Original Research Article

Agronomic and yield characteristics of grain sorghum as influenced by environment factors and genotype

ABSTRACT

Genotypes tested in different locations, years or planting dates often change in yield due to the response of genotypes to environmental factors such as temperature, soil fertility etc. The objectives of the present study were to evaluate the effects of environment factors on agronomic and yield characteristics of grain sorghum and to identify the most adapted B-line(s) to different environments in Egypt. Six environments with 25 sorghum B-lines were conducted at two locations (Giza and Shandaweel) in 2012 and 2013 years and two planting dates in Giza location. A randomised complete block design was used in each environment with three replications. Mean squares due to genotype × environment were significant for all studied traits. Increasing temperature from second planting date to first planting date in Giza across seasons caused the significant decrease in grain yield per plant (GYPP) by about 15.3%. This reduction in yield was associated with significant decreases in the number of grains/plant (GPP) (9.29%), plant height (PH) (7.31%) and days to 50% flowering (DTF) (6.92%). Moreover, higher temperature in 2012 than 2013 season in Shandaweel caused significant ($p<0.01$) reduction in GYPP by 18.04%, GPP (34.76%) and DTF (8.33%). Though the temperature was higher in Shandaweel than Giza, the increase in GYPP in Shandaweel than Giza could probably due to the better physical and chemical properties of the soil. Across all environments, the B-line BTX-TSC-20 followed by ICSB-88003 showed the highest GYPP. BTX-TSC-20 followed by ICSB-1808 under E1 and E3 environments (Giza, first planting date in 2012 and 2013), ICSB-14 and ICSB-88003 under E2 and E4 (Giza, second planting date in 2012 and 2013), ICSB-11 followed by BTX 2-1 under E5 (Shandaweel, 2012 season) and ICSB-88003 followed by ICSB-70 under E6 (Shandaweel, 2013 season) were the most adapted B-lines.

Key words: *Sorghum bicolor*, Temperature, Soil fertility, G × E interaction

1. INTRODUCTION

Grain sorghum (*Sorghum bicolor* L. Moench) is one of the most important cereals in the world as well as in Egypt. The main producers of grain sorghum in the world are USA, India, Mexico, China, Nigeria, Argentina and Sudan. In 2014 season, the cultivated area of grain sorghum in Egypt was 148,456 ha, producing about 804,000 tons with an average productivity of 5.42 ton/ha [1]. Most of grain sorghum cultivated area in Egypt is concentrated in Assiut and Sohag governorates (Upper Egypt) instead of maize, where the atmospheric temperature during the growing season is high since grain sorghum is tolerant to high-temperature stress [2-6]. Egypt ranks first among all grain sorghum producers in the world for average productivity per unit area, followed by China and Argentina [1]. Grain sorghum is mainly consumed for making bread in Upper Egypt, for feeding livestock and poultry and for green fodder and silage. Sorghum grain has high nutritive value, with 70-80% carbohydrate, 11-13% protein, 2-5% fat, 1-3% fiber, and 1-2% ash. Protein in sorghum grain is gluten-free and, thus, it is a speciality food for people who suffer from celiac disease (intolerant to food with gluten), including diabetic patients.

The mean optimum temperature range for sorghum is 21 to 35°C for seed germination, 26 to 34°C for vegetative growth and development, and 25 to 28°C for reproductive growth [7]. Recent synthesis and analyses of data on past and future climates suggest that, at the present rates of greenhouse gas emissions and population growth, the global mean surface temperatures will increase by 1.4 to 5.8°C [8]. In addition, we will experience greater climate variability characterized by increased frequency of short episodes of extreme temperatures events, including short periods of temperature stress [8]. These changes could have a significant influence on the productivity of grain crops, including sorghum. Sorghum-producing regions often experience daytime/night-time temperatures of >32/22°C [9]. High-temperature stress can cause significant decreases in sorghum grain yields [9]. Dry matter and seed yields of grain sorghum were maximum at 27/22°C (daytime/nighttime temperature).

Temperatures above 33/28°C during early stages of panicle development induce floret and embryo abortion [10]. High temperatures also decrease seed-filling duration, resulting in smaller seed size and lower seed yields [11, 12]. In a recent study, season long (from emergence to maturity) effects of a range of high temperature (HT) >35/25°C on physiology, growth, and yield of grain sorghum hybrid DK-28E were quantified [9]. Their research suggested that there were no significant influences of season-long growth temperatures in the range of 36/26 to 44/34°C on leaf photosynthetic rates. However, HT (≥36/26°C) significantly decreased seed set, seed number, seed size, seed-filling duration, and seed yields when compared with optimum temperature (OT) (32/22°C).

Effects of short episodes of temperatures >33/28°C on phenology, growth, yield, and yield components of grain sorghum are not well understood and need to be researched further. A few studies [9, 10, 13-15] compared the effects of HT stress during the vegetative and reproductive development of grain sorghum and suggested that reproductive processes (e.g., panicle initiation, seed growth, and seed size) were more sensitive to HT than were vegetative methods (e.g., leaf appearance, photosynthesis). Most studies on sorghum have investigated season-long effects of HT stress from sowing to maturity or for the entire vegetative or reproductive phase. When plants are exposed to a season long or longer periods of HT, they have an opportunity to acclimate, and such responses would be different from that of short, sudden episodes of HT stress. In addition, comparison of stage sensitivity at various growth phases is often made from different experiments conducted at different locations.

