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Yield, Yield Components and Nutritional Traits Values of Biofortified Sorghum Hybrids in Mali

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Abstract

To assess the adaptation, yield potential, nutrient content and to identify the traits contributing directly and indirectly to yield increase, a two years' study was conducted in four locations. Thus, a total of 28 F1 hybrids from two females and 14 male parents, were developed and used in this study along with the parents and four commercial hybrids. Seven (7) hybrids were identified with grain yield ranging from 4015 to 4624 kg^{-1ha}; heading from 64 to 92 days; iron content from 8.63 to 91.15 ppm; Zinc content from 8.14 to 28.71 ppm; lysine content from 2.73 to 5.61 mg/100g; threonine content from 2.50 to 6.28 mg/100g. For both phenotypic and genotypic levels, a significant correlation on grain yield through plant height, panicle length, primary branch per panicle, grain number per panicle and number of whorls per panicle were found. Based on the path analysis, positive and significant direct and indirect effect of correlation were observed in this work for a cycle, grain quality, panicle length, primary branch per panicle, grain number per panicle and number of whorls per panicle at the phenotypic level.

Keywords: sorghum hybrids, direct indirect effects, genotypic and phenotypic coefficient of correlation

1. Introduction

Sorghum [Sorghum bicolor *(L.) Moench*] is one of the main cereals crops cultivated in the world. World sorghum production for the year 2017-2018 was 63 million tons on an area of 42 million ha with an average yield of 1,450 kg^{-ha} (FAO, 2018). It is the main source of food in many African countries, especially those in arid and semi-arid zones.

Sorghum is an important component of agriculture in industrialized countries. In Mali, it is a staple food of over 80% of the population (FAO, 2019). It is generally cultivated for both the grain, which is used as human food, and for the straw, used as fodder. Sorghum is estimated over an area of 1,500778 ha with an average yield of 1,007 kg^{-1}ha (DNA,2020). This low yield is mainly due to biotic and abiotic constraints such as insufficient and poor distribution of rains, the low level of soil fertility, insects and diseases, the low productive potential of local varieties. These stresses are reinforced the socio-economic conditions such as the low income of producers, the mismatch between the prices of fertilizers and that of cereals such as sorghum.

To improve this low level of productivity, several research works have been undertaken in agronomic techniques, pest control and especially varietal improvement to increase productivity and ensure sustainable food security in the West Africa region. One of the best approaches to significantly increase the production and productivity of sorghum while maintaining its adaptability and interesting characteristics is the development of F1 hybrids with characteristics of the guinea race, the most dominant in Mali as shown by Rattunde *et al.*, (2013).

Cereals like sorghum are generally poor in amino acids and mineral content. To overcome these problems, research activities have been done across the globe and in Mali to increase the nutrient content in improved varieties. Toure *et al.*, (2018) released varieties containing lysine, threonine, iron and zinc in Mali.

Correlation studies give information on the relationship of yield and its components then to achieve high yield, it is important to define the selection index, as the yield is a complex quantitative character and tends to be subjected to different segment characters. Thus, paths analysis explains the direct and indirect impact of part traits on grain yield and this information helps to define a solid strategy for variety selection.

The correlation studies also provide a phenotypic selection index to eliminate segregating population and selection of phenotype desirable traits. Yield improvement can be possible towards the correlation characters. According to Beil and Atkins *et al*. (1967), the correlation of grain yield with its components revealed that yield was significantly and positively correlated to a number of seeds per panicle and highly negative related to the number of heads per plant. The yield was highly and positively associated with plant height and cycle and then a negative correlation was obtained for panicle length and grain yield as reported by Bello *et al.*, (2001) and Dewey *et al.*, (1959). A significant phenotypic and genotypic correlation with yield owing to the indirect effect of grain number per panicle on yield was shown by plant height as reported by Johnson *et al.* (1955). The significant positive correlation coefficient between grain yield and panicle weight, panicle breadth, number of secondary branches and 1000grain weight as mentioned by Nimbalkar (1988). No correlation was observed for grain yield with various component traits except two characters, 1000 seed weight and a number of grains per rachis as reported by Sankarapandian *et al*. (1994) which may be due to elimination effects of one or other characters contributing to grain yield. Can *et al.*, (1997) found at both genotypic and phenotypic levels a positive and high correlation between grain yield and yield components except for days to 50% flowering and days to maturity. Mahmoud (2007) revealed a significant and positive correlation between grain yield and panicle weight, grain yield and 1000 grain weight, and between 1000 grain weight and panicle weight and similarly, a significant but negative correlation exists between a number of panicle and panicle length. Plant height has high positive phenotypic and genotypic correlation coefficients with panicle weight and grain yield in sorghum.

The path coefficient analysis helps to divide the correlation coefficient into direct and indirect effects of different component traits on the grain yield. The number of grains per panicle had a significant direct effect on grain yield and then plant height had the greatest phenotypic and genotypic correlation with yield owing to the indirect effect of number of grains per panicle on yield as reported by Berenji (1988). The Number of rachis per panicle and 1000grain weight was found to be an important character for grain yield improvement as mentioned by Bidinger *et al.*, 1993. Path coefficient analysis was carried out by Jindal & Gill 1984 and they found that panicle weight, panicle length and cycle play an important role on grain yield and then observed positive direct and indirect effects among characters as panicle weight and panicle length. Singh & Govila (1989) reported that the cycle and 1000 seed weight had a positive direct effect on grain yield. The heading time and days to maturity showed for most of the traits a positive and direct effect on grain yield. The positive direct effect on grain yield in sorghum was observed with the cycle, panicle length, plant height and a number of grains per panicle as reported by Eniola 2019. The positive direct effect on seed yield was found via a number of leaves per plant, panicle length, panicle weight, number of primaries per panicle and grain mould score. Improvement of grain yield can be done simultaneously by improvement of these traits listed above as reported by Deepalakshmi and Ganesamurthy (2007).

In West Africa, especially Mali, research was not focused on the nutrient content of hybrids and also on the correlation between agronomic traits, organic and inorganic content. The goal of any plant breeder is to select a genotype with various traits. The grain yield of sorghum being quantitative in nature, selection based on the grain yield is generally not very effective. Yet, selection criteria based on its component could be more efficient and reliable.

Knowledge of the association between yield and its component traits and between the component parameters themselves can improve the efficiency of selection in plant breeding. In this work, the goal was to assess the association among organic, inorganic content, yield and its components to guide the breeding programs in the West Africa region.

2. Method

2.1 Study Area

The experiment was carried out in four locations Sotuba, Kolombada, Farako and Samanko Agricultural Research Stations and Sub-stations located in different regions and agroecological zones of Mali.

- 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 clay loam or clay sandy type.

- 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.

- Regional Center for Agronomic Research (CRRA) of Farako: Farako Agronomic Research Sub-station is located in the Sikasso Region and about 25 km from Sikasso and covers an area of about 55 ha. Its geographical coordinates are latitude 14 ° 48'0 "N", longitude 6 ° 31'0 "W and an altitude of 294 m. The climate is of the Sudano-Sahelian type with an annual rainfall varying from 1000 to 1300 mm. The soil is of sandy loam type (Figure 1).

- Regional Center for Agronomic Research (CRRA) of Samanko: Samanko agricultural research station is located west of the Bamako District on the Kangaba road. The climate is Sudano-Sahelian (latitude 12 ° 54’, longitude 08 ° 4’ and altitude 329 m) with rainfall ranging from 800 to 1000 mm. The soil is silty-clay or sandy-clay (Figure 1).

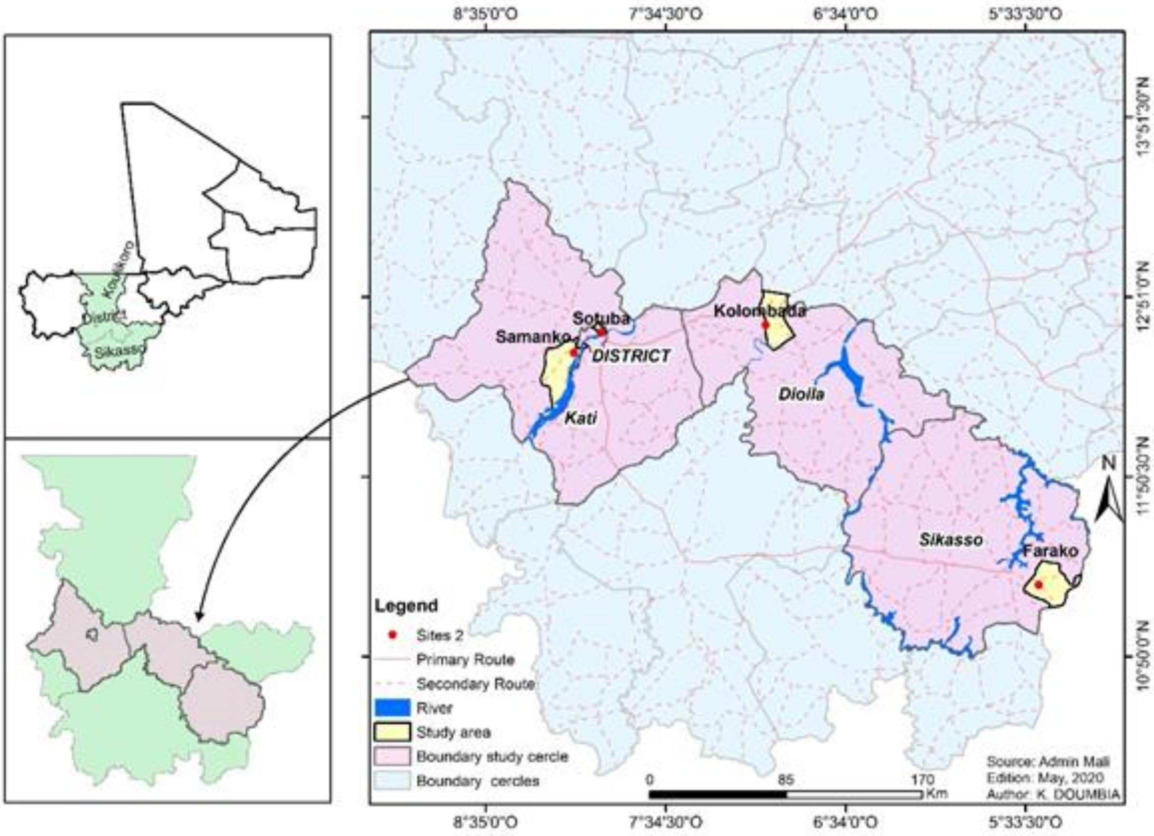

Figure 1. Maps of the study areas(Source: SIG, Sotuba 2020)

During 2018 -2019 from all localities, the average rainfall observed varied from 454.3 to 1235.9 mm (Figure 2).

