Asian Journal of Plant Sciences

ISSN 1682-3974

OPEN ACCESS

Asian Journal of Plant Sciences

ISSN 1682-3974
DOI: 10.3923/ajps.2022.243.256

Research Article
Phenotypic Stability and Genotypic Responses of Bread Wheat Genotypes Across Multiple Environments in Egypt

[1]Mohammed A. Sayed, [2]Bakry A. Bakry, [2]Abd El-Samad M. Younis and [3]Samah M. Eldemery

[1]Department of Agronomy, Faculty of Agriculture, Assiut University, 71526, Assiut, Egypt
[2]Department of Field Crops Research, Agricultural and Biological Research Institute, National Research Centre,12622, Dokki, Giza, Egypt
[3]Department of Molecular Biology, Genetic Engineering and Biotechnology Research Institute (GEBRI), University of Sadat City, Minoufiya, Egypt

Abstract

Background and Objective: Wheat plants exposed to heat stress due to late sowing often leads to great yield loss. Genotype×Environment interaction (GGE) biplot approach is a powerful tool for graphical multi-environment trials data analysis. The main objective of this investigation was to identify high yielding and stable genotypes of wheat under late sowing date over a range of environmental conditions in Egypt through GGE-biplot analysis. **Materials and Methods:** We investigated grain yield t ha^{-1} and its attributes of forty-nine CIMMYT's lines along with three local cultivars of bread wheat at two locations in two sowing dates and over two consecutive years (8 environments). **Results:** Highly significant variations were obtained for all investigated traits among all sources of variation. Since the environment was the main source of variation. Maximum reduction percentage due to late sowing date was observed for grain yield t ha^{-1} in both locations and this may be because of high temperature and short grains filling duration. The GGE biplot method revealed that L33, L40 and L44 were the highest yielding genotypes at the Assiut location. Genotypes L8, L9 and L42 were the superior yielding entries at Nubariah location environments. **Conclusion:** L30, L32, L37, L21, L27 and L33 were the most stable entries as they were subtended by relatively low PC2 scores. The results of GGE and STI indicated that L28 and L33 gave high grain yield with superior stability and could be considered as the most suitable genotype for late sowing.

Key words: Late sowing, GEI, GGE biplot method, *Triticum aestivum* L., harvest index, sorghum, breeding

Citation: Sayed, M.A., B.A. Bakry, A.S.M. Younis and S.M. Eldemery, 2022. Phenotypic stability and genotypic responses of bread wheat genotypes across multiple environments in Egypt. Asian J. Plant Sci., 21: 243-256.

Corresponding Author: Abd El-Samad Mahmoud Younis, Department of Field Crops Research, Agricultural and Biological Research Institute, National Research Centre,12622, Dokki, Giza, Egypt

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the important cereal crop in the world as well as in Egypt and is commonly considered a strategically important crop worldwide[1]. The temperature in Egypt is high in the south and moderate in the north; therefore, the time of sowing has a major effect on wheat production. Late sowing in wheat is associated with terminal or late heat stress as the main reason caused by late picking of cotton and late harvesting of maize, rice and sorghum in different areas across Egypt. This terminal or late heat stress particularly during the anthesis and grain filling period of the late-planted wheat is considered one of the major environmental factors affecting wheat production not only in Egypt but also worldwide[2,3].

Grain yield and its attributes are genetically complex and therefore impose challenges in breeding for trait improvement. Such traits exhibit continuous variation are influenced by numerous loci with little genetic effects and are highly affected by Genotype-by-Environment Interactions (GEI). This interaction refers to the differences in the ability of a genotype to exhibit changes in a particular trait across different environments[4]. Moreover, the model wheat genotype must be high yielding under any environmental conditions. However, as the genetic effects are not separated from the environmental effects, most genotypes do not perform satisfactorily in all diverse environmental conditions[5,6]. Therefore, understanding GEI and performing stability analysis are important needs of agriculture and breeding programs[7].

Finding out such genotypes which can grow and yield under late sown conditions in Egypt is an ultimate crop breeding goal. Therefore, plant breeders perform Multi-Environment Trials (MET) to choose positive genotypes dependent on both mean yield and performance stability; and to decide whether a test environment is homogeneously sought to be isolated various mega-environments[8,9].

Various statistical techniques have been widely used to measure phenotypic stability and genotypic responses. A GGE biplot method is an excellent tool for visual multi-environment trials data analysis which depends on Principal Component Analysis (PCA) to graphically display the patterns of the genotype×environment (GE) data. This allows visible examination of the relationships among the investigated environments, genotypes (entries) and the genotype×environment interactions[10,11]. Examining the genetic architecture underlying grain yield and its stability can facilitate a more accurate estimation for the improvement of trait stability in the breeding program[12,13].

For the above facts, the objective of this research was to identify high yielding and stable wheat CIMMYT genotypes under late sowing date over a range of environmental conditions in Egypt through GGE-biplot analysis.

MATERIALS AND METHODS

Study area: This study was carried out at two different locations across Egypt i.e., Assiut (at Faculty of Agricultural Farm, Assiut University) and Nubariah (at National Research Center Farm) under two sowing dates trials (normal (N) on 25th November and late (L) at 25th December) for two seasons 2017/2018 and 2018/2019.

Wheat plant material: Forty-nine CIMMYT wheat lines (CWL) were brought from the International Maize and Wheat Improvement Center (CIMMYT), MEXICO[14]. These lines (Table 1) were from the program of high rainfall wheat yield trials (abbreviated as 22HRWYT) of CIMMYT. The CIMMYT lines along with three local wheat cultivars (Misr 2, Giza 171 and Gemiza 11) were used in this research. The CW lines were reproduced in season 2016/2017 to increase the quantity of the grains to be sufficient for sown in two sowing dates for both locations.

Experimental sites, design and trial management: The CW lines and the local cultivars were evaluated at two different locations across Egypt i.e., Assiut (at Faculty of Agricultural Farm, Assiut University) and Nubariah (at National Research Center Farm) under two sowing dates trials (normal (N) on 25th November and late (L) at 25th December) for two seasons 2017/2018 and 2018/2019. The sites chosen for this experiment are representative of different agro-edaphic and ecological environments in Egypt (Table 2).

Assiut lays out the middle of Egypt and represents a hot temperature-dry environment with clay loam soil, while Nubariah locates north Egypt and represents the moderate temperature-semi-rainfall environment with sandy loam soil. Both locations are classified as desert climates. Since the average annual temperature is 24.0°C and precipitation is about 1 mm per year in Assiut. In Nubariah, the average annual temperature is 20.9°C and the annual rainfall is 62 mm.

Genotypes were sown in a Randomized Complete Block Design (RCBD) with three replications at each location. Grains were sown in six rows per entry with plot size 2.5×1.2 m = 3 m^2 at the seed rate of 120 kg ha^{-1} for each replication. At each location, the two trials were sown side by side with similar management regimes. Surface irrigation was

Table 1: Pedigree of forty-nine CIMMYT wheat lines (CWL) was obtained from the International maize and wheat improvement center (CIMMYT), Mexico

