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Impact of Planting Dates on Pepper (*Capsicum annum L.*) Genotypes Performance and Stability under Qena Governorate conditions

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Abstract

Sweet pepper is a tropical plant that thrives in warm climates. High temperature during hot summer months in Upper Egypt, however, highly reduces the yield and quality. The purpose of this experiment was to evaluate the performance and stability of nine pepper genotypes collected from Qena, Luxor and Aswan governorates planted in three planting dates (February, March, and May). Our findings showed that heat stress had a negative effect on most of the plant studied traits. Heat stress affected the vegetative, physiological and yield traits. All studied traits decreased by increasing the prevailing temperature except chlorophyll content, number of days to 50 % flowering, and No. of branches per plant. Heat stress decreased plant height, fresh weight, dry weight, and total leaf area and leaf area index. High negative correlations were observed between the prevailing temperature and plant fresh weight, plant dry weight, total leaf area, dry matter, No of fruits per plant, fruit weight, weight of fruits per plant and total yield, in all pepper genotypes. The genotypes Dandra, Al-Ashraf, Qeft 2, and Esna 2 are stable across the three planting dates, and they are considered relatively heat- tolerant and can be grown on the three planting dates. The first planting date in February was the best.

Keywords: Heat stress, genotypes evaluation, heat stress tolerance, genotypes adaptability.

INTRODUCTION

Pepper is a warm-season crop grows well in spring and autumn in Upper Egypt. During summer months, however, the yield and quality are highly affected. The ideal temperature range for pepper growth is 20 to 25°C. Growth and yield are typically decreased when the temperature rises over 32°C or drops below 15°C on average. Flower and fruit dropping may result by subjecting sweet peppers to heat stress during the flowering or fruiting season (Erickson and Markhart 2002; Saha *et al.*, 2010; Guo *et al.*, 2014; Koner *et al.*, 2015 and El-Gazzar *et al.*, 2020).

One of the elements limiting plant growth and production is temperature. Heat stress significantly lowers economic yield through changes in plants at the morpho-physiological, biochemical, and molecular levels (Wahid *et al*, 2007; Ortiz *et al.*, 2008; Feller and Vaseva, 2014 and Siddiqui *et al.*, 2015). Heat stress shows morphologically as sunburned and scorched leaves, twigs, branches, and stems; decreased abscission and leaf growth; decreased root and shoot growth; discolored fruit; and damage (Rodríguez *et al.*, 2005 and Rajametov *et al.*, 2021).

Heat stress disrupts all physiological processes in plants that are susceptible at every growth stage. Chlorophyll, proline, total soluble carbohydrates, photosynthetic rate, ion leakage, antioxidant activity, reactive oxygen species (ROS), total soluble protein, leaf area, leaf area index, net assimilation, relative growth rate, and fresh and dry weight are all affected by these changes (Bhandari *et al.*, 2018; Weng and Lai., 2005; Partelli *et al.*, 2009; Zribi *et al.*, 2009; Yang *et al.*, 2011; Olvera-Gonzalez *et al.*, 2013 and Feng *et al.*, 2014).

Heat stress has the greatest effect on the reproductive stage, whereas pollen development is the process that is affected. Therefore, heat causes metabolic imbalance and an accumulation of toxic compounds, including ROS, which affect plant vegetative and reproductive development and negatively impact fruit set and yield quality (Bita and Gerats, 2013). Increased ethylene production and a decrease in the quantity of reducing sugars in flowers were associated with decreased fruit set in peppers at higher temperatures (Aloni *et al.*, 1991, 1994). The proportion of fruit set, individual fruit weight, length, diameter, C quantity of fruits per plant in sweet peppers are all decreased by heat stress (Saha *et al.*, 2010; Lopez *et al.*, 2011 and Das *et al.* , 2014*)*. This study aims to identify pepper genotypes that exhibit relative tolerance to heat stress and to determine the optimal planting date under the environmental conditions of Qena Governorate.

MATERIALS AND METHODS

1. Plant material and experimental design

This study was carried out at the Experimental Farm, Faculty of Agriculture, South Valley University, Qena, Egypt during two successive seasons of 2020/2021 and 2021/2022 seasons. The site is 81 m above sea level with latitude of 26° 11' 22.2" N and longitude of 32° 44' 25.5" E. The experiment was designed to study the effect of heat stress on sweet pepper plant performance. The soil texture of the experimental site was sandy loam. Nine sweet pepper genotypes were collected from Qena, Luxor and Aswan governorate. The locations and the sources of the seeds are listed in Table 3.

Physical and chemical properties of the soil and water irrigation analysis of the experiment are shown in Tables 1 and 2.

Table 1. The physical and chemical properties of experimental Soil.

Physical Properties				Chemical Properties							
Sand%	Silt%	Clay%	Texture	EC dS/m	pH	Soluble cation (meq/L)				Soluble anion (meq/L)	
						Na^+	Ca^{++}	Mg^+	K^+	HCO_3^-	Cl^-
74.72	14.4	10.88	Sandy loam	2.02	8.00	29.1	3.0	3.0	0.5	11.2	12

Table 2. Water analysis of experimental irrigation sources obtained from Soil and Water Dep., Fac., of Agric., South Valley Uni. Qena., Egypt.

Chemical analysis of water										
Source level	EC dS/m	pH	Cations (meq/L)				Anions (meq/L)			
			Na^+	Ca^{++}	Mg^+	K^+	CO_3^{--}	HCO_3^-	Cl^-	SO_4^-
200 ppm	0.3	7.9	2	1	1	0.15	-	3	1.5	0.15

Table 3: Description, source and characteristics of sweet pepper genotypes (*Capsicum annuum L.*) used in the experiment.

