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Genotype x Environment Analysis of Egyptian Faba Bean Cultivars and their Resilience to Different Sowing Dates in Egypt

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ABSTRACT

The exploring unpredictable effects of climatic changes as sowing dates across different seasons under Egyptian conditions on performance of faba bean cultivars will be of great benefit for sustainable production and food security. The determination of G x E interaction and stability in performance across different sowing dates is an important goal for breeding climate-resilient cultivars. Therefore, the present studies evaluated six faba bean cultivars possessed variable genetic backgrounds under four sowing dates extended from Mid-Oct to Dec of 2017/2018 and 2018/2019 seasons at Giza. The stability analyses of performance across the generated eight environments were performed using four parametric and two nonparametric measures of stability. The parametric dynamic approaches included S^2_{di}, b_i and σ^2_i in addition to CV_i% as static parameters. The two nonparametric stability approaches are rank-sum (RS_i) and yield-stability statistic (YS_i**)** as suggested by Kang.

The environmental conditions affected highly significantly all faba bean traits. The studied cultivars varied significantly in performance for yield and components over all environments and from one environment to another for all characters except pods/plant, as proved by the significance of GEI. The fluctuations in climatic conditions seemed to have greater effects on performance of faba beans than their genetic background.

Faba bean cultivars varied significantly for mean performance and extents of stability measured by all parameters except stability variance (σ^2_i) and b_i for SYP and SYPlot, respectively. For breeding faba bean promising cultivars, it should be screened under several environmental conditions and those showing reliable performance will be evaluated for stability by using variable parameters to avoid the violation of occurring statistical errors (either type I or type II), which may conflict the trustiness of recommended cultivars.

KEYWORDS: Faba bean, Vicia faba, G X E interaction, Stability, Yield, GDD, Accumulated temperature.

1. INTRODUCTION

Faba bean (*Vicia faba* L.) is one of the most important food legume crops grown in Egypt and the Mediterranean countries. According to FAO statistics of 2020 [FAOSTAT], the global acreage of faba bean has declined in the last 5 decades from 4.8 to 2.4 million ha. In Egypt, the acreage of faba bean was decreased during the last 50 years from 110,100 to 32532 ha corresponded to declined yield from 256,533 to 112871 tons, with a similar reduction of national self-sufficient from 70 to 26.9%.

The acreage and seed yields varied among sowing dates, seasons and locations which refer to yield instability and common in faba bean than other crops (Darwish, and Abdalla, 1997 and Awaad, 2022). Such yield fluctuation of this crop could be attributed to various biotic and abiotic limitations as well as sensitivity to changing environmental conditions (Darwish *et al.*, 2016 and Quarshie *et al.,* 2021).

The impacts of elevated global CO_2 and the associated changes in temperature and precipitation had been observed as outlined by the Global Climate Report for Annual 2019. In this report, these ten years since 2005 were globally recorded as the warmest years in 1880-2019 of record. Similar trend was recorded for African climate in addition to that extreme precipitation and drought events [NOAA, 2019].

Such effects of climate change could be reduced (or at least alleviated) by the adoption of appropriate cultural practices and synergistically developing faba bean genotypes resistant/tolerant to the biotic and abiotic stresses in addition to characterized by high potential yields (Darwish, and Fahmy, 1997, Darwish, 2003, Khan *et al.*, 2010, Siddiqui *et al.*, 2015 and Quarshie *et al.,* 2021). The evaluation of genotypes is the key to utilization in breeding programs and is a continuous process. However, faba bean genotypes suffered from narrow adaptability (due to long-day sensitivity performance) and susceptibility to less favorable environments (Darwish and Fahmy, 1997 and Darwish, 2003). Thus, the most important goal of faba bean improvement programs is not only high yield, biotic and abiotic stresses tolerant cultivars, but also wide adaptability and stability (Darwish and Abdalla, 1997 and Awaad, 2022).

GEI is of major importance for faba bean breeders, given that phenotypic response to change in environment is different among genotypes (Darwish, and Abdalla, 1997). Strong G × E interaction for quantitative characters such as seed yield can severely limit gain in selecting superior genotypes for improved cultivar development (Kang, 1993 and Tadesse *et al.,* 2017). Hence, if cultivars are being selected for a wide range of environments, stability and mean yield across all environments are more important than yield for specific environments (Zong *et al*., 2019, Papastylianou *et al*., 2021 and Awaad, 2022).

The GEI could be attributed to predictable and unpredictable effects as reported by (Allard and Bradshaw, 1964). The first may be due to macro-environmental conditions, but the second one is mainly caused by climatic and micro-environmental conditions.

Several methods were proposed to analyze G x E interaction to determine the stability of performance as summarized by (Lin *et al.,* 1986, Becker J. Léon, 1988 and Kang, 1993). They classified the measures as static or dynamic, parametric or non-parametric according to their concepts or the homogeneity of error variances of environments.

Therefore, the aims of the present investigation are to explore the nature of climatic changes across a range of sowing dates under Egyptian conditions and their effects on performance of some promising faba bean cultivars. The extent of GEI of recent faba bean cultivars under the generated eight variable environmental conditions will be elucidated for upgrading cultivars of faba bean recommendation, for climate change resilient production.

