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AGRONOMIC PERFORMANCE OF DUAL-PURPOSE SORGHUM HYBRIDS IN THREE ENVIRONMENTS IN THE SUDANIAN ZONE OF MALI

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ABSTRACT

Sorghum (Sorghum bicolor (L.) Moench) is a major food crop in West Africa. In Mali, sorghum grains are used for human consumption (Tô, couscous, porridge, etc.) while the stems and leaves are used as livestock feed and building materials. However, it must be recognized that production faces many constraints such as low productivity and poor digestibility of local varieties, etc. The aim of our study is to contribute to improving human and animal nutrition through the development of sorghum hybrids combining high grain and straw yield potential. Thus, 44 F1 hybrids including 15 parents and 1 Fadda hybrid control were evaluated in three environments: Sotuba, Samanko and Kolombada for their grain and straw yield performance. The experimental design used is an Alpha Lattice with three replicates per environment. Hybrid heterosis effects of -22.66% to +254.06% for grain yield versus 26.25% to 255.97% for straw yield were observed. Thirty-five hybrids were found to be superior to control cultivars and parental pure lines in terms of productivity and stability.

Hybrids combining grain and straw yield and stability across the three environments may be proposed for registration in the catalogue of plant species and varieties..

Keywords: Sorghum, Hybrids, Combining Ability, Heterosis, Stability.

1. INTRODUCTION

Sorghum (Sorghum bicolor (L.) Moench) is a cereal and fodder grass of the Poaceae family of tropical origin with different preferences and socio-economic contexts. It is one of the main foodstuffs in the poorest regions of the world and where the food security of smallholder farmers is most threatened. Sorghum grains are consumed in human food in different forms such as Tô, porridge, couscous, local beer, cakes, etc. Sorghum, in the form of grains or fodder, is an important feed for ruminants (Nantoumé et al, 2000). Sorghum ranked fourth in the world in 2021, with a production of 61,364,996.82 tonnes, after maize (1,210,235.14 tonnes), rice (787,293,867.14 tonnes) and wheat (770,877,072.89 tonnes) (FAOSTAT, 2021).

In West Africa, millet and sorghum are among the four main cereals produced in Mali, with 1.1 million tonnes (millet) and 0.8 million tonnes (sorghum) produced in 2014. The share of sorghum and millet in total cereal production has decreased from 67 percent (1994) to 34 percent (2014). Production is progressing linearly, due to stagnant yields around 800 to 1000 kg/ha for decades. In Mali, sorghum grains are used for human consumption while the stems and

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leaves are used as livestock feed and construction materials. It is grown in rainfed conditions between the 400 and 1300 mm isohyets and in flood recession conditions in the north of the country.

Crop and livestock production activities are the backbone of Mali's socio-economic development. The main constraints to livestock production are due to the limited availability of suitable feed, especially during the dry season. With the continued reduction of natural pastures due to extensive agriculture and population growth, crop residues (sorghum, millet, corn, rice, etc.) are increasingly used as livestock feed during periods of scarcity of certain grasses.

Livestock production largely depends on natural pastures and agricultural by-products, which are characterized by a high variability in nutritional value. Addressing the most fundamental challenges in livestock feeding will require an integrated approach that encompasses grazing of pastoral lands and the strategic use of crop residue resources. Cultivation and feeding of animals with crop residues and other cultivated fodders is a key interaction between agriculture and livestock.

One of the major limitations of the nutritional value of sorghum residues is the low digestibility (local variety) that must be exploited in sorghum breeding programs. In addition, stakeholders have not conducted systematic research to optimize the total value of the crop by taking into account sorghum grains and fodder for increasing sorghum productivity and production in Mali.

Indeed, one of the best approaches to significantly increase sorghum productivity and production is the development of F1 hybrids adapted for dual use. Therefore, it is crucial for sorghum breeding programs to exploit the adaptation characteristics of local sorghums to harsh climate and poor soils to develop high grain yield varieties and hybrids, preferred by producers, combining high food quality characteristics and high fodder quality. Such a program will also strengthen livelihoods and improve fodder production in the country for the benefit of livestock farmers. Indeed, several research studies have highlighted the advantage of hybrids over parental forms. Rattunde et al, 2011, showed that the percentage increase in grain yield of a hybrid can increase by more than 30% than local varieties in the station and by 20% in a peasant environment.