Genotype	Region	Source	Seed color	**Type**	Fruit color
Dandara	Qena	Mr. Mohamed Ali	Yellow	Cherry	Yellow
Alashraf	Qena	Mr. Ayman Saed	Yellow	Cherry	Red
Qeft-1	Qena	Ms. Aya Ahmed	Yellow	Bell	Red
Qeft-2	Qena	Mr. Mohamed Essam	Yellow	Elongatee	Red
Nagada	Qena	Dr. Ahmed Mohamed	Yellow	Bell	Red
Arment	Luxor	Mr. Alaa Hany	Yellow	Elongatee	Red
Esna-1	Luxor	Mr. Mohamed Mostafa	Yellow	Bell	Red
Esna-2	Luxor	Mr. Mohamed Mostafa	Yellow	Bell	Red
Gerf Hussein	Aswan	Ms. Mona Salah	Yellow	Elongatee	Red

2. Experimental design

Three planting dates (February 15th, March 15th and April 15th) were applied in two seasons. Seeds of pepper genotypes were sown in foam seedling trays (209 cells) filled with the prepared growing media on the three planting dates. Seeds were sown one seed per cell at a depth of 1 cm. The growing media consisted of peat moss and vermiculite (1:1 volume/volume). Seeds were germinated in about 7-12 days after sowing. Good agricultural practices (irrigation, fertilization and integrated pest management) were carried out as recommended. The seedlings were hardened off by preventing irrigation for a week before transplanting in the open field to help the plants acclimatize to the environment in their final growing site. Transplants were planted in the open field at the age of 45 days.

The field plot area was (10.08 m^2). Each plot consisted of 1 row 8.40 m long and 1.2 m wide with plants transplanted 30 cm apart within rows. Each plot contained 28 plants. Thirty m^3/fed of decomposed farmyard manure and 50 kg/fed of calcium superphosphate (15.5% P_2O_5) were added during soil preparation. Plots were planted by hand with one seedling per hill and hills were spaced 30 cm apart. Plots were regularly observed to find any damaged or dead seedlings for replanting. Weeding and integrated pest management was followed as recommended by the Ministry of Agriculture. The Drip irrigation system was used to deliver the required amount of fertilizers according to Table 4. Humic acid is added 250 gm once a week. Micro-elements were sprayed three times every fifteen days after a month from transplanting.

Table 4: The fertilization regime from transplanting to harvesting of pepper plants grown in the two studied seasons.

Weeks	Sort and Amount of Fertilization				Kg/fed.	
	Urea	Ammonium Nitrate	Phosphoric acid	Potassium sulphate	Nitric acid	Calcium nitrate
The 2nd and the 3rd week *	1.4		2	0.8		0.5
The 4th and the 5th Week*	2		4	1.4		0.75
The 6th and the7th Week**		3	6	2	1	1
The 8th and the9th week **		5	8	3	1	1.5
The 10th and the 11th Week**		5	6	5	1	2
The 12th and the 13th week**		5	4	6	1	2.5
The 14th and the 1 5th week **		6	4	8	1	3
The 16th and the 1 7th week **		8	4	10		3
Till harvest**		10	6	12	1	3

* Fertilizations were added with irrigation five days per week and the last two days of irrigation without adding any fertilizers (water only). ** Fertilizations were added with irrigation five days per week, one day for nitric acid, and the last day of irrigation without adding any fertilizers (water only).

3. Measurements:

1-Plant Height: (cm)

An average of five plants were randomly chosen from each experimental unit to measure plant height in (cm) at 70 days after transplanting. It was measured from the soil surface up to the tip of the main stem.

2-No.of Branches per Plant:

An average of five plants were randomly chosen from each plot to determine the No. of branches ≠ per plant at the end of the season.

3- No of Leaves per Plant:

An average of five plants were randomly taken from each plot to count the No. of leaves per plant at 70 days after transplanting.

4-Plant Fresh Weight: (g)

Plant fresh weight was measured by taking five plants randomly from each plot at 70 days after transplanting according to the prevailing temperature during the assigned planting dates were pulled out, then their roots were removed, and the plants were immediately weighed.

5-Plant Dry Weight: (g)

The same five plants used for fresh weight traits are used for this trait too. Fresh plants were dried at 65 ºC oven for 48 hours up to constant weight and then the dried plants were weighed to obtain the dry weight.

6-Total Leaf Area: (cm^2)

A sample of ten discs of known area was taken from the second fully expanded leaf from ten leaves per plant, and then the discs were weighed. The whole leaves of the plant were weighed, and the leaf area was determined as follows:

$$\text{Total Leaf Area } (cm^2) = \frac{Discs\ areas(cm^2) X total\ leaf\ weight(g)}{Weight\ of discs(g)}$$

7-Leaf Area Index:

It was calculated as the following formula:

$$\text{Leaf area index (LAI)} = \frac{Total\ Leaf\ area(cm^2)}{Unit\ land\ area(cm^2)}$$

8- Relative Chlorophyll Content:

The chlorophyll content was determined by chlorophyll Meter (Minolta SPAD-502 meter, Tokyo, Japan) from three different spots of the second fully expanded leaf from five labeled plants per plot at 70 days after transplanting.