2. MATERIALS AND METHODS

Six faba bean cultivars were evaluated under eight field trials during the 2017/2018 and 2018/2019 seasons at the Experimental Farm of the Faculty of Agriculture, Cairo University, Egypt, (30° 02'N Latitude and 31° 13' E Longitudes, Altitude 22.50 m). In each season, four trials were carried out in four sowing dates started with October, 15th in two weeks intervals. In each sowing date (SD), a Randomized Complete Blocks Design (RCBD) with four replications experiment was conducted. Each experimental plot consisted of 4 ridges (9.6 m^2), each was 4 m long and 60 cm apart. Seeds were hand dry planted in one side of the ridge in doubled-seed hills distanced 20 cm. Twenty kg/feddan (4200m^2) of P_2O_5 as Calcium Super Phosphate (15.5%) were added during soil preparation and other 20 kg N were applied from Urea (46.0 %), whereas other cultural practices were followed the recommendations. The faba bean cultivars were Cairo 4, Cairo 5, Cairo 25 and Cairo 49 (from Agronomy Department, Faculty of Agriculture, Cairo University, Egypt) and Giza 429 and Giza 843 (from Agriculture Research Center (ARC) Ministry of Agric., Giza. Egypt). Each of the first three cultivars was constructed by synthesizing three distinct groups of local selections based on general synthesizing ability by polycross test (Abdalla, and Darwish, 2008). However, the later three cultivars were considered as *Orobanche* tolerant/resistant to cultivars (Darwish *et al*., 2016).

At harvest, the numbers of pods and seeds/plant, dry weight and seed yields/plant as well as 100-seed weight and harvest index were recorded using a random sample of 10 guarded plants from the central ridges of each plot. The seed yield of 10-individuals plus those of remainders of each plot were considered as seed yield per plot (4.8m^2).

For description of the dominated climatic features, the 135 days of the faba beans' growing days from seedling emergence to maturity in each sowing date were divided into three growth periods. Each period was 45 days as seedling and onset flowering stage (SoF), flowering and podding stage (FP) and pod filling and maturity (PfM) stage designated I, II and III, respectively. Means and rates of changing as regression coefficients, within each growth period, of the average of air temperatures, and accumulated growing degree day (GDD) day-night temperature and relative humidity (RH) were calculated. The climatic data of Giza site during 2017/2018 and 2018/2019 seasons were obtained from the NASA website (power.larc.nasa.gov).

Mechanical and chemical soil properties determined by Soil Lab analysis of Soil and Water Res Institute are presented in Table (1). The soil of the experimental site was clay loam. Growing degree days (GDD) were calculated as [(Maximum + Minimum daily temperature)/2] - Base Temperature (3.9) according to (Confalone *et al*., 2019).

Table 1. Physical and chemical properties of the soil for the experimental site at Giza, Egypt in 2017/2018 season

Mechanical analysis		Chemical properties	
Sand %	42.3	**pH (1:2.5)**	7.89
Silt %	28.4	**EC (1:2.5) ds/m**	0.57
Clay %	29.3	**CO_3^-**	0.1
Texture Class	Clay loam	**HCO_3^-**	1.6
Field Capacity %	41.3	**Cl^-**	2.6
Wilting Point %	23.2	**SO_4^-**	1.9
A.S.M %	18.1	**Ca^{++}**	1.8

2.1. Statistical analysis

The analysis of variance of the obtained data of each experiment (sowing date) as Randomized Complete Block Design (RCBD) was applied. Combined analysis of variance due to faba bean cultivars over 8 environments (4 sowing dates × 2 seasons) was performed. The homogeneity of error mean squares of separate RCBD trials were tested by Bartelett's test prior combined analysis of variance as outlined by (Gomez, and Gomez, 1984).

To detect the differences between cultivars across all the studied environments (E_i), the least significant difference (LSD) test at 5% level of probability was used.

2.2. Stability analysis:

Stability analysis of cultivars' performance across the generated 8 sowing dates (environments) was estimated in case of significant G × E interaction mean squares using the following methods:

a- Regression analysis

This daynamic concept of stability as suggested by (Eberhart, and Russel, 1966) was performed by regressed the performance of the given genotype on the environmental index (deviation of the mean character at the giving environment from the overall mean of all environments). In this analysis two parameters were obtained, the regression coefficient (b_i) and the deviation from regression mean squares (S^2_d), which were considered as parameters of response and stability, respectively.

The insignificant S^2_d of a genotype from zero, means that it is a stable in performance, whereas the significance of b_i either less than unity (negative) or more than unity (positive) indicates that the genotype is responsive to unfavorable or favorable environments, respectively.

b- **The stability variance (σ^2_i)** dealt with the contributed of each genotype to GE interaction according to (Shukla, 1972) as a measure of dynamic stability concept.

c- The coefficients of variation (CV_i%) as static stability parameter was suggested by (Francis, and Kannenberg, 1978) by estimating the coefficient of variation of performance across the given environments.

d- Rank-sum (RS):

Kang, (1988) proposed the rank-sum (RS) as a non-parametric stability parameter considering both yield in performance and stability variance (σ^2_i) developed by (Eberhart and Russel, 1966). Simply the RS is the product of assigned ranks for both mean yield (in descending order) and stability variance (σ^2_i) with asscending manner.

e- Yield-stability statistic (YS_i):

This parameter was suggested by (Kang, 1993) to determine the evaluated cultivars based on both yield and stability of performance rather than mean yield alone to avoid strong G x E interaction. The calculation of YS_i could be presented as follows:

1) Calculating σ^2_i the contribution of each genotype to GE interaction according to (Shukla, 1972).
2) Ranking the cultivars (Ý) on their yield with the lowest-yielding cultivar/s receiving a number 1 (ascending rank).
3) Calculating the adjustment Y of yield rank Ý by using LSD, as + 1 for mean yield > overall mean yield (OMY), +2 and +3, for mean yield ≥ 1LSD and 2 LSD over OMY, respectively, whereas -1, for mean yield < OMY, -2 and -3 for mean yield ≤ 1LSD and 3 LSD lower than OMY, respectively.
4) Rating the stability (S) as 0, if σ^2 was insignificant; and -2, -4, and -8 if σ^2_i was significant at 0.10, 0.05 and 0.01 probability level, respectively.
5) Summing Y (adjusted yield rank) and S (stability rating), for each genotype producing YS_i statistic.
6) The cultivar possesses higher YS_i than the grand mean of tested cultivars ($\sum YS_i/n$) considered higher yielder with stable in performance.

