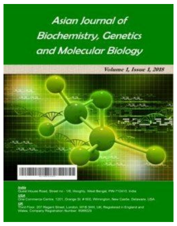

Asian Journal of Biochemistry, Genetics and Molecular Biology

1(1): 1-13, 2018; Article no.AJBGMB.41210

Variability, Heritability, Genetic Advance and Interrelationships for Agronomic and Yield Traits of Sorghum B-Lines under Different Environments

A. M. M. Al-Naggar[1*], R. M. Abd El-Salam[1], M. R. A. Hovny[2] and Walaa Y. S. Yaseen[2]

[1]*Department of Agronomy, Faculty of Agriculture, Cairo University, Egypt.*
[2]*Department of Grain Sorghum Research, Field Crops Research Institute, Agricultural Research Centre (ARC), Giza, Egypt.*

Authors' contributions

This work was carried out in collaboration between all authors. Author AMMAN designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AMMAN, RMAES and MRAH supervised the study and managed the literature searches. Author WYSY managed the experimental process and performed data analyses. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJBGMB/2018/v1i1443
Editor(s):
(1) Carlos Henrique dos Anjos dos Santos, Professor, Instituto Nacional de Pesquisas da Amazonia, Laboratorio de Ecofisiologia e Evoluçao Molecular, Av. Andre Araujo, Amazonas, Brasil.
(2) Mangala Kohli, Director Professor & Head, Department of Anatomy, VMMC & SJH, New Delhi, India.
Reviewers:
(1) Clint Magill, Texas A&M University, USA.
(2) Renata Pereira da Cruz, Universidade Federal do Rio Grande do Sul (UFRGS), Brazil.
(3) Zeynel Dalkiliç, Aydın Adnan Menderes University, Turkey.
Complete Peer review History: http://www.sciencedomain.org/review-history/24653

Original Research Article

Received 19th February 2018
Accepted 7th May 2018
Published 17th May 2018

ABSTRACT

Information on heritability and trait association in crops assist breeders to allocate resources necessary to effectively select for desired traits and to achieve maximum genetic gain with little time and resources. The objectives of this investigation were to determine the amount of genetic variability, heritability, genetic advance and strength of association of yield related traits among sorghum lines under different environments in Egypt. Six environments with 25 sorghum B-lines were at two locations in Egypt (Giza and Shandaweel) in two years and two planting dates in one location (Giza). A randomized complete block design was used in each environment with three replications. Significant variation was observed among sorghum lines for all studied traits in all

---

**Corresponding author: E-mail: medhatalnaggar@gmail.com, ahmedmedhatalnaggar@gmail.com;*

environments. Across environments, grain yield/plant (GYPP) showed positive and significant correlations with number of grains/plant (r = 0.71), days to flowering (r = 0.47), 1000-grain weight (r = 0.16) and plant height (PH) (r = 0.19). In general, the estimates of phenotypic coefficient of variation (PCV) were higher than genotypic coefficient of variation (GCV). Combined across the six environments, the highest PCV and GCV was shown by PH trait (95.14 and 43.57%) followed by GYPP (36.42 and 30.78%), respectively, indicating that selection for high values of these traits of sorghum would be effective. GYPP and PH traits showed high heritability associated with high genetic advance from selection, indicating that there are good opportunities to get success in improvement of these traits *via* selection procedures. Results concluded that PH is good selection criterion for GYPP and therefore selection for tall sorghum plants would increase grain yield.

Keywords: Sorghum bicolor; selection gain; correlations; broad-sense heritability; PCV, GCV.

1. INTRODUCTION

Sorghum [*Sorghum bicolor* L. (Moench)] is an important food and feed crop in the semi-arid regions of the world where it is grown under rain fed and irrigated conditions. Grain sorghum crop is predominantly grown in hot and dry regions due to its tolerance to heat and drought. It thrives well under temperatures and humidity, which are as high as 40 to 43°C and 15 to 30%, respectively, as long as soil moisture is available. The crop carries natural characteristics, which make it adaptable to hot, and drought conditions. Sorghum is one of the main staple for the world's poorest and most food insecure people. Among the cereals, sorghum ranks fifth in world production next to wheat, maize, rice and barley.

In Egypt, grain sorghum is an important cereal crop; it is ranked 4th in use and production after wheat, maize and rice. In 2014, the cultivated area of grain sorghum in Egypt was about 148,460 ha, producing about 804,000 tons with an average productivity of 5.42 ton/ha according to FAOSTAT [1]. Most of grain sorghum cultivated area in Egypt is concentrated in Assiut and Sohag governorates (Upper Egypt), where the atmospheric temperature during the growing season is high, since grain sorghum is more tolerant to high temperature than maize [2-8].

Genetic variability studies provide basic information regarding the genetic properties of the population based on which breeding methods are formulated for further improvement of the crop. These studies are also helpful to know about the nature and extent of variability that can be attributed to different causes, sensitive nature of the crop to environmental influence, heritability of the characters and genetic advance that can be realized in practical breeding. The progress in any crop improvement venture depends mainly on the magnitude of genetic variability and heritability present in the source material. Since the heritability is also influenced by environment, the information on heritability alone may not help in pin-pointing characters enforcing selection. Heritability of a trait is important in determining its response to selection. Estimates of heritability assist breeders to allocate resources necessary to effectively select for desired traits and to achieve maximum genetic gain with little time and resources [9]. Estimates of heritability with genetic advance are more dependable and important than individual consideration of the parameters [10]. Heritability estimates along with genetic gain are considered more useful in predicting the outcome of selecting the best individuals [11]. Furthermore, high heritability coupled with genetic advance indicates that additive gene effects are operating and selection for superior genotype is possible [12].

According to Panse [13], if heritability is mainly due to non-additive effects (dominance and epitasis), the genetic advance will be low, whereas if the heritability is due to additive effects it would be associated with high genetic advance. Swarup and Chagule [14] observed that high heritability need not be associated with high genetic advance. Nevertheless, the heritability estimates in conjunction with the predicted genetic advance will be more reliable [11]. Heritability gives the information on the magnitude of inheritance of quantitative traits while genetic advance is helpful in formulation of suitable breeding procedures. Although many sorghum breeders have used traditional breeding methods successfully, genetic potentials have not been fully utilized. The reason is the limited amount of genetic variability capitalized upon by traditional breeding methods [15].