9-Relative Water Content RWC :(%)

Five fully expanded leaves were cut out early in the morning, immediately kept in an icebox in a sealed plastic bag, and then taken to the lab. The fresh weight (FW) of the leaves was measured before they were immersed in deionized water for the night. The next day, the leaves were removed from the deionized water and placed on tissue paper. Excess water was carefully drained, and the leaves were carefully weighed to get a turgid weight (TW). The turgid leaves were dried at 70 °C for 24 hours to obtain dry weight (DW)

$$\text{RWC \%} = \frac{\text{FW} - \text{DW}}{\text{TW} - \text{DW}} \text{x100}$$

Crop growth rate (CGR) (g/m^2/day), relative growth rate (RGR) (g/g/day) and net assimilation rate (NAR) were calculated by the following formulas:

10- Crop Growth Rate: (g/m^2/day)

$$\text{Crop Growth Rate} = \frac{\text{W2} - \text{W1}}{\text{p (t2} - \text{t1)}}$$

11-Relative Growth Rate: (g/g/day)

$$\text{Relative Growth Rate} = \frac{\text{In w2} - \text{In w1}}{\text{t2} - \text{t1}}$$

12-Net Assimilation Rate: (g/g/day)

$$\text{Net Assimilation Rate} = \frac{(\text{w2} - \text{w1})(\log \text{l2} - \log \text{l1})}{(\text{t2} - \text{t1})(\text{l1} - \text{l2})}$$

Where, W_1 and W_2 are the total dry weight values at times t_1 and t_2, respectively. L_1 and L_2 are total leaves at time t_1 and t_2, respectively. P = Ground area, In = Natural log.

13-Dry Matter Content :(%)

Dry matter content (%) was calculated according to the following formula:

$$DM\ \% = \frac{DW}{FW} X100$$

14-No. of Days to 50 % Flowering:

No. of days to 50% flowering was estimated by counting from the day transplanting to the day 50% of the plants of each genotype flowered.

15- No. of Fruits per Plant:

This trait was calculated as the average No.of fruits from the five labeled plants per plot in each harvest.

16-Fruit Weight (g):

It was measured as the average weight of ten fruits of each genotype and the fruits were weighed with an electronic weighing scale.

17-Weight of Fruits per Plant(kg):

It was measured by calculating the average weight of fruits from the five labeled plants per plot in each harvest.

18-Total Yield :(ton/fed)

The sum of weight of fruit yield in each harvest and the total yield per feddan was calculated as follows:

$$\text{Total Yield}\left(\frac{\text{ton}}{\text{fed}}\right) = \frac{\text{Weight of fruits per plot (ton) x Feddan area } (m^2)}{\text{plot area } (m^2)}$$

4. Stability analysis

Pooled analysis of variance (ANOVA) was performed over the environment. The genotypes were considered as fixed factors and appropriate error terms were used to test the significance among environments, genotypes and the interactions between genotypes and environments. The response and stability of each genotype over the six seasons of 2020 and 2021 were determined. The phenotypic stability of the genotypes was measured using the means over environments, the linear regression (bi) and the deviation from regression (s^2d) (Eberhart and Russell 1966). The deviation from the linear regression mean square was tested using the pooled error mean square. The regression coefficient (bi) and genotype mean yield were used together as measures of adaptation (Bilbro and Ray 1976). The genotype with b = 1.0 was considered adapted to all environments, genotype with b < 1.0 was considered adapted for low yielding environments and genotype with b > 1.0 was considered better adapted for high yielding environments, depending upon the genotype mean yield.

5. Statistical analysis:

The experiment was performed according to a Randomized Complete Block Design (RCBD) with a split plot design. Genotypes were assigned as the main plot factor while the planting date was used as sub-plot factor. All treatments were replicated three times. Data statistical analysis was performed using (Statistix 9.1 analytical) software. Data obtained during the two seasons of the study were statistically analyzed and treatments means were compared using Duncan's multiple range tests (Gomez and Gomez, 1984). Regression was calculated and figures were created using Excel software (Microsoft Office software package 2019).

RESULTS

This study was carried out at the Experimental Farm, Faculty of Agriculture, South Valley University, Qena, Egypt during two successive seasons of 2020/2021 and 2021/2022 seasons to study the performance of nine pepper genotypes under three planting dates.

1.*The Impact of planting dates on plant height, No. of branches per plant, No. of leaves per plant, plant fresh weight (g), plant dry weight (g), total leaf area (cm^2) and leaf area index of pepper genotypes grown under Qena governorate conditions.*

Our results showed that all the vegetative growth traits were highly affected by heat stress on the third planting date. The data revealed significant differences among pepper genotypes in plant height, branch number, number of leaves, fresh weight, dry weight, total leaf area and leaf area index across both seasons and planting dates. There was a high negative correlation between the traits studied and the prevailing temperature reflecting the negative impact of heat stress.

There were significant differences between the genotypes in plant height trait (Figure 1). The maximum plant height was achieved by Esna-1 in the first and second seasons. It outperformed the control, Dandra, by 3.08 % and 3.7%, respectively. Al-Ashraf had the lowest plant height, declining by 8.9% and 12.9% in the first and second seasons, respectively, in comparison to the control. There were significant differences in the plant between the three planting dates.

Esna 2 gave the highest No.of branches per plant in the first season. In the second season, however, Esna 2 and Gerf Hussien gave the highest No. of branches per plant and surpassed the control. The lowest No. of branches per plant was obtained from Naqada and Esna 1 in the first and second seasons. The three planting dates exhibited significant differences in the No. of branches per plant in the first season but there are not significant differences between first and second planting date in second season (Figure 2).