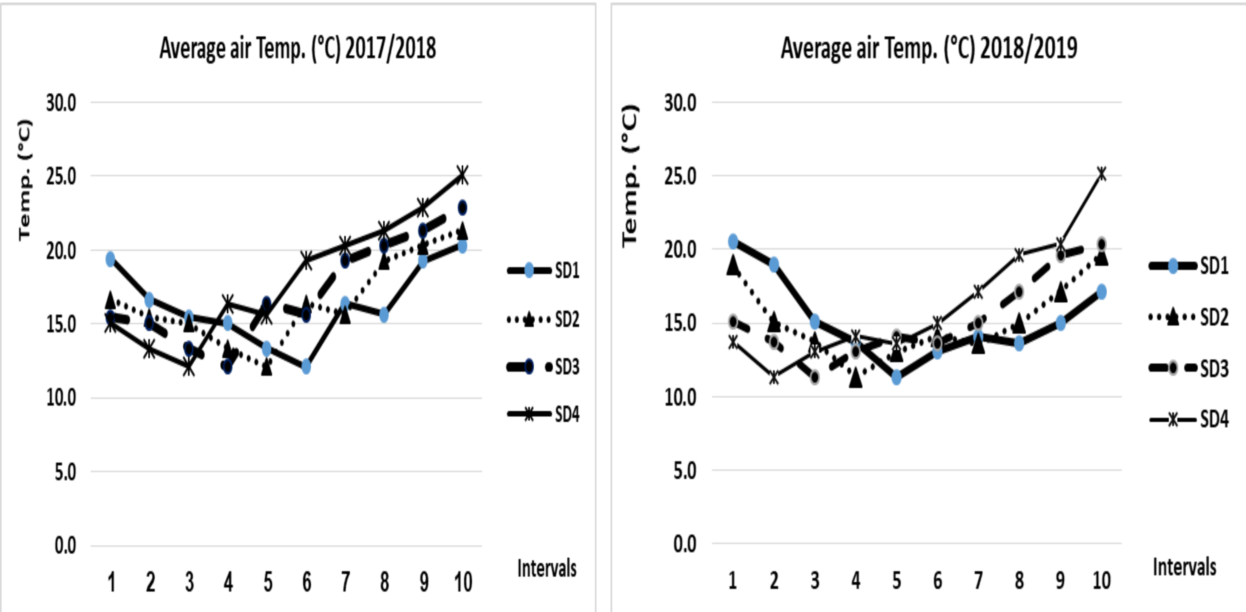
3. RESULTS AND DISCUSSION

3.1. Prevailing climatic features during sowing dates and seasons

The mean air temperatures dominated in all sowing dates during the first growth period (1-45) in the first season were higher than those of second season (Table 2 and Fig.1). However, the differences between corresponding planting dates of both seasons for air temperatures were obvious (≈ 2-3 °C) in the second and third growth periods than first two

Table 2. Prevailing air, day-night differences temperatures (°C), relative humidity (RH%) and accumulated daily heat units (GDD) during suggested growth periods of faba bean as well as their daily rates of changing as regression coefficients, within the four sowing dates (SD) of 2017/18 and 2018/19 seasons.

	Feature	Air Temp. (°C)						Day-Night Diff Temp.(°C)					
	Sowing date	I (1-45)		II (46-90)		VI (91-135)		I (1-45)		II (46-90)		VI (91-135)	
Season		Mean	Rate (b)	Mean	Rate (b)	Mean	Rate (b)	Mean	Rate (b)	Mean	Rate (b)	Mean	Rate (b)
2017/18	SD1	15.1	-0.13	14.0	-0.10	14.7	0.08	12.6	-0.05	11.2	-0.03	12.0	0.03
	SD2	14.2	-0.08	15.5	0.08	17.2	0.08	11.9	-0.04	10.9	-0.02	13.8	0.05
	SD3	13.2	-0.08	17.7	-0.10	18.6	0.06	10.8	0.01	11.7	0.08	15.7	0.09
	SD4	14.0	-0.10	19.1	-0.10	20.0	0.09	11.2	0.01	12.2	0.09	16.5	0.10
2018/19	SD1	14.2	-0.18	13.2	-0.02	13.6	0.03	12.8	-0.02	11.2	-0.02	13.3	0.05
	SD2	13.0	-0.16	13.9	0.07	14.3	0.12	11.8	0.08	11.9	0.04	13.7	0.06
	SD3	12.8	-0.11	14.7	0.03	15.3	0.16	11.3	0.03	12.9	0.07	14.1	0.06
	SD4	13.2	-0.03	16.6	0.03	17.1	0.14	11.2	0.09	13.3	0.09	14.8	0.07
Feature		RH						GDD					
2017/18	SD1	61.2	0.31	70.2	0.80	62.8	-0.21	801	0.13	584	-0.10	583	0.08
	SD2	66.7	-0.10	69.8	-0.32	56.2	-0.33	697	0.08	535	0.08	689	0.12
	SD3	70.5	0.70	66.7	-0.30	51.3	-0.08	636	0.08	550	0.11	748	0.06
	SD4	70.2	0.80	62.8	-0.21	47.7	-0.06	584	-0.10	597	0.08	830	0.09
2018/19	SD1	57.1	0.19	62.7	-0.55	52.2	0.09	822	-0.18	602	-0.02	528	0.03
	SD2	60.8	0.20	58.1	-0.09	54.4	-0.18	762	-0.16	503	0.07	557	0.14
	SD3	63.4	-0.35	53.3	0.14	55.9	-0.31	655	-0.11	501	0.03	596	0.16
	SD4	62.7	-0.55	52.2	-0.18	53.8	-0.37	543	-0.03	511	0.03	677	0.14

