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Early Maturing Wheat Genotypes to Cope with Climate Changes

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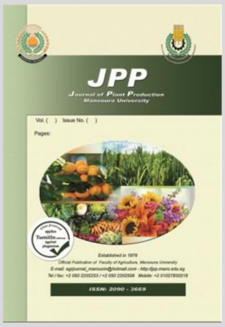

ABSTRACT

A field experiment was conducted to study the effect of climate changes on earliness and yield characteristics of bread wheat at Sakha Agricultural Research Station, Kafrelsheikh, Egypt during 2017/2018 and 2018/2019 seasons. Climate change represented by four sowing dates with one month interval starting from 5th November to 5th \February. The results showed that the first and second sowing dates recorded maximum values for all studied traits while, the fourth sowing date was the least one. The highest values for grain yield were recorded for Lines 1, 6 and 4. Interaction effects showed that the three Lines 1, 6 and 4 produced the highest grain yield under the four sowing dates with superiority of Line 1. Stability analysis showed that Lines 1, 4 and 6 exceeded the average grain yield. Generally, most early-maturing genotypes had low heat susceptibility index (HSI) under late sowing. The studied genotypes can be classified into two groups. First group, climate change tolerant(wide adapted and grain yield stable across the tested environments) consisted of the early maturing Lines 1 and 4 where they recorded low HSI under early and late sowing. Second group, climate changes sensitive (tolerant to early sowing but sensitive to late sowing and vice versa) where it can be classified based on their HSI estimates to two subgroups. Subgroup one, tolerant to early sowing but sensitive to late sowing, include the latest genotype Misr2. Subgroup two, sensitive to early sowing but it is tolerant to late sowing; include the relatively early maturing Line6

***Keywords**: Bread wheat, Early maturing, Climate changes, Stability analysis.*

INTRODUCTION

Cereal crops constitute a major global human food source among them *Triticum aestivum* L. It is an important crop, it cultivated on about 220 million hectares worldwide, and provides one fifth of the total needs of the global population (FAO 2019). It is one of the central pillars of food security, supplying 20% of total calories and a similar portion of the total protein to the world's population (Nazim Ud Dowla *et al.* 2018). In Egypt, there is a considerable gap between wheat consumption and production. This gap is continuously increasing due to steady increases in the country population with limited cultivated areas.

The agricultural sector is particularly exposed to climate variability. Climate changes have a profoundly adverse effect on agriculture production (Quan *et al.* 2019). It is expected to severely affect cropping systems and food production in many parts of the world unless local adaptation can ameliorate these impacts (Rodríguez *et al.* 2019). The severity of climate changes conditions decreased the average yield of wheat from 3% to 17% worldwide (Xie *et al.* 2018). Wheat breeders are under pressure to improve and develop new cultivars that have higher yielding, more nutritious, pest and disease resistant and climate-smart (Hickey *et al.* 2019).

In Egypt, bread wheat breeding program focused on developing early maturing and heat tolerant wheat lines.

Some advanced early maturing wheat genotypes were developed for optimum as well as for late sowing conditions. Early maturity to escape high temperature stress has been suggested as an excellent crop adaptation approach in regions suffering from terminal and continual high temperature stress (Mondal *et al.* 2013 and 2016). Mansour *et al.* (2017) reported that, early-heading genotypes are usually preferred over late ones, because earliness is an escape strategy. Flowering time and plant stature are important phenological and agronomical traits for adaptation as well as yield potential and yield stability (Thobeka *et al.* 2017). In addition, early maturity is highly desirable characteristic in grain crops, often extending their area of adaptation, permitting more than one crop per season and escaping hazards occurring at the time of maturity (Patel and Monpara 2007, Monpara and Patel 2010 and Kalariya and Monpara 2014).

Identifying stable, high-yielding genotypes is vital for food security (Zhongfu *et al.* 2018). The relative performance of yield traits under heat-stressed and non-stressed environments has been widely used as an indicator to identify heat-tolerant wheat genotypes (Sharma *et al.* 2016). The variation that cannot be explained directly by genotypic or environmental components is considered as genotype × environment interaction (GEI) (Warzecha *et al.* 2011). GEI occurs when the genotypes respond differently across environments. It is considered one of the main factors limiting progress in breeding and, hence, in agricultural production (Esuma *et al.* 2016 and Cuevas *et al.* 2017). A widely statistical univariate method for quantifying GEI, is joint regression analysis (JRA), because it is simple and provides useful information on the stability of genotypes (Rharrabti *et al.* 2003). According to this model, stable genotypes present high yield, a slope, b, close to 1, and a deviation from regression, S^2d, close to zero (Eberhart and Russell 1966).

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Using suitable sowing dates and promising cultivars is very important to increase the productivity of wheat (Wahid *et al.* 2017). Late-sown genotype takes less number of growing degree days due to which yield components decrease and hence the economic yield suffers negatively (Inamullah *et al.* 2007 and Menshawy *et al.* 2015). An optimum sowing date positively impacts the grain yield of wheat, causing better adjustment to the physiology, phenology and environmental conditions (Ribeiro *et al.* 2009). In addition, the optimum sowing date also affects water, temperature and solar radiation available for the crop (Silva *et al.* 2014). In late planting, the wheat variety should be short duration that may escape from high temperature at the grain filling stage (Menshawy 2007, Talukder *et al.* 2014 and Menshawy *et al.* 2015). Ansary *et al.* (1989) reported that delay sowing suppressed the yield, caused by reduction in the yield contributing traits like the number of tillers and number of grains per spike.

The genotypic response of wheat to planting dates varies for yield contributing characters due to different genetic potential (Menshawy *et al.* 2015, Wahid *et al.* 2017 and Ray and Ahmed 2019). Grain yield improvement is one of the most challenging objectives in wheat breeding due to being a complex trait, significantly depending on the number of spikes per unit area, number of kernels per spike and kernel weight (Flohr *et al.* 2017 and Li *et al.* 2019).