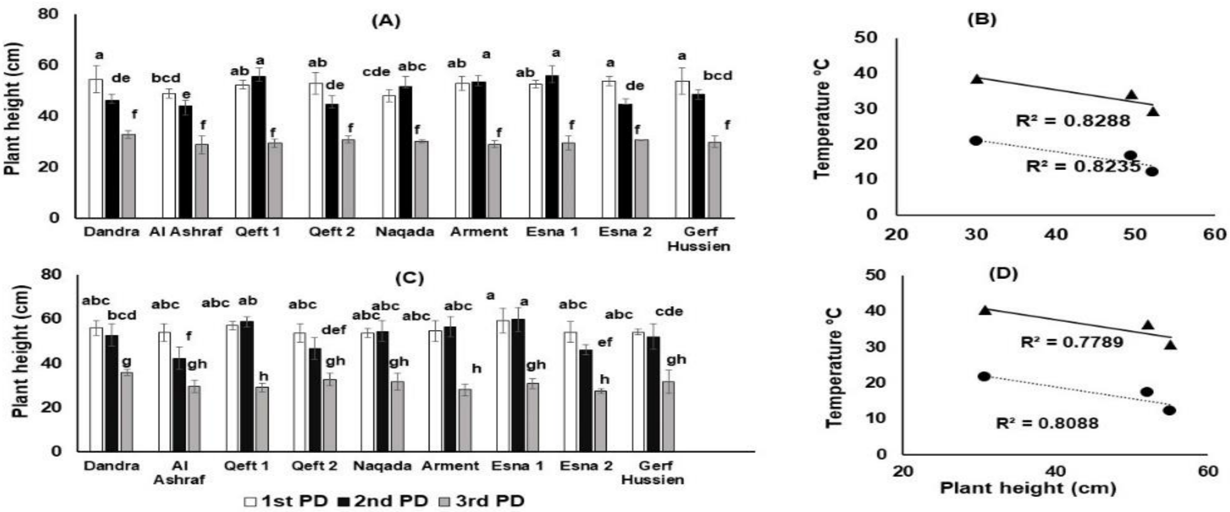


Figure 1. The Impact of planting dates on plant height of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent the plant height values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between the plant height and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

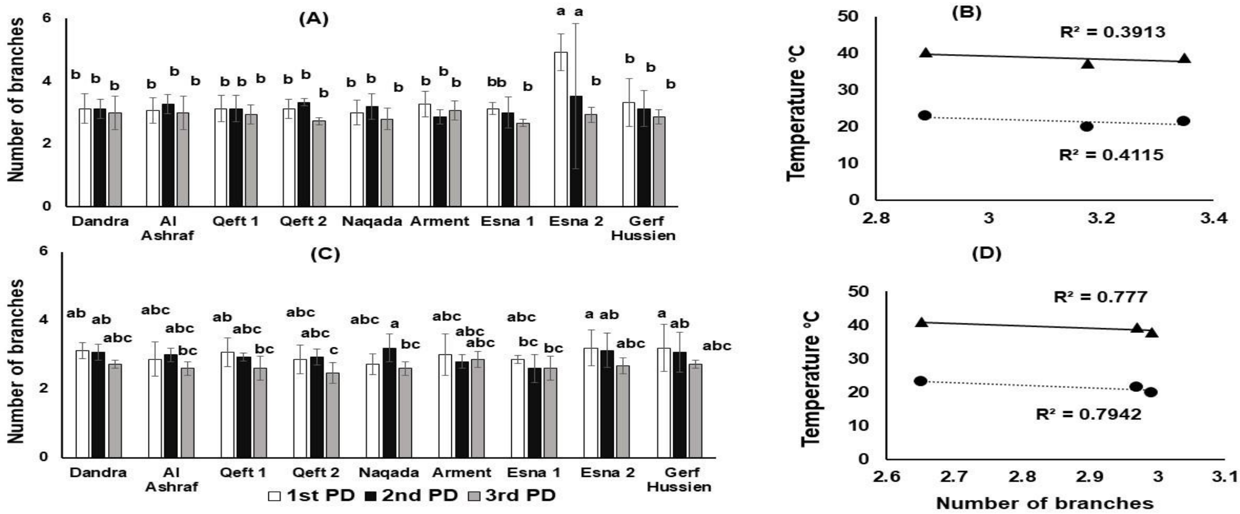


Figure 2. The Impact of planting dates on No. of branches per plant of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent the No. of branches per plant values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between the No. of branches per plant and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

Figure 4 shows that significant differences were observed among the genotypes in the plant fresh weight on all planting dates in both seasons. Qeft 2 gave the highest plant fresh weight surpassing Dandra by 21.64 % in the first season, while in the second season Esna1 gave the highest plant fresh weight outperforming Dandra by 18.86 %. The lowest plant fresh weight was obtained from Esna-2 which decreased by 23.06 % and 44.88 % in first and second season compared to control.

Data presented in Figure 5 illustrates that significant differences were exhibited among all genotypes in the dry weight on all planting dates in both seasons. Surprisingly, dry weight values were lower in the first season compared to the second season for all genotypes except Qeft 1 gave the highest dry weight and exceeded the control by 34.87 % in the first season, while in the second season Qeft 2 gave the highest dry weight and surpassed the (control) by 12.43 %. The lowest dry weight was obtained from Esna 2 which decreased by 10.65 % and 25.71 % in the first season and second season compared to the control.