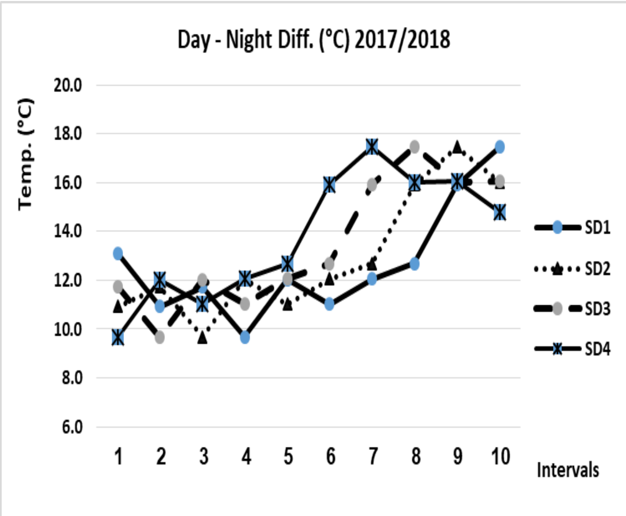


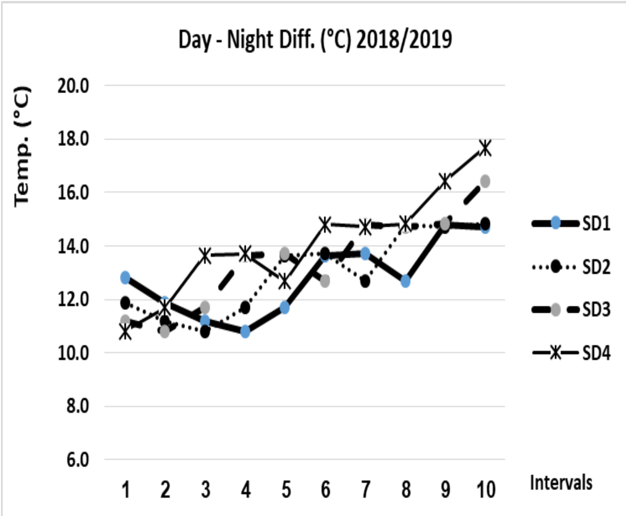
Figs 1. Average air temperature across the sowing dates of both seasons in 15 days intervals.

one (≥ 1.0 °C). The rates of changes in average air temperature were negative in both seasons in the first growth period, with higher in magnitudes in all sowing dates of the second season than first one (higher negative b's in the second season than first season for all planting dates except SD 4). However, such rates of changes of air temperatures varied in signs during the second growth period (46-90), whereas these b's are positive and higher during the late three sowing dates of third growth period (91-135) in the second season than corresponding ones.

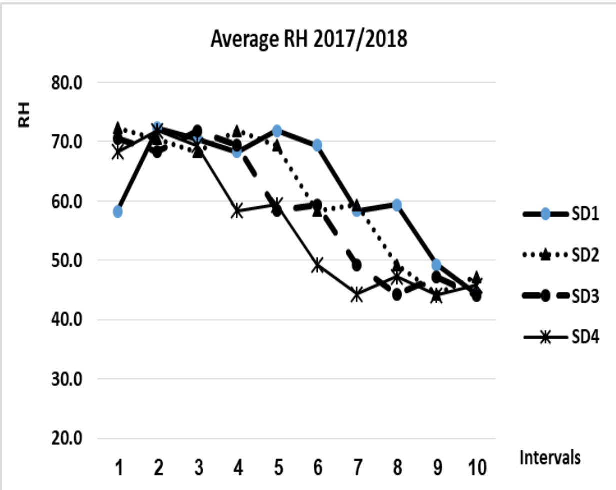
The day-night temperatures were higher in the SD 1 and SD 2 than those of SD 3 and SD 4 coupled with negative regressions during the first and second growing periods in both seasons. The estimates of day-night temperatures of third growing period (91-135) were wider than those detected in the first two periods. RH during in the I & II stages of the first season in all the sowing dates recorded higher RH than those second season, whereas the third growing period exhibited markedly lower than the earlier growing two periods. The rates of changing RH tended to reduce by progressing the faba bean growing periods during all sowing dates in both seasons as evidenced of negative regression coefficients in latter two growth periods.

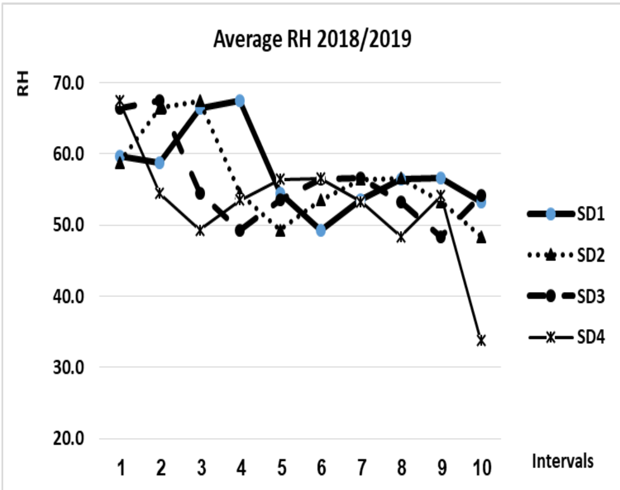
The total accumulated GDD were higher in all sowing dates of first season than those of second ones (1968, 1921, 1934 and 2011 *vs*. 1952, 1822, 1752 and 1731, respectively). The differences of the 3rd and 4th dates of 1st season were wider than corresponding dates of second season may reach to more than 200 heat units. It could be observed that the GDD during seedling and onset growth (I) decreased by delaying sowing dates and vice versa in pod filling and maturity stage (III), Fig.4. However, the relatives of estimated GDD during the second growth stage are about 30% in all sowing dates of both seasons, whereas those of I and III showed variable relatives GDD among sowing dates as presented in Fig.4.