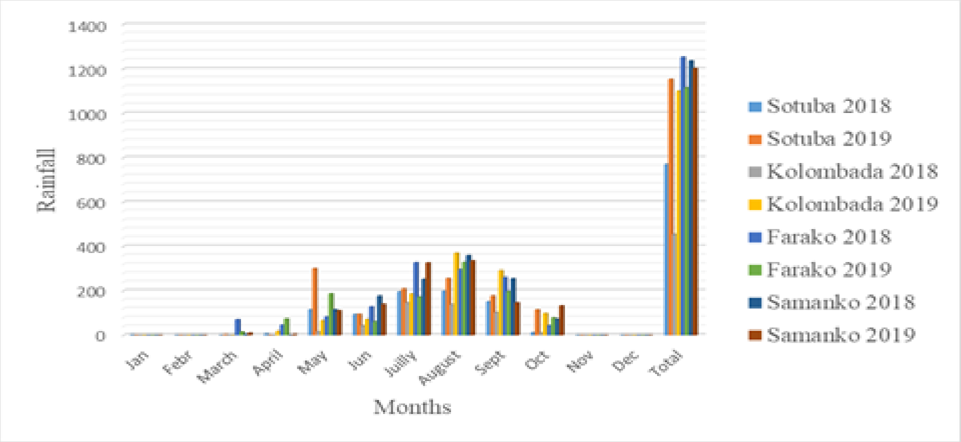

Figure 2. Rainfall amounts collected per year/ month

2.2 Plant Material

The plant material consisted of 28 hybrids resulting from crosses between 2 female parents (12A and 216-2P4-5A) and 14 male parents containing high organic (lysine and threonine) and inorganic (iron and zinc) content (Touré *et al.*, 2017) (Table 1). The 28 hybrids were compared to the 16 parents used in crosses and to four released hybrids. The trial was conducted during two rainy seasons (2018 and 2019 years) at four zones. The parents have a diversity of agronomic traits such as plant cycle, yield, zinc, iron, lysine and threonine content (Table 1).

Table 1. Materialist of hybrids parents used to develop the biofortified hybrids with their main traits

N°	**Lines**	**Pedigree**	**Cycle**	**yield (kg^{-1ha})**	**Zinc (mg/100 g)**	**Ion (mg/100g)**	**Lysine (mg/100g)**	**Threonine (mg/100g)**
1	016-BE-BC1F6-1105	Seguifa/ Axtell5	68	1880	1.03	3.13	6.82	1.24
2	016-BE-BC1F6-2070	Axtell5/Grinkan	73	2700	1.65	3.43	3.01	1.29
3	016-BE-BC1F6-1048	P721N/Grinkan	71	2730	2.33	2.26	5.4	5.98
4	016-BE-BC1F6-73	Axtell5/Darrelken	82	3333	1.19	2.31	4.67	0.21
5	016-BE-BC1F6-CT-2016	P721N/Grinkan	82	2300	2.33	2.26	5.4	5.98
6	016-SB-BC1F6-1053	Axtell5/Grinkan	92	2090	0.99	2.77	3.82	2.37
7	016-SB-BC1F6-1105	Seguifa /Axtell5	83	923	1.78	3.18	4.28	3.96
8	016-SB-BC1F6-1090	Axtell5/Grinkan	81	2800	1.97	3.33	6.16	7.06
9	016-SB-BC1F6-1036	Axtell5/Grinkan	82	2580	1.33	2.57	2.93	1.06
10	016-SB-BC1F6-1068	P851171/Seguifa	86	2080	1.62	5.53	3.2	0.82
11	016-KO-BC1F6-1053	Axtell5/ Grinkan	92	2085	1.40	2.71	3.1	2.2
12	016-KO-BC1F6-1086	P851171/ Seguifa	84	2210	1.25	2.45	3.19	4.15
13	016-KO-BC1F6-1050	Axtell5/Tiandougou coura	85	2019	1.41	3.38	2.46	0.24
14	016-KO-BC1F6-9	P851171/ Seguifa	83	1333	1.54	5.16	2.92	3.26
		CHECKS						
15	12B	Guinea// Caudatum	76	2231	-	-	-	-
16	216-2BP4-5	Guinea// Caudatum	86	2233	-	-	-	-
17	FADDA	12A/Latta	80	2500	-	-	-	-
18	GRINKANYELEWOLO	150A/Grinkan	79	3000	-	-	-	-
19	NIELINI	150A/06-SB-F4DT-15	74	3000	-	-	-	-
20	SEWA	150A/02-SB-F4-DT-298	78	2500	-	-	-	-

2.3 Experimental Design and Agronomic Practices

The experimental design used was an Alpha lattice with 3 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)-P_2O_5(17)-K_2O (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.

2.4 Data Collection

Data were collected as described in table 2.

Table 2. Traits measured along with the description and the units

Parameters	**Abbreviations**	**Description**	**Unit**
Seedling vigour	SV	It expresses the physical energy with which the seedlings emerge from the sol (height and number of leaves) 14-15 days after sowing.	Score (5=Excellent, 1= Very Bad)
Heading time	HT	Number of days from sowing until 50% of the plants in the plot reach heading time.	days
Plant height	PH	Distance from ground to top of panicle	Cm
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
Panicle length	PL	Distance from the basis to the top of the panicle	cm
Grain number/panicle	GN/P	Weigh the grains of all panicles in the elementary plot after threshing, extrapolate with the weight of 100 grains.	Number
Number de whorls /panicle	NW/P	Counting the attachment points of the whorls of primary branches	Number
Primary branches number/panicles	PBN/P	Counting of primary branches at the level of each whorls by elementary plot.	Number
1000grains weight	1000GW	1000grains weight in gram per plot	g/plot
Endosperm texture	GQ	It is a visual appreciation after cutting the seed longitudinally. Data were taken according to the scores	Scores: 1(Completely corneous; 2 (Mostly corneous); 5 (Intermediate); 7(Mostly starchy) and 9 (Completely starchy).
Biochimical analysis (lysine, threonine, ion and zinc)	BA	After harvest, 500g of grains were sampled and sent to the lab	Content in g
Remark		Problems or specific additional observations (leaf diseases, insect damage)	By a specialist

In addition to these traits, zinc (Zn) and iron (Fe) content in whole grain was measured using energy-dispersive X-ray fluorescence spectrometry (ED-XRF).

2.5 Statistical Analysis

An analysis of variance (ANOVA) was carried out with the data collected using the GenStat software twelfth edition (12.1.0.3278) to assess the variability (s) of the genotypes for each trait. It was performed using the following model described by Kempthorne (Kempthorne, 1957). Genotypes were considered fixed effects, while replications and localities were considered random effects.

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

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} site

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

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} site

E_{ijk} = Residual effects

The correlation coefficients estimation (genotypic and phenotypic) was done using the formulae suggested by Falconer (1964).

The genotypic correlation coefficient (r_g) = $r\ (x_i.\ x_j)_g = ((Cov.\ (x_i.x_j)_g)/\ [V\ (x_i)_g.\ V\ (x_j)_g]^{1/2})$

Where, $r\ (x_i.\ x_j)_g$ is genotypic correlation between i^{th} and j^{th} characters

Cov. $(x_i.x_j)_g$ is a genotypic covariance between i^{th} and j^{th} traits

$V\ (x_i)_g$ is a genotypic variance of i^{th} traits

$V\ (x_j)_g$ is genotypic variance of j^{th} traits

The phenotype correlation coefficient (r_p) = $r\ (x_i.\ x_j)_p = ((Cov.\ (x_i.x_j)_p)/\ [V\ (x_i)_p.\ V\ (x_j)_p]^{1/2})$

Where, $r\ (x_i.\ x_j)_p$ is phenotypic correlation between i^{th} and j^{th} traits

Cov. $(x_i.x_j)_p$ is a phenotypic covariance between i^{th} and j^{th} traits

$V\ (x_i)_p$ is a phenotypic variance of i^{th} traits

$V\ (x_j)_p$ is a phenotypic variance of j^{th} traits

to determine direct and indirect effects for both phenotypic and genotypic correlations levels of different component traits towards grain yield, path coefficient analysis was performed using the grain yield as a dependent variable and other independent variables. The formula used was suggested by Wright (1921) and Dewey and Lu (1959).

3. Results

3.1 Agronomic Performance of Biofortified F_1 Hybrids Compared to Checks

The analysis of variance of hybrids and checks for yield component and yield is in the table 3. Mean square due to genotype, Genotype x Year, yearxSite, year and GenotypexYearxSite showed significant differences for all traits except zinc content for genotype, zinc, lysine and threonine for genotype x site level. Thus, high variability is observed between genotypes for several traits, however, this variability depends in certain cases on the environment (site and year). Further, the mean square of the repetition was not significant for all variables except grain quality and yield. This indicated that the conditions that the trials were conducted were not similar and then revealed variability within the plant materials.

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

		Cycle	Grain quality	Plant height	Plant length	PBN/P	GN/P	NW/P	YIELD
SOURCE	Df	m.s.							
REPO_NO	2	5.65	14.0057**	1717	15.492	235.4	766297	9.097	2753204**
DESIGNATION	47	626.75**	2.7238**	39354.4**	340.241**	3181.8**	14823228**	23.802**	16100502**
YEAR	1	91.36*	0.1202	269013.2**	196.201**	3678.4**	2418936	502.144**	458271934**
DESIGNATION.YEAR	47	90.34**	0.4408	5546.3**	26.838**	345.4**	4845316**	7.041**	5340092**
YEAR.SITE	6	1642.28**	28.4645**	21554.2**	219.988**	1002.5**	21009293**	533.854**	14181408**
DESIGNATION.YEAR.SITE	274	30.47*	1.1248**	1134.5**	32.136**	376.2**	3185538**	5.44**	1626156**
Residual	771	25.72	0.4546	814.5	7.331	126.5	1156898	3.437	447095
Total	1148	62.58	0.882	3006.1	28.913	327.6	2472879	8.108	2070525
		Iron	**Zinc**	**Lysine**	**Threonine**				
SOURCE	d.f.	m.s.							
REP	95	71.25	22.58	0.0918	0.0118				
DESIGNATION	46	134.57**	34.7	26.4769**	31.7666**				
ESIGNATION.SITE	141	784.37**	26.25	0.2308	0.2425				
Residual	101	61.58	26.6	0.2103	0.3066				
Total	383	338.84	26.45	3.2771	3.9447				

*PBN/P: primary branches number per panicle; GN/P: Grain number per panicle; NW: number of whorls per panicle; *: significant at 5 % and **: significant at 1 %.*

Mean performance of heading varied from 70 to 90 days at Farako (FA). The hybrids 12A / KO-BC1-F5-9, 216-2AP4-5 / BE-BC1-F6-73, 12A / KO-BC1-F6-1086 and 12A / SB-BC1-F6-1090 were early (73, 76 and 77 days) respectively (Table 6.2). No hybrid had the precocity of the parent KO-BC1-F5-9 (70 days) (Table 4).

At Kolombada (KO), the observed mean of heading is 78 days (Table 4). The hybrids 12A/BE-BC1-F6-73 (72 days), 12A/KO-BC1-F6-1086 (73 days), 12A/BE-BC1-F6-CT-2016 (73 days), were earliness and none hybrid got earliness as the parent KO-BC1-F6-1086 (66 days). These hybrids above were early than all checks (Table 4).

At Sotuba (SB) the heading varied between 66 and 92 days with an average of 80 days. In this locality, only the hybrids 12A/BE-BC1-F6-73 (74 days), 12A/SB-BC1-F6-1105 (76 days) and 12A/BE-BC1-F6-CT-2016 (76 days) were early than the control NIELENI (77) days) (Table 4).