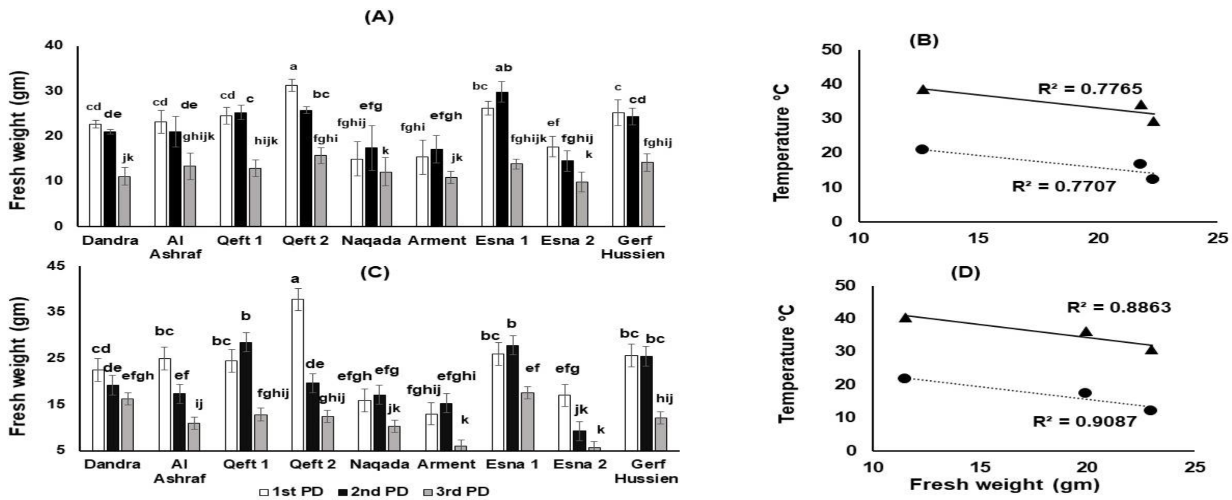


Figure 4. The Impact of planting dates on plant fresh weight of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent plant fresh weight values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between plant fresh weight and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

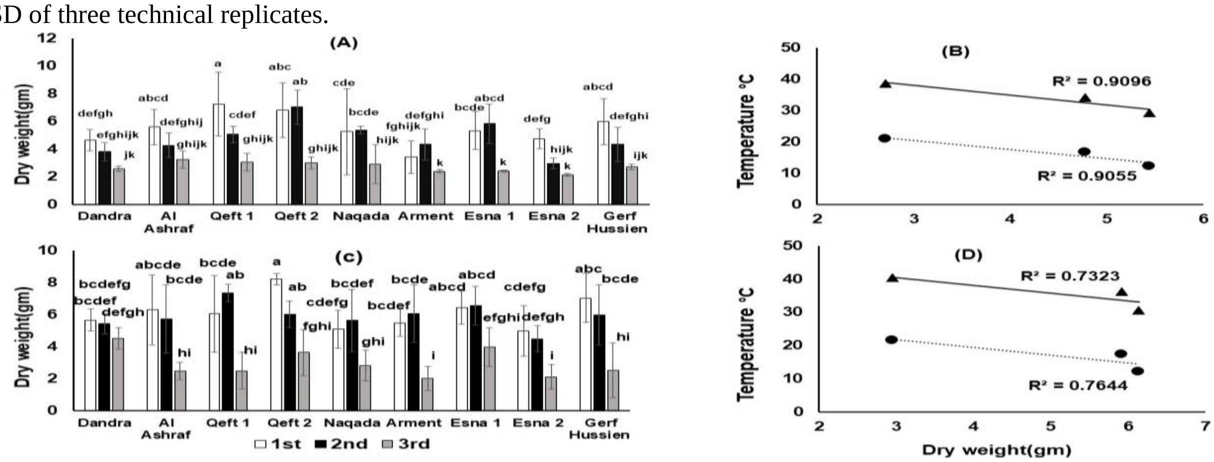


Figure 5. The Impact of planting dates on plant dry weight of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent plant dry weight values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between plant dry weight and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

The highest total leaf area values i.e. (11.19 and 13.47cm^2) were recorded in Qeft 1 and Esna 2 in the first and second seasons, respectively. Moreover, the lowest values of total leaf area i.e. (9.11 and 8.72cm^2) were obtained from Al-Ashraf and Dandra in the first and second seasons, respectively (Figure 6).

Figure 7 shows the data of the impact of planting date on leaf area index in nine genotypes of pepper. There are significant differences among the genotypes in the leaf area index in all planting dates in both seasons. Arment gave the highest leaf area index. It overpasses the control Dandra by 38.77 % and 43.02 % in the first and second seasons, respectively. The lowest leaf area index was obtained from Dandra in two studied seasons. There was a high negative correlation between the leaf area index and the temperature.