Haussmann et al, 1998b, showed the superiority of hybrids compared to the average values of the parents of 54% for grain yield and 35% for aerial biomass.

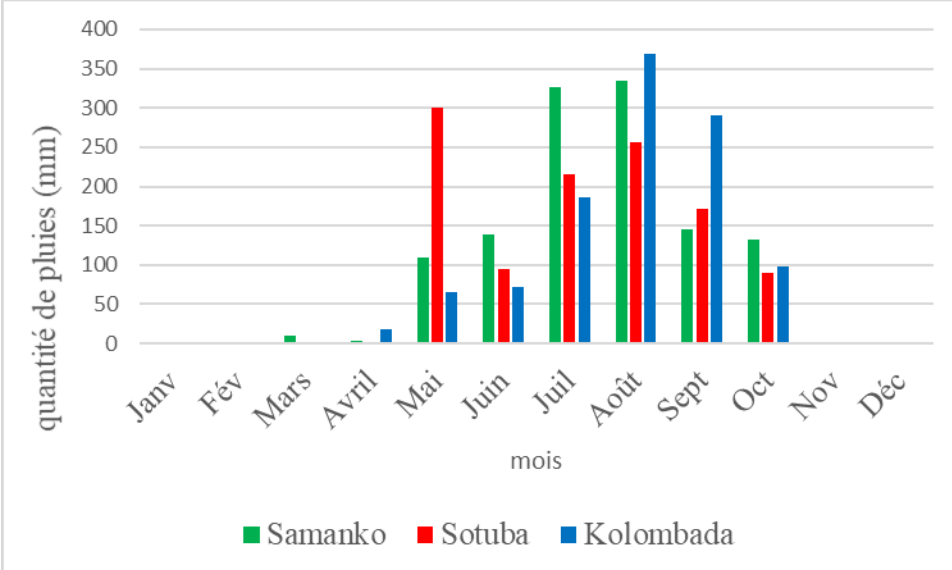
Hannachi et al, 2019, cited by Bourouh Lamia Maadadi Amina (2019), showed that the performance of genotypes in grain yield is not the only selection criterion, given that the most productive genotypes do not always give the best stabilities, approaches are needed that integrate both grain yield potential and stability. This will allow combining both performance and adaptation within genotypes.

The aim of this study is to identify hybrids that combine grain yield and forage quality in order to improve human and animal nutrition.

2. MATERIALS AND METHODS

2.1 Description of the experimental sites

The study sites are located in three agricultural research stations (Sotuba, Samanko and Kolombada) in the Sudanian zone in the 600 to 1000 mm rainfall isohyet in Mali. The soil types are silty-clay, sandy-clay and sandy-silty soils. The evolution of rainfall heights are recorded in figure (1).



2.2 Plant material

The genetic material consisted of 60 genotypes, including 44 hybrids, 11 male parents, 4 female parents and 1 hybrid control (Appendix 1). The parental lines have a diversity of traits (stay green, plant height, plant cycle, grain quality, forage and panicle shape, etc. These male and female parents were crossed to produce seed for the 44 F1 hybrids**.**

2.3 Methodology

The device used is a three-(3) repetition Alpha lattice. The elementary plot consists of 2 lines of 3 m long. The space between two blocks (alley) is 1.5 m, and the space between two repetitions is 2 m.

Sowing was carried out on ridges at spacings of 0.75 m between the rows and 0.30 m between the pockets and the plants were unmarried to 2 plants/pocket. Ammonia phosphate (DAP: 18-46-0) was applied at a dose of 100 kgha-1 at sowing and urea at a dose of 50 kg per hectare at bolting. The parameters measured were grain yield and straw yield.

1. **The grain yield** was calculated using the following formula:

GR = (PGp/Sp) X 10000 where**:** GR: Grain yield (in $^{kgha-1}$**);** PGp: Weight of Plot Grain (in kg); Sp: Plot area (m2).

2. **Straw yield**: It has been calculated in the same way as the yield.

RP= (PPp/Sp) X 10,000 where RP: Straw yield (in $^{kgha-1}$); PPp: Plot straw weight (in kg); Sp: Plot area (m2).