High-temperature stress during flowering stage decreases seed-set percentage in sorghum [15], by reducing pollen production, pollen viability, and pollen germination [9, 15, 16]. High temperatures during flowering altered carbohydrate metabolism in the developing pollen grain [17]. High nighttime temperatures increased pollen ROS content and caused loss of pollen viability in sorghum [18].

Prasad *et al.* [19] reported that periods between 10 and 5 days before anthesis; and between 5 days before- and 5 days after-anthesis were most sensitive to high temperatures causing maximum decreases in floret fertility of grain sorghum. Mean daily temperatures >25°C quadratically decreased floret fertility (reaching 0% at 37°C) when imposed at the start of panicle emergence. Temperatures ranging from 25 to 37°C quadratically decreased individual grain weight when imposed at the start of grain filling. Both floret fertility and individual grain weights quadratically reduced with increasing duration (0–35 days or 49 days during floret development or grain filling stage, respectively) of high-temperature stress. In field conditions, an imposition of temperature stress (using heat tents) during floret development or grain filling stage also decreased floret fertility, individual grain weight, and grain weight per panicle.

Genotypes tested in different locations or years often changes in yield due to the response of genotypes to environmental factors such as soil fertility, temperature, the presence of pathogenic disease etc. [20]. These fluctuations are often referred to as genotype × environment interaction (G × E) and are common in many crops including grain sorghum [2-6, 21, 22]. The present study was conducted with the following objectives: (*i*) to evaluate the effects of environment factors (temperature and soil fertility) on agronomic and yield characteristics, (*ii*) to assess the variability among 25 grain sorghum B-lines in such traits and (*iii*) to identify the best adapted grain sorghum B-line(s) to the different environments in Egypt.

2. MATERIALS AND METHODS

The field work of this study was carried out at two locations, namely Giza (30^o 02` N latitude, $31^o$ 13` E longitude, with an altitude of 22.50 meter above sea level) and Shandaweel (26^o 33` N latitude, $31^o$ 41`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.

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 breeding material of this study. Designation, name and origin of these lines are presented in Table (1).

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

Genotype No.	Name	Origin	Genotype No.	Name	Origin
G1	ICSB -1	ICRISAT- India	G14	ICSB -88005	ICRISAT- India
G2	ICSB -11	ICRISAT- India	G15	ICSB -30	ICRISAT- India
G3	ICSB -14	ICRISAT- India	G16	ICSB-88010	ICRISAT- India
G4	ICSB -20	ICRISAT- India	G17	ICS B -88015	ICRISAT- India
G5	ICSB -37	ICRISAT- India	G18	ICSB -90001	ICRISAT- India
G6	ICSB -70	ICRISAT- India	G19	ICSB -91003	ICRISAT- India
G7	ICSB -102	ICRISAT- India	G20	BTX 2-1	Texas- USA
G8	ICSB -122	ICRISAT- India	G21	BTX -407	Texas- USA
G9	ICSB -155	ICRISAT- India	G22	BTX -409	Texas- USA
G10	ICSB -1808	ICRISAT- India	G23	BTX -630	Texas- USA
G11	ICSB -88001	ICRISAT- India	G24	BTX -631	Texas- USA
G12	ICSB -88003	ICRISAT- India	G25	BTX TSC-20	Texas- USA
G13	ICSB -88004	ICRISAT- India			

Source: Grain sorghum Res. Department, Field Crops Res. Institute, Agric. Res. Center, Egypt.

Experimental procedures

Six field experiments represent 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).

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

Environ-ment	Location	Latitude	Longitude	Altitude	Planting date

E1	Giza	30^o 02` N	31^o 13`E	22.5 masl	1/6/2012
E2	Giza	30^o 02` N	31^o 13`E	22.5 masl	1/7/2012
E3	Giza	30^o 02` N	31^o 13`E	22.5 masl	1/6/2013
E4	Giza	30^o 02` N	31^o 13`E	22.5 masl	1/7/2013
E5	Shandaweel	26^o 33` N	31^o 41`E	67.0 masl	1/7/2012
E6	Shandaweel	26^o 33` N	31^o 41`E	67.0 masl	1/7/2013

masl = meter above sea level.

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.

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			

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.

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 Potasium 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.

Data recorded on B-lines:

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.

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.

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 [23].

3. RESULTS AND DISCUSSION

3.1. Analysis of variance

Combined analysis of variance for five studied traits of 25 grain sorghum B-lines 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 ($p<0.01$) 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.

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 Flowering	Plant height	Grains /plant	1000- Grain weight	Grain yield/ plant
Environment(E)	5	1231.0**	8751.19**	12003136**	528.08**	7222.2**
Genotype (G)	24	94.8**	1504.62**	465060**	60.63**	362.2**
G × E	120	28.7**	222.28**	246713**	14.29*	123.7**

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

Mean squares due to genotypes were significant ($p<0.01$) 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 ($p<0.01$) 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 [2-6, 24].