Figs 2. Day-Night Differences across the sowing dates of both seasons in 15 days intervals.





Figs 3. Average relative humidity (RH) across the sowing dates of both seasons in 15 days intervals.

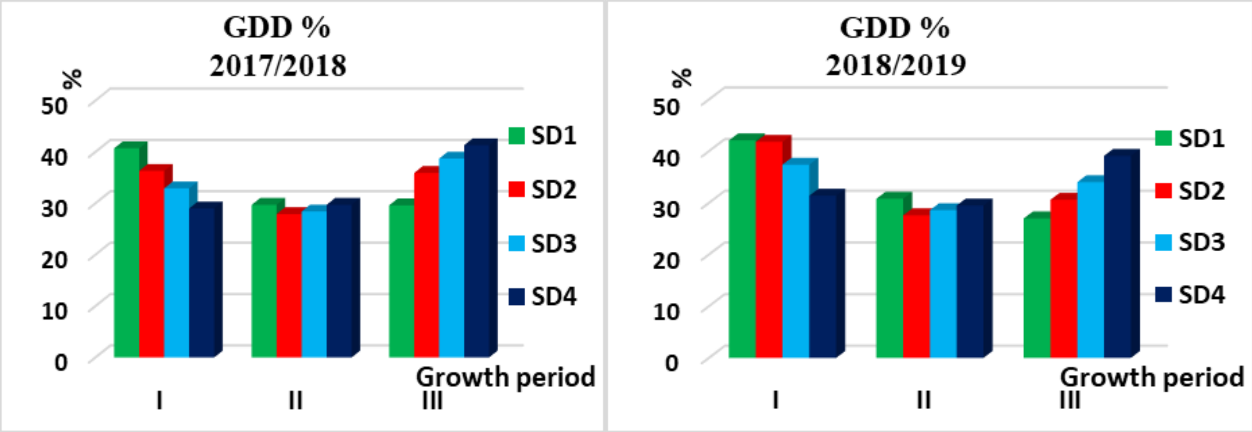


Fig. 4. The relatives of accumulated heat units (GDD) in the suggested growth periods (I, II and III) across the four sowing dates during both seasons.

3.2. Significance of mean squares

Mean squares and their significance of faba bean cultivars in each sowing date (environment) and combined across environments are presented in Table (3). Variances due to cultivars (G) are significant or highly significant in all environments for all studied traits, except for pods/plant in 4th SD of 2nd season, SYP in 3rd SD of the second season, and HI in 4th SD of both seasons. Environmental conditions as a source of variation in combined analysis affected highly significant all faba bean traits. Faba bean cultivars recorded highly significantly or significant variation across environments for all studied characters. These results indicated that both environmental conditions generated as variable sowing dates affected statistically the investigated faba bean seed yield and dry biomass production. Moreover, the studied cultivars varied significantly in performance for yield and components over all environments and from one environment to another for all characters except pods/plant, as proved by the significance of G x E interaction.

From combined analysis, the magnitudes of variances due to environments were larger than those of cultivars for all studied traits (except S.I), which ranged between 1.3 folds (for pods/plant) to 12.6 fold (for Harvest Index, HI).

Therefore, according to the above mentioned findings it could be concluded that the climatic conditions generated from different sowing dates seemed to have greater effects on performance of faba beans than their genetic background effects.

The significance of GEI is an indication of the validation of performing further stability analyses.

3.3. Mean effects of environments

The mean performance and environmental index (I) of each environment (sowing date) are presented in Table (4). The environmental index used in this table is the deviation of each environment from the grand mean of all environments.

Generally, the prevailing conditions of 3rd and 4th sowing dates of 2018/2019 season recorded significantly the highest numbers of pods and seeds/plant, seed and dry mass yields with heavier seed index as well as higher harvest index.

Regarding the SYPlot, the 3rd, 4th, 7th and 8th environments (the planting faba bean during the second half of November of both seasons) produced higher seed yield than earlier dates which reflected in considerable positive environmental indexes. The 3rd, 7th and 8th environments showed these effects may be due to the positive effects of seeds/plant and pods per plant. However, such positive effects on the seed yield per plot may be due to the compensation of other yield components, particularly in the second season.

It could be concluded that the early sowing of faba beans during mid-October in both seasons affected negatively seed yield and components except PlDwt in 1st season and SI and HI of second one. However, planting at the end of Oct or onset of November negatively affected all yield and components except PlDwt (in the first season) and seeds, SI, PlDwt and HI (in the second one). The planting during mid-Nov (3rd SD) affected positively all studied faba bean traits in both seasons except PlDwt, SI and HI (in the 1st season). Delaying faba bean sowing during Dec exhibited marked positive influences on all traits of 2018/019 season, whereas such date recorded slight positive influence only on seed yield per plot of 1st season. Similar findings of faba bean genotypes to different sowing dates were reported in Egypt by (Al-Kaddoussi, 1996, Darwish, 1996, Abou-Taleb, 2006 and Quarshie *et al*., 2021).

Table 3. Significance of mean squares due to faba bean cultivars (G) in each environment as well as environments (E), G and G x E interaction of combined analysis across eight environments for studied traits during 2017/18 and 2018/19 seasons.