The mean of heading varied between 64 and 88 days with an average of 79 days (Table 4). Hybrids 12A / KO-BC1-F5-9, 12A / BE-BC1-F6-1048 and 12A / SB-BC1-F6-1090 were early than some parents and all checks (Table 4) at Samanko.

At Farako the plant height means varied from 165 to 313.3 cm (Table 4). The hybrids 216-2AP4-5 / KO-BC1-F6-1053 (294.2 cm), 216-2AP4-5 / SB-BC1-F6-1053 (310.8 cm) and 216-2AP4-5 / BE-BC1- F6-73 (313.3 cm) were taller in terms of plant height than all controls and parents, on the other hand the hybrid 12A / BE-BC1-F6-1048 (205.8 cm) was short than the short plant height for hybrid check GRINKANYELEWOLO (206.7) cm (Table 4).

None hybrid got the taller plant height than the parents SB-BC1-F6-1068 (184.2 cm) and 12B (184.2 cm) at Kolombada. On the other hand, the hybrid 12A / KO-BC1-F6-1050 (220.8 cm) was substantially the same in terms of plant height as the parent KO-BC1-F6-1053 (220.4 cm).

At Sotuba, the hybrids 112A / BE-BC1-F6-1048 (217.5 cm), 12A / BE-BC1-F6-CT-2016 (225 cm) had an average plant height as the control hybrids GRINKANYELEWOLO (212, 5 cm) and SEWA (215 cm) (Table 6.2). The mean performance of plant height varied between 156.6 and 339.1 cm with an average of 252.2 cm (Table 4).

At Samanko the mean of plant height varied between 175.8 and 321.5 with an average of 248.3 cm (Table 6.2). Hybrid 12A / BE-BC1-F6-CT-2016 (204.3 cm) recorded a relatively average plant height than all control hybrids and many of the parents, the shortest plant height was recorded with the parent SB-BC1-F6- 1068 (175.8 cm) (Table 4).

At Farako the panicle length means varied from 25.16 to 37.33 cm (Table (4). The hybrids 216-2AP4-5/BE-BC1-F6-2070,12A/BE-BC1-F6-CT-2016,12A/BE-BC1-F6-73,216-2AP4-5/KO-BC1-F6-1050,216-2AP4-5/KO-BC1-F6-1053,12A/KO-BC1-F5-9,216-2AP4-5/SB-BC1-F6-1036, 216-2AP4-5/BE-BC1-F6-73, 216-2AP4-5/BE-BC1-F6-CT-2016, 12A/BE-BC1-F6-1048, 12A/BE-BC1-F6-1048, 12A/SB-BC1-F6-1036 and 216-2AP4-5/BE-BC1-F6-1048 had largest panicle length that varied from 36.33 to 33.50 cm than all controls and parents except a hybrid check NIELENI which got largest panicle than these above hybrids (Table 4).

None hybrid got panicle length than the check hybrid (40.53 cm) at Kolombada (Table 6.2). On the other hand, the hybrid 12A/BE-BC1-F6-CT-2016 (38.22 cm), 12A/KO-BC1-F6-1053 (36.50 cm), 12A/SB-BC1-F6-1068 (36.44 cm), 12A/BE-BC1-F6-73 (36.39 cm), 12A/BE-BC1-F6-1048 (35.95 cm) and 216-2AP4-5/SB-BC1-F6-1068 (35.83 cm) had the largest panicle length than all parents and hybrids checks (Table 4).

At Sotuba, the hybrids 12A/BE-BC1-F6-1048 ,12A/BE-BC1-F6-CT-2016, 12A/KO-BC1-F6-1053, 12A/BE-BC1-F6-1105, 12A/SB-BC1-F6-1090, 12A/KO-BC1-F5-9, 12A/SB-BC1-F6-1036 and 12A/BE-BC1-F6-2070 which averages varied from 36.67 to 40.83 (Table 6.2). The mean performance of panicle length varied between 40.83 and 36.67 cm with an average of 33.13 cm (Table 4).

At Samanko the mean of panicle length varied between 24.71 and 39.33 with an average of 33.08 cm (Table 6.2). Hybrid 12A/SB-BC1-F6-1068 (39.33 cm) recorded the largest plant length of all control hybrids and parents (Table 4).

The Mean performance of a number of primary branches varied from 53 to 92 at Farako with an average of 74 (Table 4). The hybrids 112A/SB-BC1-F6-1090, 12A/BE-BC1-F6-2070, 12A/KO-BC1-F5-9, 12A/BE-BC1-F6-CT-2016, 216-2AP4-5/BE-BC1-F6-1048, 216-2AP4-5/KO-BC1-F6-1050, 216-2AP4-5/SB-BC1-F6-1036 and 12A/SB-BC1-F6-1036 had the largest number of primary branches compared to all hybrids checks and parents (85, 82 and 83) respectively (Table 4) except two parents. No hybrid had a number of primary branches superior to two parents KO-BC1-F5-9 (92) and BE-BC1-F6-1048 (87) (Table 4).

At Kolombada (KO), the observed mean of number of primary branches per panicle (PBN/P) is 73 (Table 6.2). The hybrids 1216-2AP4-5/SB-BC1-F6-1036 (104), 216-2AP4-5/SB-BC1-F6-1053 (102), 216-2AP4-5/KO-BC1-F6-1053 (101) and

216-2AP4-5/BE-BC1-F6-2070 (98) recorded the largest PBN/P than all parents and hybrid checks (Table 4).

At Sotuba, the observed mean of number of primary branches per panicle (PBN/P) is 76 (Table 4). The hybrids 1216-2AP4-5/BE-BC1-F6-2070 (110), 216-2AP4-5/SB-BC1-F6-1053 (104), 216-2AP4-5/KO-BC1-F6-1053 (103), 216-2AP4-5/BE-BC1-F6-73 (100), 216-2AP4-5/SB-BC1-F6-1036 (95) and 216-2AP4-5/BE-BC1-F6-1048 (93) recorded the largest PBN/P than all parents and hybrid checks (Table 4).

The mean of PBN/P varied between 46 and 107 with an average of 76 (Table 4). Hybrids 216-2AP4-5/SB-BC1-F6-1036 (107), and 216-2AP4-5/SB-BC1-F6-1053 (104) registered the largest PBN/P than parents and hybrids check (Table 4) at Samanko.

The range of grain numbers per panicle varied from 511 to 5582 at Farako with an average of 2396 (Table 4). The hybrids 216-2AP4-5/KO-BC1-F5-9 (5582), 216-2AP4-5/SB-BC1-F6-1053 (4796), 216-2AP4-5/BE-BC1-F6-1048 (3792), 12A/SB-BC1-F6-1068 (3754), 216-2AP4-5/SB-BC1-F6-1105 (3673), 216-2AP4-5/KO-BC1-F6-1053 (3648) and 12A/SB-BC1-F6-1105 (3612) recorded higher significantly GN/P compared to all hybrids checks and parents (Table 4).

At Kolombada (KO), the observed mean of grain numbers per panicle (GN/P) is 2195 (Table 6.2). The hybrids 216-2AP4-5/BE-BC1-F6-1048 (3717), 216-2AP4-5/KO-BC1-F6-1053 (3349), 12A/KO-BC1-F6-1053(3283),216-2AP4-5/BE-BC1-F6-CT-2016(3155),216-2AP4-5/KO-BC1-F5-9(3120), 216-2AP4-5/SB-BC1-F6-1053 (3051) and 12A/BE-BC1-F6-1105 (3026) were superior in producing more grain numbers per panicle compared to all parents and hybrids checks (Table 4).

At Sotuba, the grain numbers per panicle was ranged between 1405 and 4952 with an average of 2767 (Table 6.2). Twenty hybrids with 3019 to 4952 grain numbers per panicle recorded significantly GN/P than all parents and hybrid checks (Table 4).

The range of grain numbers per panicle varied between 1162 and 9298 with an average of 3049 (Table 4). Twenty-five Hybrids with 2772 to 9298 grain numbers per panicle registered in producing more GN/P than parents and hybrids checks (Table 4) at Samanko.

The range of number of whorls per panicle varied from 12 to 16 at Farako with an average of 14 for NW/P (Table 6.2). Hybrid 212A/SB-BC1-F6-1036 (16) and a parent BE-BC1-F6-2070 (16) recorded higher significantly NW/P compared to all hybrids, hybrids checks and parents (Table 4).

At Kolombada (KO), the observed mean of number of whorls per panicle (GN/P) is 2195 (Table 6.2). The hybrids 216-2AP4-5/BE-BC1-F6-CT-2016 (16), 216-2AP4-5/KO-BC1-F6-1053 (16), 216-2AP4-5/KO-BC1-F6-1050 (16), 12A/BE-BC1-F6-1048 (16), hybrids checks (FADDA (16)) and parents (BE-BC1-F6-1048 (16), 216-2AP4-5 (16)) were superior in getting number of whorls per panicle compared to others parents and hybrids checks (Table 4).

At Sotuba, the number of whorls per panicle was ranged between 10 and 15 with an average of 13 (Table 4). Hybrid 12A/BE-BC1-F6-1048 (15) recorded significantly NW/P than all parents and hybrid checks (Table 4).

The range of number of whorls per panicle varied between 22 and 13 with an average of 17 (Table 4). Hybrid 216-2AP4-5/SB-BC1-F6-1036 (22) registered in producing more NW/P than parents and hybrids checks (Table 4) at Samanko.

Over two years (2018 and 2019), the average grain yield is 3171 kg $^{-1\ ha}$ (Table 4). The most productive hybrids were 216-2AP4-5 / KO-BC1-F6-1053 (4624 kg $^{-1\ ha}$), 12A / BE-BC1-F6-2070 (4618 kg $^{-1\ ha}$), 216-2AP4-5 / BE-BC1-F6-1105 (4406 kg $^{-1\ ha}$), 216-2AP4-5 / SB-BC1-F6-1090 (4384 kg $^{-1\ ha}$), 216-2AP4-5 / SB-BC1-F6-1105 (4324 kg $^{-1\ ha}$), 12A / SB-BC1-F6-1036 (4198 kg $^{-1\ ha}$), 12A / SB-BC1-F6-1105 (4116 kg $^{-1\ ha}$) and 216-2AP4-5 / SB-BC1-F6-1053 (4068 kg $^{-1\ ha}$). They were also more productive than parents and control hybrids (Table 4).

In the year 2018, the grain yield varied between 1097 kg $^{-1\ ha}$ and 4187 kg $^{-1\ ha}$. The average grain yield observed was 2514 kg $^{-1\ ha}$. The more productive hybrids were recorded by 216-2AP4-5/KO-BC1-F6-1053 (4187 kg $^{-1\ ha}$), 216-2AP4-5/SB-BC1-F6-1105 (3981 kg $^{-1\ ha}$), 12A/BE-BC1-F6-2070 (3972 kg $^{-1\ ha}$), 216-2AP4-5/BE-BC1-F6-1105 (3917 kg $^{-1\ ha}$), 216-2AP4-5/SB-BC1-F6-1090 (3870 kg $^{-1\ ha}$), 12A/SB-BC1-F6-1105 (3737 kg $^{-1\ ha}$), 216-2AP4-5/SB-BC1-F6-1036 (3696 kg $^{-1\ ha}$) and 216-2AP4-5/SB-BC1-F6-1068 (3506 kg $^{-1\ ha}$) than all parents and hybrids checks (Table 4).