3.2. Effect of environment

The mean optimum temperature range for sorghum is 21 to 35°C for seed germination, 26 to 34°C for vegetative growth and development, and 25 to 28°C for reproductive growth [7]. The six environments under study differed significantly for all studied traits (Table 5). The environment E1 (Giza, 1st planting date, 2012 season) had a minimum and maximum temperature of 23.5 and 36.9°C at germination and seedling stage, 24.8 and 37.6 °C for vegetative and development, 22.1 and 34.9 °C for reproductive growth, respectively. The minimum and maximum temperature for the three stages respectively were (24.8- 37.6 °C), (24.8- 37.6 °C) and (20,6- 33.0 °C) for E2 (Giza, 2nd planting date, 2012 season), (22,4- 36.0 °C), (23.7- 37.2 °C) and (21.9-34.8 °C) for E3 (Giza, 1st planting date, 2013 season), (22.4- 35.2 °C), (21.9-34.8 °C) and (17.3- 30.1 °C) for E4 (Giza, 2nd planting date, 2013 season), (27.6-42.3 °C), (23.8- 38.8°C) and (21.2-36.5°C) for E5 (Shandaweel, 2nd planting date, 2012), (26.2- 42.3 °C), (24.0-39.2°C) and (17.9-33.9°C) 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 soil was better in Shandaweel than in Giza and was better in Shandaweel 2013 than 2012 season.

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

Table 5. Basic statistics of six 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.	29.5	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	

It is observed from Table (6) that increasing temperature from 2nd planting date to 1st planting date in Giza across seasons caused significant ($p< 0.01$) decrease in grain yield per plant by about 15.3%. This reduction in yield was associated with significant ($p< 0.05$) reduction in number of grains/plant (9.29%), plant height (7.31%) and number of days to 50% flowering (6.92%). Moreover, increasing temperature in Shandaweel from 2013 to 2012 season (from E6 to E5) caused significant ($p<0.01$) decrease in grain yield per plant by 18.04% (Table 6). The reduction in grain yield in Shandaweel by increasing the temperature was associated by a significant reduction ($p<0.01$) in number of grains/plant (34.76%) and in number of days to 50% flowering (8.33%), but by a significant increase in plant height (11.41%) and thousand grain weight (26.17%).

Table (6). Reduction (%) in studied traits due to increase in temperature from 2nd planting date to 1st planting date in Giza across seasons and from E6 (season 2013) to E5 (season 2012) in Shandaweel.

Trait	Giza	Giza	%	E5	E6	% Reduction

	2nd date	1st date	Reduction	(Shand. 2012)	(Shand. 2013)	
Days to 50% flowering	67.9	63.2	6.92*	72	66	8.33*
Plant height (cm)	117.6	109	7.31*	114.8	127.9	-11.41*
Grains/plant	1775.3	1610.3	9.29*	2474	1614	34.76**
1000-Grain weight (g)	26.02	24.92	4.23	24.95	31.48	-26.17**
Grain yield/plant (g)	45.41	38.47	15.28**	60.96	49.97	18.04**

High-temperature stress can cause significant decreases in sorghum grain yields [9]. Dry matter and seed yields of grain sorghum were maximum at 27/22°C (daytime/nighttime temperature). Temperatures above 33/28°C during early stages of panicle development induce floret and embryo abortion [10]. High temperatures also decreases seed-filling duration, resulting in smaller seed size and lower seed yields [11, 12].

Effects of short episodes of temperatures >33/28°C on phenology, growth, yield, and yield components of grain sorghum are not well understood and need to be researched further. A few studies [9, 10, 13-15] compared the effects of HT stress during vegetative and reproductive development of grain sorghum and suggested that reproductive processes (e.g., panicle initiation, seed growth, and seed size) were more sensitive to HT than were vegetative processes (e.g., leaf appearance, photosynthesis).

High temperature stress causes an array of physiological and biochemical changes in plants that affect plant growth and development, leading eventually to lower grain yield. The adverse effects of HT stress can be mitigated by developing crop plants with improved HT tolerance using various genetic approaches [25]. Identifying the physiological basis of tolerance or susceptibility will hasten this process. Changes in the growth temperature influence leaf photosynthesis, dry matter accumulation, reproductive processes, and yield of plants. High nighttime temperatures decreased photosynthetic rate and increased membrane damage and reactive oxygen species production in grain sorghum [18].

In the present study, though the temperature was generally higher in Shandaweel than Giza location in both seasons (2012 and 2013), the grain yield per plant across seasons was significantly ($p < 0.01$) higher in Shandaweel than Giza by 22.24 and 26.42%, respectively (Table 7). This increase of grain yield in Shandaweel than Giza was associated with significant increase in number of grains/plant (15.15%) and 1000-grain weight (8.46%).

Table (7). Increase (%) in studied traits from Giza (average of E2 and E4) to Shandaweel (average of E5 and E6) in the same planting date (1st July).

Trait	Giza (E2 & E4)	Shandaweel (E5 & E6)	% Increase
Days to 50% flowering	67.9	69.0	1.62
Plant height (cm)	117.6	121.3	3.15
Grains/plant	1775.3	2044	15.15**
1000-Grain weight (g)	26.02	28.22	8.46*
Grain yield/plant (g)	45.41	55.50	22.24**

The increase in grain yield and its components in Shandaweel than Giza could probably be attributed to the better physical and chemical properties of the soil in Shandaweel than Giza (Table 3). The soil of Shandaweel is more fertile than Giza. Comparison of sorghum heat sensitivity from different experiments may often be confounded by variety, soil type, irrigation water quality and environment [15]. Yield variability of grain crops is often related to environmental conditions during the most sensitive stages of crop development [16].