However, grain shape, spike architecture, plant height and flag leaf related traits can also affect grain yield through effects on photosynthetic intensity, grain filling and dry matter translocation (Gao *et al.* 2017). Brdar *et al.* (2008) reported that grain weight, a component of yield in wheat, is a result of the grain filling process which is defined by two parameters: grain filling duration and grain filling rate. Grain yield potential increases when cultivars have physic development adapted to the environment (Harris 2015).

Early-maturing cultivars grow faster than late-maturing cultivars (Angus, 2006 and Harris, 2015).

The main objective of the present study was to evaluate the performance of early-maturing genotypes developed by Sakha Wheat Breeding Program for different natural photo thermal environments, to find out the suitable genotypes for optimum and late sowing conditions and to select the best wheat genotypes for planting under different climates conditions for Delta Region of Egypt.

MATERIALS AND METHODS

Experimental site

This investigation was conducted at the Research Farm of Sakha Agricultural Research Station, Kafrelsheikh, Egypt during 2017/18 and 2018/19 wheat growing seasons. The geographical position of the area lies between 31° 5' N latitude and 30° 56' E longitude and 7 m above sea level, in North Dellta. Weather data for the experimental site during the two wheat growing seasons 2017/18 and 2018/19 is presented in Figure (1).

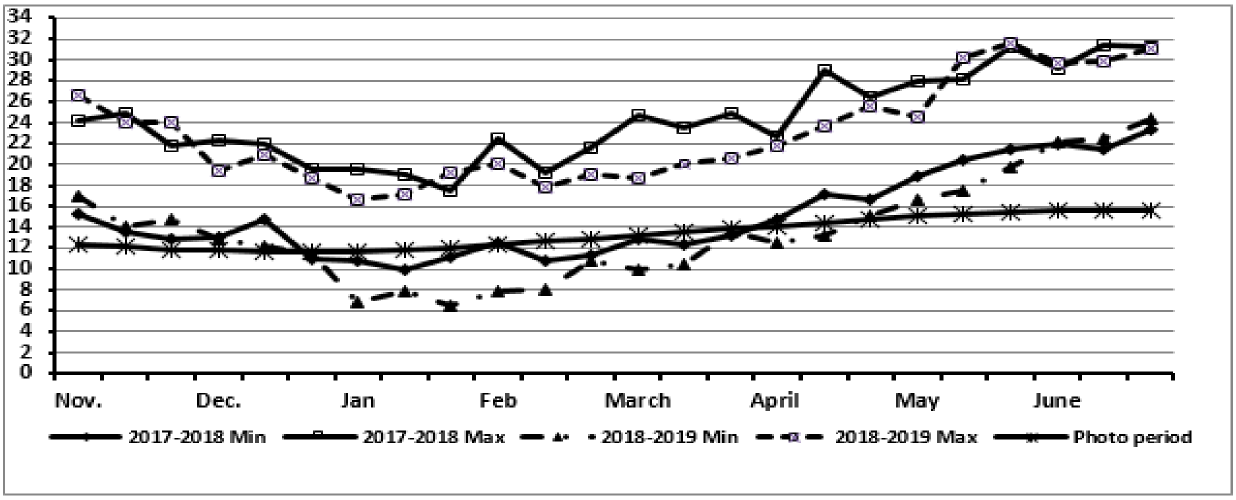


Fig. 1. Ten days mean of minimum, maximum temperature and photo period during the two wheat growing seasons (2017/18 and 2018/19) at Sakha Agricultural Research Station.

Experimental design and treatment

The experiment was laid out in a Randomized Complete Block Design with four replications. The plant materials comprised of eight bread wheat genotypes (six early maturing promising lines and two commercial cultivars). Name and pedigree of these genotypes are shown in Table (1). These genotypes were evaluated under four different sowing dates i.e., 5th of November (early sowing), 5th of December (close to normal sowing), 5th of January (late sowing) and 5th of February (very late sowing). Each sowing date was considered as a separate experiment. The area of each plot was 4.2 m^2 and consisted of six rows, 3.5 m long and 20 cm apart. Planting was done manually using sowing rate of 400 seeds m^{-2}. All the agricultural practices were applied as recommended for wheat production in North Delta Region.

Data collection and studied characters

The central four rows were used for data collection. The studied characters consisted of earliness and agronomic components. The earliness components were: the number of days to heading (DH) and to maturity (DM), grain filling period (GFP, equal to the number of days from heading to maturity) and grain filling rate (GFR, equal to grain yield divided by GFP). The agronomic characters were taken on plant height (PH), number of spikes m^{-2} (Sm^{-2}), number of kernels per spike (KS^{-1}), 1000-kernel weight (TKW), grain yield (GY), straw yield (SY) and harvest index (HI). Grain yield was measured for the four central rows to eliminate the border effect of each plot and converted into ton per hectare. In addition, the number of days to heading also was expressed as growing degree days (GDD). The accumulated heat unit system is based on the idea that plants have definite temperature requirements to attain certain phenological stage. The GDD were calculated according to Gomez and Richards 1997, in which $GDD = \sum[(T_{\max i} + T_{\min i})/2 - T_b]$ where $T_{\max i}$ and $T_{\min i}$ are the maximum and minimum daily air temperature on the ith day and T_b is the base temperature below which the rate of development is assumed to be zero. The weather data during 2017/18 and 2018/19 are illustrated in Figure (1). These data were collected from the Central Laboratory for Agricultural Climate Meteorological Station, Agricultural Research Center, Ministry of Agriculture and Land Reclamation.

Table 1. Name, pedigree, selection history and number of days to heading (DH) and to physiological maturity (DM) of the tested wheat genotypes.