Season	Sowing date	Mean squares						
		Seeds/plant	Pods/Plant	PDwt	SYP	SYPlot	SI	HI
2017/18	1st	788.44**	132.75**	4595.30 **	253.76**	204266.1**	1696.54**	47.08ns
	2nd	421.09**	157.84**	8371.37**	212.62**	791672.6**	1109.87**	269.71**
	3rd	2967.78**	412.79**	1290.17**	165.64**	5327668.8**	655.10**	379.72**
	4th	797.82**	46.24*	7507.91**	481.78**	1424125.5**	568.50**	45.11ns
2018/19	1st	881.67**	192.24**	3631.81**	391.92**	239210.5**	629.50**	104.43*
	2nd	886.74**	336.04**	447.22*	95.24**	183125.1**	1103.26**	57.37ns
	3rd	814.90**	281.25**	6447.24**	46.30ns	1216597.1**	267.09**	186.44**
	4th	936.27**	23.33 ns	5568.20**	532.43**	621360.2**	1385.21**	51.52ns
Combined	E.	256.75**	49.61**	723.78**	112.12**	601345.31**	34.87*	130.54**
	G.	57.73**	39.36**	141.63*	11.00**	105163.03**	308.46**	10.33**
	G. x E.	86.14**	6.24 ns	294.04**	18.84**	80291.24**	31.26*	6.82*

ns, * and ** indicate insignificant, significant at 5% and highly significant at 0.01%, levels of probability, respectively.

Table 4. Mean performance and environmental index (I) of studied environments (sowing dates) over investigated faba bean cultivars for studied characters from combined analysis.

Environments	Seeds/plant		Pods/Plant		PlDwt		SYP		SYPlot		SI		HI	
	Mean	I_i	Mean	I_i	Mean	I_i	Mean	I_i	Mean	I_i	Mean	I_i	Mean	I_i
1st	38.5 d	-3.3	13.6 e	-3.2	107.0 a	18.6	24.3 d	-2.7	1027.1 g	-369.7	64.0 d	-1.9	22.7 d	-8.2
2nd	38.8 d	-3.1	15.6 c	-1.2	91.3 b	2.9	25.0 c	-2.0	1163.8 e	-233.1	65.3 c	-0.6	28.2 c	-2.8
3rd	46.3 b	4.4	20.7 a	3.9	86.7 c	-1.7	30.2 b	3.2	1875.4 a	478.6	65.8 c	-0.1	34.9 b	-0.9
4th	35.59 e	-6.3	16.8 b	-0.1	88.3 c	-0.1	24.7 c	-2.3	1424.2 c	27.4	69.0 a	-4.6	28.1 c	-2.8
5th	32.8 f	-9.1	14.1 d	-2.7	72.5 d	-15.9	21.8 e	-5.2	1100.6 f	-296.2	66.7 b	0.9	30.0 c	4.0
6th	44.8 bc	2.9	15.2 c	-1.6	74.7 d	-13.7	25.0 c	-2.0	1220.9 d	-175.9	61.2 d	3.2	33.5 b	2.6
7th	52.6 a	10.8	21.4 a	4.6	93.7 b	5.3	35.0 a	8.0	1692.3 b	295.4	67.5 b	1.6	37.6 a	6.7
8th	45.5 b	3.6	17.1 b	0.3	93.1 b	4.7	30.0 b	3.0	1670.3 b	273.5	67.2 b	1.4	32.3 b	1.4

Means in the same column followed by the same letter/s are not significantly different.

Rank correlation coefficients among the environmental indices of the eight sowing dates for studied traits as well as accumulated GDD of 1st (I), 2nd (II) and 3rd (III) growth periods across all planting dates are used to elucidate the nature of environmental effects and GDD (Table 5). The correlations among the ranks of environmental indices of yield and components attributes are positive in spite of some lacking of significance. This is true for all double-combination except among indices of PlDwt and each of SYplot, SI and HI. This synchronized effects of generated environmental conditions on most studied faba bean yield and components showed negative relations with accumulated heat units either at first or second growth period (GDD-I and GDD-II) rather than the final accumulated GDD-III.

The duration and dry matter accumulation of faba bean plants before flowering greatly depended on temperature and thermal units and soil moisture (Darwish *et al*., 2016) in addition to photoperiod (Confalone, *et al.,* 2011). However, (Bishop *et al.*, 2016 and Quarshie *et al*., 2021) concluded the importance of thermal units in the growth, development and seed yield of faba bean genotypes.

Table 5. Rank correlation coefficients among the environmental indices of the eight sowing dates for studied traits as well as accumulated GDD of 1st (I), 2nd (II) and 3rd (III) growth periods across all planting dates.

	I-Pods	I-SYP	I-SYplot	I-SI	I-PDwt	I-HI	GDD-I	GDD-II	GDD-III
I-Seeds	0.786 *	0.970 **	0.786 *	0.548 ns	0.333ns	0.538 ns	-0.500 ns	-0.833 *	0.214 ns
I-Pods		0.898 **	0.952 **	0.262 ns	0.167 ns	0.548 ns	-0.738 *	-0.524 ns	0.571 ns
I-SYP			0.874 **	0.467 ns	0.275 ns	0.535 ns	-0.611 ns	-0.790 *	0.383 ns
I-SYplot				0.310ns	0.000 ns	0.624 ns	-0.786 *	-0.476 ns	0.548 ns
I-SI					-0.214 ns	0.710 *	-0.048 ns	-0.714 *	-0.548 ns
I-PDwt						-0.441 ns	-0.167 ns	-0.333 ns	0.190 ns
I-HI							-0.129 ns	-0.333 ns	-0.215 ns
GDD-I								0.333 ns	-0.690 ns
GDD-II									0.190 ns

ns, * and ** indicate insignificant, significant at 5% and highly significant at 0.01%, levels of probability, respectively.

3.4. Stability in performance

The stability parameters and mean performance of the investigated faba bean cultivars for considered seed and dry yields are presented in Table (6).