3. 3. Effect of sorghum genotype

Means of studied traits of 25 B-lines of sorghum across the six environments (E1 through E6) are presented in Tables (8 through 10) and Figures (1 through 5). It is obvious that there were significant differences among B-lines for all studied traits. The difference between the highest and lowest value, considered as a range, could express the variability among the studied B-lines).

Across all environments, the earliest B-line in flowering was G7 (ICSB-102) (61.1 days), while the latest one was G16 (ICSB-88010) (70.9 days) (Fig. 1 and Table 8). Plant height ranged from 140.8 cm for G3 (ICSB-14) to 96.5 cm for G9 (ICSB-155) (Fig. 2 and Table 9).

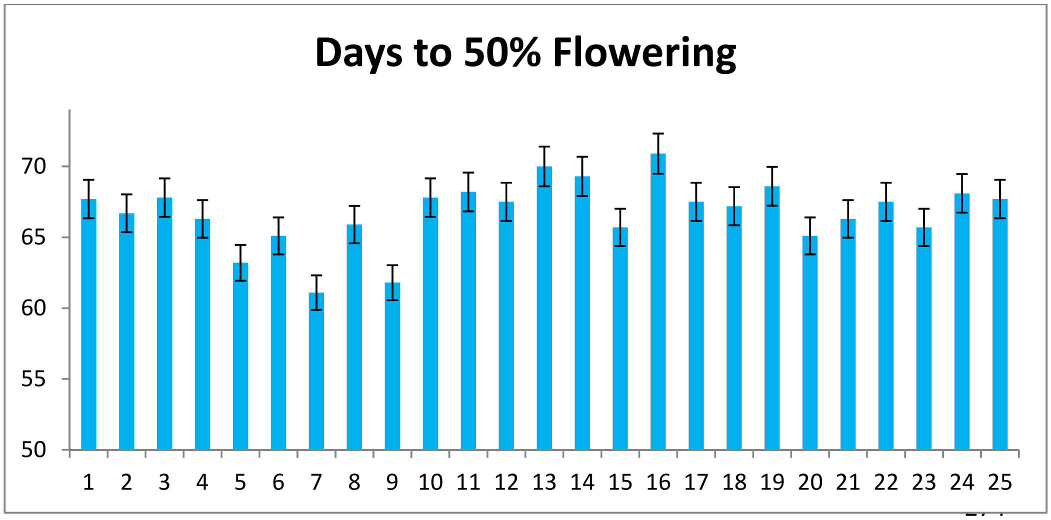

Figure 1. Mean number of days to 50% flowering of sorghum genotypes (from No. 1 to No. 25) across all the six environments.

Mean number of grains/plant across all environments ranged from 1605 to 2256 (Fig. 3). The B-line BTX TSC-20 (G25) followed by ICSB-88003 (G12) and ICSB-1808 (G10) showed the highest number of grains/plant; these lines had also the highest grain yield per plant in the same order. On the contrary, the line ICSB-102 (G7) showed the lowest number of grains/plant.

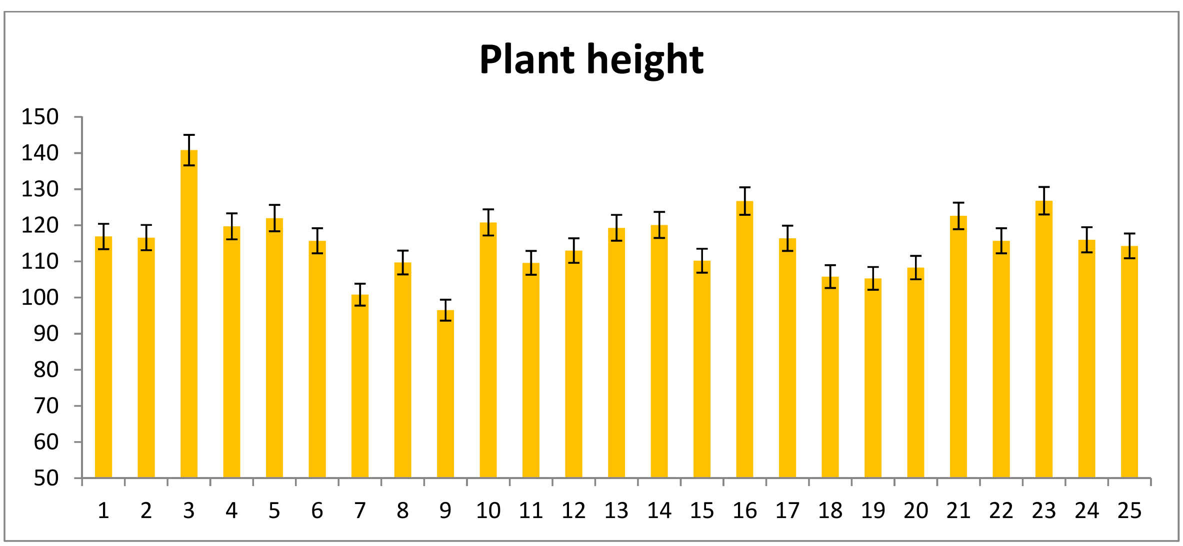

Figure 2. Mean plant height (cm) of sorghum genotypes (from No. 1 to No. 25) across all the six environments.