Abbr.	Name/Pedigree	Selection history	DH‡	DM
Line 1	SIDS1/ATTILA//GOUMRIA-17	S. 16498-042S-013S-21S -0S	91	145
Line 2	BL1133 /3/ CMH 79A.955*2/ CNO 79 // CMH 79A.955 / BOW"s"/4/GIZA 164/ SAKHA 61 /5/ MAI "S" / PJ // ENU "S" /3/ KITO / POTO. 19 // MO / JUP /4/ K 134 (60) / VEE	S. 16583-5S-1S-2S -0S	80	137
Line 3	GIZA168/5/MAI'S'/PJ//ENU'S'/3/KITO/POTO.19//MO/JUP/4/K134 (60)/VEE/8/KAUZ/ATTILA/7/KVZ/4/CC/INIA/3/CNO//ELGAU/SON6 4/5/SPARROW'S'/BROCHIS'S'/6/BAYA'S'/IMU	S.16959-6S-1S-0S-0S	79	141
Line 4	MINO/6/SAKHA12/5/KVZ//CNO 67/PJ62/3/YD'S'/BLO'S'/4/ K134(60)/VEE	S. 16869-010S-07S-2S -0S	86	145
Line 5	SHANDAWEEL1/4/BOW'S'/VEE'S'//BOW'S'/TSI/3/BANI SUEF1	S.16818-025S-03S-2S-0S	82	141
Line 6	MINO/6/SAKHA12/5/KVZ//CNO67/PJ62/3/YD"S"BLO"S"/4/K134(60)/ VEE	S.16869-010S-07S-1S-2S-0S	86	143
	Sids 4	Check	85	141
	Misr 2	Check	106	156

‡, Source: Wheat Research Department, national yield trials data, optimum sowing date, season 2016/2017.

The heat susceptibility index (HSI) was used as a measure of heat tolerance in terms of minimization of the reduction in yield caused by unfavorable versus favorable environments. HSI was calculated in two direction, early heat stress (early sowing versus normal sowing), and late heat stress (very late sowing versus normal sowing). HSI was calculated for each genotype according to the formulae of Fisher and Maurer (1978): $HSI = (1 - y_h/y_p)/H$. Where: y_h = mean yield in heat environment, y_p= mean yield in normal condition (potential yield), H = heat stress intensity = 1 - (y_h of all genotypes / y_p of all genotypes). Stability analysis of grain yield of the used genotypes was done for the eight environmental conditions (four sowing dates and two years). Yield stability was analyzed similar to that suggested by Eberhart and Russell (1966).

Statistical analysis:

The collected data for all variables were statistically analyzed using "MSTAT-C" statistical package microcomputer program (MSTATC 1990) via analysis of variance using randomized complete block, one factor model, combined across years and/or sowing dates. The means of sowing dates and genotypes were obtained and differences were assessed with LSD at 5% level of probability and Duncan multiple range test (Duncan 1955).

RESULTS AND DISCUSSION

Analysis of variance

Mean square for the studied earliness and yield characteristics is presented in Tables 2 & 3. The combined analyses showed significant differences ($P \leq 0.01$) due to years, sowing dates and genotypes for all the studied traits. Significant differences due to years reflected the differences in climate conditions during the two growing seasons (Fig.1). Moreover, the observed variation in the earliness characters (due to genotypes) among sowing dates can be considered as combination effect of planting date and weather differences. More importantly, the differences due to the interactions between genotypes and each of years and sowing dates and also among genotypes, sowing dates and years were significant for all the studied characters. The largest proportion of mean squares was detected due to year for DH, DM, GFR, KS^{-1} and GY; due to sowing date for GFP, PH, TKW, SY and HI. It was very clear that both sowing date and genotypes shared almost equal and major portion for variation in GDD. The obtained results suggested that the differences among wheat genotypes were adequate to provide a possibility to characterize the effect of sowing dates. These results coincide with the findings of Talukder *et al.* (2014), Menshawy (2015), Al-Otayk (2019) and Hagras (2019).

Year and sowing date effect

All studied characters recorded higher values in the second year comparing to the first except for straw yield. (Tables 4 & 5) , representing seasonal differences. In this respect, the first season had higher minimum and maximum temperature during most of the growing period compared to the second one (Fig.1). In general, the first and second sowing dates (5th November and 5th December) recorded the highest values for all studied traits. The second sowing date recorded the highest mean effects for DH, GDD, GFR, PH, KS^{-1}, SY and GY. These results may be due to the appropriate temperature at different developmental stages and consequently increased net assimilation rate. Meanwhile, the first sowing date recorded the highest values for DM, GFP and TKW. On the other hand, the values for both SM^{-2} and HI did not differ significantly under both the first and second sowing date. In general, the least values for all studied characters were recorded under the fourth sowing date (5th February).

Thus the late-sowing recorded the least number of DH and GDD which negatively affected yield components and hence the economic yield. Many researchers reported that an optimum sowing date positively impacts the grain yield of wheat, causing better adjustment to the physiology, phonology and environmental conditions (Menshawy *et al.* 2015, Wahid *et al.* 2017, Hagras, 2019 and Ray and Ahmed, 2019). Different reasons were reported for grain yield reductions under heat stress, especially during grain filling period. Riaz- Ud-Din *et al.* (2010) reported the reduction to be due to the reduction in tillers m^{-2} and grain weight and shortened period of heading and maturity and grain filling period, Zhao *et al.* (2008) to the reduction in activities of key enzymes involved in starch accumulation, Cossani and Reynolds (2012) to abnormal anther formation in high percentage of florets and Hedhly *et al.* (2009) to the effect on pollen chemical composition, metabolism, morphology, quantity and pollen tube growth rate.

Genotype effect

Genotype effects were highly significant for all traits, when the data were pooled across planting dates and years. Therefore; the comparisons between genotypic means are valid. Lines 2 and 3 recorded the least number of DH, GDD and DM and the longest GFP with insignificant differences between them for the four traits.

Both Lines 2 and 3 reached heading after accumulation of the least thermal units (1002 and 996 units, respectively) followed by Line 5, 1026 units. The shortest GFP was recorded for Misr 2 (46 days) followed by Sids 4 and Line 1. The highest GFR was recorded for Line 1 (160.5 kg day^{-1} ha^{-1}) followed by Line 6, Misr 2 and Line 4. Based on the genotype means in Table 4 the early heading genotypes had long grain filling period possessed low grain filling rate, while the reverse was found for late ones. These results are in accordance with the findings of Menshawy (2007) who reported that the genotypes which had long grain filling periods showed low grain filling rate in general.

