).

The average grain yield of the two locations indicates that the hybrids IER-TSR- 021-MLT-MD-FH-8 (5068 kg), IER-TSR- 021-MLT-MD-FH-19 (4679 kg), IER-TSR- 021-MLT-MD-FH-13 (4396 kg), IER-TSR- 021-MLT-MD-FH-12 (4204 kg) and IER-TSR- 021-MLT-MD-FH-10 (4198 kg) were the most productive hybrids. These hybrids were more productive than the other treatments.

- **Cycle**

At Kolombada, the cycle varied from 68 to 83 days with an average of 77 days (Table 4). The hybrids IER-TSR- 021-MLT-MD-FH-1, IER-TSR- 021-MLT-MD-FH-34 and IER-TSR- 021-MLT-MD-FH-37 (71 days), IER-TSR- 021-MLT-MD-FH-23 and 26 (68 days), and IER-TSR-021-MLT-MD-FH-22 and 27 (69 days) were the earliest than the other treatments. (Table 4).

At Sotuba, the cycle ranged from 64 to 83 days with an average of 89 days. The hybrids IER-TSR- 021-MLT-MD-FH-2, IER-TSR- 021-MLT-MD-FH-26 and IER-TSR- 021-MLT-MD-FH-3 (71 days), IER-TSR- 021-MLT-MD-FH-34 (69 days) IER-TSR- 021-MLT-MD-FH-23 (64 days) IER-TSR- 021-MLT-MD-FH-24 (65 days), IER-TSR- 021-MLT-MD-FH-27 (66 days), IER-TSR- 021-MLT-MD-FH-28, and IER-TSR- 021-MLT-MD-FH-47 ((67) days were the earliest.

For both locations the hybrids, IER-TSR- 021-MLT-MD-FH-26, IER-TSR- 021-MLT-MD-FH-4, IER-TSR- 021-MLT-MD-FH-27 (68 days), IER-TSR- 021-MLT-MD-FH-28, IER-TSR- 021-MLT-MD-FH-24 (69 days), IER-TSR- 021-MLT-MD-FH-23 (66 days) were the earliest.

- **Plant height**

At Kolombada, plant height ranged from 172 to 280 cm with an average height of 217 cm (Table 4). The hybrids, IER-TSR- 021-MLT-MD-FH-2, IER-TSR- 021-MLT-MD-FH-48 (175 cm) and, IER-TSR- 021-MLT-MD-FH-31 (72 cm) were relatively short compared to the other treatments (Table 4).

At Sotuba the height of the plants ranged from 185 to 310 cm and the average observed was 243 cm (Table 4). The hybrids, IER-TSR- 021-MLT-MD-FH-36 (185 cm), IER-TSR- 021-MLT-MD-FH-31 (188 cm) were significantly shorter than the controls and other new hybrids (Table 4).

The shortest plants in two locations were observed in the hybrids: IER-TSR- 021-MLT-MD-FH-31, IER-TSR- 021-MLT-MD-FH-48 (180 cm) and IER-TSR- 021-MLT-MD-FH-23 (181 cm) had a height less than 200 cm which is relatively short than the other treatments.

- **Midrib**

At both sites and across sites, 15 Bio fortified hybrids (IER-TSR- 021-MLT-MD-FH-2, IER-TSR- 021-MLT-MD-FH-42, IER-TSR- 021-MLT-MD-FH-24, IER-TSR- 021-MLT-MD-FH-3, IER-TSR- 021-MLT-MD-FH-38, IER-TSR- 021-MLT-MD-FH-39, IER-TSR- 021-MLT-MD-FH-5, IER-TSR- 021-MLT-MD-FH-6 ,IER-TSR- 021-MLT-MD-FH-11, IER-TSR- 021-MLT-MD-FH-25, IER-TSR- 021-MLT-MD-FH-37, IER-TSR- 021-MLT-MD-FH-41, IER-TSR- 021-MLT-MD-FH-1, IER-TSR- 021-MLT-12MD-FH-,IER-TSR- 021-MLT-MD-FH-36, and the Sassilon control had a wet (score 2) Midrib (Table 4). The wet Midrib is one of the indicators for the dual-purpose trait.