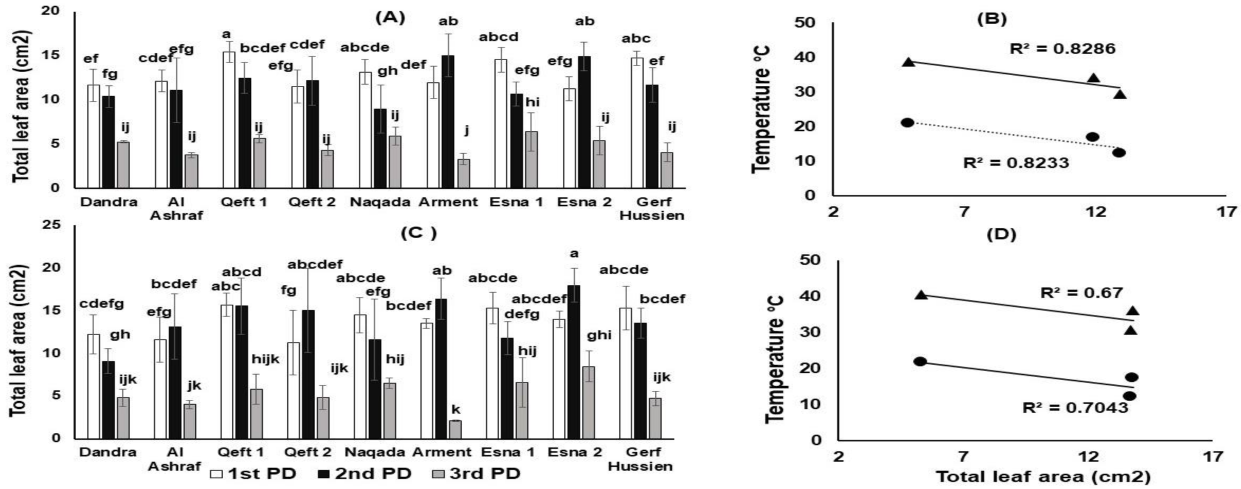


Figure 6. The Impact of planting dates on total leaf area of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent total leaf area values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between total leaf area and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

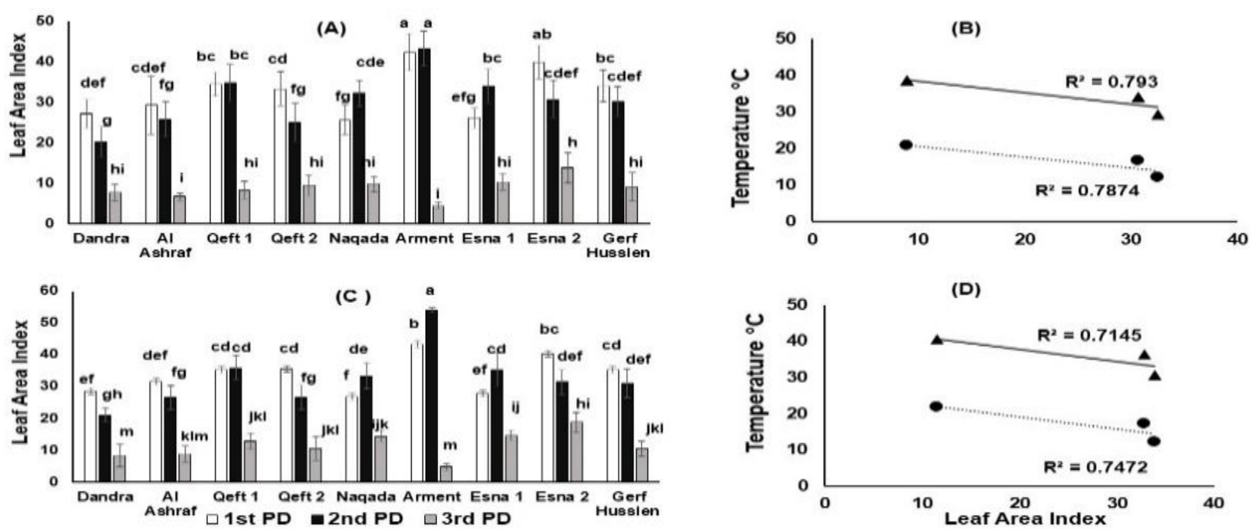


Figure 7. The Impact of planting dates on leaf area index of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent leaf area index values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between the leaf area index and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

3.2. The Impact of planting dates on chlorophyll content, relative water content, crop growth rate, crop growth rate, net assimilation rate and dry matter content (%) of pepper genotypes grown under Qena governorate conditions and means of correlation for genotypes.

The data revealed that heat stress highly reduced the relative water content, the crop growth rate, relative growth rate, net assimilation rate and dry matter content. Chlorophyll content, however, increased by high temperatures. There were significant differences among genotypes and planting dates in all studied traits. There were negative associations of all traits with high temperature except for chlorophyll content.

Significant differences were observed among genotypes in the chlorophyll content in all planting dates in both seasons. Esna 2 gave the highest chlorophyll content. It exceeded the control by 0.83 %, 1.53 % in the first and second seasons, respectively. The lowest chlorophyll content was obtained from Esna 1 which decreased by 11.12 % in the first season and by 10.31 % in the second season compared to the control (Figure 8).

Data presented in Figure 9 exhibits the differences among genotypes in the relative water content (%). Qeft 2 gave the highest percentage of relative water content (%) in both seasons. The lowest relative of water content (%) was obtained from Al-Ashraf in the first season and from Dandra in the second season.