Genotypes	Entry	Cross name and selection history	Origin
L1	202	VOROBEY	MXI12-13 MTESIGOSBW
		CMSS96Y02555S-040Y-020M-050SY-020SY-27M-0Y	8
L2	203	PROINTA FEDERAL	MXI12-13 MTESIGOSBW
		CM33203-M-8M-8Y-1M-1Y-1M-0Y-1T-2T-0ARG	9
L3	204	KLEIN CACIQUE	MXI12-13 MTESIGOSBW
		-0ARG	10
L4	205	KENYA HEROE	MXI12-13 MTESIGOSBW
		-0KEN	11
L5	206	FRANCOLIN #1/BLOUK #1	MXI12-13 M25HRWSN
		CMSS06B00010S-0Y-099ZTM-099NJ-099NJ-9RGY-0B-8BMX-0RGY	1001
L6	207	MUTUS//ND643/2*WBLL1	MXI12-13 M25HRWSN
		CMSS08Y00224S-099Y-099M-099NJ-099NJ-4RGY-0B	1008
L7	208	MUTUS//ND643/2*WBLL1	MXI12-13 M25HRWSN
		CMSS08Y00224S-099Y-099M-099NJ-099NJ-16RGY-0B	1011
L8	209	KENYA SUNBIRD/KACHU	MXI12-13 M25HRWSN
		CMSS08Y00235S-099Y-099M-099NJ-3RGY-0B	1016
L9	210	KENYA SUNBIRD/KACHU	MXI12-13 M25HRWSN
		CMSS08Y00235S-099Y-099M-099NJ-7RGY-0B	1017
L10	211	KENYA SUNBIRD/KACHU	MXI12-13 M25HRWSN
		CMSS08Y00235S-099Y-099M-099NJ-099NJ-3RGY-0B	1019
L11	212	KENYA SUNBIRD/KACHU	MXI12-13 M25HRWSN
		CMSS08Y00235S-099Y-099M-099NJ-099NJ-6RGY-0B	1020
L12	213	TUKURU//BAV92/RAYON/3/ND643/2*WBLL1	MXI12-13 M25HRWSN
		CMSS08Y00351S-099Y-099M-099NJ-099NJ-4RGY-0B	1023
L13	214	CHIBIA//PRLII/CM65531/3/FISCAL*2/4/TAM200/TURACO	MXI12-13 M25HRWSN
		CMSS08Y00850T-099TOPM-099Y-099M-099NJ-099NJ-2RGY-0B	1035
L14	215	CHIBIA//PRLII/CM65531/3/FISCAL*2/4/NIINI #1	MXI12-13 M25HRWSN
		CMSS08Y00851T-099TOPM-099Y-099M-099NJ-8RGY-0B	1037
L15	216	MUTUS*2//ND643/2*WBLL1	MXI12-13 M25HRWSN
		CMSS08Y00872T-099TOPM-099Y-099M-099NJ-099NJ-9RGY-0B	1041
L16	217	FRNCLN/BAVIS #1//FRANCOLIN #1	MXI12-13 M25HRWSN
		CMSS08Y00897T-099TOPM-099Y-099M-099NJ-099NJ-8RGY-0B	1047
L17	218	WBLL1*2/BRAMBLING//TAM200/TUI/3/VILLA JUAREZ F2009	MXI12-13 M25HRWSN
		CMSS08Y00912T-099TOPM-099Y-099M-099Y-2M-0RGY	1048
L18	219	WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1*2/4/NIINI #1	MXI12-13 M25HRWSN
		CMSS08Y00924T-099TOPM-099Y-099M-099NJ-099NJ-8RGY-0B	1052
L19	220	WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1*2/4/NIINI #1	MXI12-13 M25HRWSN
		CMSS08Y00924T-099TOPM-099Y-099M-099NJ-099NJ-12RGY-0B	1054
L20	221	WBLL1/KUKUNA//TACUPETO F2001/3/BERKUT//PBW343*2/KUKUNA	MXI12-13 M25HRWSN
		CMSS08B00153S-099M-099Y-13M-0RGY	1060
L21	222	VENDA	MXI12-13 M25HRWSN
		CMSS08B00178S-099M-099Y-15M-0RGY	1061
L22	223	WBLL1*2/BRAMBLING/4/BABAX/LR42//BABAX*2/3/SHAMA	MXI12-13 M25HRWSN
		CMSS08B00196S-099M-099NJ-099NJ-11RGY-0B	1066
L23	224	WBLL1*2/BRAMBLING/4/BABAX/LR42//BABAX*2/3/SHAMA	MXI12-13 M25HRWSN
		CMSS08B00196S-099M-099NJ-099NJ-14RGY-0B	1069
L24	225	WBLL1*2/BRAMBLING/4/BABAX/LR42//BABAX*2/3/SHAMA	MXI12-13 M25HRWSN
		CMSS08B00196S-099M-099NJ-099NJ-20RGY-0B	1072
L25	226	ND643/2*WAXWING//SAAR/2*WAXWING	MXI12-13 M25HRWSN
		CMSS08B00241S-099M-099Y-3M-0RGY	1077
L26	227	BABAX/LR42//BABAX*2/3/SHAMA/5/PRL/2*PASTOR/4/CHOIX/STAR/3/HE1/3*CNO79//2*SERI	MXI12-13 M25HRWSN
		CMSS08B00254S-099M-099NJ-099NJ-7RGY-0B	1082
L27	228	BABAX/LR42//BABAX*2/3/SHAMA/5/PRL/2*PASTOR/4/CHOIX/STAR/3/HE1/3*CNO79//2*SERI	MXI12-13 M25HRWSN
		CMSS08B00254S-099M-099NJ-099NJ-14RGY-0B	1084
L28	229	BABAX/LR42//BABAX*2/3/SHAMA/4/WAXWING*2/KRONSTAD F2004	MXI12-13 M25HRWSN
		CMSS08B00256S-099M-099NJ-099NJ-26RGY-0B	1086
L29	230	BONSU	MXI12-13 M25HRWSN
		CMSS08B00259S-099M-099NJ-17RGY-0B	1091
L30	231	BONSU	MXI12-13 M25HRWSN
		CMSS08B00259S-099M-099NJ-30RGY-0B	1092
L31	232	PFAU/WEAVER*2//TRANSFER#12,P88.272.2/4/BABAX/LR42//BABAX*2/3/SHAMA	MXI12-13 M25HRWSN
		CMSS08B00269S-099M-099Y-12M-0RGY	1096

Table 1: Continue

Genotypes	Entry	Cross name and selection history	Origin
L32	233	VINK #1	MXI12-13 M25HRWSN
		CMSS08B00381S-099M-099Y-1M-0RGY	1099
L33	234	BECARD//ND643/2*WBLL1	MXI12-13 M25HRWSN
		CMSS08B00422S-099M-099NJ-5RGY-0B	1100
L34	235	KRL 19/4/BABAX/LR42//BABAX*2/3/SHAMA	MXI12-13 M25HRWSN
		CMSS08B00575S-099M-099Y-20M-0RGY	1103
L35	236	BJY/COC//PRL/BOW/3/FRTL/4/BABAX/LR42//BABAX*2/3/SHAMA	MXI12-13 M25HRWSN
		CMSS08B00594S-099M-099Y-4M-0RGY	1105
L36	237	TACUPETO F2001*2/BRAMBLING//KENYA SUNBIRD/3/TACUPETO F2001*2/BRAMBLING	MXI12-13 M25HRWSN
		CMSS08B00703T-099TOPY-099M-099Y-16M-0RGY	1110
L37	238	KACHU*2/3/ND643//2*PRL/2*PASTOR	MXI12-13 M25HRWSN
		CMSS08B00712T-099TOPY-099M-099NJ-099NJ-14RGY-0B	1113
L38	239	KACHU*2/3/ND643//2*PRL/2*PASTOR	MXI12-13 M25HRWSN
		CMSS08B00712T-099TOPY-099M-099NJ-099NJ-15RGY-0B	1114
L39	240	KIRITATI/4/2*SERI.1B*2/3/KAUZ*2/BOW//KAUZ/5/ND643//2*PRL/2*PASTOR/6/SUP152	MXI12-13 M25HRWSN
		CMSS08B00756T-099TOPY-099M-099NJ-099NJ-6RGY-0B	1117
L40	241	ND643/2*WBLL1/4/CHIBIA//PRLII/CM65531/3/MISR 2/5/BECARD	MXI12-13 M25HRWSN
		CMSS08B00776T-099TOPY-099M-099NJ-099NJ-21RGY-0B	1124
L41	242	ND643/2*WBLL1/3/KIRITATI//2*PRL/2*PASTOR/4/BECARD	MXI12-13 M25HRWSN
		CMSS08B00777T-099TOPY-099M-099NJ-099NJ-12RGY-0B	1128
L42	243	SUP152*2/KENYA SUNBIRD	MXI12-13 M25HRWSN
		CMSS08B00798T-099TOPY-099M-099NJ-11RGY-0B	1132
L43	244	TOB/ERA//TOB/CNO67/3/PLO/4/VEE#5/5/KAUZ/6/FRET2/7/2*VORB	MXI12-13 M25HRWSN
		CMSA08Y00065T-099B-050Y-050ZTM-050Y-14BMX-010Y-0B	1141
L44	245	KA/NAC//TRCH*2/3/VORB	MXI12-13 M25HRWSN
		CMSA08Y00089T-099B-050Y-050ZTM-050Y-1BMX-010Y-0B	1145
L45	246	BAVIS/VORB/5/CROC_1/AE.SQUARROSA (205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2	MXI12-13 M25HRWSN
		CMSA08M00052T-050Y-040M-0NJ-10Y-0B	1152
L46	247	BABAX/LR42//BABAX/3/ER2000/4/NAVJ07	MXI12-13 M25HRWSN
		CMSA08M00274S-040ZTM-050Y-14ZTM-010Y-0B	1157
L47	248	PFAU/MILAN/3/BABAX/LR42//BABAX/5/CROC_1/AE.SQUARROSA (205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2	MXI12-13 M25HRWSN
		CMSA08M00414S-040ZTM-050Y-63ZTM-010Y-0B	1160
L48	249	PFAU/MILAN/3/BABAX/LR42//BABAX/4/VORB	MXI12-13 M25HRWSN
		CMSA08M00424S-040ZTM-050Y-13ZTM-010Y-0B	1162
L49	250	PFAU/MILAN/3/BABAX/LR42//BABAX/4/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1	MXI12-13 M25HRWSN
		CMSA08M00432S-040M-0NJ-10Y-0B	1166

These lines were from the program of high rainfall wheat yield trials (abbreviated as 22HRWYT) of CIMMYT.