- **Stay green**

At Sotuba, the number of stay green varied between 9 and 15 leaves with an average of 11 leaves (Table 4).

Thus the highest number of stay green (15 leaves) was recorded by two bio-fortified hybrids (IER-TSR- 021-MLT-MD-FH-8, IER-TSR- 021-MLT-MD-FH-12), while the lowest number of stay green (11 leaves) was obtained by the control Sassilon (Table 4).

At kolombada, the number of stay green varied between 7 and 13 leaves with an average of 10 leaves (Table 4).

Thus the highest number of stay green (12 leaves) was recorded by two fortified hybrids (IER-TSR- 021-MLT-MD-FH-28, IER-TSR- 021-MLT-MD-FH-25), while the controls had a number of stay green superior to some new hybrids (Table 4).

Across sites, two new hybrids ((IER-TSR- 021-MLT-MD-FH-9, IER-TSR- 021-MLT-MD-FH-13) bio fortified recorded the largest number of stay green compared to all treatments (Table 4).

- **Leaf senescence**

At both sites, the leaf senescence varied from 1(Very slightly senescent) to 5(Intermediate (about half of leaves dead) (Table 4).

The top ten (10) bio fortified Sorghum hybrids IER-TSR- 021-MLT-MD-FH-46, IER-TSR- 021-MLT-MD-FH-17, IER-TSR- 021-MLT-MD-FH-41, IER-TSR- 021-MLT-MD-FH-12, IER-TSR- 021-MLT-MD-FH-10 IER-TSR- 021-MLT-MD-FH-13, IER-TSR- 021-MLT-MD-FH-8, IER-TSR- 021-MLT-MD-FH-11, IER-TSR- 021-MLT-MD-FH-38, IER-TSR- 021-MLT-MD-FH-7 had a very slightly senescent (Table 4).

- **Index of varietal sensitivity**

Index of varietal sensitivity varied from 253.49 to 26.02 % (Table 4). The 13 bio fortified hybrids (IER-TSR- 021-MLT-MD-FH-4, IER-TSR- 021-MLT-MD-FH-24, IER-TSR- 021-MLT-MD-FH-26, IER-TSR- 021-MLT-MD-FH-49, IER-TSR- 021-MLT-MD-FH-9,IER-TSR- 021-MLT-MD-FH-27, IER-TSR- 021-MLT-MD-FH-5, IER-TSR- 021-MLT-MD-FH-8, IER-TSR- 021-MLT-MD-FH-25, IER-TSR- 021-MLT-MD-FH-45, IER-TSR- 021-MLT-MD-FH-3, IER-TSR- 021-MLT-MD-FH-22, IER-TSR- 021-MLT-MD-FH-29,IER-TSR- 021-MLT-MD-FH-1, IER-TSR- 021-MLT-MD-FH-10, IER-TSR- 021-MLT-MD-FH-39and IER-TSR- 021-MLT-MD-FH-6 had the largest value of sensitivity index with 253.43 to 81.12 % compared to all other treatment (Table 4).