Misr 2 recorded the highest values for PH, SM^{-2}, and KS^{-1} and SY. The differences were insignificant among Lines 2, 4, 6 and Sids 4 in PH; Lines 3, 4, and 6 in SM^{-2}; Lines 1, 4, and 6 in number of KS^{-1}; Lines 4, 5 and 6 in TKW; Lines 4 and 6 in SY. Line 1 was superior over all genotypes for GY. The highest value for both GY and HI were recorded for Line 1, 6, and 4 (8.34, 7.85 and 7.54 t ha^{-1} for GY and 38.4, 37.8 and 35.7 % for HI, respectively). Line 1, 6, and 4 which had the highest value for both GY and HI belong to early maturing genotypes comparing with commercial cultivar, Misr 2. These results coincide with the findings of Mondal *et al.* (2016) who reported that, early maturing genotypes are an excellent crop adaptation approach in regions suffering from terminal and continual high temperature stress. Although both Lines 4 and 6 belong to the same cross and did not differ in most traits but Line 6 was superior to Line 4 in GY and HI. The mean performance of individual genotype indicated that different genotypes manifested their superiority for different characters. Many researchers found significant differences among genotypes for earliness and agronomic characters (Talukder *et al.* 2014, Menshawy *et al.* 2015, Wahid *et al.* 2017, Hagras, 2019 and Al-Otayk 2019).

Table 2. Mean squares for the number of days to heading (DH), growing degree days (GDD), days to maturity (DM) gain filling period (GFP) and rate (GFR) and plant height (PH) for eight wheat genotypes grown under four sowing dates during 2017/2018 and 2018/2019 seasons.

SOV	df	DH	GDD	DM	GRP	GFR	PH
Years	1	5881.0 **	41044.2**	19026.8 **	3743.9 **	175189.3 **	2990.7 **
Sowing dates	3	4643.1 **	424092.**	18600.0 **	14487.4 **	56414.7 **	8959.0 **
Y*SD	3	445.0 **	7566.0**	136.8 **	654.5 **	28672.4 **	1081.3 **
Rep (SD*Y)	24	3.3 **	6488.9**	2.6 **	3.9 **	240.0 **	22.8 **
Genotypes	7	1771.0 **	426799.3**	608.9 **	332.3 **	14536.6 **	2034.5 **
Y*G	7	14.2 **	2022.8**	7.8* **	11.4 **	2922.5 **	68.2 **
SD*G	21	165.2 **	26687.9**	57.1 **	35.7 **	1724.8 **	115.3 **
Y*SD*G	21	17.0 **	5056.7**	8.4 **	7.1 **	468.2 **	28.1 **
Error	168	4.1	610.5	3.0	1.4	120.7	12.1
CV%		2.9	2.28	1.4	2.2	8.5	3.5

*** and** : significant at 0.05 and 0.01 levels of probability , respectively.**

Table 3. Mean squares for number of spikes per m^{2} (SM^{-2}), kernels per spike (KS^{-1}), thousand kernels weight (TKW), straw yield (SY), grain yield (GY) and harvest index (HI) for eight wheat genotypes grown under four sowing dates during 2017/2018 and 2018/2019 seasons.

SOV	df	SM^{-2}	KS^{-1}	TKW	SY	GY	HI
Years	1	2799765.6 **	3632.3 **	2249.1 **	19.1 **	672.8 **	1054.2 **
Sowing dates	3	87458.1 **	3571.4 **	2786.4 **	701.7 **	261.4 **	1573.4 **
Y*SD	3	82635.7 **	409.3 **	170.5 **	75.0 **	17.4 **	1537.0 **
Rep (SD*Y)	24	6710.1*	55.7*	27.2ns	5.4 **	0.8 **	9.9*
Genotypes	7	119851.4 **	1199.0 **	1022.8 **	135.2 **	31.7 **	362.8 **
Y*G	7	30512.7 **	147.6 **	179.3 **	18.1 **	4.6 **	65.4 **
SD*G	21	7468.4 **	204.9 **	57.9 **	34.0 **	2.7 **	25.8 **
Y*SD*G	21	8362.2 **	124.3 **	56.4 **	17.7 **	1.1 **	54.1 **
Error	168	4160.1	34.7	17.4	1.1	0.4	7.1
CV%		15.1	13.4	9.8	7.0	8.9	7.7

ns, * and : insignificant, significant at 0.05 and 0.01 levels of probability , respectively.**

Interaction effects

All factors except genotypes and sowing dates were considered random. Therefore, only the most interesting interactions, genotypes × sowing dates, will be discussed. Interaction effects presented in Figures (2 and 3) showed that the least DH and GDD were recorded for Lines 2 and 3 under the first sowing date while, Misr 2 recorded the highest values for DH under the second sowing date and for GDD under the first sowing date. The shortest DM were recorded for Lines 2 and 3 and Sids 4 under the fourth sowing date, while the longest one was recorded for Misr 2 under the first sowing date. The shortest GFP was recorded for Misr 2 under the fourth sowing date while the longest one was recorded for Line 3 under the first sowing date. The highest GFR was recorded for both Line 1 and Misr 2 under the second sowing date, while the lowest one was recorded for Sids 4 and Line 3 under the forth and first sowing dates, respectively. The tallest plants were recorded for Misr 2 under the first sowing date, while the shortest one was recorded for Line 3 under the fourth sowing date. The highest SM^{-2} was recorded for Misr 2 under the second sowing date while the lowest was recorded for Sids 4 under the fourth sowing date. The highest KS^{-1} was recorded for Sids 4 under the second sowing date while the lowest one was recorded for Lines 2 and 3 under the fourth sowing date.

Table 4. Mean effects for earliness traits and plant height for eight wheat genotypes grown under four sowing dates during the two growing 2017/2018 and 2018/2019 seasons.