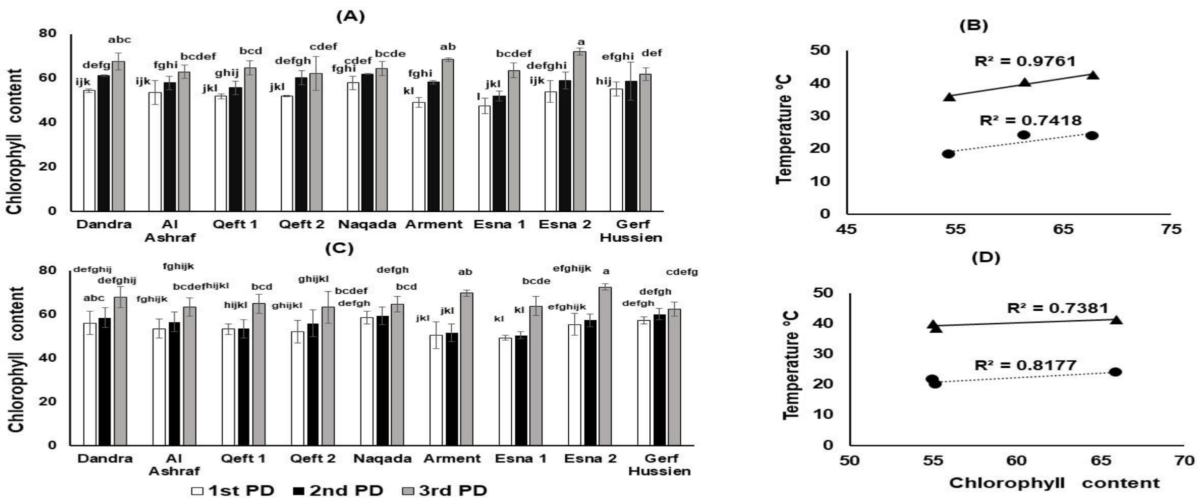


Figure 8. The Impact of planting dates on chlorophyll content of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent chlorophyll content values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between chlorophyll content and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates

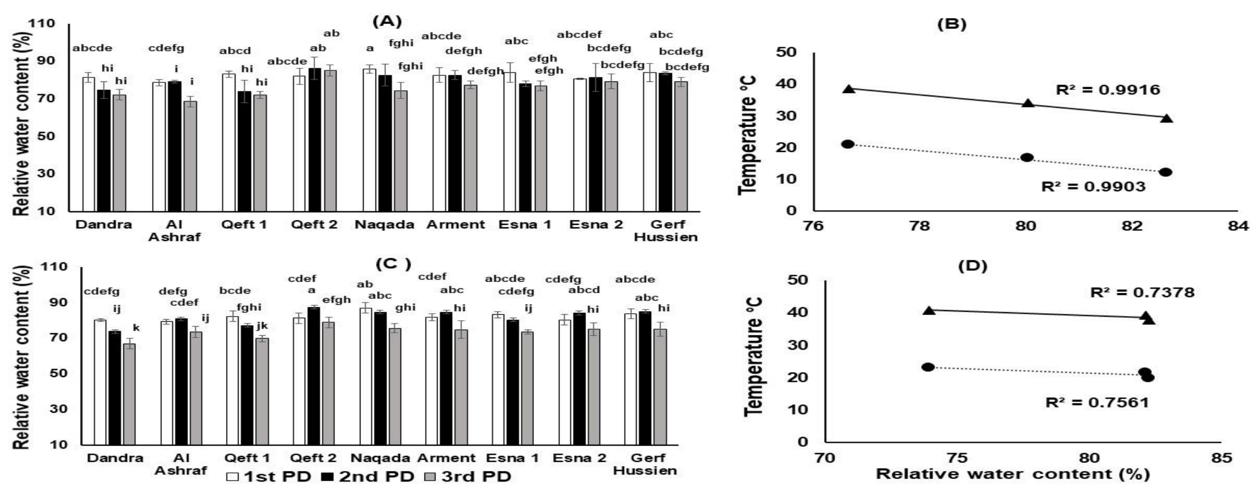


Figure 9. The Impact of planting dates on relative water content (%) of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent relative water content (%) values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between relative water content (%) and prevailing

temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

Data presented in Figure 10 demonstrates that there are significant differences among the genotypes in the crop growth rate in all planting dates in both seasons. Qeft 2 gave the highest crop growth rate in both seasons. It exceeded the (control) Dandra by29.72 % and 26.31 % in the first and second seasons, respectively. The lowest crop growth rate was obtained from Esna 2 in the two studied seasons.

Figure 11 revealed the differences among the relative growth rate values in the first and second seasons. Al-Ashraf gave the highest relative growth rate. It exceeded the (control) Dandra by 28.57 % in the first season. While, in the second season Dandra, Qeft 2 and Esna 1 gave the highest relative growth rate. The lowest relative growth rate was obtained from Esna 2 in both seasons.

Figure 12 shows that there are significant differences among the net assimilation rate values in the first season compared to the second season for all genotypes. Qeft 1 gave the highest net assimilation rate in the first season, while in the second season Qeft 1 and Dandra gave the highest assimilation rate. The lowest net assimilation rate was obtained from Esna 2 in both seasons.

Data presented in Figure 13 showed that dry matter content (%) of all genotypes varied significantly (%) in all planting dates. In the first season the highest percentage of dry matter content (%) was obtained from the genotype Naqada. It increased over control, Dandra, by 33.16 %. In the second season Esna 2 gave the highest dry matter content. It increased over the control Dandra by 34.66 %. Meanwhile, the lowest dry matter content obtained from the Esna 1 (19.49 %) in the first season. Meanwhile Gerf Hussien gave the lowest percentage of dry matter content (23.53 %) in second season.