In the year 2019, the grain yield ranged between 1632 kg $^{-1\ ha}$ and 5775 kg $^{-1\ ha}$. The average grain yield observed was 3802 kg $^{-1\ ha}$. The more productive hybrids were recorded by 12A/BE-BC1-F6-CT-2016 (5775 kg $^{-1\ ha}$), 12A/BE-BC1-F6-1048 (5351 kg $^{-1\ ha}$), 216-2AP4-5/BE-BC1-F6-2070 (5337 kg $^{-1\ ha}$), 216-2AP4-5/SB-BC1-F6-1053 (5333 kg $^{-1\ ha}$), 12A/BE-BC1-F6-2070 (5239 kg $^{-1\ ha}$), 12A/SB-BC1-F6-1036 (5055 kg $^{-1\ ha}$) and 216-2AP4-5/KO-BC1-F6-1053 (5043 kg $^{-1\ ha}$) as compared to all parents and hybrids checks (Table 4).

In this study one type of endosperm texture: 2, 3 and 4 can be considered as Mostly corneous was observed (Table 4). All treatments had mostly floury endosperm texture at four sites (Table 4).

At Farako, the lysine content varied between 0.60 mg and 5.61 mg /100g (Table 4). The average lysine value for all samples is 3.14 mg. The highest content was observed in the hybrid 12A / SB-BC1-F6-1090 (5.61 mg / 100g), 216-2AP4-5 / SB-BC1-F6-1090 (5.40 mg) and 216-2AP4-5 / SB-BC1-F6-1036 (4.95 mg) then these contents were significantly higher than the parents and the control hybrids (Table 4).

The lysine content ranged between 0.49 mg and 5.53 mg /100g (Table 4). The average lysine value for all samples is 2.99 mg. The hybrid 216-2AP4-5 / SB-BC1-F6-1090 (5.53 mg / 100g) recorded higher significantly content of lysine compared to all others treatments (Table 4) at Kolombada, Sotuba and Samanko.

None hybrid had a higher threonine content than the parent SB-BC1-F6-1090 in Farako and Kolombada (6.05 and 6.10 mg / 100g). On the other hand, the hybrid 12A / SB-BC1-F6-1090

(5.94) had a high content compared to the other treatments (Table 4).

At Sotuba and Samanko, the hybrid 216-2AP4-5 / SB-BC1-F6-1090 (6.91 and 6.28 mg / 100g) respectively recorded higher significantly content of threonine compared to all others treatments (Table 4).

The iron content varied from 8.63 ppm to 39.88 ppm (Table 4) with an average of 20.86 at Farako. The highest iron content was observed in the 216-2AP4-5 / SB-BC1-F6-1053 hybrid (39.88 ppm). The hybrid (12A / KO-BC1-F6-1050) (33.53 ppm) and the hybrid control (NIELENI) (33.71ppm) had approximatively the same iron content (Table 4).

None hybrid had a higher iron content than the parents BE-BC1-F6-2070 (45.40 ppm) and SB-BC1-F6-1068 (42.24 ppm) at Kolombada. On the other hand, the hybrid 12A/KO-BC1-F6-1050(36.30 ppm) had a high content of iron compared to the other treatments (Table 4).

The iron content varied from 41.23 ppm 95.14 ppm (Table 4) with an average of 61.50 ppm at Sotuba. None hybrid had a higher iron content than the parents BE-BC1-F6-2070 (95.14 ppm) while the hybrid 216-2AP4-5/KO-BC1-F6-1050 (91.15 ppm) had a high content of iron compared to the others treatments (Table 4).

At Sotuba, it should also be noted that the iron content was the highest in the other three localities and then the highest iron content was also obtained in this locality.

The iron content varied from 12.06 ppm to 54.42 ppm (Table 4) with an average of 30.65 at Samanko. The higher significantly iron content was observed in the hybrids 12A/KO-BC1-F6-1050 (54.42 ppm), 12A/BE-BC1-F6-CT-2016 (46.75 ppm), 12A/KO-BC1-F6-1053 (44.63 ppm), 216-2AP4-5/BE-BC1-F6-73 (40.75 ppm) and BE-BC1-F6-1048 (40.23 ppm) as compared to all others treatments.

Regarding zinc content at Farako, its content in sorghum samples varied between 21.74 and 8.14 ppm with an average of 15.34 ppm (Table 4). The highest content was observed with the hybrids 216-2AP4-5 / KO-BC1-F6-1086 (21.74 ppm). It is followed by the hybrid 12A / SB-BC1-F6-1105 (21.32 ppm). The content of these hybrids above was higher than all other treatments (Table 4).

The zinc content varied from 6.11 ppm to 28.71 ppm (Table 4) with an average of 17.03 at Kolombada. The higher significantly zinc content was observed in the hybrids 12A/KO-BC1-F6-1050 (28.71 ppm), 12A/SB-BC1-F6-1105 (27.35 ppm), 12A/SB-BC1-F6-1068 (26.04 ppm), 12A/SB-CS-BC1-F6-1053 (25.06 ppm), 12A/KO-BC1-F6-1086 (22.91), 216-2AP4-5/KO-BC1-F6-1053 (21.98 ppm) and 216-2AP4-5/SB-BC1-F6-1053 (21.70 ppm) than all others treatments.

The zinc content varied from 6.97 ppm to 30.86 ppm (Table 4) with an average of 19.54 ppm at Sotuba. The hybrids 12A/SB-CS-BC1-F6-1053 (30.86 ppm) and 12A/SB-BC1-F6-1105 (29.93 ppm) had higher significantly zinc content than all other parents and hybrids checks (Table 4).

The zinc content varied from 7.68 ppm to 26.79ppm (Table 4) with an average of 16.75 ppm at

Samanko. The hybrids 12A/BE-BC1-F6-2070 (26.79 ppm), 216-2AP4-5/SB-BC1-F6-1036 (26.59 ppm) and 12A/SB-CS-BC1-F6-1053 (25.77 ppm) had higher significantly zinc content than all treatments (Table 4).

Table 4. Fortified hybrids and checks performance in two years for all studied traits at four locations

	FA	KO	SB	SKO	FA	KO	SB	SKO	FA	KO	SB	SKO	FA	KO	SB	SKO
Designation	Cycle				Grain quality				Plant height				Panicle length			
12A/BE-BC1-F6-1048	79	76	77	75	4	2	2	2	205.8	237.5	217.5	211.6	34.33	35.95	40.83	36.50
12A/BE-BC1-F6-1105	82	80	82	84	3	2	3	3	242.3	315.8	306.7	315.0	28.67	34.61	37.66	35.16
12A/BE-BC1-F6-2070	87	81	85	85	3	2	2	3	249.6	287.5	261.7	266.5	32.83	35.11	36.67	33.38
12A/BE-BC1-F6-73	81	72	74	75	3	2	2	2	260.0	327.5	300.0	271.7	35.00	36.39	35.83	35.00
12A/BE-BC1-F6-CT-2016	80	73	76	76	4	2	2	3	230.0	265.0	225.0	204.3	36.33	38.22	39.83	37.60
12A/KO-BC1-F5-9	73	74	77	74	3	2	2	2	288.3	293.3	294.2	300.8	34.66	32.83	37.17	36.66
12A/KO-BC1-F6-1050	84	80	79	79	4	2	2	3	218.9	220.8	255.8	251.7	31.33	35.22	35.33	38.67
12A/KO-BC1-F6-1053	86	79	90	88	4	2	2	2	263.3	310.8	311.7	278.2	32.17	36.50	38.50	34.05
12A/KO-BC1-F6-1086	77	73	77	76	4	2	2	2	238.3	302.5	282.5	285.0	32.83	33.78	34.33	35.66
12A/SB-BC1-F6-1036	84	81	86	82	3	2	2	2	235.0	255.8	248.3	255.7	33.67	34.89	37.00	36.38
12A/SB-BC1-F6-1068	81	77	78	77	4	2	2	3	238.4	286.7	258.3	275.0	33.00	36.44	35.83	39.33
12A/SB-BC1-F6-1090	77	74	78	75	4	2	2	3	288.3	305.8	300.8	311.7	33.17	35.00	37.17	37.00
12A/SB-BC1-F6-1105	78	79	76	77	3	2	2	2	262.5	299.2	296.6	291.6	29.50	32.06	35.17	32.16
12B	84	80	66	77	3	3	2	2	181.7	184.2	170.0	188.3	33.33	35.22	35.67	31.48
216-2AP4-5/BE-BC1-F6-1048	81	80	88	85	4	3	3	2	247.5	274.2	308.3	250.1	33.50	33.45	33.83	36.76
216-2AP4-5/BE-BC1-F6-1105	84	80	85	83	4	3	2	3	272.5	294.2	307.5	300.8	27.67	29.61	31.17	34.14
216-2AP4-5/BE-BC1-F6-2070	82	81	85	83	4	3	4	2	226.6	240.8	262.5	223.2	35.16	30.61	33.50	37.72
216-2AP4-5/BE-BC1-F6-73	76	77	81	79	4	3	3	3	313.3	345.8	339.1	321.5	34.50	30.72	33.17	35.55
216-2AP4-5/BE-BC1-F6-CT-2016	84	80	83	83	4	3	3	2	238.3	245.8	271.7	279.1	34.50	30.45	33.00	34.48
216-2AP4-5/KO-BC1-F5-9	84	81	86	82	3	3	3	3	250.8	292.5	280.8	275.0	31.00	28.67	30.83	37.50
216-2AP4-5/KO-BC1-F6-1050	82	82	85	85	4	2	3	3	243.3	233.3	263.8	224.8	34.83	35.33	36.16	36.88
216-2AP4-5/KO-BC1-F6-1053	81	81	88	85	4	3	3	3	294.2	286.7	288.3	275.7	34.83	34.11	35.00	35.88
216-2AP4-5/KO-BC1-F6-1086	83	82	88	82	4	2	3	2	267.5	274.2	303.3	295.8	32.83	25.78	30.00	32.66
216-2AP4-5/SB-BC1-F6-1036	83	79	83	81	5	2	4	3	248.3	241.7	250.0	237.5	34.50	32.44	35.33	35.00
216-2AP4-5/SB-BC1-F6-1053	84	82	86	86	4	3	4	3	310.8	276.7	265.0	269.0	34.17	34.06	35.83	36.21
216-2AP4-5/SB-BC1-F6-1068	87	82	84	85	3	3	3	3	241.7	265.0	254.2	267.6	33.00	35.83	35.50	38.60
216-2AP4-5/SB-BC1-F6-1090	84	80	82	81	4	2	3	3	257.5	281.7	280.0	288.3	32.67	31.61	34.00	36.48
216-2AP4-5/SB-BC1-F6-1105	83	83	89	85	4	2	2	2	270.8	290.0	293.3	299.0	29.67	27.22	33.67	34.05
216-2BP4-5	90	87	92	88	3	3	3	2	173.3	188.3	200.8	185.8	26.50	27.83	30.83	31.00
BE-BC1-F6-1048	80	80	79	80	3	3	3	2	220.0	231.7	230.8	215.8	30.00	29.39	29.66	27.33
BE-BC1-F6-1105	71	70	70	69	3	2	5	2	208.3	221.6	217.5	209.2	25.67	21.78	25.33	25.67
BE-BC1-F6-2070	75	75	79	76	4	3	4	3	200.8	200.0	193.3	191.5	28.66	27.28	28.33	25.38
BE-BC1-F6-73	75	76	70	71	3	3	3	3	271.6	315.8	291.7	302.5	28.17	30.89	33.67	27.31
BE-BC1-F6-CT-2016	76	75	78	77	3	3	3	3	191.7	207.5	200.8	206.7	27.00	28.56	28.83	26.81
FADDA	85	82	90	85	3	3	3	4	263.3	322.5	320.8	314.8	32.83	40.53	41.83	38.71
GRINKANYELEWOLO	84	84	81	87	4	3	4	3	206.7	215.8	212.5	208.2	31.16	35.50	36.33	31.38
KO-BC1-F5-9	70	72	69	68	3	3	4	3	210.8	252.5	215.8	225.0	27.00	24.33	25.16	26.81
KO-BC1-F6-1050	82	82	79	82	4	3	3	2	194.2	187.5	172.5	178.3	28.83	26.05	29.33	31.50
KO-BC1-F6-1053	84	84	87	85	4	3	4	3	232.1	220.4	226.3	218.2	25.67	26.28	27.08	27.11
KO-BC1-F6-1086	71	66	66	64	2	3	3	2	187.5	199.2	187.5	194.8	25.16	21.39	23.67	24.71
NIELENI	81	76	77	78	3	3	3	3	234.2	248.3	239.2	234.0	37.33	34.61	33.50	32.88
SB-BC1-F6-1036	79	75	79	75	3	3	4	3	190.0	192.5	180.0	182.5	32.33	25.45	27.67	27.16
SB-BC1-F6-1068	79	77	78	78	2	3	3	2	165.0	184.2	156.6	175.8	30.50	30.61	32.00	32.33
SB-BC1-F6-1090	75	70	71	69	2	3	4	2	193.3	246.7	238.3	241.5	29.17	24.89	26.67	26.05
SB-BC1-F6-1105	72	72	71	68	3	4	5	4	206.7	234.2	206.7	226.8	28.83	22.78	23.83	32.26
SEWA	82	82	85	85	3	3	4	2	211.7	212.5	215.0	198.3	33.33	33.17	32.33	26.50
Mean	81	78	80	79	4	3	3	3	235.8	256.8	252.2	248.3	31.56	31.38	33.13	33.08
LSD (5%)	8	7	7	9	1	2	1	2	46.2	46.8	47.5	48.9	4.33	3.50	3.61	4.01
CV%	6	7	6	8	23	22	24	23	11.5	12.6	13.9	18.9	8.10	9.40	10.25	12.54