Table 2: Summary description of the experimental sites

Location	Assiut				Al-Nubaria			
Climate	Desert climate				Desert climate			
Latitude	27°18'N				30°32'N			
Longitude	32°40'E				30°17'E			
Sea level	62 m				10 m			
Soil type	Clay loam				Sandy loam			
Season	2017-2018		2018-2019		2017-2018		2018-2019	
Rainfall (mm)	1 mm		2 mm		47 mm		62 mm	
Temperature*	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
October	31.9	16.9	32.3	18.2	29.6	21.0	30.2	21.6
November	24.7	11.4	26.2	12.9	24.2	16.2	25.6	16.6
December	22.7	9.2	20.5	8.3	22.3	14.0	20.4	13.1
January	19.6	6.9	19.0	6.1	19.4	11.5	18.2	9.8
February	25.7	11.9	21.4	7.9	23.8	13.7	20.4	11.5
March	30.2	14.6	24.4	10.0	28.0	16.3	22.6	13.6
April	32.1	16.4	29.6	14.1	29.3	18.2	26.6	15.5
May	37.5	22.1	37.4	22.4	34.1	22.2	34.6	19.5

*Monthly average minimum and maximum temperature of Assiut and Al-Nubaria sites from October to May at the Assiut location, while at Nubariah received supplemental water through sprinkler irrigation as needed. All experiments were harvested and dates vary by location. Agricultural practices such as fertilizer and weed control were conducted as recommendations in each location.

Data collection: Observations on grain yield and its attributes were taken from the middle rows per plot. Plant height (PH, cm) was measured as an average of five middle plants per entry in each plot. Several spikes/m^2 (SN) was counted on the middle-squared meter in each plot. Days to heading (DH), biological yield ha^{-1} (BYH), Grain yield ha^{-1} (GYH) were measured on the whole field plot basis. Days to heading represents days required for the heading of 50% plants in a plot from the date of sowing. Thousand kernel weight (TKW, g), 1000 grains from each entry was weighed and recorded (g).

Statistical analyses: A combination of location, year and sowing dates were regarded to be eight environments. Analysis of split split-plot combined analysis of variance (ANOVA) was conducted for each of normal and late sowing dates and across eight environments was carried out using PROC GLM of SAS (SAS Institute 2010) using raw data from each location to assess the differences among tested genotypes and to assess the presence of G×E interaction. Based on results of ANOVA indicating significant G×E interaction for all studied traits in the trials. The genotype-genotype by environment (abbreviated as GGE) biplot approach[15] was conducted to assess relationships among testing environments as well as among genotypes and environments. The GGE biplot method was carried out using Genstat software version 15[16]. The graphical GGE biplot indicates the 1st and 2nd Principal Components (PC1 and PC2) derived from subjecting environment-centred character data[17]. The graphs were created based on (i) The polygon view of the GGE biplot to detect the winning genotypes and their mega environments by "which, won and where" fashion, (ii) Classification and ranking of the genotypes based on grain yield and stability performance. Mean comparisons of environments and genotypes were calculated using revised LSD according to Lawal[18].

RESULTS AND DISCUSSION

Analysis of variance: A summary of the sources of variation and the mean squares is shown in Table 3. Significant variation was observed between both seasons for only DH, SN and BYH. There were highly significant differences between both locations (i.e., Assiut and Nubariah) for most of the studied traits. Seasons by locations interaction was highly significant in the case of DH, PH, HI, BYH and GYH. In addition, the analysis of variance exhibited highly significant variation between both sowing dates for all the studied traits in both locations indicating the climate conditions effect on wheat grain yield and its attributes. The 1st and 2nd order interactions of sowing dates with each of the seasons and locations significantly affected the studied traits in almost half of the cases. The ANOVA also revealed the presence of highly significant (p<0.01) variations among the genotypes for all traits. Moreover, the genotypes exhibited highly significant interactions with each of the seasons, locations and sowing dates for all traits indicating the presence of GEI (Table 3).

Table 3: Analysis of variance for studied traits of wheat genotypes under normal and late sowing dates across locations and years

Source	df	HD	PH	SN	HI	TKW	BYH	GYH
Years (Y)	1	1572.05**	44.48^{ns}	159280*	592.61^{ns}	151.20^{ns}	291.05**	1.61^{ns}
Locations (L)	1	27078.1**	4302.6**	80689*	926.41*	99.42^{ns}	429.80**	131.64**
Y×L	1	661.49**	1372.28**	1106.4^{ns}	4558.1**	115.15^{ns}	396.70**	7.32^{ns}
Error (a)	8	9.71	20.34	14204	180.89	30.52	0.81	4.36
Dates (D)	1	150760**	83676**	1165475**	3501.7**	12431**	4353.00**	965.55**
D×Y	1	16.35^{ns}	9.56^{ns}	70387*	77.41^{ns}	234.78**	7.92^{ns}	3.75^{ns}
D×L	1	9262.18**	2143.29**	12494^{ns}	3549.9**	2595.7**	381.25**	1.51^{ns}
D×Y×L	1	34.35^{ns}	636.40**	265.2^{ns}	544.71**	9.71**	68.49**	1.76^{ns}
Error (b)	8	7.30	14.75	13235	43.81	0.65	5.36	1.24
Genotypes (G)	51	148.88**	280.30**	21488.**	195.68**	94.76**	53.68**	4.79**
G×Y	51	15.32**	83.10**	1778.2^{ns}	78.50**	16.63**	18.44**	1.88**
G×L	51	27.65**	168.96**	18390.3**	138.77**	76.70**	52.05**	5.99**
G×D	51	21.35**	130.09**	16021.**	58.69**	34.60**	21.29**	2.35**
G×Y×L	51	16.67**	60.23**	1440.6^{ns}	80.14**	15.32**	17.11**	1.66**
G×L×D	51	17.70**	107.07**	13073.3**	56.89**	34.23**	3.79**	2.30**
G×Y×L×D	102	12.06**	81.28**	1816.7*	14.54**	3.87**	3.79**	0.70**
Error (c)	816	7.87	10.39	1378.39	7.50	4.09	2.50	0.39

*,**Significant at 0.05 and 0.01 levels of probability, respectively. ns: Not significant

Table 4: Combined ANOVA for all studied traits

Traits	Source	df	MS	TSS (%)
Heading date (DH)	Genotypes	51	148.78**	3.61
	Environments	7	27085.35**	90.28
	G×E	357	17.46**	2.97
Plant height (PH)	Genotypes	51	279.44**	9.40
	Environments	7	13187.31**	60.89
	G×E	357	101.74**	23.96
Spikes number (SN)	Genotypes	51	21251.11**	16.18
	Environments	7	215564.42**	22.53
	G×E	357	7796.50**	41.56
Harvest index (HI)	Genotypes	51	195.61**	18.41
	Environments	7	1959.62**	25.31
	G×E	357	63.06**	41.54
1000 kernel weight (TKW)	Genotypes	51	94.88**	14.43
	Environments	7	2236.41**	46.69
	G×E	357	26.48**	28.19
Biological yield (BYH)	Genotypes	51	53.39**	15.40
	Environments	7	852.16**	33.73
	G×E	357	19.42**	39.19
Grain yield (GYH)	Genotypes	51	4.79**	9.69
	Environments	7	159.12**	44.20
	G×E	357	2.23**	31.66

** Significantly at 0.01 levels of probability

Table 5: Means of the studied traits at each environment, location and average reduction percentage