Treatment	DH	GDD (ºC)	DM	GFP (day)	GFR (kg/ha/day)	PH (cm)
Years						
2017/2018	64.5	1070	114.0	49.4	102.9	97.0
2018/2019	74.1	1096	131.2	57.1	155.2	103.9
F-test	**	**	**	**	**	**
Sowing dates						
Nov. 5th	63.9c	1096b	137.8a	74a	105.6c	104.5b
Dec. 5th	79.6a	1181a	133.2b	53.6b	168.5a	111.2a
Jan. 5th	72.9b	1073c	119.6c	46.7c	135.2b	102.5c
Feb. 5th	61.0d	983d	99.8d	38.9d	106.8c	83.6d
Genotypes						
Line 1	69.8b	1088b	122.6b	52.8d	160.5a	97.5c
Line 2	64.2e	1002e	119.6d	55.3a	114.9e	100.5b
Line 3	63.8e	996e	120.3cd	56.5a	102.0f	89.1e
Line 4	68.2c	1066c	122.4b	54.3c	139.7c	101.7b
Line 5	65.8d	1026d	120.1cd	54.3c	121.1d	95.6d
Line 6	67.8c	1062c	122.3b	54.5c	146.9b	100.3b
Sids 4	68.2c	1068c	120.6c	52.4d	104.8f	101.7b
Misr 2	87a	1357a	133a	46e	142.3bc	117.2a

DH: number of days to heading, GDD: growing degree days, DM: number of days to maturity, GFP: grain filling period, GFR: grain filling rate and PH: plant height.

Table 5. Mean effects for yield characters and harvest index for eight wheat genotypes grown under four sowing dates during the two growing 2017/2018 and 2018/2019 seasons.

Treatment	SM^{-2}	KS^{-1}	TKW (g)	SY (t ha^{-1})	GY(t ha^{-1})	HI (%)
Year						
2017/2018	321.7	40.4	39.5	15.4	5.23	32.3
2018/2019	530.9	47.9	45.4	14.9	8.47	36.4
Fest-t	**	**	**	**	**	**
Sowing dates						
Nov. 5th	453.1a	42.6c	51.1a	16.3b	7.75b	38.0a
Dec. 5th	460.3a	51.0a	43.5b	18.7a	9.01a	38.5a
Jan. 5th	409.8b	48.6b	39.6c	14.9c	6.36c	33.0b
Feb. 5th	382.1c	34.3d	35.6d	10.8d	4.29d	28.0c
Genotypes						
Line 1	438.5bc	46.0b	43.5b	16.7b	8.34a	38.4a
Line 2	407.8cd	36.4c	51.6a	14.8d	6.32e	33.2f
Line 3	456.2ab	38.0c	36.8d	12.6f	5.78f	34.4e
Line 4	470.8ab	43.3b	44.0b	15.8c	7.54c	35.7c
Line 5	401.7d	39.4c	45.0b	14.1e	6.59de	35.1d
Line 6	468.4ab	45.3b	45.4b	15.9c	7.85b	37.8b
Sids 4	291.9e	53.4a	40.2c	12.8f	5.54f	32.8f
Misr 2	475.3a	51.3a	33.2e	18.7a	6.85d	27.7g

SM^{-2}: number of spikes per square meter, KS^{-1}: number of grains per spike, TKW: one thousand grain weight, SY: straw yield, GY: grain yield and HI: harvest index.

The highest grain weight was recorded for Lines 2 and 5 under the first sowing date while, the lowest one was recorded for Misr 2 under the fourth date. The highest SY was recorded for Misr 2 under the first sowing date while; the lowest one was recorded for Sids 4 under the fourth sowing date. The three Lines 1, 6, and 4 produced the highest GY under the four sowing dates with superiority of Line 1 (Table 6). Meanwhile, Misr 2 produced high GY under the first and second sowing date, while its yield turned to be very low under the fourth sowing date. The highest HI was produced by Line 1 under the second, third and fourth sowing dates while, the lowest HI was produced by the cultivar Misr 2 under all sowing dates. These results revealed that the studied genotypes responded differently to different natural photo thermal environments, suggesting the importance of assessment of genotypes under different environments in order to identify the best genetic make up for a particular environment. Similar results were obtained by Talukder *et al.* (2014), Menshawy *et al.* (2015), Wahid *et al.* (2017), Al-Otayk (2019) and Hagras (2019).

Table 6. Mean of two years (2017/18 and 2018/19) grain yield and harvest index of eight bread wheat genotypes grown under for sowing dates.

Genotypes	Grain yield (t ha^{-1})				Harvest index (%)			
	Nov. 5th	Dec. 5th	Jan. 5th	Feb. 5th	Nov. 5th	Dec. 5th	Jan. 5th	Feb. 5th
Line 1	9.09	10.09	8.44	5.76	39.4	43.4	38.5	32.4
Line 2	6.88	8.51	5.84	4.05	35.8	37.1	32.3	27.4
Line 3	6.74	7.56	5.01	3.80	40.4	38.0	31.5	27.8
Line 4	8.45	9.61	7.14	4.95	40.7	39.6	35.3	27.2
Line 5	7.07	8.91	6.24	4.13	39.0	39.5	35.0	26.7
Line 6	8.06	10.18	7.70	5.47	41.3	40.9	38.5	30.6
Sids 4	6.19	8.21	4.90	2.86	35.6	37.7	30.3	27.5
Misr 2	9.50	8.99	5.60	3.30	32.2	32.0	22.3	24.1
LSD $_{0.05}$	0.59				2.60			

Stability analysis

Identifying stable, high-yielding genotypes is essential for food security. Therefore, stability of grain yield is important to ensure wheat production, particularly under climate changes and increasing adverse conditions. Therefore, yield stability could be achieved by selecting genotypes adapted to the target environment. Combined analysis of variance for grain yield showed significant effects for environments, genotypes, and their interaction (Table 7).

Table 7. Mean squares of combined analysis of variance for grain yield.