Table 4. (cont.)

	FA	KO	SB	SKO	FA	KO	SB	SKO	FA	KO	SB	SKO	2YEARS	2018	2019
DESIGNATION	PBN/P				GN/P				NWP				YIELD		
12A/BE-BC1-F6-1048	77	62	60	63	2378	2003	2944	2772	15	16	15	18	3447	1464	5351
12A/BE-BC1-F6-1105	70	67	65	71	1805	3026	3147	3215	14	15	14	17	3262	2251	4232
12A/BE-BC1-F6-2070	85	67	81	78	2990	2602	2792	4091	15	14	14	18	4618	3972	5239
12A/BE-BC1-F6-73	77	57	59	62	1405	1781	2350	3659	14	15	14	16	2767	1917	3582
12A/BE-BC1-F6-CT-2016	83	67	68	60	3066	2428	3260	2947	14	15	13	18	3657	1451	5775
12A/KO-BC1-F5-9	85	58	58	59	2433	1709	2616	3549	14	14	13	16	3771	3038	4476
12A/KO-BC1-F6-1050	66	55	73	65	2474	1473	1827	9298	13	13	13	16	2173	1784	2545
12A/KO-BC1-F6-1053	76	70	75	71	3460	3283	3180	3610	14	14	14	17	3768	2676	4817
12A/KO-BC1-F6-1086	74	60	57	60	2329	2224	2936	2895	14	13	13	15	3602	3320	3873
12A/SB-BC1-F6-1036	81	72	75	79	3248	2432	3335	3648	16	14	14	19	4198	3305	5055
12A/SB-BC1-F6-1068	72	59	60	65	3754	2599	3194	5148	13	13	14	17	3163	1825	4449
12A/SB-BC1-F6-1090	85	55	65	63	3390	2437	3419	4080	13	14	14	16	3710	3003	4389
12A/SB-BC1-F6-1105	74	55	56	61	3612	2083	3036	3594	13	13	14	16	4073	3737	4395
12B	54	47	43	46	3545	1420	2097	1661	13	13	12	17	2379	2275	2478
216-2AP4-5/BE-BC1-F6-1048	83	93	93	93	3792	3717	3706	3101	15	15	14	19	3443	2553	4298
216-2AP4-5/BE-BC1-F6-1105	61	70	79	74	3047	2451	2720	3895	13	13	14	16	4406	3917	4876
216-2AP4-5/BE-BC1-F6-2070	74	98	110	94	2982	2166	3388	3376	15	15	14	19	3961	2527	5337
216-2AP4-5/BE-BC1-F6-73	74	85	100	87	1967	2449	3019	3873	15	14	13	17	3742	3273	4192
216-2AP4-5/BE-BC1-F6-CT-2016	70	89	90	89	2950	3155	3084	3152	15	16	14	20	3602	2699	4469
216-2AP4-5/KO-BC1-F5-9	74	81	78	81	5582	3120	3630	3535	14	15	12	17	3443	2338	4504
216-2AP4-5/KO-BC1-F6-1050	82	91	89	94	2497	2411	3521	1431	14	16	13	20	2458	1430	3446
216-2AP4-5/KO-BC1-F6-1053	72	101	103	89	3648	3349	4522	4885	14	16	14	16	4624	4187	5043
216-2AP4-5/KO-BC1-F6-1086	74	73	88	81	2627	1978	3120	3207	14	14	13	17	3920	3234	4579
216-2AP4-5/SB-BC1-F6-1036	81	104	95	107	2829	2600	3515	3126	14	13	13	22	4116	3696	4518
216-2AP4-5/SB-BC1-F6-1053	76	102	104	104	4796	3051	4952	4482	14	14	14	18	4068	2750	5333
216-2AP4-5/SB-BC1-F6-1068	75	88	90	93	1891	2623	4265	3858	13	14	12	16	3720	3506	3925
216-2AP4-5/SB-BC1-F6-1090	76	87	86	80	3063	2393	4119	3435	14	14	13	16	4384	3870	4877
216-2AP4-5/SB-BC1-F6-1105	74	75	89	86	3673	2547	4405	4462	13	13	13	18	4324	3981	4653
216-2BP4-5	71	95	89	94	1797	1651	1839	1916	13	16	14	18	2381	2031	2716
BE-BC1-F6-1048	87	78	85	80	1566	1874	1671	2333	14	16	14	16	2311	1566	3027
BE-BC1-F6-1105	71	61	60	61	511	1331	1435	2006	13	12	11	13	2177	2008	2340
BE-BC1-F6-2070	92	86	89	91	2263	1534	2219	2338	16	14	13	17	2860	2682	3031
BE-BC1-F6-73	80	82	88	81	1194	1712	1908	1926	14	15	12	15	2436	1970	2883
BE-BC1-F6-CT-2016	67	69	70	74	1074	1973	1671	1811	12	14	13	14	2400	1812	2964
FADDA	60	70	71	73	1826	2452	2264	2543	12	16	14	19	3640	2611	4628
GRINKANYELEWOLO	69	76	65	81	1548	2622	2819	2508	14	15	14	17	2746	2673	2817
KO-BC1-F5-9	68	62	65	64	881	1410	1496	1893	12	12	12	16	2212	2195	2228
KO-BC1-F6-1050	72	68	68	70	1043	1224	1499	1316	13	15	13	15	1383	1123	1632
KO-BC1-F6-1053	69	86	91	96	2049	1824	2175	2248	13	14	14	16	2844	2294	3372
KO-BC1-F6-1086	73	58	63	63	1617	1300	1405	1979	13	12	10	13	1959	2030	1888
NIELENI	68	54	55	63	1638	2070	1874	2291	12	13	12	16	2537	1978	3073
SB-BC1-F6-1036	73	94	92	81	1729	1522	2080	1651	14	13	13	15	2455	1948	2941
SB-BC1-F6-1068	81	72	74	67	1218	1444	2421	1162	14	13	12	14	1733	1097	2343
SB-BC1-F6-1090	53	61	59	62	929	1808	1967	2351	13	13	12	13	2345	1889	2782
SB-BC1-F6-1105	63	58	60	63	924	1617	1451	2206	13	13	10	13	2143	1988	2299
SEWA	71	54	71	77	1197	2097	3013	1821	13	15	14	17	2515	1772	3229
Mean	74	73	76	76	2396	2195	2767	3049	14	14	13	17	3171	2514	3802
LSD (5%)	18	18	17	17	1754	1528	1852	1989	3	3	3	3	1087	1121	1258
CV%	15	14	14	15	41	40	39	38	13	13	14	13	23	25	28

Table 4. (cont.)