Environments	HD (day)	PH (cm)	SN	HI (%)	KW (g)	BYH (t)	GYH (t)
A1	101.24	92.68	392.46	34.40	43.30	17.35	5.86
A3	104.38	95.65	427.28	41.42	45.64	14.94	6.12
Normal Mean	102.81	94.16	409.87	37.91	44.47	16.15	5.99
A2	73.24	80.17	351.76	29.49	35.14	14.41	4.21
A4	77.50	80.64	358.37	32.87	35.40	12.62	4.11
Late mean	75.37	80.40	355.06	31.18	35.27	13.51	4.16
Assiut	89.09	87.28	382.47	34.54	39.87	14.83	5.07
N1	106.28	95.11	412.03	37.83	40.63	18.03	6.66
N3	107.10	91.07	453.46	34.62	41.42	18.85	6.48
Normal Mean	106.69	93.09	432.74	36.23	41.03	18.44	6.57
N2	89.79	74.50	360.55	37.09	37.89	13.82	5.01
N4	90.48	73.63	369.09	35.47	37.29	13.35	4.75
Late mean	90.14	74.07	364.82	36.28	37.59	13.58	4.88
Al-Nubaria	98.41	83.58	398.78	36.25	39.31	16.01	5.72
R. LSD 0.05	0.55	0.63	7.76	0.60	0.40	0.31	0.13
Reduction (%) because of late sowing date in each location for each season							
Assiut location							
Season 1	27.66	13.49	10.37	14.26	18.84	16.95	28.08
Season 2	25.75	15.70	16.13	20.63	22.44	15.54	32.90
Average	26.70	14.60	13.25	17.45	20.64	16.24	30.49
Al-Nubaria location							
Season 1	15.51	21.67	12.49	1.97	6.74	23.38	24.76
Season 2	15.52	19.15	18.61	-2.46	9.98	29.18	26.74
Average	15.51	20.41	15.55	-0.25	8.36	26.28	25.75

A1: Normal sowing date at Assiut site in the first season, A2: Late sowing date at Assiut site in the first season, A3: Normal sowing date at Assiut site in the second season, A4: Late sowing date at Assiut site in the second season, N1: Normal sowing date at Nubaria site in the first season, N2: Late sowing date at Nubaria site in the first season, N3: Normal sowing date at Nubaria site in the second season and N4: Late sowing date at Nubaria site in the second season

The pooled ANOVA exhibited highly significant variation among the eight environments, among wheat genotypes and GE interactions for all studied traits (Table 4). Since the environment was the prevalent source of variation, the contribution of the environmental effects to the total sum of squares ranged between 22.53% (SN) and 90.28% (DH). Furthermore, the genotypes contributed to the total sum of squares by values ranged between 3.61% (DH) and 18.41% (HI), (Table 4). For the effects of GE interactions, the contribution of GE effects varied from 2.97% (DH)-41.56% (SN).

Sowing dates, reduction percentage and stress tolerance index: The illustrated data in Table 5 show the means of the studied traits in each environment and for each location. It could be observed that the average of all studied traits in all locations was reduced significantly due to late sowing compared to the normal sowing date. Since time to heading was declined from 102.81-75.37 days in Assiut with an average reduction percentage of 26.70% and from 106.69-90.14 days in Nubariah with a 15.51% reduction. Plant height was reduced from 94.16-80.40 cm in Assiut with an average reduction percentage of 14.60% and from 93.09-74.07 cm in Nubariah with 20.41%. Spikes number was declined from 409.87-355.06 with a reduction percentage of 13.25% in Assiut, while at Nubariah it reduced from 432.74-364.74 with a reduction percentage of 15.55% due to late sowing date. Harvest index was reduced by 17.45 and -0.25% in Assiut and Nubariah, respectively. About 1000 kernel weight was reduced by 20.64 and 8.36% at Assiut and Nubariah, respectively. The biological yield was declined by 16.24 and 26.28% in both locations, respectively. Moreover, grain yield t ha^{-1} was decreased from 5.99-4.16 t ha^{-1} in Assiut and from 6.57-4.88 t ha^{-1} in Nubariah (Table 5).

The earliest maturation period genotypes were L34 and L37 under normal and late sowing dates, respectively. While the shortest maturation period genotypes were recorded by L17 and L27 under both sowing dates, respectively. The highest spikes number under late sowing date was obtained from L39 and registered 425.5 spike m^{-1} while the lowest spikes number was recorded for the genotype L3. The values of BYH and GYH traits were obtained also from the genotype L3 under late sowing date. L8 was the superior genotype overall locations in GYH under late sowing date and recorded 5.86 t ha^{-1} (Table 6). According to the stress tolerance index, L33, L8, L42, L28 and L26 had greater stability and high yielding genotypes.

Locations comparison: With the comparison of location means of the studied traits (Table 5), the wheat genotypes were earlier at the Assiut location with an average of 89.09 days across sowing dates, while Nubariah location gave the latest mean of days to head with an average of 98.41 days. The tallest plants were observed in the Assiut location with an average of 87.28 cm, while the shortest plants were observed in Nubariah at 83.58 cm. The highest number of spikes (398.78 m^{-1}), heaviest biological yield (16.01 t ha^{-1}), highest harvest index (36.25%) and highest grain yield (5.72 t ha^{-1}) were recorded in the Nubariah location compared to the Assiut location. In addition, the 1000 kernel weight was higher at the Assiut location (39.87 g) compared to the Nubariah location.

Mega environments and best genotypes

Days to the heading: GGE biplot method explained 71.94% of the total variance (57.20% for PC1 and 14.74% for PC2) in DH trait for wheat genotypes across environments. The polygon view of the GGE showed genotypes with relatively better performance in each environment. In Fig. 1a, the genotypes Gemiza 11, L42, L21, L2 and L4 had the greatest distance to the centre of the biplot and are among the most

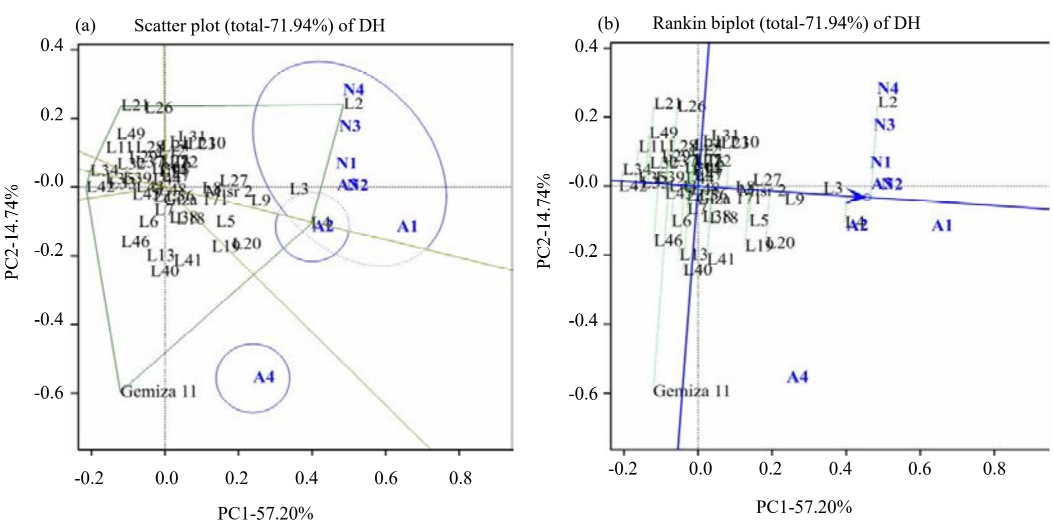

Fig. 1(a-b): Polygon view of GGE-biplot analysis for different wheat lines in the environment for days to heading. (a) Scatter plot showing the mega-environments based on mean days to the heading of wheat genotypes evaluated across eight environments days and (b) GGE-biplot showing the ranks of the genotypes based on both DH and stability performance

49 CIMMYT wheat lines and three local wheat cultivars were evaluated in eight environments for days to heading (DH) showing the first and the second principal components (PC1 and PC2)

Table 6: Means of studied traits for all genotypes under normal and late sowing dates