2.4 Heterosis effect of hybrids compared to best parents

The heterosis effect of the hybrids with respect to the parents was calculated on the average of three (3) environments according to the formula:

EH%= ((MH - MP)/MP)*100 where EH: heterosis effect; MH: hybrid medium; MP: average best parent.

2.5 Data Analysis

The analysis of variance (ANOVA) by site was carried out using the GenStat software (Release 12.1) using the regression method. The following model was used:

Yijl = μ + Ti+ Rj+ eijl

Yijl = observed value of the line

μ = average of the population

Ti = treatment effect

Rj = replication effect

eijl = random error.

3. RESULT

3.1 Grain yield

The analysis of variance showed significant (Pr=0.015) to highly significant (Pr= <0.001) differences between hybrids and controls for grain yield. The coefficient of variation varies between 24.62% and 52.83% (Table 1).

In Kolombada, the average yield varied from 348 kgha-1 (Niolagne) to 4899 kgha-1 (Fadda) with an overall average of 2104 kgha-1 (Table 4). The hybrid control Fadda (4899 kgha-1) was the most productive.

In Samanko, the average grain yield varied from 316 kgha-1 to 5044 kgha-1 with an average of (2891 kgha-1). Seven hybrids had the highest grain yields (4081 kgha-1 to 5044 kgha-1) compared to the control Fadda hybrid (1628 kgha-1) (Table 2).

In Sotuba, the average grain yield fluctuated between 355 kgha-1 to 4002 kgha-1 with an average of 1806 kgha-1. Seven hybrids had the highest grain yields (2684 kgha/ha to 4002 kgha-1) compared to the control Fadda hybrid (2862 kgha-1a) (Table 2).

The heterosis of the hybrids compared to the best parent for grain yield ranged from -22.66% to +254.06%. Eleven hybrids recorded the highest values of the heterosis effect in grain yield from 144.82% to 254.06%. (Table 2).

The gain in grain yield compared to the Fadda hybrid control ranged from -70.11% to 15.51%. Three hybrids have grain yield gains ranging from 5.19% to 15.51% (Table 2).

The variance stability of the grain yield compared to the Fadda hybrid control ranged from 0.00% to 637%. Ten hybrids and the Fadda hybrid control recorded the lowest values of 5.30% to 67 % (Table 2).

Table 1: Analysis of grain yield variance in the localities of Kolombada, Samanko and Sotuba, 2019 campaign.

SOURCES	Environments									
	Kolombada				Samanko			Sotuba		
	DDL	CM	F.cal	Pr	CM	F.cal	Pr	CM	F.cal	Pr
Repetition	2	6614495	5,3	0,006	5203272	10,27	<0,001	3711441	9,33	<0,001
Varieties	59	2002337	1,61	0,015	3344048	6,6	<0,001	1684031	4,23	<0,001
Residual		1247547			506687			398009		
CV%	52,83				24,62			34,89		

DDL: Degree of freedom, CM: Root mean square of deviations; F.cal: Variance ratio; Pr: probability of significance; CV%: Coefficient of variation in percentage.

Table 2: average grain yield (kgha-1), heterosis effect, grain yield gain and variance stability of hybrids compared to parents/Fadda control in the localities of Kolombada, Samanko and Sotuba, 2019 campaign