	FA	KO	SB	SKO	FA	KO	SB	SKO
DESIGNATION	IRON				ZINC			
12A/BE-BC1-F6-1048	13.11	26.55	50.80	20.01	11.50	10.02	6.97	12.08
12A/BE-BC1-F6-1105	13.68	26.59	60.50	27.34	14.75	19.21	23.52	12.90
12A/BE-BC1-F6-2070	15.64	28.74	66.24	27.08	11.31	11.65	17.57	26.79
12A/BE-BC1-F6-73	30.77	35.81	60.33	25.41	19.24	21.68	22.97	15.15
12A/BE-BC1-F6-CT-2016	23.37	23.38	47.08	46.75	11.67	18.19	26.09	17.92
12A/KO-BC1-F5-9	13.18	28.45	82.53	27.21	16.71	19.83	20.99	17.13
12A/KO-BC1-F6-1050	33.53	36.30	83.38	54.42	12.83	28.71	25.13	21.31
12A/KO-BC1-F6-1053	25.51	32.06	73.64	44.63	20.37	14.39	26.58	22.67
12A/KO-BC1-F6-1086	25.50	29.41	59.33	26.40	13.48	22.91	25.97	16.28
12A/SB-BC1-F6-1036	18.39	19.47	71.71	36.37	19.21	18.12	17.88	15.33
12A/SB-BC1-F6-1068	25.63	29.85	51.91	20.39	19.95	26.04	14.67	14.09
12A/SB-BC1-F6-1090	28.39	31.11	70.90	37.66	16.77	15.75	18.21	22.23
12A/SB-BC1-F6-1105	22.15	31.92	77.97	25.85	21.32	27.35	29.93	19.16
12A/SB-CS-BC1-F6-1053	10.49	26.29	74.39	38.40	13.58	25.06	30.86	25.77
12B	29.82	18.18	87.73	36.92	17.72	17.85	18.22	14.93
216-2AP4-5/BE-BC1-F6-1048	21.75	20.79	67.81	31.44	8.14	15.49	15.96	17.75
216-2AP4-5/BE-BC1-F6-1105	18.88	31.67	69.90	39.86	9.99	14.63	19.10	14.76
216-2AP4-5/BE-BC1-F6-2070	30.84	24.41	61.24	21.55	11.45	13.12	10.87	11.98
216-2AP4-5/BE-BC1-F6-73	16.74	28.75	64.88	40.75	16.53	13.47	21.00	17.95
216-2AP4-5/BE-BC1-F6-CT-2016	26.98	19.33	56.27	28.00	14.88	8.28	12.83	13.16
216-2AP4-5/KO-BC1-F5-9	8.63	23.93	49.34	36.63	11.53	19.83	17.28	17.97
216-2AP4-5/KO-BC1-F6-1050	17.87	36.16	91.15	27.51	19.53	17.05	28.57	16.27
216-2AP4-5/KO-BC1-F6-1053	13.65	18.36	44.63	38.55	9.60	21.98	15.36	19.00
216-2AP4-5/KO-BC1-F6-1086	17.86	21.23	46.37	21.17	21.74	9.50	22.04	19.37
216-2AP4-5/SB-BC1-F6-1036	13.94	26.02	48.95	30.30	13.76	14.59	19.77	26.59
216-2AP4-5/SB-BC1-F6-1053	39.88	14.17	61.66	38.35	13.52	21.70	25.36	14.43
216-2AP4-5/SB-BC1-F6-1068	10.31	14.76	61.99	25.35	19.58	13.24	17.16	15.72
216-2AP4-5/SB-BC1-F6-1090	12.55	17.01	59.63	34.32	9.88	17.42	23.91	14.09
216-2AP4-5/SB-BC1-F6-1105	23.73	23.10	58.27	22.97	11.66	18.98	15.14	11.33
216-2BP4-5	19.70	20.60	53.02	21.20	12.58	19.47	18.30	18.79
BE-BC1-F6-1048	22.31	31.57	66.58	40.23	19.36	14.46	15.10	25.31
BE-BC1-F6-1105	18.27	17.98	42.58	12.06	16.44	17.80	17.40	12.40
BE-BC1-F6-2070	17.36	45.40	95.14	29.11	12.65	14.21	18.07	7.68
BE-BC1-F6-73	16.55	27.75	55.91	34.31	19.77	16.31	17.95	16.69
BE-BC1-F6-CT-2016	18.98	26.45	53.30	33.45	9.88	20.37	14.23	10.31
FADDA	17.32	27.42	43.65	32.24	16.03	11.48	21.47	23.79
GRINKANYELEWOLO	14.11	16.16	44.10	29.60	12.38	12.61	18.57	15.52
KO-BC1-F5-9	32.77	36.21	72.90	21.82	17.44	6.11	11.49	8.69
KO-BC1-F6-1050	26.93	16.61	41.95	32.94	21.31	21.01	16.83	15.62
KO-BC1-F6-1053	17.70	22.49	76.84	28.79	14.21	14.54	21.98	17.72
KO-BC1-F6-1086	25.77	28.91	56.46	24.62	15.34	12.94	22.18	15.03
NIELENI	33.71	19.83	59.27	27.50	13.40	20.04	17.89	10.49
SB-BC1-F6-1036	23.30	28.92	54.70	37.17	20.55	21.69	23.56	23.77
SB-BC1-F6-1068	16.27	42.24	52.48	30.90	21.19	15.94	15.74	15.77
SB-BC1-F6-1090	22.87	16.20	58.27	33.05	19.17	11.72	17.63	11.02
SB-BC1-F6-1105	20.03	17.61	61.82	14.20	15.46	17.81	29.23	13.85
SEWA	13.77	15.09	41.23	25.78	11.66	15.63	10.88	20.69
Mean	20.86	25.56	61.50	30.65	15.34	17.03	19.54	16.75
LSD (5%)	21.69	22.30	25.63	25.00	14.26	14.00	13.90	13.54
CV%	22.63	20.66	21.85	23.03	30.05	28.00	27.00	23.00

Table 4. (cont.)

	FA	KO	SB	SKO	FA	KO	SB	SKO
DESIGNATION	Lysine				Threonine			
12A/KO-BC1-F6-1053	2.73	3.65	3.50	4.80	2.91	2.50	2.95	3.06
12A/SB-BC1-F6-1036	4.12	3.02	3.12	3.28	3.06	2.36	2.06	2.59
12A/SB-BC1-F6-1090	5.61	4.08	4.61	5.13	5.94	5.94	5.94	5.90
216-2AP4-5/KO-BC1-F6-1053	4.09	4.54	3.54	3.92	3.98	3.98	2.98	3.49
216-2AP4-5/SB-BC1-F6-1036	4.95	4.63	4.40	4.95	4.58	4.34	3.58	3.87
216-2AP4-5/SB-BC1-F6-1090	5.40	5.53	5.53	5.39	5.11	4.91	6.91	6.28
FADDA	0.60	0.56	0.56	0.52	1.32	1.35	1.02	0.99
GRINKANYELEWOLO	0.76	0.54	0.49	0.78	1.13	1.00	1.05	1.02
KO-BC1-F6-1053	2.99	3.05	3.15	3.10	2.36	2.05	2.35	2.39
NIELENI	1.25	1.26	1.20	1.05	1.02	0.95	0.98	1.06
SB-BC1-F6-1036	2.98	2.06	2.36	2.35	1.25	1.36	1.28	1.32
SB-BC1-F6-1090	4.25	4.90	5.96	5.08	6.05	6.10	6.32	6.73
SEWA	1.05	1.10	1.32	1.23	0.63	0.59	0.89	0.98
Mean	3.14	2.99	3.06	3.20	3.02	2.88	2.95	3.05
LSD (5%)	0.92	0.89	0.78	0.63	1.11	1.01	1.00	1.12
CV%	14.33	14.00	13.90	13.87	18.66	17.56	16.50	17.00

- Genetic Advance as a percentage of Mean for all traits.

The highest values were observed by genetic advance as percentage of mean was recorded by plant height (31.30%), primary branch number per panicle (24.40 %), grain number per panicle (40.21%), lysine content (40.25 %), threonine content (56.63 %) and grain yield (41.07 %) (Table 5). These traits above obtained also high values of heritability, indicating that these traits were under additive gene action control. Selection can be improved for these traits.

Table 5.Genetic advance and Genetic advance as a percentage of mean for all traits in this study

3.2 Correlations Between Traits and Effects of Yield Components on Grain Yield

3.2.1 Phenotypic (PCV) and Genotypic (GCV) Coefficient of Correlation

The coefficients of Genotypic (r_g) and Phenotypic (r_p) correlation between each trait were estimated and presented in table 6.

✓ ***Genotypic (GCV) coefficient of correlation***

For heading time, a positive and highly significant ($P< 0.01$) genotypic correlation was observed with panicle length (r_g: 0.4881), primary branches number per panicle (r_g:0.5801), grain number per panicle (r_g: 0.6037), number of whorls per panicle (r_g: 0.7522) and grain yield (r_g: 0.4454).

Positive and highly significant ($P< 0.01$) genotypic coefficient of correlation was observed for grain quality with primary branches number per panicle (r_g:0.6871) while negative correlation was observed with panicle length (r_g:-0.4225), plant height (r_g:-0.3204), grain number per panicle (r_g: -0.4245), iron content (r_g:-0.4197), zinc content (r_g:-0.5053) and yield (r_g:-0.3588) (Table 6).

A positive and highly significant ($P< 0.01$) genotypic coefficient correlation was indicated for plant height with panicle length (r_g: 0.514), grain number per panicle (r_g: 0.6958), number of whorls per panicle (r_g: 0.3235) and grain yield (r_g: 0.6068) (Table 6.).

As indicated in the table 6, higher significant and positive genotypic correlation coefficient was obtained for panicle length with grain number per panicle (r_g: 0.7319), number of whorls per panicle (r_g: 0.7248), threonine content (r_g: 0.3606) and grain yield (r_g: 0.7127).

The primary branch per panicle recorded a positive and highly significant ($P< 0.01$) genotypic correlation coefficient with grain number per panicle (r_g: 0.4168), number of whorls per panicle (r_g: 0.6297) and grain yield (r_g: 0.3568) while a negative genotypic correlation coefficient was indicated with threonine content (r_g: -0.3996) (Table 6).

The grain number per panicle recorded a positive and highly significant ($P< 0.01$) genotypic correlation coefficient with number of whorls per panicle (r_g: 0.6246) and grain yield (r_g: 0.6653) (Table 6.).

Higher significant and positive genotypic correlation coefficient was obtained for number of whorls per panicle with grain yield (r_g: 0.7128). The negative genotypic correlation coefficient was observed with the threonine content (r_g: -0.5096).

The iron content recorded a positive and highly significant ($P< 0.01$) genotypic correlation coefficient with zinc content (r_g: 0.378) (Table 6.).

The lysine content recorded a positive and highly significant ($P< 0.01$) genotypic correlation coefficient with threonine content (r_g: 1.021) (table 6).

✓ *Phenotypic (PCV) coefficient of correlation*

Table 6. indicates for heading time a positive and highly significant ($P< 0.01$) phenotypic correlation with plant height (r_p: 0.2055), panicle length (r_p: 0.3551), primary branches number per panicle (r_p:4909), grain number per panicle (r_p: 0.3815), number of whorls per panicle (r_p: 0.4968) and grain yield (r_p: 0.3336).

Positive and significant ($P< 0.01$) phenotypic coefficient correlation was observed for grain quality with primary branches number per panicle (r_p: 0.1795) while negative correlation was also observed with plant length (r_p:-0.216) ,iron content (r_p:-0.1923) and zinc content (r_p:-0.1547) (Table 6).

A positive and highly significant ($P< 0.01$) phenotypic coefficient correlation was indicated for plant height with panicle length (r_p: 0.514), grain number per panicle (r_p: 0.6958), number of whorls per panicle (r_p: 0.3235) and grain yield (r_p: 0.6068) (table 6).

As indicated in the table 6, higher significant and positive phenotypic correlation coefficient was obtained for panicle length with grain number per panicle (r_p: 0.4945), number of whorls per panicle (r_p: 0.5037) and grain yield (r_p: 0.4822).

The primary branch per panicle recorded a positive and highly significant ($P< 0.01$) phenotypic correlation coefficient with grain number per panicle (r_p: 0.2409), number of whorls per panicle

(r_p: 0.4343) and grain yield (r_p: 0.2681) (Table 6).

The grain number per panicle recorded a positive and highly significant (P< 0.01) phenotypic correlation coefficient with number of whorls per panicle (r_p: 0.3052) and grain yield (r_g: 0.5175) (Table 6).

As indicated in the table 6, higher significant and positive phenotypic correlation coefficient was obtained for number of whorls per panicle with grain yield (r_p: 0.3766).