Yield being a polygenic character is highly influenced by the fluctuations in environment.

Hence selection of plants based directly on yield would not be very reliable. Improvement in sorghum yield depends on the nature and extent of genetic variability, heritability and genetic advance in the base population [16,17]. Selection for yield is one of the most important and difficult challenge of plant breeding. Grafius et al. [18] indicated that individual yield components might contribute valuable information in breeding for yield. Johnson et al. [19] emphasized that increase in yield levels are progressively more difficult to be obtained and that evaluation of individual yield components might provide a better basis for progeny evaluation than yield itself. Sorghum in general possesses a wide range of genetic variability [20]. Adequate variability provides options from which selections are made for improvement and possible hybridization. Binodh et al. [21] reported that information on trait association in crops is essential for effective selection in crop improvement. The phenotype of a plant is the result of interaction of a large number of factors and final yield is the sum of effects of several component factors [22]. Correlation coefficients assist in deciding the direction of selection and number of traits to be looked at in improving grain yield. When more traits are involved in a correlation study, it becomes hard to determine the traits that really contribute to yield due to the existence of some amount of mutuality. According to Tah [23] the extent of variability is measured by genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) which provide information about relative amount of variation in different traits studied. The present study was aimed to determine the amount of genetic variability, heritability, genetic advance and strength of association of yield related traits among 25 sorghum B-lines under different environments in Egypt.

2. MATERIALS AND METHODS

The field work of this study was carried out at two locations, namely Giza (30º02` N latitude, 31º13` E longitude, with an altitude of 22.50 meter above sea level) and Shandaweel (26º33` N latitude, 31º41`E longitude, with an altitude of 67 meter above sea level) Research Stations of the Agricultural Research Center, Egypt in 2012 and 2013 seasons of grain sorghum.

2.1 Breeding Materials

Twenty five grain sorghum [*Sorghum bicolor* L. (Moench)] B-lines kindly provided by Grain Sorghum Res. Dept. of Agric. Res. Center (ARC), Egypt were used as the breeding material of this study. Designation, name and origin of these lines are presented in Table 1.

Seven of these lines are used as female parents (seed parents) in the commercial Egyptian hybrids of grain sorghum; namely ICSA -1, ICSA-37, ICSA -88005, ATX 2-1, ATX -407, ATX -631 and ATX TSC-20.

Table 1. Designation, name and origin of grain sorghum B-lines used in this study

Genotype no.	Name	Origin	Genotype no.	Name	Origin
G*1*	**ICSB-1**	ICRISAT- India	**G*14***	**ICSB-88005**	ICRISAT- India
G*2*	**ICSB-11**	ICRISAT- India	**G*15***	**ICSB-30**	ICRISAT- India
G*3*	**ICSB-14**	ICRISAT- India	**G*16***	**ICSB-88010**	ICRISAT- India
G*4*	**ICSB-20**	ICRISAT- India	**G*17***	**ICSB-88015**	ICRISAT- India
G*5*	**ICSB-37**	ICRISAT- India	**G*18***	**ICSB-90001**	ICRISAT- India
G6	**ICSB-70**	ICRISAT- India	**G*19***	**ICSB-91003**	ICRISAT- India
G*7*	**ICSB-102**	ICRISAT- India	**G*20***	**BTX-2-1**	Texas- USA
G*8*	**ICSB-122**	ICRISAT- India	**G*21***	**BTX-407**	Texas- USA
G*9*	**ICSB-155**	ICRISAT- India	**G*22***	**BTX-409**	Texas- USA
G*10*	**ICSB-1808**	ICRISAT- India	**G*23***	**BTX-630**	Texas- USA
G*11*	**ICSB-88001**	ICRISAT- India	**G*24***	**BTX-631**	Texas- USA
G*12*	**ICSB-88003**	ICRISAT- India	**G*25***	**BTX-TSC-20**	Texas- USA
G*13*	**ICSB-88004**	ICRISAT- India			

Source: Grain sorghum Res. department, Field crops res. institute, agric. res. center, Egypt

2.2 Experimental Procedures

2.2.1 Field experiments

Six field experiments represented different environments (E1, E2, E3, E4, E5 and E6) were carried out; four of them (E1 through E4) at Giza (two planting dates x two seasons) and two (E5 and E6) at Shandaweel (one planting date x two seasons). The two planting dates at Giza were on 1st of June and 1st of July in both growing seasons (2012 and 2013). The planting date at Shandaweel was on 1st July in both seasons (2012 and 2013). Characterization of the six environments used in this study is presented in Table 2.

2.2.2 Soil analyses

Physical and chemical soil analyses of the field experiments (Table 3) were performed at laboratories of Soil and Water Research Institute of ARC, Egypt.

2.2.3 Experimental design

A randomized complete block design in three replications was used in each of the six experiments. Each experimental plot consisted of one ridge of five meters length and 0.7 width. Therefore, the experimental plot area for each B-line was 3.5 m^2. Seeds were sown in hills at 20 cm apart, thereafter (before the first irrigation) were thinned to two plants/hill to achieve a plant density of 142,800 plants/ha.

2.2.4 Cultural practices

Flood irrigation was given at planting, the first irrigation after 21 days and the next irrigations at 10-15 day intervals depending on the requirement of plants. Nitrogen fertilizer was added at the rate of 238 kg/ha as Urea (46.5% N) in two equal doses; the first dose before the first irrigation and the second before the second irrigation. Calcium Superphosphate fertilizer (15% P_2O_5) was added at the rate of 70 kg P_2O_5/ha as soil application before sowing during preparation of the soil for planting. Potassium fertilizer at the rate of 57 kg K_2O/ha was added as soil application before the second irrigation as potassium sulfate (48% K_2O) Other cultural practices were carried out following the recommendations of ARC, Egypt. Weed control was performed chemically with Stomp herbicide (active constituent: 455 g/l Pendimethalin; manufactured by BASF, Australia) before the planting irrigation and just after sowing and manually by hoeing twice, the first before the first irrigation and the second before the second irrigation. Pest control was performed when required by spraying plants with Lannate (Methomyl) 90% (manufactured by DuPont, USA) against borers.