Genotypes	Yield grain en kgha^{-1}			Moy	H/MP%	Gain/ Fadda	Variance stability
	KO	SKO	SB				
Hybrides							
12A/016-SB-CS-DU-12	1940	2976	1810	2242	99,64	-28,36	310,3
12A/016-SB-CS-DU-15	2640	4552	2684	3292	172,29	5,19	206,3
12A/016-SB-CS-DU-25	2191	4236	1696	2708	179,18	-13,48	6,3
12A/016-SB-CS-DU-34	1974	2936	2756	2555	111,33	-18,35	175
12A/016-SB-CS-DU-38	2048	3852	1194	2365	143,81	-24,44	5,3
12A/BC_1-F_5-62	1427	2721	1810	1986	104,74	-36,54	156
12A/F4DT-298	2450	3273	1685	2469	67,39	-21,1	234,3
12A/Grinkan	2429	2135	1982	2182	42,71	-30,28	124,3
12A/Niobougouma	3031	2727	2928	2895	239,79	-7,49	254,3
12A/Niolagne	2248	3987	2645	2960	205,15	-5,42	102,3
12A/Tiandougou-coura	2312	2128	2329	2256	57,32	-27,9	193
150A/016-SB-CS-DU-12	2602	4357	2033	2997	166,87	-4,23	149,3
150A/016-SB-CS-DU-15	2760	1623	2450	2278	88,42	-27,22	537,3
150A/016-SB-CS-DU-25	2263	3300	2551	2705	254,06	-13,58	40,3
150A/016-SB-CS-DU-34	2249	2431	1777	2152	78,00	-31,23	108,3
150A/016-SB-CS-DU-38	1538	882	386	935	-22,66	-70,11	91
150A/BC_1-F_5-62	1329	3973	2366	2556	234,55	-18,33	421,3
150A/F4DT-298	2856	1266	554	1559	5,69	-50,2	556,3
150A/Grinkan	1988	2788	1346	2041	33,49	-34,8	12,3
150A/Niobougouma	2417	1562	726	1568	84,04	-49,89	475
150A/Niolagne	2513	815	355	1228	60,73	-60,77	92,3
150A/Tiandougou-coura	1777	1556	1426	1586	10,6	-49,31	272,3
216-2P4-5A/016-SB-CS-DU-12	3136	4673	1123	2977	144,82	-4,87	91
216-2P4-5A/016-SB-CS-DU-15	2602	3899	4002	3501	187,91	11,86	33,3
216-2P4-5A/016-SB-CS-DU-25	2342	3886	2575	2934	141,28	-6,24	21,3
216-2P4-5A/016-SB-CS-DU-34	2019	2768	3336	2708	122,7	-13,48	350,3
216-2P4-5A/016-SB-CS-DU-38	2348	3636	2118	2701	122,12	-13,71	19,1
216-2P4-5A/BC_1-F_5-62	2208	4081	2134	2808	130,92	-10,29	100,3
216-2P4-5A/F4DT-298	3094	1845	1797	2245	52,20	-28,26	444
216-2P4-5A/Grinkan	2924	3024	3187	3045	99,15	-2,71	254,3
216-2P4-5A/Niobougouma	3527	3441	2588	3185	161,92	1,78	136,3
216-2P4-5A/Niolagne	2262	3374	2184	2607	114,39	-16,71	6,3

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Genotypes	Yield grain en kgha^{-1}			Moy	H/MP%	Gain/ Fadda	Variance stability
	KO	SKO	SB				
216-2P4-5A/Tiandougou-coura	3061	5044	2740	3615	152,09	15,51	49
3009A/016-SB-CS-DU-12	1986	3293	1356	2212	11,38	-29,33	169
3009A/016-SB-CS-DU-15	1928	3246	861	2012	4,36	-35,72	208
3009A/016-SB-CS-DU-25	1741	3104	1480	2108	21,08	-32,63	64,3
3009A/016-SB-CS-DU-34	2958	3172	2275	2802	-5,27	-10,48	133
3009A/016-SB-CS-DU-38	2513	3259	1320	2364	-5,93	-24,46	450,3
3009A/BC_1-F_5-62	1912	4182	1739	2611	36,56	-16,57	625,3
3009A/F4DT-298	2573	3044	1268	2295	-10,80	-26,67	306,3
3009A/Grinkan	2832	3953	1440	2742	-3,18	-12,4	292,3
3009A/Niobougouma	2827	3481	1181	2496	-11,71	-20,24	172
3009A/Niolagne	2557	3448	787	2264	-11,46	-27,66	637
3009A/Tiandougou-coura	3135	3811	1527	2824	-9,92	-9,76	421,3
Témoin hybride							
Fadda	4899	2862	1628	3130			67
Parents mâles							
BC_1-F_5-62	680	2316	1295	1430			64,3
F4DT-298	1475	2222	1460	1719			0
Grinkan	1529	1569	1224	1441			34,3
Niobougouma	852	1407	1329	1196			10,3
Niolagne	348	2256	1470	1358			96,3
Tiandougou-coura	1434	1717	2198	1783			202,3
016-SB-CS-DU-12	1123	3266	1864	2084			244
016-SB-CS-DU-15	1209	3704	3164	2692			632,3
016-SB-CS-DU-25	492	3636	911	1680			602,1
016-SB-CS-DU-34	1552	1825	2514	1964			277,3
016-SB-CS-DU-38	980	3091	1598	1890			145,3
12B	970	1906	1726	1534			91
Parents femelles							
3009B	1273	316	1076	888			26,3
150B	764	1279	918	987			0,3
216-2P4-5B	1216	2343	1477	1679			25
Moyenne	2104	2891	1806	2267			200,42
Minimum	348	316	355			-70,11	0
Maximum	4899	5044	4002			15,51	637
Fpr (5%)	0,015	<,001	<,001				
CV%	52,83	24,62	34,89				
PPDS	1813	1151	1049				