The studied faba bean cultivars varied significantly for mean performance and extents of stability measured by all parameters except stability variance (σ^2_i) and b_i for SYP and SYPlot, respectively.

The regression model of stability proposed by (Eberhart, and Russel, 1966), considering that b_i is a parameter of response, weheras S^2_d is a measure of stability. On the other hand, the significance of the coefficient of regression (b) means responsiveness either to favorable environments (when b is more than unity) or poor ones (b is less than unity). But the genotype with S^2_d not significantly deviated from 0.0 are considered stable in performance. The third used stability parametric dynamic measure is stability variance (σ^2_i) which proposed by (Shukla, 1972) measuring the contribution of each genotype to sum squares on GE interaction.

For PDwt, only two cultivars could be described as stable by using S^2_{di} (C.4) and $\boldsymbol{\sigma^2_i}$ (G. 843) but the other four cultivars are significance for these two parameters. C.5 may be recommended under favorable environments resilient for dry wt production. Regarding, seed yield/plant (SYP), only G.429 and G.843 are insignificant by S^2_d. However, all cultivars recorded insignificant by using $\boldsymbol{\sigma^2_i}$. This indicates that out of 6 cultivars, 2 were stable across the studied environments measured by S^2_d for seed yield/plant and C.25 seemed to be recommended for good environment for seed yield production. Again, C.4 and G.843 seed yield/plot by S^2_d and C.4 and G.429 by $\boldsymbol{\sigma^2_i}$. The remainder cultivars seemed to be instable for seed production by using dynamic parameters of stability.

According to the coefficients of variation (CV_i%) as static stability parameter suggested by (Francis, and Kannenberg, 1978), G.843, G.429 and C.4 exhibited the least CV% for PDwt, SYP and SYPlot. However, the other tested faba bean cultivars seemed to be possessing different degrees of variation across the investigated environments.

The Kang's two non-parametric measures (rank-sum, RS_i and yield-stability statistic, YS_i evaluated cultivars based on both yield and stability of performance rather than mean yield alone to avoid strong GxE interaction. These parameters considered both yield and stability statistics to identify high-yielding and stable cultivars.

Table 6. Mean performance and stability parameters of studied cultivars corresponding to ranks for seed and dry weight production combined across the eight sowing dates during 2017/18 and 2018/19 seasons.

CVs	Mean	b_i 1)	S^2_{di} 2)	CV%	RS 3)	YS_i 4)	σ^2_i 5)
				PDwt			
C.4	86.3	1.41^{ns}	90.5^{ns}	21.1	6	-6	92.6^{*}
C.5	95.9	1.86 *	406.1^{**}	29.9	7	0+	670.4^{*}
C.25	85.6	1.20^{ns}	248.1^{**}	24.0	9	-7	305.9^{*}
C.49	90.1	0.83^{ns}	211.4^{**}	19.1	5	-2+	248.7^{*}
G.429	88.2	0.25^{ns}	246.2^{**}	18.1	8	-3+	396.8^{*}
G.843	84.3	0.44^{ns}	44.7^{ns}	9.8	7	-9	49.9^{ns}
$LSD_{0.05}$	**1.7**						
				SYP			
C.4	27.2	1.06^{ns}	9.5^{*}	20.4	5	5+	9.7^{ns}
C.5	27.9	0.95^{ns}	32.7^{**}	25.2	8	0+	44.4^{ns}
C.25	25.5	1.59^{*}	13.3^{*}	30.5	11	-11	24.8^{ns}
C.49	28.5	0.81^{ns}	10.9^{*}	16.9	5	10+	12.6^{ns}
G.429	27.1	0.56^{ns}	7.8^{ns}	13.7	7	2+	12.4^{ns}
G.843	25.8	1.03^{ns}	9.2^{ns}	20.8	6	-2	9.1^{ns}
$LSD_{0.05}$	**0.3**						
				SYPlot			
C.4	1458.1	1.07^{ns}	28239.1^{ns}	25.9	4	-2+	22951.5^{ns}
C.5	1299.8	0.67^{ns}	168192.2^{**}	35.6	11	-10	248287.4^{*}
C.25	1218.7	0.70^{ns}	57419.2^{*}	26.7	11	-11	79874.2^{*}
C.49	1492.1	1.12^{ns}	46619.5^{*}	27.8	6	0+	51961.4^{*}
G.429	1407.6	1.04^{ns}	33867.3^{*}	26.7	6	-6	30920.6^{ns}
G.843	1504.8	1.41^{ns}	28411.2^{ns}	31.7	4	2+	47752.4^{*}
$LSD_{0.05}$	**26.5**						

1) * and **= significant at 5% and 1% of regression coefficient from unity.
2) ns = stable genotype/s, * and ** = unstable genotype/s at 5% and 1%, respectively of S^2_d from zero.
3) The lowest RS is the most desirable as stable corresponding with relatively high yield.
4) + Stable cultivars on basis of yield stability statistics (YS_i).
5) ns = stable genotype/s, * and ** = unstable genotype/s at 5 % and 1%, respectively of σ^2_i.

The genotype with the highest yield and lower σ^2_i are assigned a rank of one. Then, the ranks of yield and stability variance are added for each genotype and the cultivars with the lowest rank-sum are the most desirable. RS identified C.4 and C.49 (for PDwt and SYP) and C.4 and G.429 (for SYPlot) as the most stable cultivars. However, YSi detected C.5, C.49 and G.843 (for PDwt), C.4, C.5, C.49 and G.429 (for SYP) and C.4, C.49 and G.843 (for SYPlot) as stable and high yielding cultivars.