2.2.5 Data recorded

1. **Days to 50% flowering (DTF)** measured as the number of days from the date of emergence to the date at which about 50% of the plants in a plot showed blooming.
2. **Plant height (PH)** in cm measured on 10 guarded plants $plot^{-1}$ as the average height from the ground level to the tip of the panicle at the time of harvesting. The panicles of B-lines were covered by paper bags before flowering and then self-pollinated panicles were harvested after ripening. The following traits were recorded.
3. **Number of grains/plant (GPP)** measured on five guarded plants/plot.
4. **1000-grain weight (TGW)** in g measured on five samples/plot adjusted at 14% grain moisture.
5. **Grain yield/plant (GYPP)** in g estimated on 10-guarded plants/plot as the average weight of grain yield/plant adjusted at 14% grain moisture.

2.2.6 Biometrical and genetic analyses

Analysis of variance of the randomized complete block design (RCBD) was performed for each of the six environments on the basis of individual plot observation using the DSAASTAT Version 1.1 (Update: 18/03/2011). Combined analysis of variance across the six environments was also performed after carrying out the homogeneity test. Least significant difference (LSD) values were calculated to test the significance of differences between means according to Steel and Torrie [24]. Expected mean squares at separate and across the six environments were estimated from ANOVA table according to Hallauer et al. [25].

For one environment: Genotypic (σ^2_g), phenotypic (σ^2_{ph}), and error variances were computed as follows: $\sigma^2_g = (M_2 - M_1)$ /r and $\sigma^2_{ph} = \sigma^2_g + \sigma^2_e / r$. Where r = number of replications.

Table 2. Location, latitude, longitude, altitude, planting date, air temperature and relative humidity (RH) of the six tested environments (E1 to E6)

Environment	Location	Latitude	Longitude	Altitude	Planting	Temperature (°C)			RH%
					date	Max.	Aver.	Min.	
E1	Giza	30º02` N	31º13`E	22.5 masl	1/6/2012	*37.6*	29.6	24.8	64.0
E2	Giza	30º02` N	31º13`E	22.5 masl	1/7/2012	37.7	*29.4*	*24.8*	58.7
E3	Giza	30º02` N	31º13`E	22.5 masl	1/6/2013	*35.2*	*28.8*	*22.4*	60.4
E4	Giza	30º02` N	31º13`E	22.5 masl	1/7/2013	*37.2*	*30.3*	*23.7*	60.7
E5	Shandaweel	26º33` N	31º41`E	67.0 masl	1/7/2012	*41.1*	*30.5*	*26.2*	33.7
E6	Shandaweel	26º33` N	31º41`E	67.0 masl	1/7/2013	*40.8*	*33.6*	*25.5*	32.2

masl = meter above sea level

Table 3. Soil analysis at 0-30 cm depth in the experimental fields at Giza and Shandaweel in 2012 and 2013 growing seasons

Soil characteristics	Season 2012	Season 2013	Soil characteristics	Season 2012	Season 2013
		Giza			
Physical analysis			**Soluble cations (mEqu/l)**		
Coarse sand %	3.68	5.8	Ca^{++}	8.69	9.21
Fine sand %	19.52	9.0	Mg^{++}	3.4	2.84
Silt %	26.55	38.3	Na^{+}	14.6	11.9
Clay %	50.25	46.9	K^{+}	3.5	2.05
Texture	Clayey	Clayey	**Available nutrients (mg/kg)**		
Chemical analysis			N	38.16	39.6
pH (paste extract)	8.25	8.09	K	220	370
EC (dS/m)	3.21	1.78	P	7.32	12.8
Calcium carbonate %	2.94	2.8	Cu	1.4	2.84
Organic matter %	1.86	1.7	Fe	9.2	10.48
			Mn	5.8	5.24
Soluble anions (mEqu/l)			Zn	0.78	2.80
HCO$_3$	4.25	2.91			
Cl	5.7	15.1			
SO$_4$	2.30	7.99			
		Shandaweel			
Physical analysis			**Soluble cations (mEqu/l)**		
Coarse sand %	13.3	12.26	Ca++	42.5	62.1
Fine sand %	21.7	18.38	Mg++	31.5	24.8
Silt %	31.84	24.26	Na+	28.3	24.3
Clay %	33.16	45.15	K+	2.5	2.2
Texture	Clay loam	Clay	**Available nutrients (mg/kg)**		
Chemical analysis			N	18.7	22.8
pH (paste extract)	7.4	7.7	K	175.0	204.0
EC (dS/m)	0.80	0.67	P	11.2	13.7
Calcium carbonate %	2.15	1.8	Cu	3.6	4.7
Organic matter %	1.89	1.32	Fe	8.2	10.1
Soluble anions (mEqu/l)			Mn	7.1	9.4
HCO3	31.1	38.3	Zn	5.5	7.4
Cl	28.5	19.8			
SO$_4$	45.2	55.3			

Across environments: Genotypic (σ^2_g), phenotypic (σ^2_{ph}), genotype x environment (σ^2_{ge}) and error (σ^2_e) variances were computed as follows: $\delta^2_{ge} = (M_2\text{-}M_1)/r$, $\sigma^2_g = (M_3 - M_2)/re$, $\sigma^2_{ph} = \sigma^2_g + \sigma^2_{ge}/e + (\sigma^2_e / re)$. Where r = number of replications, g= number of genotypes and e= number of environments.

2.2.7 Heritability in the broad sense

Heritability in the broad sense (h^2_b%) for a trait in a separate environment and combined across environments was estimated according to Singh and Narayanan [26] using the following formula: $h^2_b\% = 100 \times (\sigma^2_g / \sigma^2_{ph})$ Where: σ^2_g = genetic variance, and σ^2_{ph} = phenotypic variance.