KO: Kolombada; SKO: Samanko; SB: Sotuba; Avg: mean; H: Heterosis; MP: Best parent; Fpr: probability of significance CV%: Percentage coefficient of variation: PPDS: Least significant difference

3.2 Straw yield

There are highly significant differences (Pr<0.001) between treatments for straw yield in all environments with a coefficient of variation ranging from 32.49 to 38.35% (Table 3).

The average straw yield observed in Kolombada is 4111 kgha-1 (Table 4). Five hybrids recorded the highest straw yields (6532 kg/ha to 7438 kgha-1) compared to the Fadda hybrid control (3852 kgha-1).

In Samanko, the average straw yield recorded is 6390 kgha-1 (Table 4). Three hybrids were the most productive in straw yield (11465 kgha-1 to 17690 kgha-1) compared to the control hybrid Fadda (8061 kgha-1) (Table 4).

The average straw yield in Sotuba is 10548 kgha-1. Three hybrids were the most productive in straw yield (12859 kgha-1 to 13754 kgha-1) compared to the control Fadda hybrid (7027 kgha-1) (Table 4).

The heterosis effect in straw yield of the hybrids compared to the best parents varied from -16.16% to +255.97%. Thirty-five hybrids recorded the highest values (26.25% to 255.97%) of the heterosis effect in straw yield compared to the best parents (Table 4).

The gain in straw yield compared to the Fadda hybrid control ranged from -70.11% to +15.51%. Three hybrids have gains in straw yield ranging from +5.19% to +15.51%.

The variance stability of the straw yield ranged from 0.00% to 847.00%. Twenty-two hybrids recorded the lowest values from 0.00% to 97%.

Table 3: Analysis of straw yield variance in the localities of Kolombada. Samanko and Sotuba

SOURCES	Kolombada				Samanko			Sotuba		
	DDL	CM	F.cal	Pr	CM	F.cal	Pr	CM	F.cal	Pr
Répétition	2	37844683	16,33	<0,001	13870157	3,22	0,044	73072117	7,93	<0,001
Variétés	59	5643316	2,44	<0,001	24811381	5,76	<0,001	20505234	2,22	<0,001
Résiduel	118	2317074			4309421			9218379		
CV%	37,03				32,49			38,35		

DDL: Degree of freedom, CM: Root mean square of deviations; F.cal: Variance ratio; Pr: probability of significance; CV%: Coefficient of variation in percentage.

Table 4: average straw yield (kgha-1), heterosis effect, straw yield gain and variance stability of hybrids compared to parents/Fadda control in the localities of Kolombada, Samanko and Sotuba.

Genotypes	Straw yield (kg/ha) by environment				H/MP%	Gain/Fadda	Variance stability
	KO	SKO	SB	Moy			
Hybrids							