To elucidate the interrelationship between mean performance and each of estimated all stability parameters, the rank correlation was calculated (Table 7). The obtained rank correlation coefficients among the mean performance are significantly positive only with YS_i (for PDwt) and negative with bi (for SYPlot) and YSi (for SYP and SYPlot). However, the measure of response, i.e bi related significantly positive with CV% (for PDwt) and YSi (for SYPlot). The Eberhart and Russel's stability measure, S^2_{di} could be ranked the evaluated cultivars like the stability variance for the studied three traits and rank-sum for SYPlot. Surprisingly, the ability of RS_i and YSi for ranking cultivars is contradicted for SYP and SYPlot.

Such correlations proved that the mean performance of tested faba bean cultivars for yield and components was not related to the extent of stability measured most used parameters. Thus, it may be concluded for breeding faba bean promising cultivars, it should be evaluated firstly under separately several conditions and those showing reliable performance will be tested for stability across environmental conditions prior to recommendations. The testing of stability by using variable parameters is preferred to avoid the violation due to the occurring of any type of statistical errors, which may conflict the trustiness of recommendations.

Table 7. Rank correlation coefficients among the ranks of faba bean cultivars for dry weight and seed yields and corresponding stability ranks of stability measurements.

Parameter	b_i	S^2_{di}	CV%	RS_i	YS_i	σ^2_i
			PDwt			
Mean	-0.343ns	-0.600ns	-0.486ns	0.375ns	1.000**	-0.714ns
b_i		0.457ns	0.914*	-0.100ns	0.229ns	0.229ns
S^2_{di}			0.771ns	0.471ns	0.600ns	0.943**
CV%				0.129ns	0.486ns	0.600ns
RS_i					-0.329ns	0.414ns
YS_i						0.714ns
			SYP			
Mean	0.543ns	-0.257ns	0.429ns	0.514ns	-0.829*	-0.257ns
Bi		0.371ns	0.771ns	0.114ns	-0.543ns	-0.029ns
$S^2_d i$			0.714ns	0.286ns	-0.200ns	0.829*
CV%				0.571ns	-0.771ns	0.429ns
RS_i					-0.958**	0.514ns
YS_i						-0.143ns
			SYPlot			
Mean	-0.943**	0.657ns	-0.086ns	0.800ns	-1.000**	0.486ns
b_i		-0.714ns	-0.086ns	-0.800ns	0.943**	-0.543ns
$S^2_d i$			0.600ns	0.914*	-0.657ns	0.943**
CV%				0.343ns	0.086ns	0.771ns
RS_i					-0.800ns	0.800ns
YS_i						-0.486ns

ns and * indicate insignificant and significant correlation coefficients at 5% and 1%, respectively

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الملخص العربي

تحليل تفاعل التركيب الوراثي مع البيئات لبعض أصناف الفول البلدي وقدرتها على التكيف مع مواعيد زراعة مختلفة فى مصر

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إن إستكشاف التأثيرات غير المتوقعة للتغيرات المناخية من خلال الزراعة فى مواعيد ومواسم مختلفة في الظروف البيئية المصرية على آداء أصناف الفول البلدي له فائدة كبيرة على إستدامة الإنتاج الزراعى لتحقيق الأمن الغذائي. ويعتبر تقدير تفاعل التراكيب الوراثية مع البيئات وثبات آدائها فى مواعيد الزراعة المختلفة هدفاً هاماً لتربية أصناف تتكيف مع تقلبات الظروف المناخية. لذا فلقد تم تقييم سته من أصناف من الفول البلدي ذات خلفيات وراثية متباينه فى أربعة مواعيد من الزراعة بداية من منتصف أكتوبر وحتى ديسمبر خلال موسمي الزراعة ٢٠١٨/٢٠١٧ و ٢٠١٩/٢٠١٨ فى الجيزة. وتم إجراء تحليلات التباين عبر البيئات الثمانية بإستخدام أربعة مقاييس ثبات معلمية وإثنتين من مقاييس الثبات اللامعلمية. وتضمنت الطرق المعلمية مجموع مربعات الإنحرافات عن خط الإنحدار، معامل الإنحدار، تباين الثبات، بالإضافة إلى معامل الإختلاف. اما المقاييس اللامعلمية فكانتا مجموع ترتيب الآداء وإحصاء ثبات المحصول.

كانت تأثيرات الظروف البيئية عالية المعنوية على آداء جميع صفات أصناف الفول البلدي. ولقد اختلف أداء التراكيب الوراثية معنوياً للمحصول ومكوناتة في جميع البيئات ومن بيئة إلى أخرى لجميع الصفات تحت الدراسة فيما عدا عدد القرون/النبات كما وضح من معنوية تباين مكون التراكيب الوراثية وكذلك تفاعل التراكيب الوراثية مع البيئات. وتبرهن هذه النتائج على أن تأثيرات تقلبات الظروف المناخية كانت ذات تأثير أكبر على أداء التراكيب الوراثية للفول البلدى أكثر من التباينات الراجعة لتبايناتها الوراثية.

ولقد تباينت أصناف الفول البلدي معنوياً من حيث متوسطات الآداء ومقاييس الثبات لجميع الصفات تحت الدراسة فيما عدا تباين الثبات ومعامل الإنحدار لصفتي محصول بذور النبات ومحصول بذور القطعة، على التوالي. ويمكن الإستخلاص أنه لتربية أصناف مبشرة من الفول البلدي من حيث تميز المحصول وتكيف الآداء مع التغيرات المناخية، فإنه يجب تقييمها فى العديد من الظروف البيئية المتباينة وكذلك بإستخدام معايير ثبات مختلفة وذلك لتجنب وقوع أى من الأخطاء الإحصائية سواء من النوع الأول أو الثانى والتى قد تؤثر فى مصداقية آداء الأصناف الموصي حال حدوث التقلبات المناخية أو إختلاف خصائص التربة.