The iron content recorded a positive and highly significant (P< 0.01) phenotypic correlation coefficient with zinc content (r_p: 0.2367) (Table 6).

The lysine content recorded a positive and highly significant (P< 0.01) phenotypic correlation coefficient with threonine content (r_p: 0.2157) and grain yield (r_p: 0.1812) (Table 6).

Table 6. Estimation of genotype (above diagonal) and phenotype (below diagonal) coefficient of correlation for 12 traits

	Cycle	Gain quality	Plant height	Panicle length	PBN/P	GN/P	NWP	Iron	Zinc	Lysine	Threonine	Yield
CYCLE	1 **	0.0483 NS	0.2388 NS	0.4881 **	0.5801 **	0.6037 **	0.7522 **	-0.1472 NS	0.0557 NS	0.0881 NS	-0.0897 NS	0.4454 **
Gain quality	-0.024 NS	1 **	-0.3204 *	-0.4225 **	0.6871 **	-0.4245 **	0.0146 NS	-0.4197 **	-0.5053 **	0.013 NS	0.0626 NS	-0.3588 *
plant height	0.2055 **	-0.1044 NS	1 **	0.514 **	0.1609 NS	0.6958 **	0.3235 *	0.106 NS	0.2882 NS	0.1093 NS	0.0811 NS	0.6068 **
Panicle lenght	0.3551 **	-0.216 **	0.4629 **	1 **	0.097 NS	0.7319 **	0.7248 **	0.1664 NS	0.271 NS	0.0581 NS	0.3606 *	0.7127 **
PBN/P	0.4909 **	0.1795 *	0.1083 NS	0.0296 NS	1 **	0.4168 *	0.6297 **	-0.0504 NS	-0.1759 NS	0.1428 NS	-0.3996 **	0.3568 *
GN/P	0.3815 **	0.0362 NS	0.5017 **	0.4945 **	0.2409 **	1 **	0.6246 **	0.2465 NS	0.2609 NS	0.1835 NS	-0.1056 NS	0.6653 **
NW/P	0.4968 **	-0.0831 NS	0.2134 **	0.5037 **	0.4343 **	0.3052 **	1 **	0.149 NS	-0.2062 N	5e-04 NS	-0.5096 **	0.7128 **
Iron	-0.0511 NS	-0.1923 **	0.0807 NS	0.0895 NS	-0.0595 NS	0.0862 NS	0.0126 NS	1 **	0.378 **	-0.0373 NS	0.0773 N	0.231 NS
Zinc	0.0587 NS	-0.1547 *	0.107 NS	0.1101 NS	-0.0329 NS	0.0036 NS	0.0219 NS	0.2367 **	1 **	0.133 NS	0.0505 NS	0.2218 NS
Lysine	0.0764 NS	0.0179 NS	0.1069 NS	0.0468 NS	0.1206 NS	0.1308 N	0.0098 NS	-0.0127 NS	0.0676 N	1 **	1.021 **	0.2157 NS
Threonine	-0.0081 NS	0.0163 NS	0.0061 NS	0.0083 NS	-0.0609 NS	-0.0277 N	-0.0611 NS	-0.0258 NS	-0.0895 NS	0.2157 **	1 **	-0.0911 NS
Yield	0.3336 **	0.0021 NS	0.4716 **	0.4822 **	0.2681 **	0.5175 **	0.3766 **	-0.0301 NS	-0.0135 N	0.1812 *	-0.0034 NS	1**

*Significant at 5% level: 0.05 and ** significant at 1% level :0.01

3.2.2 Path Coefficient Analysis

The heading time at phenotypic (P) correlation level, presented positive (0.013) direct effect on grain yield (Table 7). It had also exhibited positive indirect effect on grain yield through plant height (0.04), primary branches number per panicle (0.05), number of whorls per panicle (0.047), iron content (0.003), lysine content (0.008) and threonine content (0.0001) while it presented indirectly negative effect on grain yield through grain quality (-0.0008) and zinc content (-0.003) (Table 7).

The cycle at genotypic (G) correlation level, the path coefficient analysis showed not direct effect on grain yield (Table 7). Positive indirect effect on grain yield was observed with grain quality (0.01), iron content (0.006), zinc content (0.01), lysine content (0.03) and threonine content (0.01). It also had negative indirect effect on grain yield through panicle length (-0.009) (Table 7).

There was a positive (0.03) direct effect for grain quality on grain yield at phenotypic correlation (Table 7). It showed positive indirect effect on grain yield with primary branches number per panicle (0.01), grain number per panicle (0.008), iron content (0.01), lysine content (0.007) and lysine content (0.001) (Table 7) while negative indirect effect was observed on grain yield through plant height (-0.02), panicle length (-0.04), number of whorls per panicle (-0.007), threonine content (-0.0002) and cycle (0.0032).

At genotypic correlation for grain quality, there was not a direct effect on grain yield (0.21) (Table 7). It showed positive indirect effect on grain yield with panicle length (0.0078), number of whorls per panicle (0.01), iron content (0.01), lysine content (0.005) and threonine content (0.01). Grain quality showed negative influence on grain yield through grain number per panicle (-0.04) and cycle (-0.01).

Plant height at phenotypic correlation showed no direct effect on grain yield (0.222) (Table 7). Its influence on grain yield was observed to be in positive indirect direction through cycle (0.002), primary branches number per panicle (0.01) , number of whorls per panicle (0.02) and lysine content (0.011) while its influence on grain yield was shown to be in negative indirect direction with grain quality (-0.003), iron content (-0.005) , zinc content (-0.005) and threonine content (-0.0001) (Table 7).

The genotypic correlation for plant height shown also no direct effect on grain yield (0.30) (Table 7). There was a positive indirect effect for plant height on grain yield through lysine content (0.04) while negative indirect effect was observed for plant height on grain yield with panicle length (-0.009), iron content (-0.004) and threonine content (-0.01) (Table 7).

Panicle length at phenotypic correlation showed direct effect on grain yield (0.0226) (Table 7). Its influence on grain yield was observed to be in positive indirect direction through cycle (0.004), primary branches number per panicle (0.003), number of whorls per panicle (0.04) and lysine content (0.005) while its influence on grain yield was shown to be in negative indirect direction with grain quality (-0.007), iron content (-0.005), zinc content (-0.005) and threonine content (-0.00015) (Table 7).

At genotypic correlation for panicle length, there was negative direct effect on grain yield (-0.01) (Table 6.5). It showed positive indirect effect on grain yield with lysine content (0.02). Panicle length showed negative influence on grain yield through primary branches number per panicle (-0.04) and iron content (-0.007) (Table 7).

Primary branches number per panicle had direct effect of 0.011 towards grain yield (Table 7). It had positive indirect effect on grain yield through cycle (0.006), grain quality (0.005), plant height (0.02), panicle length (0.006), grain number per panicle (0.05), number of whorls per panicle (0.04), iron content (0.003), zinc content (0.001), lysine content (0.01), threonine content (0.001) (Table 7) at phenotypic correlation level.

Genotypic correlation for Primary branches number per panicle shown no direct effect toward grain yield (Table 7). Its influence on grain yield was observed to be in positive indirect direction through plant height (0.004), grain number per panicle (0.04) and iron content (0.002) (Table 7). while its influence on grain yield was found to be in negative indirect effect with panicle length -0.001 (Table 7).

Grain number per panicle had direct effect of 0.0222 towards grain yield (Table 7). It had positive indirect effect on grain yield through cycle (0.005), grain quality (0.001), plant height (0.02), primary branch number per panicle (0.02), number of whorls per panicle (0.02), lysine content (0.01) and threonine content (0.0005) while it obtained negative indirect effect on grain yield with iron content (-0.005) and zinc content (-0.0001) (Table 7) at phenotypic correlation level.

Genotypic correlation for grain number per panicle shown no direct effect toward grain yield (Table 7). Its influence on grain yield was observed to be in positive indirect direction through threonine content (0.02) (Table 7) and then its influence on grain yield was found to be in negative indirect effect with panicle length (-0.001) and iron content (-0.01) (Table 7).

There was direct effect 0.009 for number of whorls per panicle towards grain yield at phenotypic correlation (Table 7). It shown positive indirect effect on grain yield with cycle 0.006, plant height 0.04, primary branches number per panicle (0.04), iron content (0.01), lysine content (0.001) and threonine content (0.001) (Table 6.5) while negative indirect effect was observed on grain yield through grain quality (-0.002), iron content (-0.0007) and zinc content (-0.001) (Table 7).

At genotypic correlation for number of whorls per panicle, there was not a direct effect on grain yield (1.02) (Table 7). It showed positive indirect effect on grain yield with grain quality 0.003 and lysine content (0.0002). Number of whorls per panicle shown negative influence on grain yield through panicle length (-0.01) and iron content -0.006 (Table 7).

Iron content at phenotypic correlation showed no direct effect on grain yield (-0.06) (Table 7). Its influence on grain yield was observed to be in positive indirect direction through plant height (0.0.1), panicle length (0.02) , grain number per panicle (0.01) and threonine content (0.0004) while its influence on grain yield was shown to be in negative indirect direction with cycle (-0.0006), grain quality (-0.006), primary branch per panicle (-0.006), zinc content (-0.01) and lysine content (-0.001) (Table 7).

At genotypic correlation level for iron content, there was negative direct effect on grain yield (-0.04) (Table 7). It showed positive indirect effect on grain yield with cycle (0.04), plant height (0.03), lysine content (0.02), primary branch per panicle (0.02) and grain number per panicle (0.02). Iron content shown negative influence on grain yield through panicle length (-0.003), lysine content (-0.01) and threonine content (-0.01) (Table 7).

The zinc content at phenotypic (P) correlation level, presented negative (-0.05) direct effect on grain yield (Table 7). It had also exhibited positive indirect effect on grain yield through cycle (0.0007), plant height (0.02), panicle length (0.02), grain number per panicle (0.0008). number of whorls per panicle (0.002), lysine content (0.007) and threonine content (0.0001) while it presented indirectly negative effect on grain yield through grain quality (-0.005), primary branch per panicle (-0.003) and iron content (-0.01) (Table 7).

The zinc content at genotypic (G) correlation level, the path coefficient analysis showed not direct effect on grain yield (Table 7). Positive indirect effect on grain yield was observed with grain number per panicle (0.02) and lysine content (0.05). It also had negative indirect effect on grain yield through cycle (-0.01), panicle length (-0.005), iron content (-0.01) ant threonine content (-0.01) (Table 7).

Lysine content had not directed effect of 0.222 towards grain yield (Table 7). It had positive indirect effect on grain yield through cycle (0.001), grain quality (0.00051), plant height (0.02), panicle length (0.01), primary branch number per panicle (0.01), grain number per panicle (0.02), number of whorls per panicle (0.0009), iron content (0.0007) and threonine content (0.0005) while it obtained negative indirect effect on grain yield with zinc content (-0.001) and threonine content (-0.003) (Table 7) at phenotypic correlation level.

Genotypic correlation for lysine content shown no direct effect toward grain yield (Table 7). Its influence on grain yield was observed to be in positive indirect direction through grain quality (0.002), plant height (0.03), grain number per panicle (0.01), number of whorls per panicle (0.0005), iron content (0.001) and zinc content (0.04) (Table 7) and then its influence on grain yield was found to be in negative indirect effect with cycle (-0.0.2) and panicle length -0.001(Table 7).