Table 4: Mean values of seven traits

	Grain Yield			Plant height			Cycle			Mibrid			Stay green			Leaf senescence			IVS
DESIGNATION	KO	SB	Moy	KO	SB	Moy	KO	SB	Moy	KO	SB	Moy	KO	SB	Moy	KO	SB	Moy	Moy
IER-TSR- 021-MLT-MD-FH-1	1737	2061	1899	193	238	215	71	72	72	2	2	2	9	12	11	4	5	5	84.28
IER-TSR- 021-MLT-MD-FH-10	3820	4576	4198	280	310	295	81	83	82	2	2	2	7	10	9	1	2	2	83.48
IER-TSR- 021-MLT-MD-FH-11	3012	4589	3801	212	302	257	83	82	82	2	2	2	8	12	10	1	2	2	65.64
IER-TSR- 021-MLT-MD-FH-12	2892	5515	4204	240	318	279	83	83	83	2	2	2	10	12	11	1	2	2	52.44
IER-TSR- 021-MLT-MD-FH-13	3795	4996	4396	215	273	244	82	83	83	1	1	1	10	15	13	1	2	2	75.96
IER-TSR- 021-MLT-MD-FH-14	1747	3465	2606	270	260	265	75	73	74	2	2	2	9	14	12	4	5	5	50.42
IER-TSR- 021-MLT-MD-FH-15	2077	5266	3672	198	257	228	79	74	77	2	2	2	7	11	9	4	5	5	39.44
IER-TSR- 021-MLT-MD-FH-16	1219	4320	2770	213	278	245	80	76	78	1	1	1	7	10	9	4	5	5	28.22
IER-TSR- 021-MLT-MD-FH-17	2576	4054	3315	230	257	244	78	79	78	2	2	2	8	12	10	1	2	2	63.54
IER-TSR- 021-MLT-MD-FH-18	1155	3057	2106	197	193	195	76	76	76	1	1	1	10	12	11	4	5	5	37.78
IER-TSR- 021-MLT-MD-FH-19	3237	6121	4679	233	283	258	79	76	77	2	2	2	10	12	11	4	5	5	52.88
IER-TSR- 021-MLT-MD-FH-2	1323	1903	1613	175	202	189	73	69	71	3	3	3	13	13	13	4	5	5	69.52
IER-TSR- 021-MLT-MD-FH-20	515	1848	1182	180	198	189	84	81	82	1	1	1	7	9	8	4	5	5	27.87
IER-TSR- 021-MLT-MD-FH-21	1279	3061	2170	208	213	210	81	77	79	1	1	1	6	10	8	4	5	5	41.78
IER-TSR- 021-MLT-MD-FH-22	2377	2616	2497	217	240	229	69	70	70	2	2	2	6	11	9	4	5	5	90.86
IER-TSR- 021-MLT-MD-FH-23	1313	1784	1549	180	183	181	68	64	66	2	2	2	9	10	10	4	5	5	73.6
IER-TSR- 021-MLT-MD-FH-24	1822	808	1315	220	248	234	73	65	69	3	3	3	7	10	9	4	5	5	225.5
IER-TSR- 021-MLT-MD-FH-25	2776	2690	2733	227	272	250	73	71	72	2	2	2	12	11	12	4	5	5	103.2
IER-TSR- 021-MLT-MD-FH-26	3773	2037	2905	220	240	230	68	69	68	2	2	2	10	11	11	4	5	5	185.2
IER-TSR- 021-MLT-MD-FH-27	2509	1545	2027	225	268	246	69	66	68	1	1	1	13	9	11	4	5	5	162.4
IER-TSR- 021-MLT-MD-FH-28	2384	3869	3127	203	268	235	70	67	69	2	2	2	12	11	12	4	5	5	61.62
IER-TSR- 021-MLT-MD-FH-29	2105	2488	2297	182	200	191	73	75	74	1	1	1	10	12	11	4	5	5	84.61
IER-TSR- 021-MLT-MD-FH-3	2096	2131	2114	240	278	259	74	69	72	3	3	3	8	10	9	4	5	5	98.36
IER-TSR- 021-MLT-MD-FH-30	2569	3774	3172	247	268	258	72	70	71	1	1	1	9	10	10	4	5	5	68.07
IER-TSR- 021-MLT-MD-FH-31	1357	1986	1672	172	188	180	83	83	83	1	1	1	7	10	9	4	5	5	68.33
IER-TSR- 021-MLT-MD-FH-32	1737	3030	2384	233	133	183	76	75	75	2	2	2	11	14	13	4	5	5	57.33