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Genotypes	Straw yield (kg/ha) by environment				H/MP%	Gain/Fadda	Variance stability
	KO	SKO	SB	Moy			
12A/016-SB-CS-DU-12	3704	10347	6706	6919	88,37	9,59	44,30
12A/016-SB-CS-DU-15	5000	6663	9634	7099	153,99	12,44	112,00
12A/016-SB-CS-DU-25	4421	5875	9276	6524	214,11	3,34	27,00
12A/016-SB-CS-DU-34	3364	6778	9533	6558	65,36	3,88	292,30
12A/016-SB-CS-DU-38	3586	7929	7178	6231	200,00	-1,30	30,30
12A/BC$_1$-F$_5$-62	4404	5808	11003	7072	141,44	12,01	56,30
12A/F4DT-298	5313	7687	6516	6505	45,70	3,04	217,00
12A/Grinkan	6532	6037	11861	8143	82,38	28,99	0,00
12A/Niobougouma	6822	11212	9074	9036	88,45	43,13	37,30
12A/Niolagne	5717	12141	11726	9861	247,84	56,20	12,30
12A/Tiandougou-coura	5758	17690	12859	12102	153,29	91,69	12,30
150A/016-SB-CS-DU-12	3966	6108	6913	5662	54,16	-10,31	114,30
150A/016-SB-CS-DU-15	5094	10260	10112	8489	203,71	34,46	97,00
150A/016-SB-CS-DU-25	3077	8148	8403	6543	255,97	3,63	305,30
150A/016-SB-CS-DU-34	2545	4822	8280	5216	31,51	-17,39	226,30
150A/016-SB-CS-DU-38	2313	2916	5215	3481	73,46	-44,86	4,00
150A/BC$_1$-F$_5$-62	1872	4125	13506	6501	121,95	2,97	847,00
150A/F$_4$DT-298	2811	3811	6138	4253	-4,74	-32,63	12,00
150A/Grinkan	3333	5401	10476	6403	32,35	1,43	111,00
150A/Niobougouma	3377	4788	3895	4020	-16,16	-36,33	96,30
150A/Niolagne	2727	2963	7422	4371	54,17	-30,77	46,30
150A/Tiandougou-coura	3741	2667	6365	4258	-10,89	-32,56	139,00
216-2P4-5A/016-SB-CS-DU-12	4832	6545	5827	5735	54,41	-9,17	241,30
216-2P4-5A/016-SB-CS-DU-15	6013	10795	8208	8339	124,52	32,08	120,30
216-2P4-5A/016-SB-CS-DU-25	4646	6451	7573	6223	0,68	-1,43	14,30
216-2P4-5A/016-SB-CS-DU-34	3822	4121	6759	4901	23,57	-22,38	72,30
216-2P4-5A/016-SB-CS-DU-38	5283	8249	6120	6551	76,38	3,76	374,30
216-2P4-5A/BC$_1$-F$_5$-62	4380	7556	11381	7772	109,27	23,11	84,30
216-2P4-5A/F$_4$DT-298	5027	7582	6964	6524	46,12	3,34	100,30
216-2P4-5A/Grinkan	4104	4822	9398	6108	26,25	-3,25	182,30
216-2P4-5A/Niobougouma	4340	4303	6840	5161	7,63	-18,25	91,00
216-2P4-5A/Niolagne	5798	11465	8909	8724	134,89	38,18	44,30
216-2P4-5A/Tiandougou-coura	7438	8670	8738	8282	73,34	31,18	81,30
3009A/016-SB-CS-DU-12	2869	6721	7919	5836	5,89	-7,56	237,00
3009A/016-SB-CS-DU-15	3764	4828	6494	5029	79,92	-20,35	13,00

Genotypes	Straw yield (kg/ha) by environment				H/MP%	Gain/Fadda	Variance stability
	KO	SKO	SB	Moy			
3009A/016-SB-CS-DU-25	3785	8458	4691	5645	104,22	-10,59	506,30
3009A/016-SB-CS-DU-34	4949	3859	7343	5384	35,75	-14,73	274,30
3009A/016-SB-CS-DU-38	4007	5690	5741	5146	8,62	-18,49	120,30
3009A/BC_1-F_5-62	3158	7145	13754	8019	173,78	27,02	556,30
3009A/F4DT-298	3623	7879	6649	6050	35,51	-4,17	171,00
3009A/Grinkan	3650	7172	7660	6161	27,34	-2,42	94,30
3009A/Niobougouma	5650	4712	5292	5218	8,82	-17,35	481,00
3009A/Niolagne	6828	6108	5939	6292	121,93	-0,34	492,30
3009A/Tiandougou-coura	6643	7960	10548	8384	75,46	32,79	25,30
Témoin hybride							
Fadda	3852	8061	7027	6313			114,30
Parents mâles							
BC_1-F_5-62	2929	3037	14806	6924			849,30
F_4DT-298	4465	3690	2252	3469			401,30
Grinkan	4838	5340	8867	6348			114,30
Niobougouma	4795	7165	6610	6190			121,30
Niolagne	2835	5178	8563	5525			199,00
Tiandougou-coura	4778	11219	8867	8288			72,30
016-SB-CS-DU-12	3673	5630	5288	4864			89,30
016-SB-CS-DU-15	2795	4761	8538	5365			241,30
016-SB-CS-DU-25	1219	4236	4059	3171			52,00
016-SB-CS-DU-34	3966	3785	3928	3893			212,30
016-SB-CS-DU-38	2007	4997	6618	4541			120,30
Parents femelles							
3009B	2764	3407	5346	3839			2,40
12B	2077	3158	11167	5467			737,30
150B	1838	2451	7553	3947			300,00
216-2P4-5B	3714	1993	4048	3252			171,00
Moyenne	4111	6390	7906	6136		3,22	164,11
Minimum	1219	1993	2252			-44,86	0,00