SOV	df	Mean squares	Sig.	% SS
Environments (E)	7	215.58	**	78.46
Error 1	24	0.78	-	0.97
Genotypes (G)	7	31.66	**	11.52
GEI	49	2.28	**	5.82
Error 2	168	0.37	-	3.23

**** = Significant at 0.01 levels of probability**

Environments effects accounted for the largest proportion of sums of squares, 78.46%, followed by genotypic effects (11.52%) then GEI effects captured5.82%, all terms being significant. Environmental variation was clearly dominated by the sowing date effect. Singh and Narayanan (2000) reported that if GEI is found to be significant, the stability analysis can be carried out.

Many statistical methods have been proposed for quantifying GEI, varying from univariate to multivariate models (De Leon *et al.* 2016). A widely used univariate method is joint regression analysis (JRA), because it is simple and provides useful information on the stability of genotypes (Rharrabti *et al.* 2003). According to this model, stable genotypes present high yield, a slope, *bi*, close to 1, and a deviation from regression, S^{2}d, close to zero (Eberhart and Russell 1966).

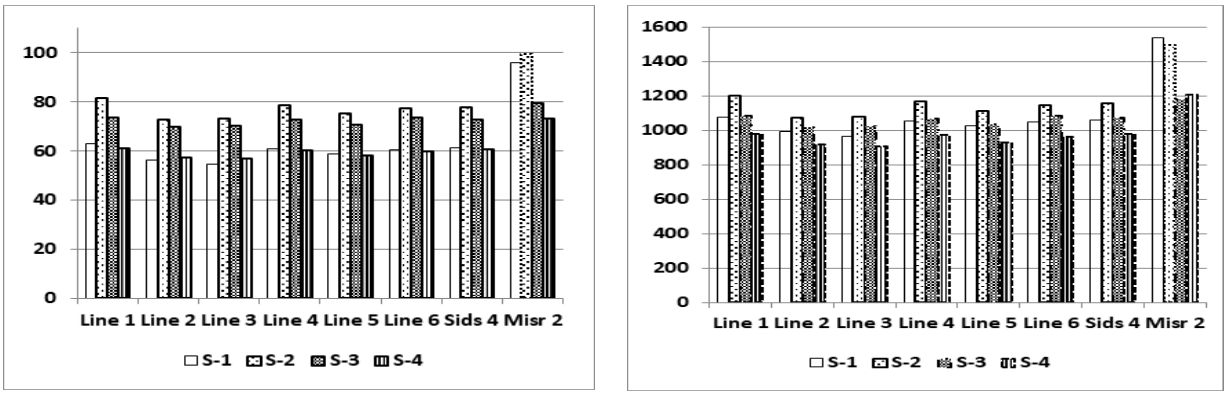
Regression slopes (*bi*) indicate overall genotypic responsiveness to the overall gradient of variation. The values of *bi* varied from 0.87 to 1.39 revealing large differences in genotypic responsiveness across environments (Table 8). The simultaneous consideration of the three stability parameters for the individual genotype revealed that Lines 1, 4 and 6 recorded the highest yield, 8.34, 7.54 and 7.85 ton ha^{-1}, over the grand mean yield with the regression coefficients 0.93, 1.09 and 0.90, respectively, and not significantly different from regression. The three genotypes (Lines 1, 4 and 6) recorded regression coefficients almost close to one, and insignificant standard deviation revealing wide adaptability and stability for grain yield across the tested environments. Similar results were also reported by Khan *et al.* (2012) and Menshawy *et al.* (2015). Due to greater value of regression coefficient (b_i > 1.0), Misr 2 is expected to give good yield under favorable environmental conditions (early sowing).

Table 8. Stability parameters for grain yield of the studied wheat genotypes across eight environments and mean values of heat susceptibility index (HIS).

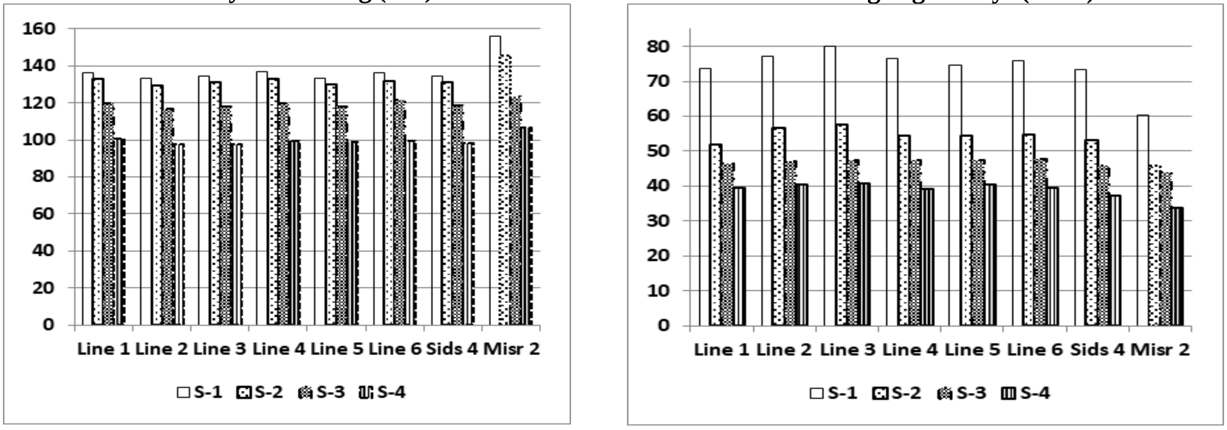
Genotypes	Mean yield (t ha^{-1})	Relative yield to average (%)	Regression coefficient (*bi*)	t-value	(S^{2}d)	HSI (Mean of two seasons)	
						Early Sowing	Late Sowing
Line 1	8.34	21.79	0.93	0.90	0.19	0.71	0.82
Line 2	6.32	-7.77	0.87	2.77	0.01	1.37	1.00
Line 3	5.78	-15.66	0.90	1.91	0.02	0.78	0.95
Line 4	7.54	10.03	1.09	1.33	0.12	0.86	0.93
Line 5	6.59	-3.84	0.99	0.25	0.02	1.48	1.02
Line 6	7.85	14.63	0.90	1.30	0.20	1.49	0.88
Sids 4	5.54	-19.12	0.93	0.64	0.45	1.76	1.24
Misr 2	6.85	-0.06	1.39	2.36	1.19	-0.41	1.21