IER-TSR- 021-MLT-MD-FH-33	1606	3148	2377	228	253	240	74	72	73	2	2	2	9	11	10	4	5	5	51.02
IER-TSR- 021-MLT-MD-FH-34	2481	4296	3389	238	312	275	71	69	70	1	1	1	10	12	11	4	5	5	57.75
IER-TSR- 021-MLT-MD-FH-35	1805	4613	3209	233	235	234	74	71	72	1	1	1	8	9	9	4	5	5	39.13
IER-TSR- 021-MLT-MD-FH-36	1924	5020	3472	178	185	181	74	70	72	2	2	2	9	12	11	4	5	5	38.33
IER-TSR- 021-MLT-MD-FH-37	404	1549	977	273	260	266	71	75	73	2	2	2	9	11	10	4	5	5	26.08
IER-TSR- 021-MLT-MD-FH-38	2455	3576	3016	235	225	230	74	74	74	3	3	3	8	9	9	1	2	2	68.65
IER-TSR- 021-MLT-MD-FH-39	2616	3172	2894	213	255	234	78	75	76	3	3	3	10	13	12	4	5	5	82.47
IER-TSR- 021-MLT-MD-FH-4	2066	815	1441	270	308	289	70	67	68	1	1	1	10	12	11	4	5	5	253.5
IER-TSR- 021-MLT-MD-FH-40	2273	2976	2625	255	260	258	76	79	78	1	1	1	7	10	9	4	5	5	76.38
IER-TSR- 021-MLT-MD-FH-41	2118	2822	2470	195	207	201	80	79	80	2	2	2	10	12	11	1	2	2	75.05
IER-TSR- 021-MLT-MD-FH-42	2293	4397	3345	230	270	250	77	73	75	3	3	3	10	12	11	4	5	5	52.15
IER-TSR- 021-MLT-MD-FH-43	1579	2606	2093	202	208	205	83	79	81	2	2	2	10	10	10	4	5	5	60.59
IER-TSR- 021-MLT-MD-FH-44	1975	2976	2476	198	255	226	82	70	76	2	2	2	13	14	14	4	5	5	66.36
IER-TSR- 021-MLT-MD-FH-45	2330	2364	2347	208	193	200	79	81	80	1	1	1	8	12	10	4	5	5	98.56
IER-TSR- 021-MLT-MD-FH-46	825	1960	1393	215	220	218	77	72	74	2	2	2	10	11	11	1	2	2	42.09
IER-TSR- 021-MLT-MD-FH-47	1599	3495	2547	190	239	214	77	67	72	2	2	2	10	11	11	4	5	5	45.75
IER-TSR- 021-MLT-MD-FH-48	1633	2263	1948	175	185	180	83	78	80	1	1	1	13	13	13	4	5	5	72.16
IER-TSR- 021-MLT-MD-FH-49	3222	1909	2566	218	278	248	76	70	73	2	2	2	12	13	13	4	5	5	168.8
IER-TSR- 021-MLT-MD-FH-5	1857	1465	1661	180	220	200	75	71	73	3	3	3	13	10	12	4	5	5	126.8
IER-TSR- 021-MLT-MD-FH-6	1754	2162	1958	188	225	206	76	73	74	3	3	3	12	9	11	4	5	5	81.13
IER-TSR- 021-MLT-MD-FH-7	1769	3125	2447	200	255	228	82	80	81	2	2	2	12	12	12	1	2	2	56.61
IER-TSR- 021-MLT-MD-FH-8	5395	4741	5068	190	232	211	82	83	83	1	1	1	10	12	11	1	2	2	113.8
IER-TSR- 021-MLT-MD-FH-9	1944	1175	1560	263	255	259	80	84	82	1	1	1	12	15	14	4	5	5	165.4
Sassilon	2939	3693	3316	253	225	239	82	84	83	2	2	2	9	10	10	4	5	5	79.58
Sewa	707	2717	1712	158	213	185	86	79	82	1	1	1	10	11	11	4	5	5	26.02
Fadda	2788	3939	3364	293	298	295	80	77	78	1	1	1	10	13	12	4	5	5	70.78
MG	2145	3088	2617	217	243	230	77	75	76	2	2	2	10	11	11	3	4	4	69.48
MIN	707	808	977	172	185	179	68	64	66	3	3	3	13	15	14	1	2	2	26.02
MAX	5395	6121	4679	280	310	295	83	83	83	1	1	1	7	9	8	4	5	5	253.4
SIGNIFICANCE	HS	HS	HS	HS	HS	NS	HS	HS	NS	HS	HS	HS	HS	HS	HS	HS	HS	HS	HS
CV%	26	22	24	13.7	15.2	12	4	5	4	21	21	21	13	16	14	22	23	23	22.2