2.2.8 Expected genetic advance from selection

Expected genetic advance from selection for all studied traits as a percent of the mean was calculated [26] as follows: GA (%) = $100\ K\ h^2_b\ \sigma_{ph} / \bar{x}$, Where: $\bar{x}$ = General mean, σ_{ph} = Square root of the denominator of the appropriate heritability, h^2_b = The applied heritability, K = Selection differential (K = 1.76, for 10% selection intensity, used in this study).

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance

Combined analysis of variance for five studied traits of 25 grain sorghum B-lines, namely days to 50% flowering, plant height, grains/plant, 1000-grain weight and grain yield/plant across six environments (four at Giza; *i.e.* two planting dates × two seasons and two at Shandaweel; *i.e.* two seasons × one planting date) is presented in Table (4). Mean squares due to environments were significant (≤ 0,01) for all studied traits, indicating significant differences among the six environments for all studied traits, due to climate, particularly temperatures (Table 2) and/or soil (Table 3) differences among these environments.

Mean squares due to genotypes were significant (≤ 0.01) for all studied traits, indicating significant differences among the studied lines of grain sorghum for all five studied traits. Mean squares due to genotype × environment were significant (≤ 0.01) for all studied traits, suggesting that rank of grain sorghum genotypes differed from one environment to another and that selection would be efficient in a specific environment (specific in temperatures and other climatic and soil conditions during the growing season). These results are in agreement with previous investigations [2-8].

Analysis of variance of randomized complete blocks design performed at each environment separately (data not presented) showed that mean squares due to genotypes of grain sorghum under all environments were significant (p≤ 0,01 or p≤ 0.05) for all studied traits, except for 1000-grain weight trait under Shandaweel location in the two seasons (2012 and 2013). This indicates the existence of significant differences among studied genotypes for most studied traits and environments.

Table 4. Mean squares of combined analysis of variance across six environments for studied traits of 25 grain sorghum lines

SOV	df	Mean squares		
		Days to 50% flowering	**Plant height**	**Grains/plant**
Environment (E)	5	1231.0**	8751.19**	12003136**
Error	12	11.7	113.6	305769
Genotypes (G)	24	94.8**	1504.62**	465060**
G × E	120	28.7**	222.28**	246713**
Error	288	8.1	71.2	151819
		1000-Grain weight	**Grain yield/plant**	
Environment(E)	5	528.08**	7222.2**	
Error	12	14.03	134.7	
Genotypes(G)	24	60.63**	362.2**	
G × E	120	14.29*	123.7**	
Error	288	11.3	34.4	

**, ** indicate significant at 0.05 and 0.01 probability levels, respectively*

3.2 Means and Ranges

The mean optimum temperature range for sorghum is 21 to 35ºC for seed germination, 26 to 34ºC for vegetative growth and development, and 25 to 28ºC for reproductive growth [27]. The six environments under study differed significantly for all studied traits (Table 4). The environment E1 (Giza, 1st planting date, 2012 season) had a minimum and maximum temperature of 23.5 and 36.9ºC at germination and seedling stage, 24.8 and 37.6ºC for vegetative and development, 22.1 and 34.9ºC for reproductive stages, respectively. The minimum and maximum temperature for the three stages respectively were (24.8-37.6 °C), (24.8- 37.6ºC) and (20,6- 33.0ºC) for E2 (Giza, 2nd planting date, 2012 season), (22,4- 36.0ºC), (23.7- 37.2ºC) and (21.9-34.8ºC) for E3 (Giza, 1st planting date, 2013 season), (22.4- 35.2ºC), (21.9-34.8ºC) and (17.3- 30.1ºC) for E4 (Giza, 2nd planting date, 2013 season), (27.6- 42.3ºC), (23.8- 38.8ºC) and (21.2-36.5ºC) for E5 (Shandaweel, 2nd planting date, 2012), (26.2- 42.3ºC), (24.0-39.2ºC) and (17.9-33.9ºC) for E6 (Shandaweel, 2nd planting date, 2013). The temperature was higher in the first planting date than the second planting date, was higher in Shandaweel than Giza and in Shandaweel was higher in the 2013 than 2012 season. The physical and chemical properties of the site soil were better in Shandaweel than in Giza and were better in Shandaweel 2013 than 2012 season (Table 3).

The environment E1 (Giza, 1st planting date, 2012 season) exhibited the lowest mean number of days to 50% flowering (earliness), plant height and number of grains/plant (Table 5). However, the environment E3 (Giza, 1st planting date, 2013 season) showed the lowest mean weight of 1000 grains and grain yield/plant. On the contrary, the highest mean grain yield per plant (60.96g), number of grains/plant (2474.2) and the latest in 50% flowering (72.0 day) were shown by E5 (Shandaweel, 1st July, 2012 season).

The difference between the highest and lowest value, considered as a range, could express the variability among the studied B-lines (Table 5). Across all environments, the earliest B-line in flowering was ICSB-102, while the latest one was ICSB-88010. The tallest plant was shown by ICSB-14, while the shortest plant was shown by

Table 5. Basic statistics of five agronomic traits of sorghum B-lines under six environments