	DH (day)		PH (cm)		SN		HI (%)		TKW (g)		BYH (t)		GYH (t)		
Genotypes	Normal	Late	Normal	Late	Normal	Late	Normal	Late	Normal	Late	Normal	Late	Normal	Late	STI
L1	104.5	83.0	94.5	71.0	422.3	345.8	27.3	27.9	45.6	40.4	21.9	14.9	5.92	4.09	0.61
L2	114.7	89.8	98.2	75.4	337.5	355.3	28.7	28.7	37.8	30.5	20.1	15.6	5.75	4.40	0.64
L3	110.6	89.4	92.4	75.7	365.8	286.8	34.1	41.6	40.7	41.2	16.5	8.3	5.60	3.39	0.48
L4	112.2	89.5	100.9	71.9	419.7	307.2	30.0	25.4	40.2	33.6	19.8	14.6	5.80	3.80	0.56
L5	107.4	84.8	84.5	71.0	435.8	291.8	39.6	31.5	42.2	34.2	17.1	11.0	6.42	3.53	0.57
L6	104.3	80.6	91.5	75.2	376.0	295.2	36.2	33.3	42.2	35.2	16.2	10.7	5.76	3.53	0.52
L7	104.4	82.3	93.1	74.9	447.3	287.5	39.0	29.5	43.9	35.9	16.7	11.8	6.51	3.66	0.60
L8	107.2	84.1	95.5	73.0	405.2	366.0	36.8	36.0	41.9	36.5	18.0	16.1	6.54	5.86	0.97
L9	109.0	86.9	98.7	73.8	431.2	355.7	37.6	31.2	43.2	35.7	16.8	16.0	6.32	5.04	0.81
L10	105.7	84.8	98.1	74.9	446.8	333.8	34.6	34.5	43.4	33.3	18.4	14.2	6.30	4.92	0.79
L11	101.9	79.6	93.3	79.8	447.8	359.3	40.9	35.4	41.7	34.5	16.3	13.0	6.61	4.60	0.77
L12	103.8	83.3	98.8	80.0	466.7	341.3	38.6	35.9	46.2	37.2	17.7	13.2	6.68	4.77	0.81
L13	102.8	83.3	90.8	75.4	433.3	297.7	35.8	33.7	42.0	33.7	18.9	11.8	6.70	4.05	0.69
L14	104.9	81.6	93.3	75.4	439.8	307.7	34.6	29.8	39.0	33.1	18.6	12.5	6.18	3.68	0.58
L15	103.5	83.8	95.4	75.6	459.2	368.2	35.9	31.3	39.1	33.4	18.8	15.0	6.66	4.73	0.80
L16	104.7	82.4	97.0	78.8	438.2	389.3	37.8	32.7	42.1	32.8	17.3	14.3	6.44	4.55	0.74
L17	103.7	82.5	83.7	70.8	391.5	295.2	38.0	32.7	45.7	36.0	16.4	11.1	6.13	3.65	0.57
L18	105.8	83.1	90.0	79.6	423.0	332.3	38.9	30.9	42.0	30.8	15.9	12.6	6.10	3.76	0.58
L19	107.8	84.8	96.2	75.8	341.5	364.7	30.6	29.8	45.0	38.3	18.5	14.0	5.65	4.15	0.59
L20	108.8	85.6	87.1	77.7	433.7	369.7	36.3	30.8	41.9	34.5	18.9	15.7	6.61	4.86	0.81
L21	102.3	80.3	88.4	82.6	441.3	358.2	40.7	40.8	44.4	38.3	15.6	11.9	6.23	4.83	0.76
L22	107.1	80.2	90.8	77.8	450.0	390.7	39.2	37.5	41.2	36.1	17.5	13.0	6.66	4.81	0.81
L23	105.8	83.4	88.5	74.9	356.8	372.8	37.1	38.2	43.7	38.4	15.8	12.0	5.71	4.52	0.65
L24	105.2	81.4	91.1	72.2	420.8	385.5	36.7	36.3	43.0	37.3	16.6	12.1	5.90	4.38	0.65
L25	105.1	81.8	87.1	73.5	383.7	384.8	33.8	33.8	41.7	36.0	16.9	13.4	5.60	4.51	0.64
L26	104.5	80.4	87.9	76.0	438.0	385.3	37.4	35.7	42.9	35.5	18.8	14.5	6.98	5.08	0.90
L27	108.1	84.3	89.1	69.4	459.0	327.8	40.5	34.5	40.8	34.8	17.9	11.7	7.19	4.06	0.74
L28	104.2	80.2	90.5	71.3	476.2	413.7	40.2	35.9	40.6	38.6	17.0	14.9	6.76	5.37	0.92
L29	102.4	81.4	91.9	72.3	454.7	412.5	35.4	30.3	38.8	39.6	18.4	15.9	6.36	4.78	0.77
L30	104.0	82.2	94.7	81.1	471.3	410.0	35.4	33.5	42.6	33.9	18.3	15.8	6.42	5.23	0.85
L31	106.7	81.6	94.9	78.9	397.0	339.2	39.2	37.0	44.9	39.6	14.9	10.9	5.63	4.03	0.57
L32	102.4	80.4	94.1	80.7	475.7	364.0	40.8	36.8	43.3	37.6	15.8	12.3	6.32	4.51	0.72
L33	100.6	81.5	92.5	75.4	485.3	390.2	40.8	35.7	45.8	36.9	19.3	16.1	7.83	5.67	1.13
L34	99.2	81.4	91.7	74.1	437.0	305.3	42.1	37.2	42.3	35.0	15.1	11.2	6.36	4.26	0.69
L35	100.6	81.1	96.5	73.4	396.7	317.2	37.4	32.7	39.7	35.0	16.7	12.7	6.15	4.20	0.66
L36	103.8	84.0	96.6	78.0	425.0	385.3	38.1	37.3	43.8	36.4	17.6	12.9	6.65	4.48	0.76
L37	105.2	78.8	93.8	77.8	441.0	372.3	38.3	33.8	42.4	33.7	17.2	12.7	6.51	4.25	0.70
L38	105.3	82.6	91.9	77.1	404.7	384.3	39.7	35.1	43.9	37.4	15.8	13.9	6.08	4.84	0.75
L39	102.3	81.3	92.7	75.7	357.5	425.5	31.3	30.5	43.5	37.5	18.5	17.6	5.60	5.31	0.75
L40	103.7	82.8	95.7	84.4	417.3	411.7	33.1	36.0	47.5	37.3	20.0	14.0	6.61	4.97	0.83
L41	104.8	84.3	94.6	85.6	457.2	361.3	39.3	32.1	41.1	36.4	17.3	12.9	6.65	4.01	0.68
L42	100.7	79.3	95.1	85.1	477.3	400.8	38.1	33.6	42.2	36.9	19.9	14.9	7.48	5.02	0.95
L43	103.7	80.8	96.3	82.6	400.3	397.2	36.7	35.4	44.4	38.0	17.8	14.8	6.47	4.87	0.80
L44	104.7	81.8	100.4	79.0	425.3	411.5	38.0	35.5	43.3	39.3	17.2	14.0	6.51	4.91	0.81
L45	102.7	81.7	98.0	77.8	454.5	407.7	38.2	33.5	41.6	35.7	17.7	14.2	6.69	4.63	0.79
L46	103.2	80.5	98.1	80.8	381.8	355.8	36.6	31.6	40.6	39.5	16.5	13.2	5.93	4.15	0.62
L47	103.6	84.0	93.1	80.7	411.3	415.7	41.3	35.3	42.6	39.3	13.8	13.8	5.70	4.77	0.69
L48	104.7	82.3	95.5	79.5	388.7	385.2	36.5	31.0	44.8	37.9	16.1	17.2	5.80	5.22	0.77
L49	102.2	80.3	101.0	87.0	423.7	373.3	37.7	29.4	47.2	40.3	17.0	15.8	6.27	4.64	0.74
Gemiza 11	101.3	83.8	92.0	81.5	332.8	302.0	35.4	34.7	44.9	37.1	15.0	11.1	5.32	4.01	0.54
Giza 171	104.0	83.3	95.3	78.3	437.3	305.3	39.3	32.5	46.2	41.6	15.0	12.3	5.80	4.15	0.61
Misr 2	105.6	85.4	96.4	86.5	366.3	414.3	42.0	38.4	41.4	37.1	13.6	14.7	5.69	5.56	0.80
R.LSD	2.71	3.17	2.58	3.86	38.29	38.56	2.8	2.82	1.48	2.54	1.87	1.37	0.76	0.56	

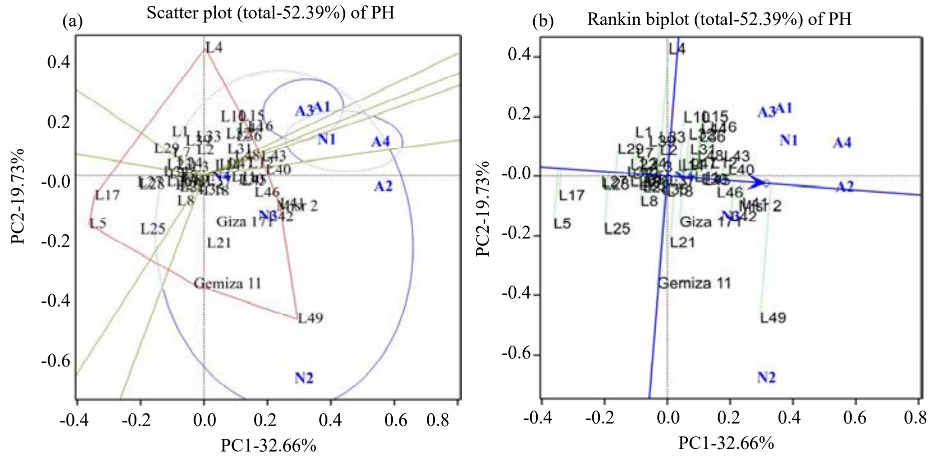

Fig. 2(a-b): Polygon view of GGE-biplot analysis for different wheat lines in the environment for plant height. (a) Scatter plot showing the mega-environments based on mean plant height of wheat genotypes evaluated across eight environments days and (b) GGE-biplot showing the ranks of the genotypes based on both PH and stability performance

49 CIMMYT wheat lines and three local wheat cultivars evaluated in eight environments for plant height (PH) showing the first and the second Principal Components (PC1 and PC2)

reactive data. They were the earliest or latest performance genotypes in one or more environments. The first mega environment including the environments N1, N2. N3, N4, A1 and A3which they are located in one area in the biplot (Fig. 1a), indicating identical conditions. The most adequate genotype for DH trait in sowing dates is L3 followed by genotype L2. The second mega environment consisted of A2 and the most suitable genotype in this date L4 followed by L9 and L20. The third mega environment is A4, there was not any genotype that has good performance in this environment and may have been affected by terminal or late heat stress. GGE biplot analysis in Fig. 1b revealed several genotypes such as L2, L19, L40, L26 and Gemiza 11 having mean scores greater than the average environment coordinate point and considered as unstable genotypes for days to heading.