Heat susceptibility index

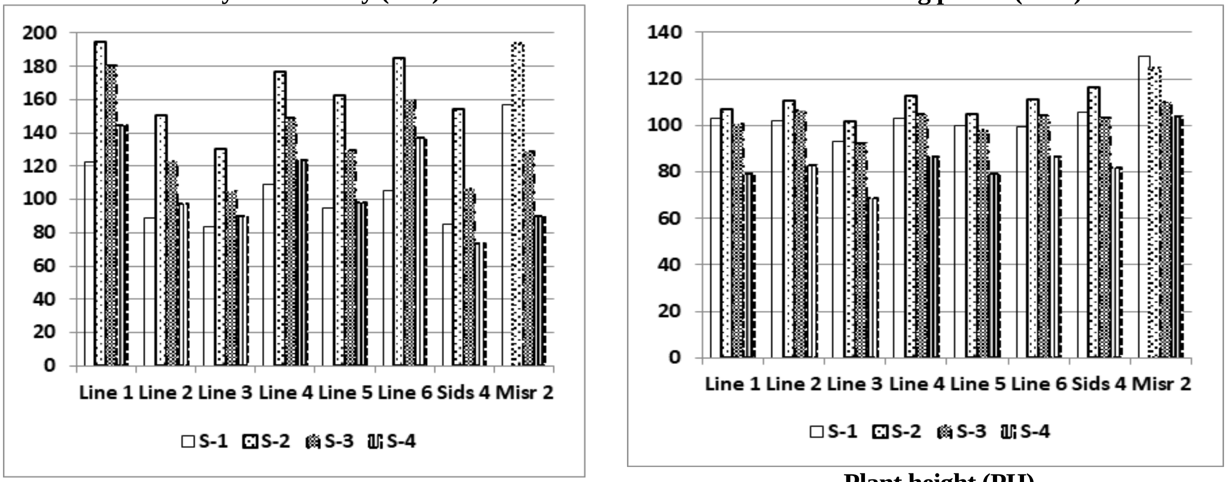
The heat susceptibility index (HSI) was used to estimate relative stress injury because it was accounted for variation in yield potential and stress intensity. Low stress susceptibility index estimate (HSI < 1) is synonymous to higher stress tolerance (Fisher and Mourer 1978). The HSI estimates ranged among genotypes from - 0.41 to 1.76 under early sowing stress and from - 0.82 to 1.24 under late sowing stress (Table 8). The early maturing genotypes, Lines 1 and 4 recorded low HSI under early and late sowing heat stress confirming the previous finding as these two lines have a wide adaptability and stability for grain yield across the tested environments. The latest genotype, Misr 2, recorded the lowest estimate of HSI (-0.41) under early sowing heat stress and high value (1.21) under late sowing heat stress, indicating that this cultivar is recommended for early sowing but sensitive to late sowing. Line 6, which was relatively early-maturing genotype, had reverse trend to Misr 2 (high estimate of HSI under early sowing heat stress and low value under late sowing heat stress, indicating that this genotype is sensitive to early sowing, but it has better performance under late sowing. In general, most early-maturing genotypes had low HSI under late sowing heat stress indicating that lines with early heading date might be more tolerant to late planting than late genotypes. Meanwhile, the late genotypes in heading date were more suitable to early planting therefore, Misr 2 might be more adapted to early sowing. These results agreed with the findings of Menshawy (2007) and Talukder *et al.* (2014) where they reported that early maturing genotypes might be more suitable for late planting. On the other hand, Menshawy (2008) reported that late genotypes in heading date more suitable to early planting. The estimates for Sids 4 were conflicting because of its susceptibility to rust diseases where late planting increased disease severity.