Parameter	E1	E2	E3	E4	E5	E6	$LSD_{.05}$(E)
			Day to 50% flowering				
Mean	62.9	64.5	63.5	71.3	72.0	66.0	4.6
Min.	56.3	54.7	55.3	65.0	66.7	61.3	
Max.	70.3	74.7	67.70	77.0	76.7	74.7	
$LSD_{.05}$(G)	3.6	4.5	4.6	5.8	3.3	5.3	
			Plant height (cm)				
Mean	98.0	111.0	119.9	124.2	114.8	127.9	11.7
Min.	85.3	95.0	95.0	102.7	98.3	101.7	
Max.	121.0	137.7	151.3	150.0	133.3	165.0	
$LSD_{.05}$(G)	10.0	16.2	13.2	13.9	6.1	19.7	
			Grains/plant				
Mean	1538.0	1741.0	1682.5	1809.5	2474.2	1614.1	653.2
Min.	1024.0	1387.0	1272.0	1369.7	2051.0	1139.3	
Max.	2242.0	2561.3	2825.7	2629.0	2837.7	2191.7	
$LSD_{.05}$(G)	498.3	501.5	1128.7	484.0	436.5	506.3	
			1000-Grain weight(g)				
Mean	25.88	26.67	23.96	25.37	24.95	31.48	4.35
Min.	19.5	21.77	18.00	21.33	22.80	26.67	
Max.	32.47	29.87	28.6	31.07	27.30	35.07	
$LSD_{.05}$(G)	5.74	5.98	5.21	5.29	3.69	6.73	
			Grain yield/plant(g)				
Mean	39.44	45.44	37.50	45.37	60.96	49.97	7.78
Min.	29.50	38.07	18.77	35.00	54.33	36.07	
Max.	56.06	63.37	56.13	64.17	71.67	66.47	
$LSD_{.05}$(G)	8.84	7.24	10.63	9.99	5.70	13.41	

ICSB-155. Across all environments, the highest grain yield per plant was shown by the B-line BTX TSC-20 followed by ICSB-88003, ICSB-1808, ICSB-14 and ICSB-1. On the contrary, the lowest grain yield per plant was shown by the B-line ICSB-155. The highest number of grains/plant was shown by the B-line BTX TSC-20 followed by ICSB-88003 and ICSB-1808; these lines had also the highest grain yield per plant in the same order. On the contrary, the lowest number of grains/plant was shown by the line ICSB-102. The heaviest kernel was exhibited by the B-line ICSB-88005, followed by BTX-631 and ICSB-88003. The line BTX-631 that occupied the second place in kernel weight occupied the first place with regard of grain yield per plant. In contrast, the lightest kernel weight was exhibited by the B-line BTX 2-1.

3.3 Trait Interrelationships

Phenotypic correlation coefficients among studied traits under each environment (from E1 to E6) were calculated and presented in Table (6). In general, correlation coefficients among all studied traits combined across all studied environments were significant ($p \leq 0.01$), except between days to flowering and 1000-grain weight and between plant height and grains/plant, which were not significant. The significance was positive for all correlation coefficients, except between grains/plant and 1000-grain weight, which was negative.

Grain yield/plant showed the strongest positive correlations with number of grains/plant ($r \geq 0.68$) in all environments, except in E3 and combined across environments; with the highest magnitude in E6 (r=0.83).

However, correlation coefficients between grain yield/plant and 1000-grain yield/plant were positive and significant in three environments, namely E1, E3 and E4 and combined across environments, but were weak (≤ 0.26). The correlations were negative and significant ($p \leq 0.01$) between number of grains/plant and 1000-grain weight in all environments; with the highest magnitude (-0.62) under E5.

Significant and positive correlations were found between grain yield/plant and each of plant height in three environments (E1, E3 and E4) and combined across environments (≤ 0.47) and days to flowering in two environments (E3 and E4) and combined across environments (≤ 0.47). Moreover, there was a weak and significant correlation between plant height and days to flowering in E4 only.

The results of the present study are in agreement with previous investigations with regard of the positive association between grain yield/plant and each of plant height [28-32], 1000-grain weight [33-36], number of grains/plant [32] and days to 50% flowering [37].

Table 6. Correlation coefficients among pairs of studied traits under each environment (from E1 to E6) and combined across environments

Trait 1	Trait 2	E1	E2	E3	E4	E5	E6	Combined
Days to 50% flowering	Plant height	0.18	0.07	0.2	0.27*	-0.08	0.22	0.23**
Days to 50% flowering	Grains/plant	0.13	0.11	-0.02	0.22	0.02	-0.02	0.36**
Days to 50% flowering	1000-Grain weight	0.15	0.08	0.05	0.16	0.16	0.09	0.02
Days to 50% flowering	Grain yield/plant	0.18	0.19	0.38**	0.37**	0.14	0.04	0.47**
Plant height	Grains/plant	0.29*	0.03	-0.09	0.29*	-0.02	-0.07	0.02
Plant height	1000-Grain weight	0.23	0.15	0.27*	0.2	-0.16	0.22	0.25**
Plant height	Grain yield/plant	0.44**	0.15	0.47**	0.44**	-0.15	0.05	0.19**
1000-Grain weight	Grains/plant	-0.44**	-0.61*	-0.29*	-0.41**	-0.62**	-0.37**	-0.38**
1000-Grain weight	Grain yield/plant	0.26*	0.12	0.24*	0.25*	0.05	0.10	0.16**
Grain yield/plant	Grains/plant	0.70**	0.68**	0.15	0.76**	0.73**	0.83**	0.71**

3.4 Phenotypic and Genotypic Coefficient of Variation

The estimates of phenotypic (PCV) and genotypic (GCV) coefficients of variation for studied traits of grain sorghum B-lines under the six environments are presented in Table (7). In general, the estimates of PCV were higher than those of GCV, since phenotypic variance includes both genotypic and environmental variances. Combined across the six environments, the highest PCV and GCV was shown by plant height trait (95.14 and 43.57%, respectively) followed by grain yield/plant (36.42 and 30.78%, respectively), indicating that selection for high values of these traits of sorghum would be effective. On the contrary, the lowest estimate of PCV and GCV was exhibited by (0.48 and 31%, respectively) followed by days to flowering (18.53 and 10.29%).

Comparing the six environments, the estimate of GCV was the highest under E1 for plant height (71.82%) and 1000-grain yield (15.58%), under E2 for grains/plant (22.51%) and days to flowering (17.99%) and under E4 for grain yield/plant (22.78%). On the contrary, the lowest estimate of GCV was exhibited under E3 for grain yield/plant, grains/plant and days to flowering (0.0, 0.0 and 5.36%, respectively, under E1 for (0.36%), E4 for plant height (32.26%) and E5 for 1000-grain weight (0.0%).