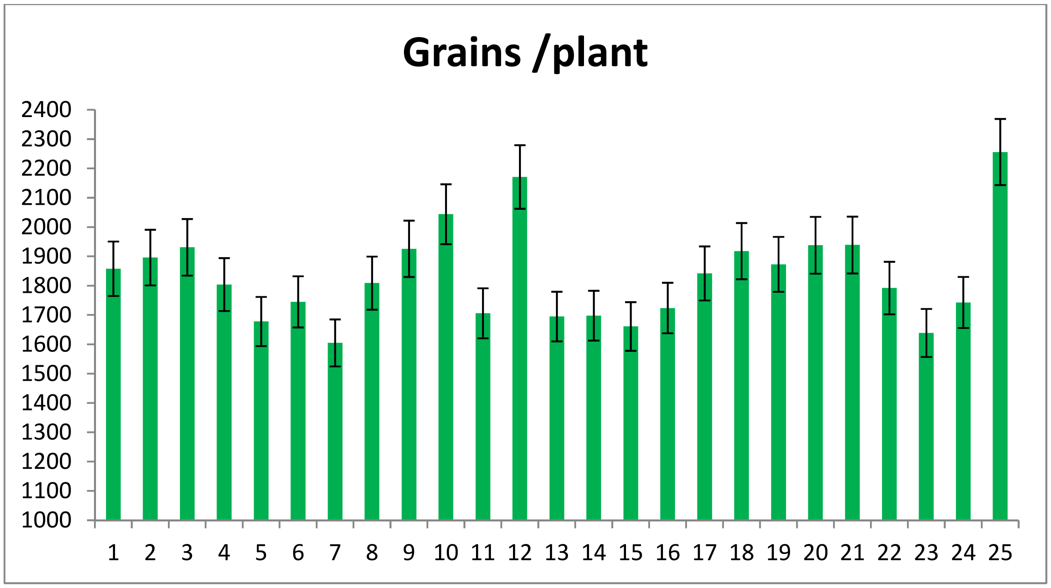

Figure 3. Mean number of grains/plant of sorghum genotypes (from No. 1 to No. 25) across all the six environments.

Mean weight of 1000 kernels (Fig. 4) ranged from 29.36 to 23.51 g across all environments under study. The heaviest kernel was exhibited by the B-line ICSB-88005 (G14), followed by BTX-631 (G24) and ICSB-88003 (G12). The line BTX-631 (G24) that occupied the second place in kernel weight occupied the first place with regard of grain yield per plant and per feddan. In contrast, the B-line BTX 2-1 (G20) exhibited the lightest kernel weight.

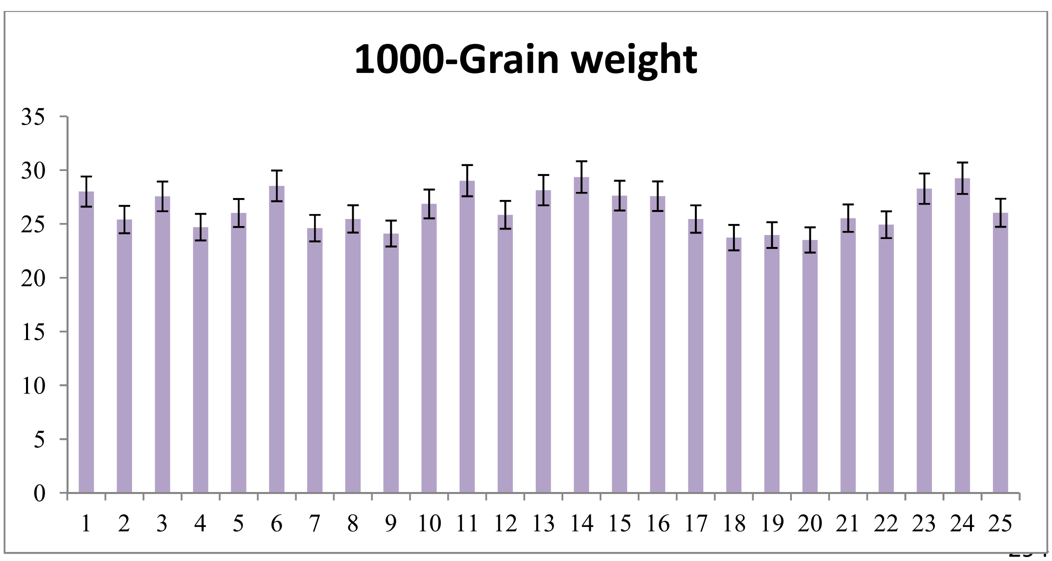

Figure 4. Mean 1000-grain weight (g) of sorghum genotypes (from No. 1 to No. 25) across all the six environments.