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Genotypes	Straw yield (kg/ha) by environment				H/MP%	Gain/Fadda	Variance stability
	KO	SKO	SB	Moy			
Maximum	7438	17690	14806			91,69	847,00
Fpr (5%)	<0,001	<0,001	<0,001				
CV%	37,03	32,49	38,35				
PPDS	2461	3357	4929				

KO: Kolombada; SKO: Samanko; SB: Sotuba; Avg: mean; H: Heterosis; MP: Best parent; Fpr: probability of significance CV%: Coefficient of variation in percentage: PPDS: Least significant difference.

4. DISCUSSION

There is significant variability between hybrids and parental lines and the Fadda hybrid for grain and straw yield. The heterosis effect of the hybrids relative to the best parent for grain yield across the 3 environments ranged from -22.66% to +254.06%. and from -16.16% to 255.97% for straw yield. Eleven hybrids recorded the highest values of heterosis effect (144.82% to 254.06%) in grain yield. On the other hand, thirty-five hybrids recorded the highest values (26.25% to 255.97%) of the heterosis effect in straw yield compared to the best parents. Grain yield heterosis effects of 13 to 88% (Haussmann et al, 1998a) and a relative superiority of hybrids of 47.10% (Haussmann et al, 1998b) were reported in sorghum. This demonstrates the advantages of hybrid cultivars compared to varieties and pure lines. The gain in straw yield compared to the hybrid control Fadda varied from -44.86 to 91.69%. Three hybrids have gains in straw yield varying from 43.13% to 91.69%. The control hybrid Fadda (4899 kgha-1), the hybrid 216-2P4-5A (5004 kgha-1) and the hybrid 216-2P4-5A/016-SB-CS-DU-15 (4002 kgha-1) were the most productive in grain yield respectively in the localities of Kolombada, Samanko and Sotuba. For straw yield, hybrids 216-2P4-5A/Tiandougou-coura (7438 kgha-1) in Kolombada, (12A/Tiandougou-coura (17690 kgha-1) in Samanko and the male parent BC1-F5-62 (14806 kgha-1) in Sotuba, obtained the best grain yields. The male parents 016-SB-CS-DU-25 (1219 kgha-1) in Kolombada, 216-2P4-5B (1993 kgha-1) in Samanko and F4DT-298 (2252 kgha-1) were the least productive in straw yield.

The stability of variance of grain yield varied from 0.00% to 637% and for straw yield from 0.00% to 847.10%. Twenty-two hybrids were more stable in straw yield (0.00% to 97%) than the hybrid control Fadda (114%).

Three hybrids combined grain yield potential from 32.79% to 91.69% and were stable from 12.3% to 25.30% across the three environments. Similar results were obtained by Hannachi et al, 2019.

5. CONCLUSION

The study reveals significant variability among hybrids for grain yield and straw yield across environments. Eleven hybrids recorded the highest values of heterosis effect (144.82% to 254.06%) in grain yield compared to the best parent. In straw yield, thirty-five hybrids recorded the highest values (26.25% to 255.97%) of heterosis effect. The selection of more productive and

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adapted sorghum hybrids can improve the productivity of this crop in Mali. Three hybrids 12A/Tiandougou-coura (91.69%), 12A/Niolagne (56.20%) and 3009A/Tiandougou-coura (32.79%) were more productive and the most stable by 12.30% to 25.30% than the reference hybrid control Fadda. These hybrids can be used as dual-purpose sorghum cultivars (food and feed).