Recorded high estimates of PCV and GCV in grain sorghum in this study for grain yield and plant height means that there are good opportunities to get success in improvement of these traits *via* selection procedures. Al-Naggar et al. [2-8] reported similar conclusion.

3.5 Heritability and Genetic Advance

Estimates of phenotypic (δ^2_p), genetic (δ^2_g), environmental (δ^2_e), and genotype × environment (δ^2_{ge}) variances of grain sorghum under conditions of the six environments are presented in Table 8. The highest contributor to phenotypic variance (δ^2_p) was the genotypic variance (δ^2_g) for all studied traits under each and across environments, except for grain yield/plant under E3 and 1000-grain weight under E5 and E6, where environmental error (δ^2_e) was the highest contributor.

For the combined analysis, the second contributor to δ^2_{ph} was genotype × environment (δ^2_{ge}) for all traits, except for 1000-grain weight, where environmental error (δ^2_e) was the second highest contributor.

Comparing the six environments, the estimate of δ^2_g was the highest under E2 for DTF and, under E4 for grains/plant and grain yield/plant, under E6 for plant height and E1 for 1000-grain weight. On the contrary, the lowest estimate of δ^2_g was exhibited under E3 for grains/plant and days to flowering, E5 for plant height and 1000-grain weight and E1 for grain yield/plant.

Table 7. Phenotypic (PCV) and genotypic (GCV) coefficients of variation

Environment	Parameter	DTF	PH	GPP	TGW	GYPP
E1	**PCV**	7.06	78.07	21.88	23.15	50.80
	GCV	5.76	71.82	11.90	15.28	38.54
E2	**PCV**	19.95	83.86	31.44	21.37	66.27
	GCV	17.99	69.30	22.51	13.08	59.14
E3	**PCV**	7.72	52.27	37.71	15.94	66.57
	GCV	5.36	43.30	0.00	8.93	47.93
E4	**PCV**	8.86	41.92	30.79	13.09	79.59
	GCV	5.94	32.36	22.78	6.27	65.98
E5	**PCV**	6.99	36.90	18.21	3.39	35.79
	GCV	6.04	34.89	13.44	0.00	32.49
E6	**PCV**	9.32	85.66	18.91	7.43	60.76
	GCV	6.73	66.85	12.18	0.00	38.51
Combined	**PCV**	18.53	95.18	33.61	33.36	36.42
	GCV	10.29	43.57	23.57	17.23	30.78

DTF=days to flowering, PH=plant height, GPP=grains/plant, TGW= 1000-grain weight, GYPP=grain yield/plant

Table 8. Phenotypic (δ^2_{ph}), genotypic (δ^2_g), environmental (δ^2_e) and genotype x environment (δ^2_{ge}) variance, heritability (h^2_b) and genetic advance (GA %)

Parameter	E1	E2	E3	E4	E5	E6	Combined
Day to 50% flowering							
δ^2_g	3.62	11.6	3.40	4.23	4.35	4.44	11.02
δ^2_e	0.82	1.27	1.50	2.09	0.68	1.71	1.35
δ^2_{ge}	--	--	--	--	--	--	6.87
δ^2_{ph}	4.44	12.87	4.90	6.32	5.03	6.15	12.37
h^2_b	81.61	90.16	69.41	67.00	86.49	72.15	89.08
GA%	4.81	8.83	4.26	4.16	4.74	4.77	8.26
Plant height							
δ^2_g	70.38	76.94	51.9	40.19	40.05	85.32	214.00
δ^2_e	6.12	16.17	10.75	11.88	2.31	24.00	11.87
δ^2_{ge}	--	--	--	--	--	--	50.36
δ^2_{ph}	76.50	93.11	62.65	52.07	42.36	109.32	225.6
h^2_b	92.00	82.63	82.84	77.19	94.56	78.05	94.74
GA%	14.45	12.64	9.63	7.89	9.43	11.25	21.67
Grains/plant							
δ^2_g	18296	39186	0.0	41219	33259	19665	36391
δ^2_e	15358	15552	78786	14487	11784	10853	25303
δ^2_{ge}	--	--	--	--	--	--	31631
δ^2_{ph}	33653.9	54737	63444	55707	45044	30519	61694
h^2_b	54.4	71.6	0.0	74.0	73.8	64.4	58.99
GA%	11.4	16.9	0.0	17.0	11.1	12.3	14.05
1000-Grain weight							
δ^2_g	3.96	3.49	2.14	1.59	0.00	0.0	7.72
δ^2_e	2.04	2.21	1.68	1.73	0.85	2.80	1.88
δ^2_{ge}	--	--	--	--	--	--	1.00
δ^2_{ph}	5.99	5.70	3.82	3.32	0.85	2.34	9.61
h^2_b	66.03	61.22	56.05	47.94	0.00	0.0	80.40
GA%	10.99	9.64	8.04	6.06	0.00	0.0	16.62
Grain yield/plant							
δ^2_g	15.2	26.87	17.98	29.94	19.81	19.24	39.75
δ^2_e	4.84	3.24	6.99	6.18	2.01	11.12	5.73
δ^2_{ge}	--	--	--	--	--	--	29.77
δ^2_{ph}	20.04	30.12	24.97	36.11	21.82	30.36	45.48
h^2_b	75.86	89.24	72.00	82.90	90.79	63.38	87.39
GA%	15.15	18.97	16.88	19.33	12.24	12.30	22.02

Negative estimate was considered zero

The estimate of δ^2_{ph} was the highest under E2 for days to flowering, under E6 for plant height, E1 for 1000-grain weight, E3 for grains/plant and E4 for grain yield/plant. On the contrary, the lowest estimate of δ^2_{ph} was exhibited under E1 for days to flowering, under E4 for plant height, E5 for 1000-grain weight and E6 for grains/plant.

The highest estimate of heritability in broad sense (h^2_b) was shown for grain yield/plant (90.79%) and plant height (94.56%) under E5, 1000-grain weight under E1, DTF, and grains/plant under E4. On the contrary, the lowest estimate of h^2_b was exhibited under E4 for DTF and PH, E3 for GPP, E5 and E6 for 1000-grain weight and E6 for grain yield/plant.