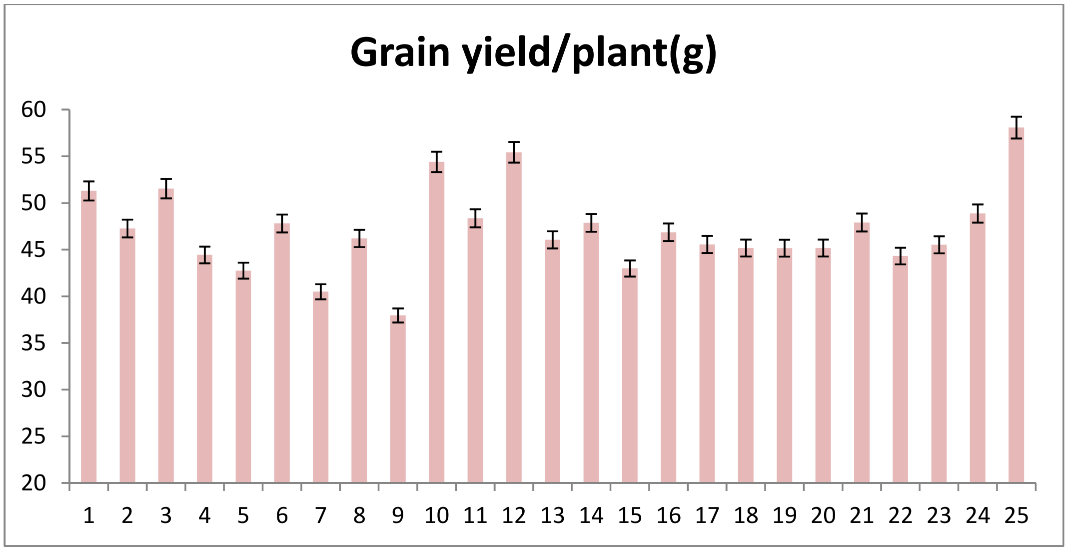

Figure 5. Mean grain yield/plant (g) of sorghum genotypes (from No. 1 to No. 25) across all the six environments.

Across all environments, the highest grain yield per plant (58.08 g) was shown by the B-line BTX TSC-20 (G25) followed by ICSB-88003 (G12) (55.43g), ICSB-1808 (G10) (54.40g), ICSB-14 (G3) (51.54g) and ICSB-1 (G1) (51.30 g), respectively (Fig. 5 and Table 10). On the contrary, across all environments, the B-line ICSB-155 (G9) showed the lowest grain yield per plant (37.96 g).

3. 4. Effect of genotype × environment interaction

Variances due to genotype x environment interaction were significant ($p< 0.01$ or 0.05) for all studied traits of grain sorghum (Table 4). For days to flowering, the earliest B-line (54.7 days) was recorded by ICSB-02 under E2 environment (Giza, 2nd planting date, 2012 season), while the latest B-line (78.3 days) was recorded by BTX-630 under E5 environment (Shandaweel, 2nd planting date, 2012 season), with a significant ($p< 0.01$) difference of 23.6 days between them (Table 8).

Table 8. Mean number of days to 50% flowering of 25-grain sorghum B-lines under each of the six environments (E1 to E6).

Line No.	B-line Name	Environments E1	E2	E3	E4	E5	E6	Average
1	**ICSB -1**	63.7	62.3	67.7	75.0	73.7	64.0	67.7
2	**ICSB -11**	63.3	64.7	64.3	69.7	72.0	66.0	66.7
3	**ICSB -14**	60.7	63.7	62.3	73.0	72.3	74.7	67.8
4	**ICSB -20**	63.3	65.0	65.3	66.7	73.0	64.3	66.3
5	**ICSB -37**	58.7	59.0	60.3	73.7	62.3	65.0	63.2
6	**ICSB -70**	61.0	64.0	60.0	70.3	69.7	65.7	65.1
7	**ICSB -02**	56.3	54.7	55.3	66.3	70.7	63.0	61.1

8	**ICSB -22**	61.7	69.7	63.7	66.3	71.7	62.3	65.9
9	**ICSB -55**	58.7	55.3	55.7	65.0	74.7	61.3	61.8
10	**ICSB-1808**	61.7	65.7	61.0	75.3	71.7	71.7	67.8
11	**ICSB -88001**	62.0	62.7	65.7	75.7	74.3	69.0	68.2
12	**ICSB -88003**	63.7	67.0	63.3	72.3	76.7	62.0	67.5
13	**ICSB -88004**	66.0	72.3	67.0	77.0	72.0	65.7	70.0
14	**ICSB -88005**	67.3	69.3	67.7	73.3	71.7	66.3	69.3
15	**ICSB -30**	62.7	63.7	63.7	67.0	76.3	60.7	65.7
16	**ICSB-88010**	70.3	74.7	64.3	74.0	73.0	69.0	70.9
17	**ICS B-8015**	62.0	66.0	65.0	73.0	71.3	67.7	67.5
18	**ICSB -90001**	63.0	65.3	63.3	69.7	71.7	70.3	67.2
19	**ICSB -91003**	67.0	60.7	67.0	76.0	71.7	69.3	68.6
20	**BTX 2-1**	62.7	64.0	63.0	71.7	66.0	63.0	65.1
21	**BTX -407**	62.0	64.7	63.0	71.7	72.3	64.3	66.3
22	**BTX -409**	64.0	64.7	63.7	73.0	74.7	65.0	67.5
23	**BTX -630**	63.3	55.3	64.7	65.3	78.3	67.0	65.7
24	**BTX -631**	66.7	64.7	65.0	70.0	72.3	69.7	68.1
25	**BTX TSC-20**	61.7	73.0	65.0	71.7	72.3	62.3	67.7
	Average	62.9	64.5	63.5	71.3	72.3	66.0	66.7
	LSD 0.05	3.6	4.5	4.6	5.8	3.3	5.3	4.6
	LSD 0.01	4.9	6.0	6.6	7.7	4.4	7.0	6.1

For plant height (Table 9), the shortest plant in this experiment (67.3 cm) was shown by the B-line ICSB-155 under E1 (Giza, 1st planting date, 2012 season), followed by ICSB-122 under E2 (Giza, 2nd planting date, 2012 season) (82.7 cm) and ICSB-91003 under E1 (86.3 cm). On the contrary, the tallest plant (165 cm) was shown by the B-line ICSB-14 under E6 environment (Shandaweel, 2nd season). The significant ($p < 0.01$) difference in plant height between the shortest and the tallest B-lines was 97.7 cm.