The threonine content at phenotypic (P) correlation level, presented negative (-0.01) direct effect on grain yield (Table 6.5). It had also exhibited positive indirect effect on grain yield through grain quality (0.0005), plant height (0.001), panicle length (0.001), iron content (0.001), zinc content (0.004) and lysine content (0.02) while it presented indirectly negative effect on grain yield through cycle (-0.0001), primary branch per panicle (-0.006), grain number per panicle (-0.006) and number of whorls per panicle -0.005 (Table 7).

The threonine content at genotypic (G) correlation level, the path coefficient analysis showed not direct effect on grain yield (Table 7). Positive indirect effect on grain yield was observed with cycle (0.02), plant height (0.02) and zinc content (0.01). It also had negative indirect effect on grain yield through grain quality (-0.01), panicle length (-0.006), grain number per panicle (-0.01) and iron content -0.003 (Table 7).

Table 7. Estimation of phenotype (P) and genotype (G) direct (diagonal and bold) and indirect (off diagonal) effects of 11 traits on grain yield

		Cycle	Grain quality	Plant height	Panicle length	PBN/P	GN/P	NW/P	Iron	Zinc	Lysine	Threonine
Cycle	P	**0.01322**	-0.00080	0.04570	0.08053	0.05423	0.08502	0.04710	0.00317	-0.00302	0.00829	0.00015
	G	**-0.27840**	0.01046	0.07230	-0.00911	-0.26285	0.05853	0.77201	0.00657	0.01908	0.03743	0.01937
Grain quality	P	-0.00032	**0.03311**	-0.02322	-0.04901	0.01983	0.00807	-0.00787	0.01193	0.00796	0.00191	-0.00029
	G	-0.01345	**0.21660**	-0.09701	0.00789	-0.31135	-0.04116	0.01495	0.01874	-0.17304	0.00554	0.01353
Plant height	P	0.00272	-0.00345	**0.22238**	0.10497	0.01196	0.11181	0.02023	-0.00501	-0.00550	0.01159	-0.00011
	G	-0.06647	-0.06940	**0.30279**	-0.00959	-0.07293	0.06746	0.33203	-0.00473	0.09870	0.04648	-0.01751
Panicle lenght	P	0.00469	-0.00714	0.10294	**0.0227**	0.00327	0.11021	0.04776	-0.00556	-0.00567	0.00506	-0.00015
	G	-0.13587	-0.09152	0.15564	**-0.01867**	-0.04395	0.07096	0.74393	-0.00743	0.09279	0.02472	-0.07789
PBN/P	P	0.00649	0.00593	0.02408	0.00671	**0.0110**	0.05369	0.04118	0.00369	0.00169	0.01307	0.00109
	G	-0.16149	0.14882	0.04873	-0.00181	**-0.45315**	0.04041	0.64626	0.00225	-0.06024	0.06071	0.08632
GN/P	P	0.00504	0.00120	0.11157	0.11214	0.02661	**0.0223**	0.02894	-0.00535	-0.00019	0.01418	0.00050
	G	-0.16806	-0.09195	0.21067	-0.01366	-0.18889	**0.09696**	0.64112	-0.01101	0.08933	0.07801	0.02282
NW/P	P	0.00657	-0.00274	0.04746	0.11423	0.04798	0.06802	**0.0095**	-0.00078	-0.00112	0.00108	0.00110
	G	-0.20941	0.00316	0.09795	-0.01353	-0.28533	0.06056	**1.02638**	-0.00665	-0.07060	0.00022	0.11008
Iron	P	-0.00068	-0.00635	0.01795	0.02030	-0.00657	0.01921	0.00119	**-0.06207**	-0.01217	-0.00138	0.00046
	G	0.04098	-0.09090	0.03210	-0.00311	0.02282	0.02390	0.15296	**-0.04465**	0.12943	-0.01587	-0.01669
Zinc	P	0.00078	-0.00511	0.02379	0.02499	-0.00363	0.00080	0.00207	-0.01469	**-0.05141**	0.00732	0.00161
	G	-0.01552	-0.10945	0.08726	-0.00506	0.07971	0.02529	-0.21160	-0.01688	**0.34245**	0.05652	-0.01091
Lysine	P	0.00101	0.00058	0.02377	0.01059	0.01332	0.02915	0.00095	0.00079	-0.00347	**0.10838**	-0.00387
	G	-0.02451	0.00282	0.03310	-0.00109	-0.06471	0.01779	0.00053	0.00167	0.04553	**0.42514**	-0.22056
Threonine	P	-0.00011	0.00054	0.00136	0.00188	-0.00673	-0.00617	-0.00579	0.00160	0.00460	0.02338	**-0.01796**
	G	0.02497	-0.01357	0.02454	-0.00673	0.18107	-0.01024	-0.52302	-0.00345	0.01730	0.43407	**-0.21601**

Residual effect of (P): 0.5784 and Residual effect of (G): 0.2198

4. Discussion

Notable differences between hybrids and controls were observed in all study environments for heading. This situation can be explained by the fact that the hybrids are the result of crosses between early parents and intermediate parents which had different degrees of photosensitivity. Such hybrids do not necessarily have the same reaction when it comes to their heading date. The parent's earliness genes show up in hybrids, and results indicated that some hybrids are earlier than most the parents used in combinations. This result also presents an opportunity for breeding programs to identify hybrids for different agro-ecologies going to the Sub-Sahel to the Guinea zones.

Significant variability was observed for the plant height in all environments. In environments with a high amount of rainfall, the treatments are of a fairly large height resulting in an increase in the height of the plants compared to other environments. These results indicate that hybrids tend to produce plants that are closer in height to the parents used in the crosses. This offers an opportunity to select short to medium height for the intensification but allows farmers who are looking for tall plants to use later stover for garden and other needs. However, it should be noted that tall hybrids are not recommended due to their susceptibility to lodging which can cause yield losses. It is therefore important to note that hybrids of reduced height, resistant to lodging, are the most recommended for intensification of sorghum cultivation.

In general, hybrids were more productive than varieties (controls and parents) across all 4 environments confirming the performance of hybrids over open pollinated varieties. Similar results have been obtained by several authors (Rattunde *et al* (2013); Kante *et al* (2017).

Differences were observed between treatments in all locations for grain quality, panicle length, primary branches per panicle, grain number per panicle, iron, lysine, threonine content and number of whorls per panicle. The overall treatment averages also vary by environment. This difference could be explained by the genetic background of the hybrid's parents. Our results are in agreement with those found by Fayeun *et al.* 2012, Arunkumar 2013, Menezes *et al.* 2015, Eniola 2019; who have shown significant variability in sorghum hybrids.

Important genetic advances as per cent of mean was observed for plant height, primary branch number per panicle, grain number per panicle, lysine content, threonine content and grain yield indicating that these traits were in the control of additive gene action. It means that selection can be made for these traits. This result is in accordance with those found by Godbharle *et al*. (2010) for plant height and number of primary branches. Moderate genetic advance as per cent of mean was obtained by Cycle, panicle length, iron and zinc content obtained, indicating that, these characters are controlled by both additive and non-additive gene actions.

Study of correlation allowed us to understand the relationship between two or more traits simultaneously in theoretical and practical value since selection is usually made based on various traits explained. The genetic correlation coefficients were high for some traits in this study, therefore a strong heritability existed among traits as explained by Johnson *et al. (1955*). This indicated that the selection can be made from fews traits only. Small values of the genotypic correlation coefficient found may slow the progress of selection. Negative values of genotypic coefficient correlation were identified by some of the traits indicating that selection for some of traits would affect each other in the opposite direction as earlier suggested by Bello *et al.* (2001).

Improvement of grain yield can be achieved by a correlation coefficient, which helps to determine the direction of selection with the number of traits. It is therefore very important for plant breeders to discover which traits are correlated with yield and also how they are associated with themselves.

Positive significant association with some traits for all studied characters on grain yield were found in this study at genotypic and phenotypic levels, indicating that selection for those traits improves simultaneously grain yield. Negative significant associations were obtained at genotypic and phenotypic levels on grain yield for all studied traits which means selection of those traits makes it impossible to achieve at the same time improvement of those traits along with each other's. Our results are in agreement with many results found by various scientists. Some outcomes are in opposite for those obtained by workers.

Path coefficient analysis measures the direct influence of one variable upon the other and permits the separation of correlation coefficient into components of direct and indirect effects. Partitioning of total correlation into direct and indirect effects provides actual information on the contribution of characters and thus forms the basis for selection to improve yield. Hence genotypic correlations were partitioned into direct and indirect effects to know the relative importance of the components.

This study, it found that the cycle, grain quality, panicle length, grain number per panicle, primary branch and a number of whorls per panicle had a positive and direct effects on grain yield. These traits should be considered at the same time when developing criteria for grain yield improvement in sorghum. Our outcomes are in accordance with several works found by (Jindal & Gill 1984, Singh & Govila 1989, Bidinger *et al.* 1993, Eniola 2019). It is inferred from correlation and path analysis these traits recorded significant positive correlation co-efficient and also had a high positive direct effect that might be regarded as the primes characters. This indicates that the traits are the most important influencing the grain yield. Thus, selection for these traits is important to attaining higher grain yield in sorghum. Its indirect effect through cycle, grain quality, panicle length, grain number per panicle, primary branch and number of whorls per panicle have been high among all traits that contributed significantly to grain yield.

5. Conclusion

The evaluation of fortified hybrids compared to parents and checks hybrids yielded interesting results. This study provided a better understanding of the performance of fortified hybrids to develop hybrids containing amino acids and mineral elements content that meet consumer criteria. Thus, the different origins of the genetic material to be used in the development of hybrids is important to consider. 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 fortified hybrids 216-2AP4-5 / KO-BC1-F6-1053, 216-2AP4-5 / BE-BC1-F6-1105, 216-2AP4-5 / SB-BC1-F6-1090, 216-2AP4-5 / SB-BC1-F6-1105, 12A / SB-BC1-F6-1036, 216-2AP4-5 / SB-BC1-F6-1036, 12A / SB-BC1-F6-1105 and 216 -2AP4-5 / SB-BC1-F6-1053 had a grain yield over 4 tons and better components of yield and then which combined with a high amino acid and mineral content. 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.

Plant height, primary branch number per panicle, grain number per panicle, lysine, threonine content and grain yield had high genetic advance as percentage of mean.

Regarding, correlations for grain yield and its components and to understand their direct and indirect effects on grain yield. For both a phenotypic and genotypic levels, a significant correlation on grain yield through plant height, panicle length, primary branch per panicle, grain number per panicle and number of whorls per panicle were found. The inheritance of association among traits at genotypic correlation level on grain yield, indicating that selection will be effective for improvement of grain yield of the genotypes.

Based on the path analysis, positive and significant direct and indirect effects of correlation were observed in this work for cycle, grain quality, panicle length, primary branch per panicle, grain number per panicle and number of whorls per panicle at the phenotypic level, which indicates selection would be effective for these traits in the improvement of grain yield in development of hybrid sorghum.

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