The estimate of genetic advance from selection (GA) was the highest under E1 for plant height and grain yield/plant, under E4 for grains/plant and grain yield/plant and E2 for days to flowering. On the contrary, the lowest estimate of GA was exhibited under E4 for DTF and PH, E3 for grains/plant, E5 and E6 for 1000-grain weight, E5 for grain yield/plant.

Combined across environments, the highest heritability in broad sense (h^2_b) was expressed by (95.27%) followed by plant height (94.74%), but the lowest h^2_b was exhibited by grains/plant (58.99%). The highest expected genetic advance from selection of the best 10% (GA %) was shown by grain yield/plant (22.02%) followed by plant height (21.67%), but the lowest GA was exhibited by (0.70%) followed by days to flowering (8.26%). Grain yield/plant and plant height traits in this study indicated high heritability associated with high genetic advance from selection, indicating that the type of gene action dominated in the inheritance of these two traits is additive, which means that there are good opportunities to get success in improvement of these traits *via* selection procedures. Al-Naggar et al. [38-40] reported similar conclusion.

It is observed that, the two environments E2 and E4 showed the highest expected genetic advance from selection for grain yield (18.97 and 19.33%, respectively), while the lowest GA was shown by the two environments E5 and E6 (12.24 and 12.30%, respectively), indicating that Giza location (2nd planting date) was better environment than Shandaweel location in getting higher gain from selection. The soil in Giza is less fertile than Shandaweel, which was reflected in higher productivity in Shandaweel than Giza. The higher GA in Giza than Shandaweel could confirm the opinion of some investigators [38-44] that heritability and genetic advance is higher under stressed than non-stressed environment.

Results concluded that plant height is good selection criterion for grain yield/plant and, therefore, selection for tall plants would increase grain yield. Several investigators [28-32] reported a similar conclusion.

4. CONCLUSION

The results concluded that the grain sorghum B-line BTX TSC-20 followed by ICSB-88003, ICSB-1808, ICSB-14 and ICSB-1 showed the highest grain yield per plant (GYPP). These lines had also the highest number of grains per plant in the same order and could, therefore, be used in future breeding programs. Across environments, GYPP showed positive and significant correlations with number of grains/plant, days to flowering, 1000-grain weight and plant height (PH). A significant variability was observed among sorghum lines for all studied traits in all environments. The highest PCV and GCV was shown by plant height trait followed by grain yield/plant, indicating that selection for high values of these traits of sorghum would be effective. GYPP and PH traits showed high heritability associated with high genetic advance from selection, indicating that the type of gene action dominated in the inheritance of these two traits is additive, which means that there are good opportunities to get success in improvement of these traits *via* selection procedures. Results concluded that PH is good selection criterion for GYPP and, therefore, selection for tall sorghum plants would increase grain yield.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. FAOSTAT. Food and agriculture organization of the United Nations. Statistics Division; 2017.
   (Accessed on 02/08/2017)
   Available:http://faostat3.fao.org/
2. Al-Naggar AMM, El-Nagouly OO, Abo-Zaid Zeinab SH. Genotypic differences in leaf free amino acids as osmoprotectants against drought stress in grain sorghum. Egypt. J. Plant Breed. 2002;6(1):85–98.
3. Al-Naggar AMM, El-Nagouly OO, Abo-Zaid Zeinab SH. Genetic behaviour of the compatible osmolytes free amino acids that contribute to drought tolerance in grain sorghum. Egypt. J. Plant Breed. 2002;6(1): 99–109.
4. Al-Naggar AMM, El-Nagouly OO, Abo-Zaid Zeinab SH. Differential responses of grain sorghum genotypes to water stress at different growth stages. Egypt. J. Plant Breed. 2002;6(1):111–124.
5. Al-Naggar AMM, El-Nagouly OO, Abo-Zaid Zeinab SH. Genetics of some grain sorghum traits under different water stress conditions. Egypt. J. Plant Breed. 2002; 6(1):125–141.
6. Al-Naggar AMM, El-Kadi DA, Abo–Zaid Zeinab SA. Genetic parameters of grain sorghum traits contributing to low–N tolerance. Egypt. J. Plant Breed. 2006; 10(2):79-102.
7. Al-Naggar AMM, El-Kadi DA, Abo–Zaid Zeinab SA. Inheritance of nitrogen use efficiency traits in grain sorghum under low-and high-N. Egypt. J. Plant Breed. 2007;11(3):181-206.
8. Al-Naggar AMM, El-Kadi DA, Abo–Zaid Zeinab SA. Genetic analysis of drought tolerance traits in grain sorghum. Egypt. J. Plant Breed. 2007;11(3):207-232.
9. Smalley MD, Fehr WR, Cianzio SR, Han F, Sebastian SA, Streit LG. Quantitative trait

loci for soybean seed yield in elite and plant introduction germ plasm. Crop Sci. 2004;44(2):436-442.