Days to heading (DH) **Growing degree days (GDD)**

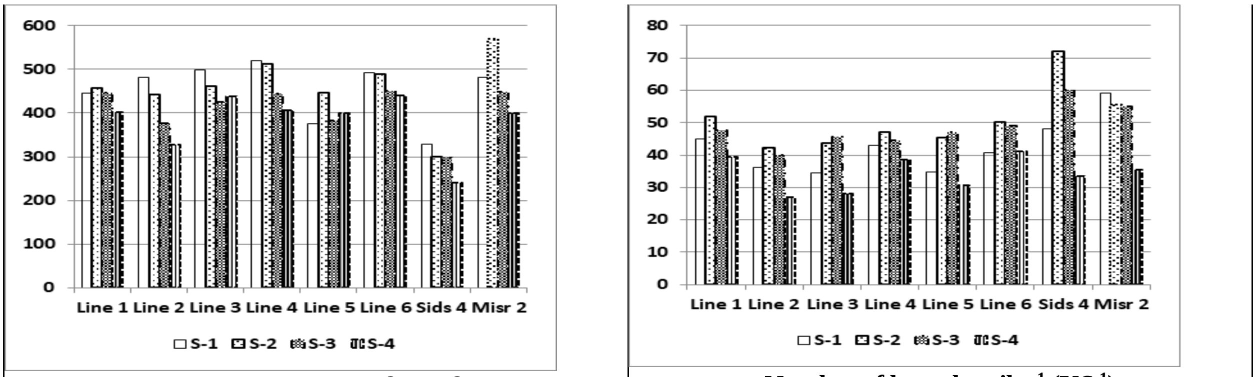


Days to maturity (DM) **Grain filling period (GFP)**



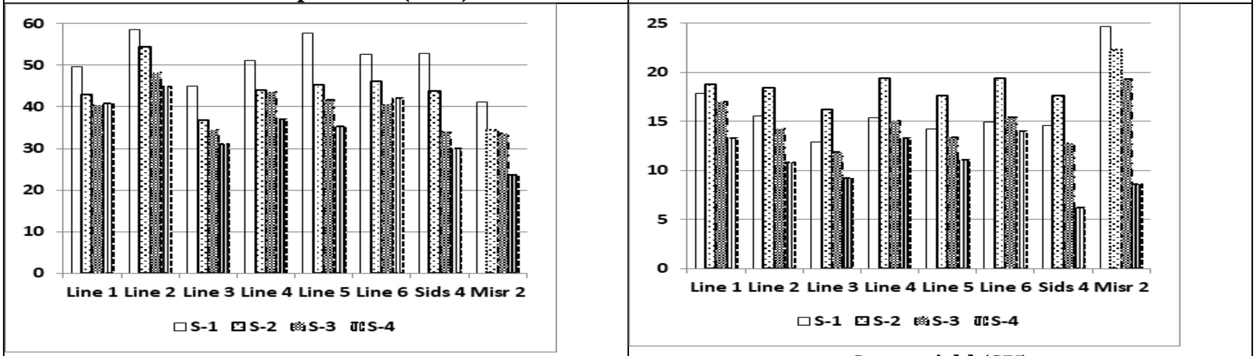
Grain filling rate (GFR) **Plant height (PH)**

Figure 2. Interaction effects for genotypes and sowing dates on earliness characters and plant height.



Number of spikes m^{-2} (SM^{-2})

Number of kernels spike^{-1} (KS^{-1})



1000 kernels weight (TKW)

Straw yield (SY)

Figure 3. Interaction effects for genotypes and sowing dates on yield components and straw yield.

CONCLUSION

Wheat planting in time around early December, in Delta is the best for getting higher yields, and even the tested early maturing lines for late sowing cannot recover the yield losses due to delay in sowing. Significant differences existed among the commercial cultivars and the new promising lines in grain yield, especially under late sowing. Therefore, wheat breeders should select those genotypes, which could compensate up to a great extent. The promising Line 1 produced higher yield, and recorded minimum yield reduction under late sowing. This line is in process to be released as a new variety.

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مجابهة التغيرات المناخية بزراعة تراكيب وراثية مبكرة النضج من القمح

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أجرى هذا البحث في محطة البحوث الزراعية بسخا ـ محافظة كفر الشيخ ـ مصر ـ خلال الموسمين 2018/2017 و 2019/2018. تهدف الدراسة الى دراسة تأثير التغيرات المناخية على صفات التبكير والمحصول لثمانية تراكيب وراثية من القمح. تمثل التراكيب الوراثية ست سلالات مبشرة مبكرة النضج بالإضافة إلى صنفي المقارنة سدس 4 ومصر 2 ومثلت التغيرات المناخية بأربعة مواعيد زراعة بفاصل زمنى شهر حيث تم زرعة الموعد الأول من التجربة في الخامس من شهر نوفمبر و زرعت فى الموعد الرابع في الخامس من شهر فبراير. أوضح تحليل التباين المشترك وجود اختلافات معنوية راجعة إلى كل من موسمي الزراعة ومواعيد الزراعة والتراكيب الوراثية. سجل موعدا الزراعة الأول والثاني (الخامس من نوفمبر والخامس من ديسمبر) اعلى القيم لجميع الصفات تحت الدراسة ، بينما سجل موعد الزراعة الرابع (الخامس من فبراير) أقل القيم. كما سجل موعد الزراعة الأول أعلى القيم لصفات عدد الأيام حتى النضج وفترة امتلاء الحبوب ، ووزن الألف حبة ، بينما سجل موعد الزراعة الثاني أعلى القيم لصفات عدد الأيام حتى طرد السنابل والحرارة المتجمعة ومعدل امتلاء الحبوب وارتفاع النبات وعدد حبوب السنبلة وكل من محصولي القش والحبوب. أظهرت النتائج تفوق السلالة رقم 1 على جميع التراكيب الوراثية فى صفة محصول الحبوب حيث سجلت السلالات أرقام 1 و 6 و 4 أعلى قيم لمحصول الحبوب. سجلت السلالات أرقام 2 و 3 اقل القيم للحرارة المتجمعة للوصول لطرد السنابل يليها السلالة رقم 5. سجلت السلالتان أرقام 2 و 3 أطول فترة لامتلاء الحبوب، بينما سجل الصنف مصر 2 اقصر فترة لامتلاء للحبوب، يليه الصنف سدس 4 والسلالة رقم 1. سجلت السلالة رقم 1 أعلى معدل امتلاء للحبوب يليها السلالة رقم 6 ثم الصنف سدس 4. أوضح التفاعل ان السلالات أرقام 1 و 4 و 6 سجلت اعلى محصول للحبوب تحت مواعيد الزراعة الأربعة ، حيث كان محصول السلالة رقم 1 هو الأعلى ، وعلى العكس من ذلك سجل الصنف مصر 2 أعلى محصول له تحت موعدي الزراعة الأول والثاني فقط ، كما أوضح تحليل الثبات تميز السلالات أرقام 1 و 4 و 6. وبصفة عامة سجلت التراكيب الوراثية مبكرة النضج أقل تقديرات لدليل الحساسية للحرارة وطبقا لنتائج هذه الدراسة يمكن تقسيم التراكيب الوراثية تحت الدراسة إلى مجموعتين. المجوعة الأولى تتميز بالاقلمة الواسعة والثبات في محصول الحبوب تحث البيئات محل الدراسة ، وتمثلها السلالتان أرقام 1 و 4 ، حيث سجلت قيما منخفضة لدليل الحساسية للحرارة تحت الإجهاد الحرارى لكل من الزراعة المبكرة والمتأخرة جدا. المجموعة الثانية وهى حساسة للتغير المناخي (قوية التحمل لظروف الزراعة المبكرة بينما تكون حساسة للزراعة المتأخرة والعكس). ويمكن تقسيمها حسب تقديرات دليل الحساسية للحرارة إلى مجموعتين فرعيتين. تحت المجوعة الأولى قوية التحمل لظروف الزراعة المبكرة بينما تكون حساسة للزراعة المتأخرة ويمثلها الصنف مصر 2. تحت المجموعة الثانية قوية التحمل للزراعة المتأخرة ، ولكنها حساسة جدا للزراعة المبكرة وتشمل السلالة رقم 6.