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3.2 Farmers preferences with agronomic traits and Index of varietal sensitivity

The top ten (10) biofortified Sorghum hybrids IER-TSR- 021-MLT-MD-FH-46, IER-TSR- 021-MLT-MD-FH-17, IER-TSR- 021-MLT-MD-FH-41, IER-TSR- 021-MLT-MD-FH-12, IER-TSR-021-MLT-MD-FH-10 IER-TSR- 021-MLT-MD-FH-13, IER-TSR- 021-MLT-MD-FH-8, IER-TSR- 021-MLT-MD-FH-11, IER-TSR- 021-MLT-MD-FH-38, IER-TSR- 021-MLT-MD-FH-7 with a producer preference ranging from 66. 92- 79.71%. However, they had a grain yield productivity fluctuating between 3774- 5068 kg/ha with an average cycle of 74-83 days. The index of varietal sensitivity 83.47 to 42.09 varied from 200 to 289 cm (Table 4).

Table 4: Top 10 hybrids with their agronomic characteristics

DESIGNATION	PP%	IVS	RDT	CYCLE
IER-TSR- 021-MLT-MD-FH-46	79.71	42.09	3774	74
IER-TSR- 021-MLT-MD-FH-17	78.77	63.54	4054	78
IER-TSR- 021-MLT-MD-FH-41	77.12	75.05	4397	80
IER-TSR- 021-MLT-MD-FH-12	76.55	52.88	4204	83
IER-TSR- 021-MLT-MD-FH-10	76.21	83.47	4198	82
IER-TSR- 021-MLT-MD-FH-13	73.21	75.96	4396	83
IER-TSR- 021-MLT-MD-FH-8	71.3	65.63	5068	83
IER-TSR- 021-MLT-MD-FH-11	68.93	65.63	4598	82
IER-TSR- 021-MLT-MD-FH-38	68.87	68.65	3576	74
IER-TSR- 021-MLT-MD-FH-7	66.92	56.6	3125	81
CONTROLS				
Sassilon	67.13	79.58	3316	83
Sewa	61.55	26.02	1712	82
Fadda	84.31	70.77	3364	78
Maximun	84.31	83.47	5068	83
Minimum	61.55	42.09	1712	74
probability	HS	HS	HS	HS
CV%	31.34	22.2	24	4

3.3 Correlation among grain yield, plant height, cycle and drought tolerance indices.

Correlation coefficients were used to identify the best criterion for selecting drought tolerant genotypes. As shown in Table 5, indix of variety sensitivity were highly correlated with Mibrid, stay green and leaf senescence. A positive and negative correlation among grain yield, stay green and Mibrid were observed (Table 5). A positive and negative correlation were shown among stay green, leaf senescence, plant height and cycle. As shown in the table 5 a negative correlation was observed between plant height and cycle.

Therefore, evaluating correlations between stress tolerance indices and the seed yield in both environments can lead to identification of the most suitable index.

Table 5: Correlation among grain yield, plant height, cycle and drought tolerance indices.

		IVS	Grain yield	Mibrid	Stay green	Leaf senesce	Plant height
Grain yield	**R**	-0.188					
	P	0.183					
Mibrid		0.056	-0.053				
		0.641	0.708				
Stay green		0.018	0.021	0.047			
		0.233	0.884	0.743			
Leaf senesce		0.010	-0.432	-0.079	-0.003		
		0.470	0.001	0.578	0.982		
Plant height		0.234	0.383	-0.011	-0.027	-0.166	
		0.095	0.005	0.937	0.851	0.239	
Cycle		-0.346	0.288	-0.298	0.008	-0.436	-0.053
		0.012	0.038	0.032	0.957	0.001	0.655

4. DISCUSSION

There was significant variability between hybrids and controls for all parameters.

Eight hybrids were earlier (sowing cycle-50% heading =66-70 days) than the hybrid controls which were later. Earliness is a desired trait to cope with climate change. It is good to have early hybrids in order to enhance sorghum production in the Sahelian zone.

Significant variability was observed between hybrids and controls for plant height. The majority of the hybrids tested have a relatively small height (<255 cm) which is recommended for intensification of sorghum cultivation because of their resistance to lodging [19].

For all locations combined, five hybrids were more productive (4003 kg/ha to 5024 kg/ha) compared to the best hybrid control Fadda (3551 kg/ha) which confirms the performance of the new fortified hybrids compared to the released hybrids. Similar results were obtained by several authors [9].