Plant height: GGE biplot method explained 52.39% of the total variance (32.66% for PC1 and 19.73% for PC2) in PH trait for wheat genotypes across environments. The polygon view of the GGE exhibited the entries which have relatively desirable performance in each environment. In Fig. 2a, the genotypes Misr 2, L49, Gemiza 11, L5, L17 and L4 had the greatest distance to the origin of the biplot and are among the most reactive data and have the tallest or shortest performance in one or more environments. The genotypes in the origin of the biplot are less reactive and have the same rank in all environments and therefore do not react to the environment. The GGE biplot method revealed three mega environments. The first mega environment including environments N2. N3, N4 and A2 and located in one area of the biplot, indicating identical conditions and represent Nubariah location. The majority of the genotypes were suitable to this mega environment such as L49, Gemiza 11, L21, L10, L5 and Misr 2. The second mega environment consisted of Assiut normal sowing dates A1 and A3. The most desirable genotype in this environment is L4 followed by L46 and L15. The third mega environment consisted of A4 and N1, the closest genotypes to these environments were L43 and L40. Furthermore, the GGE biplot method in Fig. 2b revealed several genotypes such as L49, L15, L46, L21 and Gemiza 11 having mean scores greater than the average environment coordinate point and considered as unstable genotypes for plant height. Genotypes L40, L25 and L2had greater stability degree as they were subtended by relatively low PC2 score.

Spikes number (m^{-1}): In Fig. 3(a-b), PC1 and PC2 accounted for 82.59% (50.80 and 31.80% for PC1 and PC2, respectively) of the total variance for spikes number m^{-1} of the genotypes evaluated at eight environments. Four mega environments were obtained by GGE analysis. They consider more responsive to the changes in the environmental conditions and are considered as specifically adapted genotypes. Genotype L32 was the best entry in the number of spikes m^{-1} at A1 and A3 (represent normal conditions at Assiut location), while genotypes Misr 2, L39, L47 and L40 were the best at A2 and A4 (represent late sowing dates at Assiut location). Most of the entry that located a round the centre of the biplot was performed well in the other environments. Gemiza 11 was the

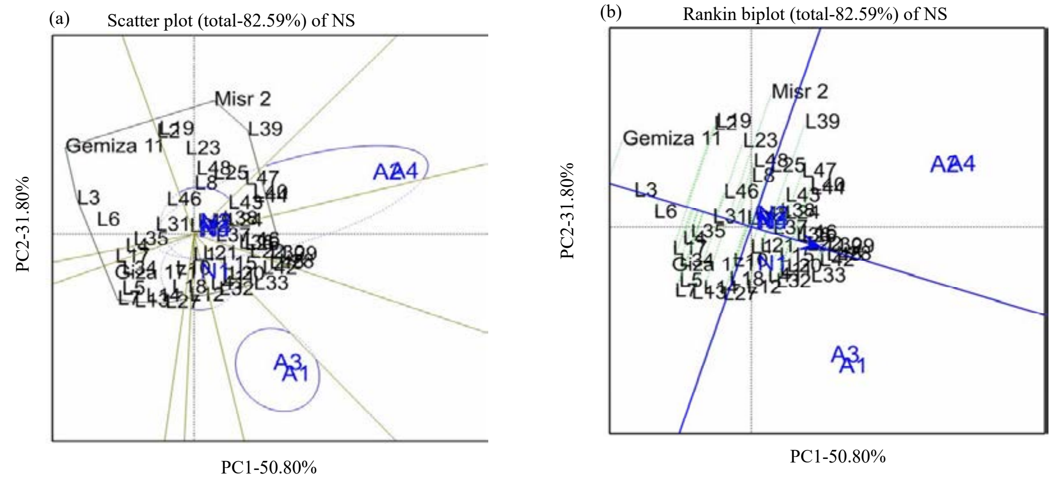

Fig. 3(a-b): Polygon view of GGE-biplot analysis for different wheat lines in the environment for the number of spikes m^{-2}. (a) Scatter plot showing the mega-environments based on the mean number of spikes m^{-2} of wheat genotypes evaluated across eight environment stays and (b) GGE-biplot showing the ranks of the genotypes based on both NS and stability performance

49 CIMMYT wheat lines and three local wheat cultivars evaluated in eight environments for the number of spikes m^{-2} (NS) showing the first and the second Principal Components (PC1 and PC2)

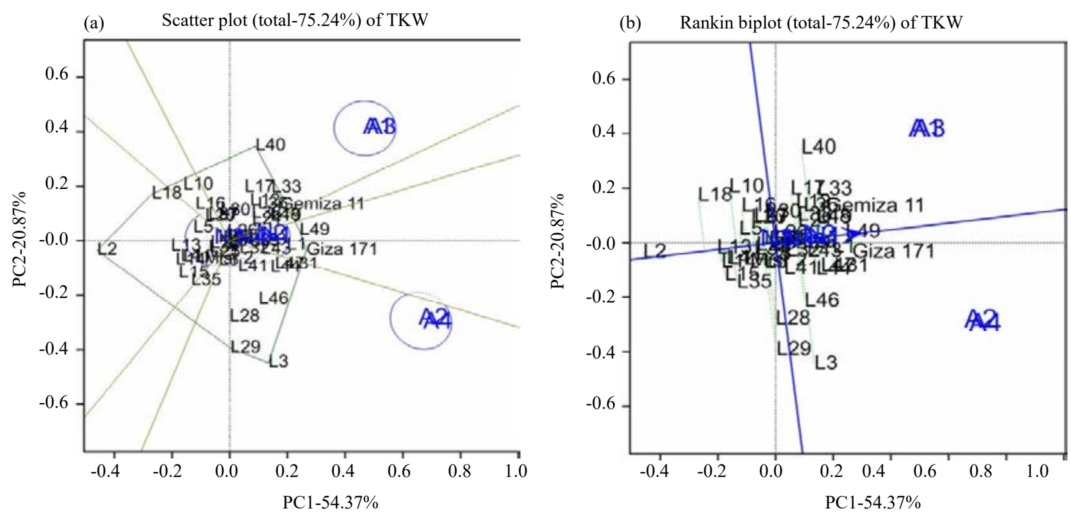

Fig. 4(a-b): Polygon view of GGE-biplot analysis for different wheat lines in the environment for 1000 kernel weight. (a) Scatter plot showing the mega-environments based on the mean 1000 kernel weight of wheat genotypes evaluated across eight environment stays and (b) GGE-biplot showing the ranks of the genotypes based on both TKW and stability performance

49 CIMMYT wheat lines and three local wheat cultivars evaluated in eight environments for the 1000 kernel weight (TKW) showing the first and the second Principal Components (PC1 and PC2)

poorest genotype in almost all the test environments since it had the longest distance from the origin of the biplot on the opposite side of the environments. In Fig. 3b, genotypes Gemiza 11, L2, L19, L39 and Misr 2 were the most unstable entries for spikes number m^{-1} across sowing dates and locations. While genotypes L3, L6, L31, L42 and other genotypes were the most stable entries as they were subtended by relatively low PC2 score.