Table 9. Mean plant height (cm) of 25-grain sorghum B-lines under each of the six environments (E1 to E6).

Line No.	**B-line Name**	**Environment E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**Average**
1	**ICSB -1**	101.0	109.0	123.7	123.7	112.7	131.7	116.9
2	**ICSB -11**	95.0	120.0	117.3	117.3	116.7	133.3	116.6
3	**ICSB -14**	121.0	137.7	151.3	150.0	120.0	165.0	140.8
4	**ICSB -20**	108.7	115.3	116.3	127.3	107.3	143.3	119.7
5	**ICSB -37**	105.0	124.0	121.0	123.7	130.0	128.3	122.0
6	**ICSB -70**	97.3	103.7	121.0	124.0	105.0	143.3	115.7
7	**ICSB -102**	71.7	86.7	103.7	117.7	120.0	105.0	100.8
8	**ICSB -122**	91.0	82.7	122.0	105.0	127.3	130.0	109.7
9	**ICSB -155**	67.3	95.0	95.0	102.7	107.3	111.7	96.5
10	**ICSB -1808**	110.7	117.3	134.3	127.3	112.0	123.3	120.8
11	**ICSB -88001**	93.0	96.7	116.3	126.3	106.7	118.3	109.6
12	**ICSB -88003**	85.3	103.0	122.0	136.0	106.7	125.0	113.0
13	**ICSB -88004**	102.7	122.7	121.3	124.3	120.0	125.0	119.3
14	**ICSB -88005**	94.0	120.0	119.0	133.3	122.3	131.7	120.1
15	**ICSB -30**	95.0	94.3	114.7	117.0	118.3	121.7	110.2
16	**ICSB-88010**	118.0	124.0	132.0	129.3	105.0	151.7	126.7
17	**ICS B -88015**	105.7	106.0	123.7	129.7	106.7	126.7	116.4
18	**ICSB -90001**	89.3	115.0	106.0	119.3	101.7	103.3	105.8
19	**ICSB -91003**	86.3	122.0	109.3	107.3	105.0	101.7	105.3
20	**BTX 2-1**	100.3	104.3	111.7	118.0	102.3	113.3	108.3
21	**BTX -407**	108.3	116.0	127.3	134.0	106.7	143.3	122.6
22	**BTX -409**	97.0	106.3	123.7	123.3	117.3	126.7	115.7

23	**BTX -630**	105.7	134.3	133.7	133.7	121.7	131.7	126.8
24	**BTX -631**	96.0	108.0	116.3	126.7	122.3	126.7	116.0
25	**BTX TSC-20**	104.3	111.7	114.0	128.3	92.3	135.0	114.3
	Average	98.0	111.0	119.9	124.2	112.5	127.9	115.6
	LSD 0.05	10.0	16.2	13.2	13.9	6.1	19.7	13.7
	LSD 0.01	13.3	21.6	17.6	18.5	8.2	26.3	18.0

For number of grains per plant (data not presented), the lowest number in this experiment (1023.4) was shown by the B-line ICSB-155 under E1 (Giza, 1st planting date, 2012 season), followed by ICSB-102 under E1 (1195.3). On the contrary, the highest number of grains/plant (3232.7) was shown by the B-line BTX 2-1 under E5 environment (Shandaweel, 1st season) followed by ICSB-11 (3134.0) under E5 and ICSB-88004 (3029.7) under E5. The significant ($p< 0.01$) difference in number of grains/plant between the highest and the lowest B-lines in grains/plant was 2209.3 grain; the number of grains of BTX 2-1 under E5 was 3.2 fold greater than number of grains of ICSB-155 under E1.

For 1000-grain weight (data not presented), the heaviest weight in this experiment (35.07 g) was shown by the B-line ICSB-88010 under E6 (Shandaweel, 2013 season), followed by ICSB-1 under E6 (34.93 g) and ICSB-37 under E6 (34.67). On the contrary, the lightest weight of 1000 grains (18.00 g) in this experiment was shown by the B-line ICSB-90001 under E3 environment (Giza, 1st planning date, 2013 season) followed by BTX 2-1 (19.50 g) under E1 (Giza, 1st planning date, 2012 season). The significant ($p< 0.01$) difference in 1000-grain weight between the heaviest and the lightest B-lines was 17.07 g.

Grain sorghum B-lines ranked differently for mean grain yield/plant from environment to another environment, due to the significant interaction variance between genotype and environment. The highest grain yield/plant in this experiment (79.0 g) was recorded by the B-line ICSB-11 (G2) under E5 (Shanaweel, 2012 season), followed by BTX 2-1 (G20) (75.67 g), BTX-409 (G22) (72.0 g) and ICSB-88004 (G13) (71.67 g) all under E5 (Table 10). In contrast, the lowest grain yield/plant (23.37 g) was shown by the B-line ICSB-155 under E1 (Giza, 1st planting date and 2012 season). The difference between the highest and lowest B-lines for grain yield/plant in the whole experiment was 35.63 g; the grain yield/plant of the highest yielding line was 3.38 fold greater than that of the lowest yielding line.