Ten hybrids were better appreciated by producers, with a preference ranging from 67% to 80%, although it should be noted that producers' choice is not necessarily linked to grain yield potential. The hybrid IER-TSR- 021-MLT-MD-FH-46 with a low yield potential (1197 kg/ha) was better appreciated by the producers (overall preference = 80%). Other criteria (earliness, grain quality, forage, etc.) are taken into account in the choice of varieties/hybrids by producers [20].

The positive correlation between the assessment of midrib, index of varietal sensitivity and stay green after maturity shows that midrib and stay green play as important in the expression of dual purpose and drought tolerance. Our results are in agreement with those [21 and 22]. This strong increase in sugar concentration during the transition from doughy to mature stages would be due to the "stay-green" effect which is the ability that the sweet stem sorghum plant possesses to remain green even under water stress conditions; thus a longer photosynthetic period. According to [23]. the stem and leaves of sweet-stemmed sorghums remain green and photosynthetic activity persists even after grain maturation. Indeed, sugar accumulation would be proportional to the duration of photosynthetic activity and is related to the developmental stage of the plant [24].The percentage of extractable juice in the stem is high at the grain filling stage and becomes low at maturity. This implies a high water content in the stem at the milky grain stage and its gradual decrease during its development towards maturity

5. CONCLUSION

Satisfactory results have been achieved through adaptation of bio-fortified sorghum hybrids (sorghum bicolor) to drought resilience in southern Mali. This study provided a better understanding of the performance of bio-fortified hybrids to develop hybrids containing amino acids, mineral elements content and tolerant to drought stress that meet consumer criteria. The agro-ecological zone targeted in the development of hybrids will play a crucial factor for in large-scale success of hybrids.

For all the characters studied, the ten bio-fortified hybrids (IER-TSR- 021-MLT-MD-FH-46, IER-TSR- 021-MLT-MD-FH-17, IER-TSR- 021-MLT-MD-FH-41, IER-TSR- 021-MLT-MD-FH-12, IER-TSR- 021-MLT-MD-FH-10 IER-TSR- 021-MLT-MD-FH-13, IER-TSR- 021-MLT-MD-FH-8, IER-TSR- 021-MLT-MD-FH-11, IER-TSR- 021-MLT-MD-FH-38, IER-TSR- 021-MLT-MD-FH-7) had a grain yield between 3 to 4 tons, and then combined the components of drought resilient.

These hybrids can be further evaluated in collaboration with farmers to identify the most stable across different conditions and social needs for their registration in the seed catalog.

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REFERENCES

[1] DNA-Mali. (2020). Evolution des superficies et des productions. *Rapport bilan champagne* 2019/2020.

[2] FAOSTAT, (2018). Food and Agriculture Organization of the United Nations Cropping Database(http://faostat3.fao.org/home/index.htm

[3] House L.R., B.N Verma, G. Ejata, B.S. Rana, I., Kapran, A.B. Obilina, B.V.S. Reddy, (1996). Developing Countries Breeding and Potential of hybrid Sorghum, In proceeding of the International Conference on Genetic Improvement of Sorghum and Pearl millet,September 23-27, 1996-Lubbock, Texas, USA.

[4] Toure A. (1980). Etude de l'effet Hétérosis Chez le Sorgho au Mali, Mémoire de fin d'études cycle Ingénieur d'Agriculture, Institut Polytechnique Rural de Katibougou, Mali.

[5] Toure A. (1998). Potential of local cultivars in sorghum improvement in Mali, *African Crop Science journal*, 6 (1) PP: 1-7.

[6] Sundström, J. F., Albihn, A., Boqvist, S., Ljungvall, K., Marstorp, H., Martiin, C., ... & Magnusson, U. (2014). Future threats to agricultural food production posed by environmental degradation, climate change, and animal and plant diseases–a risk analysis in three economic and climate settings. *Food Security*, 6(2), 201-215..

[7] Adeniyi, M. O. (2016). The consequences of the IPCC AR5 RCPs 4.5 and 8.5 climate change scenarios on precipitation in West Africa. *Climatic change*, 139(2), 245-263.