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Appendix 1: Table 2: list of hybrids, parents and controls used in the tests

Parents/Hybrides	N°	Génotypes	Cycle (Jours)	Hauteur (cm)	Rendement grain kgha^{-1}
Lignées mâles (R)	1	016-SB-CS-DU-12	125	240	2092
	2	016-SB-CS-DU-15	120	285	2595
	3	016-SB-CS-DU-25	110	200	2000
	4	016-SB-CS-DU-34	120	240	3000
	5	016-SB-CS-DU-38	119	186	2900
	6	F4DT-298	125	200	2000
	7	Grinkan	120	200	2500
	8	Niobougouma	125	220	3000
	9	Niolagne	115	300	2000
	10	Tiandougou-coura	125	250	2500
	11	BC1-F5-62	110	200	2333
Lignées femelles (A)	1	12B	100	200	2000
	2	150B	110	200	2000
	3	Pr-3009B	110	300	2000
	4	216-2P4-5B	125	200	2500
Hybrides F1 (A/R)	1	12A/016-SB-CS-DU-12	-	-	-
	2	12A/016-SB-CS-DU-15	-	-	-
	3	12A/016-SB-CS-DU-25	-	-	-
	4	12A/016-SB-CS-DU-34	-	-	-
	5	12A/016-SB-CS-DU-38	-	-	-
	6	12A/BC_1-F_5-62	-	-	-
	7	12A/F4DT-298	-	-	-
	8	12A/grinkan	-	-	-
	9	12A/Niobougouma	-	-	-
	10	12A/Niolagne	-	-	-
	11	12A/Tiandougou-coura	-	-	-
	12	150A/016-SB-CS-DU-12	-	-	-
	13	150A/016-SB-CS-DU-15	-	-	-
	14	150A/016-SB-CS-DU-25	-	-	-
	15	150A/016-SB-CS-DU-34	-	-	-
	16	150A/016-SB-CS-DU-38	-	-	-
	17	150A/BC_1-F_5-62	-	-	-
	18	150A/F4DT-298	-	-	-
	19	150A/Grinkan	-	-	-

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Parents/Hybrides	N°	Génotypes	Cycle (Jours)	Hauteur (cm)	Rendement grain $kgha^{-1}$
	20	150A/Niobougouma	-	-	-
	21	150A/Niolagne	-	-	-
	22	150A/ Tiandougou-coura	-	-	-
	23	216-2P4-5A/016-SB-CS-DU-12	-	-	-
	24	216-2P4-5A/016-SB-CS-DU-15	-	-	-
	25	216-2P4-5A/016-SB-CS-DU-25	-	-	-
	26	216-2P4-5A/016-SB-CS-DU-34	-	-	-
	27	216-2P4-5A/016-SB-CS-DU-38	-	-	-
	28	216-2P4-5A/BC_1-F_5-62	-	-	-
	29	216-2P4-5A/F4DT-298	-	-	-
	30	216-2P4-5A/Grinkan	-	-	-
	31	216-2P4-5A/Niobougouma	-	-	-
	32	216-2P4-5A/Niolagne	-	-	-
	33	216-2P4-5A/ Tiandougou-coura	-	-	-
	34	PR3009A/016-SB-CS-DU-12	-	-	-
	35	PR3009A/016-SB-CS-DU-15	-	-	-
	36	PR3009A/016-SB-CS-DU-25	-	-	-
	37	PR3009A/016-SB-CS-DU-34	-	-	-
	38	PR3009A/016-SB-CS-DU-38	-	-	-
	39	PR3009A/F4DT-298	-	-	-
	40	PR3009A/Grinkan	-	-	-
	41	PR3009A/Niobougouma	-	-	-
	42	PR3009A/Niolagne	-	-	-
	43	PR3009A/ Tiandougou-coura	-	-	-
	44	PR3009A/BC_1-F_5-62	-	-	-
Témoin hybride	1	Fadda	300	125	3500