Thousand kernel weight (g): In Fig. 4(a-b), PC1 and PC2 accounted for 75.24% (54.37 and 20.87% for PC1 and PC2, respectively) of the total variance for the 1000 kernel weight

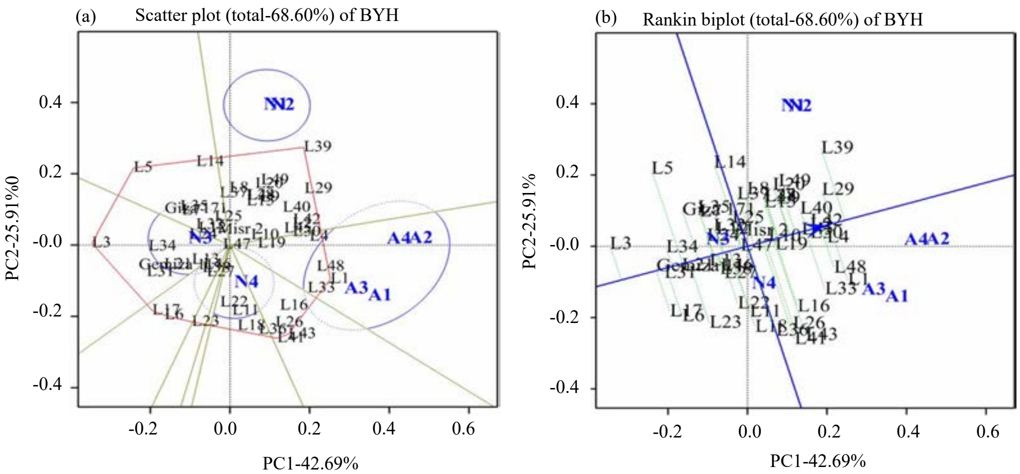

Fig. 5(a-b): Polygon view of GGE-biplot analysis for different wheat lines in the environment for biological yield ha^{-1}. (a) Scatter plot showing the mega-environments based on mean biological yield/ha of wheat genotypes evaluated across eight environment stays and (b) GGE-biplot showing the ranks of the genotypes based on both BYH and stability performance

49 CIMMYT wheat lines and three local wheat cultivars evaluated in eight environments for biological yield ha^{-1} (BYH) showing the first and the second Principal Components (PC1 and PC2)

of the genotypes evaluated at eight environments. Three mega environments were obtained by GGE analysis. The vertex entries were L40, Giza 171, L3, L29, L2 and L18 which were the best or worst in some or all environments because they are farthest from the origin of the biplot. They consider more responsive to the change in the environments and are considered as specifically adapted genotypes. Genotypes L40, L33, Gemiza 11 and L49 were the best entry in TKW at A1 and A3 (represent normal conditions at Assiut location), while genotypes Giza 171, L31, L44, L46 and L3 were the best at A2 and A4 (represent late sowing dates at Assiut location). Most of the entry that located around the centre of the biplot was performed well in the other environments. L2 was the poorest genotype in almost all the test environments since it had the longest distance from the origin of the biplot on the opposite side of the environments. In Fig. 4b, genotypes L40, L33, L46, L28, L29 and L3 were the most unstable entries for TKW across sowing dates and locations.

Biological yield (t ha^{-1}): GGE biplot analysis explained 68.60% (42.69 and 25.91% for PC1 and PC2, respectively) of the total variation of BYH for wheat genotypes across environments (Fig. 5a-b). The GGE analysis revealed four mega environments and divide the biplot into twelve sectors. The vertex genotypes L39, L1, L41, L17, L3 and L5 were the best or worst in BYH at some or all environments because they have a long distance from the origin of the biplot. Genotypes L33 and L48 performed well under all sowing dates at the Assiut location and genotypes L29 and L39 were the best under N1 and N2 sowing dates in the Nubariah location.

Grain yield (t ha^{-1}): In Fig. 6(a-b), PC1 and PC2 accounted for 59.82% (36.22 and 23.60% for PC1 and PC2, respectively) of the total variation for grain yield (t ha^{-1}) of the genotypes evaluated at eight environments. Four mega environments were obtained by GGE biplot analysis. The vertex genotypes L42, L33, L29, L25, L17, Gemiza 11, L3, L7 and L8 have high or low yields in some or all environments because they are farthest from the origin of the biplot.

DISCUSSION

The environment (E) portion was the largest among all sources of variation in most cases. Also, it could be observed that the interaction genotype × environment (GE) effects were about three times greater than wheat genotype (G) effects in all studied traits except in Days to Heading (DH). The presence of highly significant GE effects indicates the different responses of tested wheat genotypes towards environments and may suggest the possible existence of different mega environments with different top-yielding genotypes. These results are following those obtained previously[1,9,19-21]. The results suggest that sowing date affected most of the studied traits in both locations (El-Nubaria and Assuit) probably due to

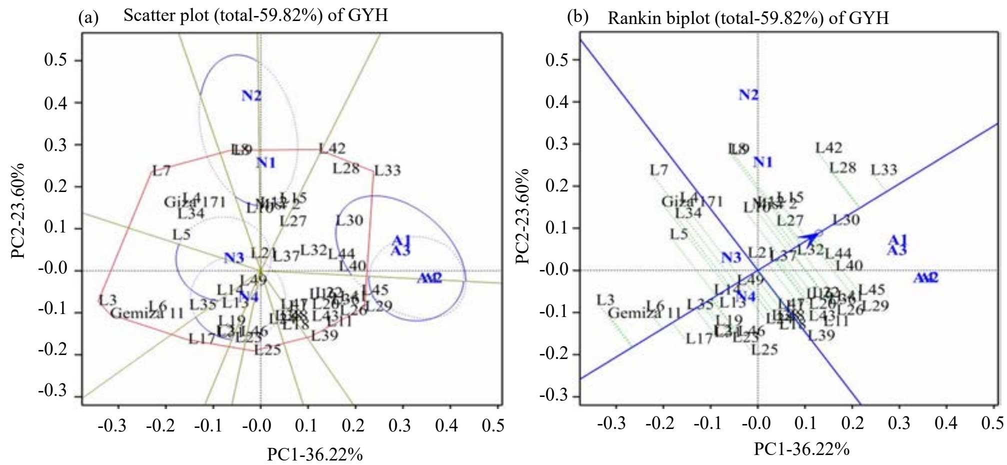

Fig. 6(a-b): Polygon view of GGE-biplot analysis for different wheat lines in the environment for biological yield ha^{-1}. (a) Scatter plot showing the mega-environments based on mean grain yield/ha of wheat genotypes evaluated across eight environment stays and (b) GGE-biplot showing the ranks of the genotypes based on both GYH and stability performance

49 CIMMYT wheat lines and three local wheat cultivars were evaluated in eight environments for grain yield ha^{-1} (BYH) showing the first and the second principal components (PC1 and PC2)

changes in both temperature and day photoperiod Similar results were obtained by authors[1,22,23]. All studied traits were affected by genotype; some genotypes positively responded to the sowing dates and show stability in grain yield (such as L33 and L26 genotypes). Some other genotypes negatively responded to spike number and other traits such as BYH and GYH (Table 5). Similar results were observed in wheat genotypes subjected to late sowing stress Ahmed *et al.*[1] and Pandey *et al.*[24]. The differences between locations caused to early flowering of the entries at the Assiut location under the late sowing date. that earliness may be affected in grain yield. According to heading Dates; the GGE biplot method revealed three mega environments, since the environments that are in the same area are similar, these environments are highly correlated, they are closer together in this biplot. Genotypes L3, L9, Misr2, L42 and L8 had greater stability levels as they were subtended by relatively low PC2 scores. These results are in agreement with the findings of researchers[1,24] and for Plant height; Genotypes L40, L25 and L2 had greater stability degree as they were subtended by relatively low PC2 score. Genotypes L17, L5 and L25 were among the undesirable genotypes (negative PC1) while L4 and L49 were the most variable genotypes having the highest PC2 projection. These results are contiguous with those found previously[24]. While genotypes Giza 171, L43, L49 and other genotypes were the most stable entries as they were subtended by relatively low PC2 score for 1000 kernel weight. These results are following those obtained by researchers[24,25]. Spikes number (m^{-1}): The vertex entries were Misr 2, L39, L28, L7 and Gemiza 11 which were the best or worst in some or all environments because they are farthest from the origin of the biplot8. But biological yield; the entries L11 and L22 were the best under N4 and genotypes L1, Giza 171, Gemiza 11, Misr 2 and L34 were the best for the N3 environment. Furthermore, entries L39, L41, L43 and other genotypes were the most unstable genotypes, while entries L4, L19, L47, L34 and Gemiza 11 were the most stable genotypes for BYH across environments. These results are in line with the findings of authors[24]. Grain yield per plant; they have specifically adapted genotypes to the environments that lie within their respective sector in the polygon view of the GGE-biplot. L33, L30, L44, L40 and L45 were the highest yielding genotypes at the Assiut location. Genotypes L14, L49, L13 and L35 were the best under N3 and N4 environments. Genotypes L8, L9 and L42 were the best yielding entries at N1 and N2 environments. Furthermore, the genotypes L8, L9, L42, L7, L29, L39 and L25 were the most unstable genotypes across environments because they are having to mean scores greater than the average environment coordinate point. While genotypes L30, L32, L37, L21, L27 and L33 were the most stable genotypes as they were subtended by relatively low PC2 scores. These results are following the findings of[1,24,26].