10. Nwangburuka CC, Denton OA. Heritability character association and genetic advance in six agronomic and yield related characters in leaf *Corchorus olitorius*. Int. J. Agric. Res. 2012;7(7):365-375.
11. Johnson HW, Robinson HF, Comstock HF. Estimates of genetic and environmental variability in soybean. Agron. J. 1955;47: 314-318.
12. Arunkumar B, Biradar BD, Salimath PM. Genetic variability and character association studies in rabi sorghum. Karnataka J. Agric. Sci. 2004;17(3):471-475.
13. Panse VG. Genetics of quantitative characters in relation to plant breeding. Indian J. Genet. Cyto. 1957;17:318-327.
14. Swarup V, Chagule DS. Studies on genetic variability in sorghum II. Correlation of some important quantitative characters for varietal selection. Indian. J. Gen. 1962;22: 37-40.
15. Flores GL, Ross WM, Maranville JW. Qualitative genetics of agronomic and nutritional traits in related grain sorghum random-mating populations 6 affected by selection. Crop Sci. 1986;26:49-494.
16. Elangovan M, Kiran Prabhu P, Chandra Sekara Reddy D, Saxena U, Vincent Reddy G. Tonapi VA. Genetic and environmental variability in sorghum (*Sorghum bicolor* (L) Moench) germ plasm collected from Rajasthan and Madhya Pradesh. Indian Journal of Plant Genetic Resources. 2013;26(1):19-24.
17. Seetharam K, Ganeshmurthy K. Characterization of sorghum genotypes for yield and other agronomic traits through genetic variability and diversity analysis. Electronic Journal of Plant Breeding. 2013; 4(1):1073-1079.
18. Grafius FE, Thomas RL, Barnard J. Effect of parental component complementation on yield and components of yield in barley. Crop Sci. 1976;16:673-677.
19. Johnson VA, Schmidit JW, Mekasha W. Comparison of yield components and agronomic characteristics of four winter wheat varieties differing in plant height. Agron. J. 1966;58:438-441.
20. Sharma H, Jain DK, Sharma V. Genetic variability and path coefficient analysis in sorghum. Indian J. Agric. Res. 2006;40(4): 310-312.
21. Binodh AK, Manivannan N, Varman PV. Character association and path analysis in sunflower. Madras Agric. J. 2008;95(7-12): 425-428.
22. Biradar BD, Parameshwarappa R, Patil SS, Parameshwargouda P. Inheritance of seed size in sorghum (*Sorghum bicolor* L. Moench). Crop Res. 1996;11(3):331-337.
23. Tah J, Roychowdhury R. Genetic variability study for yield and associated quantitative characters in mutant genotypes of *Dianthus caryophyllus* L. Int. J. Biosci. 2011;1(5):38-44.
24. Steel RGD, Torrie JH. Principles and procedures of statistics 2nd ed. McGraw-Hill Book Co. New York. 1980;663.
25. Hallauer AR, Carena MJ, Miranda JBF. Quantitative Genetics in Maize Breeding. Springer Science + Business Media, LLC 2010, New York, NY 10013, USA; 2010.
26. Singh P, Narayanan SS. Biometrical techniques in plant breeding. Kalayani Publishers, New Delhi, India; 2000.
27. Maiti R. Sorghum science. Science Publishers, Inc., Lebanon, NH, USA; 1996. [Provides comprehensive knowledge of all aspects of sorghum].
28. Jeyaprakash P, Ganapathy S, Pillai MA. Correlation and path analysis in sorghum [*Sorghum bicolor* (L.) Moench]. Ann. of Agric. Res. 1997;18(3):309-312.
29. Sunku SSK, Reddy MB, Reddy PRR. Character association and path analysis in grain sorghum (*Sorghum bicolor* (L.) Moench) vis-à-vis the sudan grass. Forage Res. 2002;28(1):42-45.
30. Umakanth AV, Madhusudhana R, Latha KM, Rafiq SM, Kiran VSS. Analysis of genetic variation and trait interrelationships in sorghum [*Sorghum bicolor* (L.) Moench]. Natl. J. Pl. Improv. 2004;6(2):104-107.
31. Rekha BC. Genetic studies on grain quality and productivity traits in Rabi sorghum. M. Sc. (Agri.) Thesis, Univ. Sci. Dharwad; 2006.
32. Mahajan RC, Wadikar PB, Pole S, Dhuppe, MV. Variability, correlation and path analysis studies in sorghum. Res. J. Agric. Sci. 2011;2(1):101-103.
33. Bello D, Kadams AM, Simon SY. Correlation and path coefficient analysis of grain yield and its components in sorghum. Niger. J. Trop. Agric. 2007;3:4-9.
34. Ezeaku IE, Mohammed SG. Character association and path analysis in grain sorghum. African J. Biotec. 2006;5(14): 1337-1340.

35. Warkad YN, Potdukhe NR, Dethe AM, Kahate PA, Kotgire RR. Genetic variability, heritability and genetic advance for quantitative traits in sorghum germ plasm. Agric. Sci. Digest. 2008;28(3):165-169.
36. Vijaya KN, Reddy CM, Reddy PV. Study on character association in rabi sorghum (*Sorghum biocolar* L. Moench). Intl. J. Agric. Sci. 2012;6(1):100-104.
37. Gedifew GM. Morphological Characterization of Sorghum [*Sorghum bicolor* (L.) Moench] Landraces in Benishangul Gumuz. Ph. D. Thesis, North-western Ethiopia; 2012.
38. Al-Naggar AMM, Sabry SRS, Atta MMM, Abd El-Aleem Ola M. Effect of salt stress in the field on performance, correlations, heritability and selection gain of wheat doubled haploids. International Journal of Plant & Soil Sci. 2015;8(1):1-14.
39. Al-Naggar AMM, Abdalla AMA, Gohar AMA, Hafez EHM. Heritability, genetic advance and correlations in 254 maize doubled haploid lines × tester crosses under drought conditions. Archives of Current Research International. 2016;6(1): 1-15.
40. Al-Naggar AMM, Abd El-Salam RM, Badran AEE, El-Moghazi Mai MA. Heritability and interrelationships for agronomic, physiological and yield traits of quinoa (*Chenopodium quinoa* Willd.) under elevated water stress. Archives of Current Research International. 2017;10(3):1-15.
41. Blum A. Plant breeding for stress environment. CRC Press Inc. Boca Raton. Florida; 1988.
42. Hefny MM. Estimation of quantitative genetic parameters for nitrogen use efficiency in maize under two nitrogen rates. Int. J. Pl. Breed. Genet. 2007;1:54-66.
43. Al-Naggar AMM, Shabana R, Al Khalil TH. Tolerance of 28 maize hybrids and populations to low-nitrogen. Egypt. J. Plant Breed. 2010;14(2):103-114.
44. Al-Naggar AMM, Shabana R, Mahmoud AA, Abdel El-Azeem MEM, Shaboon SAM. Recurrent selection for drought tolerance improves maize productivity under low-N condition. Egypt. J. Plant Breed. 2009;13: 53-70.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/24653