[8] Toure , A., (2018). Développement des lignées de sorgho [Sorghum bicolor (L.) Moench] fortifiées, à haut potentiel de rendement, adaptées aux zones soudano-sahéliennes du Mali, Thèse de Doctorat pour l'obtention du titre de Docteur de l'Institut Supérieur de Formation et de Recherche Appliquée (ISFRA) de Bamako. 146 pages.

[9] Maiga.A.M., Diallo.G.A, Nebie.B., Toure. A., Danquah. E., Danquah. A., 2022 . Yield, Yield Components and Nutritional Traits Values of Biofortified Sorghum Hybrids in Mali, *Journal of Agricultural Studies I*SSN 2166-0379 2022, Vol. 10, No. 1. *Macrothink Instiute*.

[10] Singh, R., & Axtell, J. D. (1973). High Lysine Mutant Gene (hi) that Improves Protein Quality and Biological Value of Grain Sorghum.

[11] Boyer, J., and Westgate, M. 2004. Grain yields with limited water. *Journal of Experimental Botany* 55:2385-2394.

[12] Ashraf, M. and Foolad, M. 2007. Role of glycine betaine and proline in improving plant abiotic stress resistance. *Environ Exp Bot* 59: 206-216.

[13] Rosenow, D.T., Quisenberry, C., and Clark, L.E. 1983. Drought tolerant sorghum and cotton germplasm. *Agricultural Water Management* 7:207-222.

[14] Borrell, A.K., Hammer, G.L. and Henzell, R.G. 2000b. *Crop Sci*. 40:1037-1048.

[15] Kebede, H.S., Rosenow, D.T. and Nguyen, H.T. 2001. Quantitative trait loci influencing drought tolerance in grain sorghum. *Theoretical and Applied Genetics* 103:266-276.

ISSN: 2456-8643

[16] Haussmann, B.I., Mahalakshmi, V., Reddy, B., Seetharama, N., Hash, C. and Geiger, H. 2002b. QTL mapping of stay-green in two sorghum recombinant inbred populations. *TAG Theoretical and Applied Genetics* 106:133-142.

[17] Henzell, R.G., Jordan, D.R., Fletcher, D.S., McCosker, A.N., Bunker, G. and Persley, D.S. 2001. Sorghum breeding in Australia: public and private endeavours. In: Borrell, A.K. Henzell, R.G. Eds. *Proceedings of the 4th Australian sorghum conference Kooralbyn, Australia.*

[18] Maiga.A.M., Diallo.G.A, Nebie.B., Toure. A., Danquah. E., Danquah. A., 2021 . Combining ability for grain yield and grain components of sorghum hybrid containing high lysine, threonine, iron and zinc content in Mali, *Journal of Genetics, Genomics & Plant Breeding* 5(3) 72-83 (July, 2021) ISSN (Online): 2581-3293.

[19] Diallo.G.A., 2013. Aptitude à la combinaison et la performance agronomique des hybrides de sorgho de type Guinea au Mali. Thèse de doctorat en amélioration des végétaux : Faculté des sciences et techniques de Bamako (Mali).

[20] Sissoko.S., 2015.Marker assisted selection for post-flowering drought tolerance in *sorghum bicolor moench.PhD* west africa centre for crop improvement college of basic and applied sciences university of ghana legon. 155-176P.

[21] Lingle S. E., Tew T. L., Rukavina H. and Boykin D. L., 2012. Post-harvest Changes in Sweet Sorghum I: Brix and Sugars. *Bioenerg. Res*., 5:158–167.

[22]Maiga.A.M.,2015.Caracterisation des descendances de croisement (F_4DT) pour le developpement des varietes et hybrides de sorgho à double usage.

[23] NAN L. and MA J., 1989. Research on sweet sorghum and its synthetic application. *Biomass*, 20: 129-139.

[24] Teetor V. H., Duclos D. V., Wittenberg E. T., Young K. M., Chawhuaymak J., Riley M. R. and Ray D. T., 2011. Effects of planting date on sugar and ethanol yield of sweet sorghum grown in Arizona. *Industrial Crops and Products,* 34, 1293– 1300.