The results of the study discovered significant phenotypic diversity of wheat genotypes. Furthermore, this diversity among wheat genotypes could be related to different plant responses to locations and sowing dates at each location. Therefore, these promising wheat genotypes could be potentially utilized for the introgression of adaptive traits, which may be found in extreme environments[27]. The biplot method was first recommended by Yan *et al.*[28] and allowed easy and better assessment of correlations between the traits in each environment. Evaluating GEI using the GGE biplot approach was appropriate for the datasets in isolating high-yielding and stable genotypes for late sowing dates and overall environments as well. Different mega-environments were observed based on the investigated trait.

CONCLUSION

GGE biplot as a statistical strategy was used to gain insights into the phenotypic performance of forty-nine CIMMYT lines and three local cultivars of wheat (*Triticum asetivum* L.) for traits of grain yield and its attributes evaluated across different environments in Egypt. Variation among the tested Genotypes (G), Environments (E) and GE interactions was highly significant for all studied traits. The present study has identified the presence of four mega environments for grain yield in each location for the two sowing dates L33, L30, L44, L40 and L45 were the highest yielding genotypes at the Assiut location (under normal and late sowing dates). Genotypes L14, L49, L13 and L35 were the best under N3 and N4 environments. Genotypes L8, L9 and L42 were the best yielding entries at N1 and N2 environments. Overall environments, L33, L8, L42, L28 and L26 were the most stable high yielding genotypes based on STI.

SIGNIFICANCE STATEMENT

This study discovers the GGE-biplot analysis that can be beneficial for identifying high yielding and stable wheat genotypes under late sowing dates under different environmental conditions in Egypt. This study will help the wheat breeders to classify wheat genotypes according to the suitable environment and recommended high yielding genotype(s) to use by farmers in each location.

REFERENCES

1. Ahmed, A.A., M.B. Tawfelis, M.A. Sayed, R.E. Mahdy and M.O. Mostafa, 2020. Stability analysis of bread wheat genotypes for heading time and grain yield using AMMI model. Assiut J. Agric. Sci., 51: 24-42.
2. Hays, D., E. Mason, J.H. Do, M. Menz and M. Reynolds, 2007. Expression Quantitative Trait Loci Mapping Heat Tolerance During Reproductive Development in Wheat (*Triticum aestivum*). In: Wheat Production in Stressed Environments, BuckJ. H.T., E. Nisi and N. Salomón (Eds.)., Springer, pp: 373-382.
3. Abdelmageed, K., X.H. Chang, D.M. Wang, Y.J. Wang, Y.S. Yang, G.C. Zhao and Z.Q. Tao, 2019. Evolution of varieties and development of production technology in Egypt wheat: A review. J. Integr. Agri., 18: 483-495.
4. Laitinen, R.A.E. and Z. Nikoloski, 2018. Genetic basis of plasticity in plants. J. Exp. Bot., 70: 739-745.
5. Khan, M.A.U., F. Mohammad, F.U. Khan, S. Ahmad, M.A. Raza and T. Kamal, 2020. Comparison among different stability models for yield in bread wheat. Sarhad J. Agric., 35: 282-290.
6. Okuyama, L.A., L.C. Federizzi and J.F.B. Neto, 2005. Grain yield stability of wheat genotypes under irrigated and non-irrigated conditions. Braz. Arch. Biol. Technol., 48: 697-704.
7. Van Eeuwijk, F.A., D.V. Bustos-Korts and M. Malosetti, 2016. What should students in plant breeding know about the statistical aspects of genotype × environment interactions? Crop Sci., 56: 2119-2140.
8. Gauch, H.G., 2006. Statistical analysis of yield trials by AMMI and GGE. Crop Sci., 46: 1488-1500.
9. Yan, W. and M.S. Kang, 2003. GGE Biplot Analysis: A Graphical Tool for Breeders, Geneticists and Agronomists. CRC Press, New York, USA., ISBN 13: 9780849313387, Pages: 288.
10. Yan, W., 2014. Crop Variety Trials: Data Management and Analysis. John Wiley and Sons, Pages: 351.
11. Sharma, M., R. Ghosh, R. Telangre, A. Rathore and M. Saifulla *et al.*, 2016. Environmental influences on pigeonpea-*Fusarium udum* interactions and stability of genotypes to fusarium wilt. Front. Plant Sci., Vol. 7. 10.3389/fpls.2016.00253.
12. Wang, Y., M.F. Mette, T. Miedaner, P. Wilde, J.C. Reif and Y. Zhao, 2015. First insights into the genotype–phenotype map of phenotypic stability in rye. J. Exp. Bot., 66: 3275-3284.
13. Liu, G., Y. Zhao, V. Mirdita and J.C. Reif, 2017. Efficient strategies to assess yield stability in winter wheat. Theor. Appl. Genet., 130: 1587-1599.
14. Ali, M.B., A.N. El-Sadek, M.A. Sayed and M.A. Hassaan, 2015. AMMI biplot analysis of genotype × environment interaction in wheat in Egypt. Egypt. J. Plant Breed., 19: 1889-1901.
15. Yan, W. and N.A. Tinker, 2006. Biplot analysis of multi-environment trial data: Principles and applications. Can. J. Plant Sci., 86: 623-645.
16. Payne, R.W., D.A. Murray, S.A. Harding, D.B. Baird and D.M. Soutar, 2011. Introduction to GenStat for Windows. 14th Edn., Hertfordshire: VSN International.

17. Yan, W., 2001. GGEbiplot-A windows application for graphical analysis of multi environment trial data and other types of two-way data. Agron. J., 93: 1111-1118.
18. Lawal, B., 2014. Applied Statistical Methods in Agriculture, Health and Life Sciences. 1st Edn., Springer International Publishing, Switzerland, ISBN-13: 978-3-319-37834-3, Pages: 799.
19. Rashid, M.H., S.C. Samanta, P. Biswas, M.A. Mannan and A.K.M.M. Zaman, 2004. Performance of thirty wheat genotypes under late sown conditions in Southern region of Bangladesh. Asian J. Plant Sci., 3: 286-289.
20. Mohammadi, R. and A. Amri, 2012. Analysis of genotype × environment interaction in rain-fed durum wheat of Iran using GGE-biplot and non-parametric methods. Can. J. Plant Sci., 92: 757-770.
21. Lozada, D.N. and A.H. Carter, 2020. Insights into the genetic architecture of phenotypic stability traits in winter wheat. Agronomy, Vol. 10. 10.3390/agronomy10030368.
22. Irfaq, M., T. Muhammad, M. Amin and A. Jabbar, 2005. Performance of yield and other agronomic characters of four wheat (*Triticum aestivum* L.) genotypes under natural heat stress. Int. J. Bot., 1: 124-127.
23. Pandey, G.C., H.M. Mamrutha, R. Tiwari, S. Sareen and S. Bhatia *et al*., 2015. Physiological traits associated with heat tolerance in bread wheat (*Triticum aestivum* L.). Physiol. Mol. Biol. Plants, 21: 93-99.
24. Mohammadi, R., M. Armion, D. Sadeghzadeh, A. Amri and M. Nachit, 2011. Analysis of genotype-by-environment interaction for agronomic traits of durum wheat in Iran. Plant Prod. Sci., 14: 15-21.
25. Ali, M.M.A., 2017. Stability analysis of bread wheat genotypes under different nitrogen fertilizer levels. J. Plant Prod., 8: 261-275.
26. Poudel, M.R., S. Ghimire, M.P. Pandey, K. Dhakal, D.B. Thapa and H.K. Poudel, 2020. Yield stability analysis of wheat genotypes at irrigated, heat stress and drought condition. J. Biol. Today's World, Vol. 9.
27. Stephen, A., Y.T. Antonia, T. Patrick, B.A. Kingsley and A.A. Richard, 2016. Genetic diversity in lowland, midaltitude and highland African maize landraces by morphological trait evaluation. Afr. J. Plant Sci., 10: 246-257.
28. Yan, W., J. Fregeau-Reid, D. Pageau, R. Martin and J. Mitchell-Fetch *et al*., 2010. Identifying essential test locations for oat breeding in Eastern Canada. Crop Sci., 50: 504-515.