Table 10. Mean grain yield/plant (g) of 25-grain sorghum B-lines under each of the six environments (E1 to E6).

Line number	B-line Name	Environments						Average
		E1	E2	E3	E4	E5	E6	

1	**ICSB -1**	43.03	54.83	41.53	54.07	58.00	56.33	51.30
2	**ICSB -11**	38.30	39.60	36.87	38.97	79.00	50.87	47.27
3	**ICSB -14**	43.33	63.00	43.10	64.17	59.33	36.33	51.54
4	**ICSB -20**	44.83	39.10	37.37	35.00	61.00	49.33	44.44
5	**ICSB -37**	36.63	44.23	32.53	44.10	50.00	49.00	42.75
6	**ICSB -70**	45.67	43.97	38.93	42.87	52.67	62.73	47.81
7	**ICSB -102**	29.50	37.47	26.80	36.70	60.00	52.53	40.50
8	**ICSB -122**	36.80	39.17	36.40	37.90	68.00	59.00	46.21
9	**ICSB -155**	23.37	38.10	18.77	36.77	67.67	43.07	37.96
10	**ICSB -1808**	48.03	55.73	48.70	57.87	70.00	46.07	54.40
11	**ICSB -88001**	39.33	46.93	38.57	45.37	67.00	53.00	48.37
12	**ICSB -88003**	40.67	63.37	39.73	64.67	57.67	66.47	55.43
13	**ICSB -88004**	41.13	39.33	39.27	38.90	71.67	46.07	46.06
14	**ICSB -88005**	42.20	46.33	41.67	49.67	62.00	45.33	47.87
15	**ICSB -30**	36.57	41.00	36.70	39.90	67.33	36.47	42.99
16	**ICSB-88010**	42.33	38.03	41.67	44.57	68.33	46.27	46.87
17	**ICS B -88015**	38.43	40.83	35.90	38.97	65.33	53.87	45.56
18	**ICSB -90001**	37.50	43.00	37.33	42.03	65.00	46.20	45.18
19	**ICSB -91003**	33.23	44.77	28.67	46.63	62.67	55.00	45.16
20	**BTX 2-1**	31.47	49.33	29.90	48.67	75.67	36.07	45.18
21	**BTX -407**	39.20	47.33	37.67	47.50	66.67	49.13	47.92
22	**BTX -409**	37.33	38.07	37.13	37.17	72.00	44.20	44.32
23	**BTX -630**	40.70	39.00	38.57	38.37	65.00	51.53	45.53
24	**BTX -631**	40.27	46.67	37.57	46.50	62.67	59.60	48.88
25	**BTX TSC-20**	56.07	56.77	56.13	57.07	67.67	54.80	58.08
	Average	39.44	45.44	37.50	45.37	64.89	49.97	47.10
	LSD 0.05	8.84	7.24	10.63	9.99	5.7	13.41	9.78
	LSD 0.01	11.79	9.66	14.18	13.33	10.6	17.89	12.89

It is worthy to note that the B-lines ICSB-11 (G2), BTX 2-1 (G20) and ICSB-88004 (G13) were the highest in number of grains/plant, grain yield/plant under E5 (Shandaweel, 2nd planting date, 2012 season). On the contrary, the B-line ICSB-155 (G9) was the lowest in the same traits (GPP and GYPP) as well as the shortest in plant height. The significant interaction of genotype x environment in grain sorghum was previously reported by several investigators [2-6, 22, 24, 26].

The most adapted B-line (expressed in GYPP) was G25 (BTX TSC-20) followed by G10 (ICSB -1808) under the two environments E1 and E3 (Giza, 1st planting date in 2012 and 2013). Under E2 and E4 (Giza, 2nd planting date in 2012 and 2013), the most adapted B-lines were G3 (ICSB -14) and G12 (ICSB -88003). Under E5 environment (Shandaweel, 2nd planting date, 2012 season), the most adapted B-line was ICSB -11 (G2) followed by BTX 2-1 (G20). For E6 environment (Shandaweel, 2nd planting date, 2013 season), the most adapted one was ICSB-88003 (G12) followed by ICSB-70 (G6). Across all the tested environments, the highest yielding B-lines were G25 (BTX TSC-20) followed by G12 (ICSB -88003) and G10 (ICSB -1808). These genotypes could be offered to grain sorghum breeding programs as adapted germplasm for the conditions of respective environments.

4. CONCLUSION

Variances due to the two studied factors (sorghum genotypes, environments) and their interaction were significant for all studied traits. Results indicate significant differences among the six tested environments, due to climate, mainly temperatures and soil differences. The increased temperature in the first planting date than second planting date at Giza and in 2012 season than 2013 season in Shandaweel caused a significant decrease in grain yield/plant, suggesting that it is better to delay planting date at Giza to the beginning of June. Across all the tested environments, the highest yielding B-lines were G25 followed by G12 and G10. The genotypes G25 followed by G10 under both environments E1 and E3, G3 and G12 under both environments E2 and E4, G2 followed by G20 under E5 environment and G12 followed by G6 under E6 environment, were the most adapted B-lines. We recommend these genotypes to the grain sorghum breeding program in Egypt to be used as adapted germplasm for the conditions of respective environments.

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