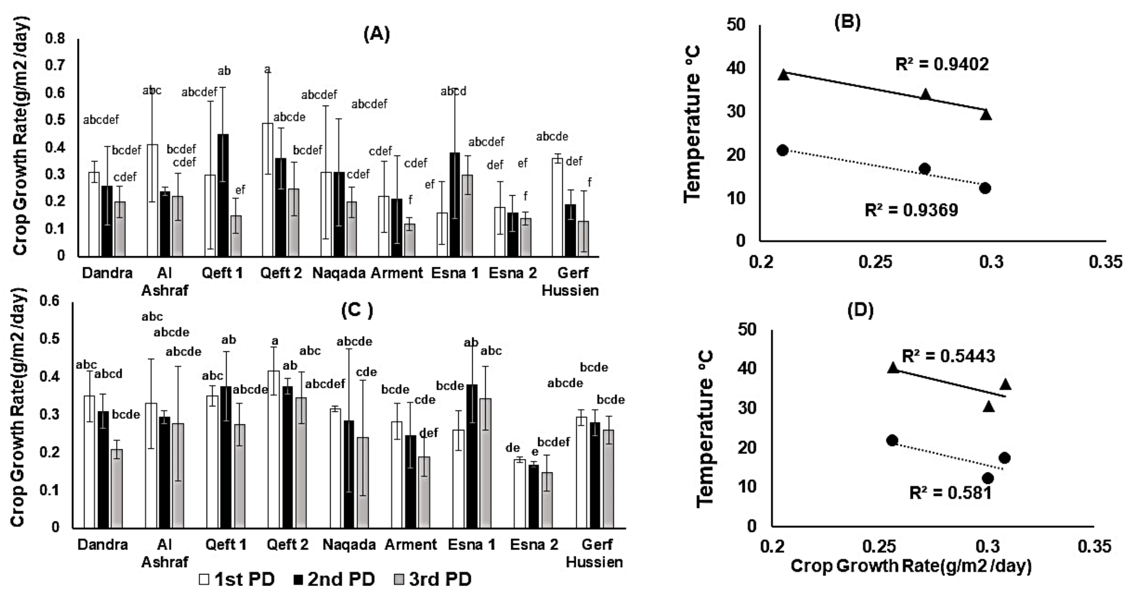


Figure 10. The Impact of planting dates on crop growth rate of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent crop growth rate values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between crop growth rate and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

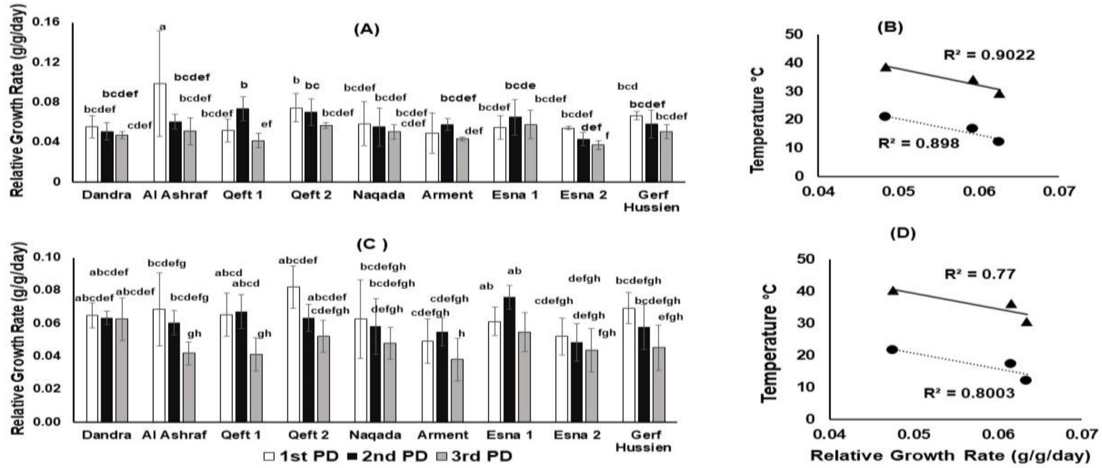


Figure 11. The Impact of planting dates on the relative growth rate of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent relative growth rate values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between relative growth rate and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three techenical replicates.

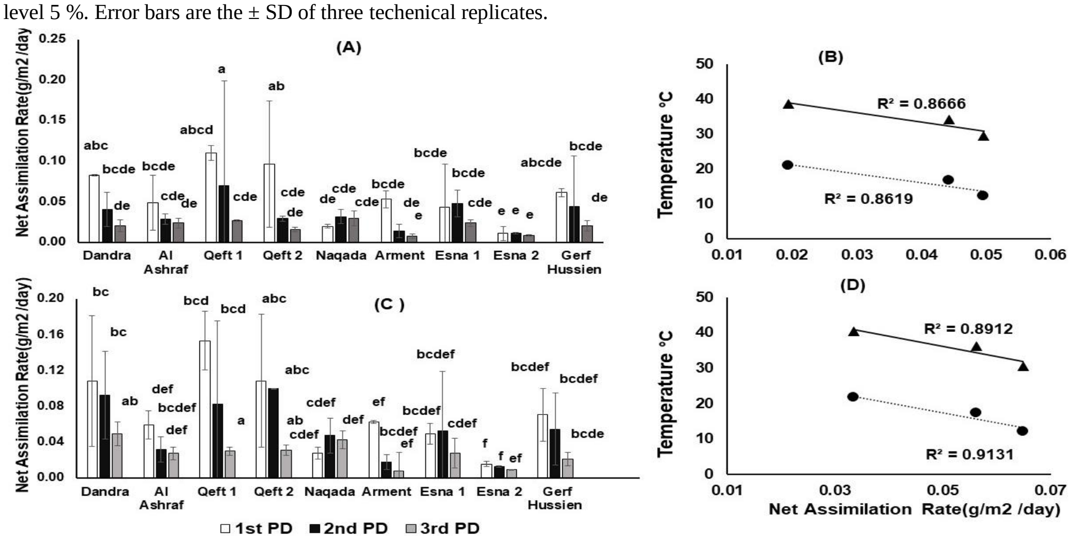


Figure 12. The Impact of planting dates on net assimilation rate of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent net assimilation rate values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between net assimilation rate and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

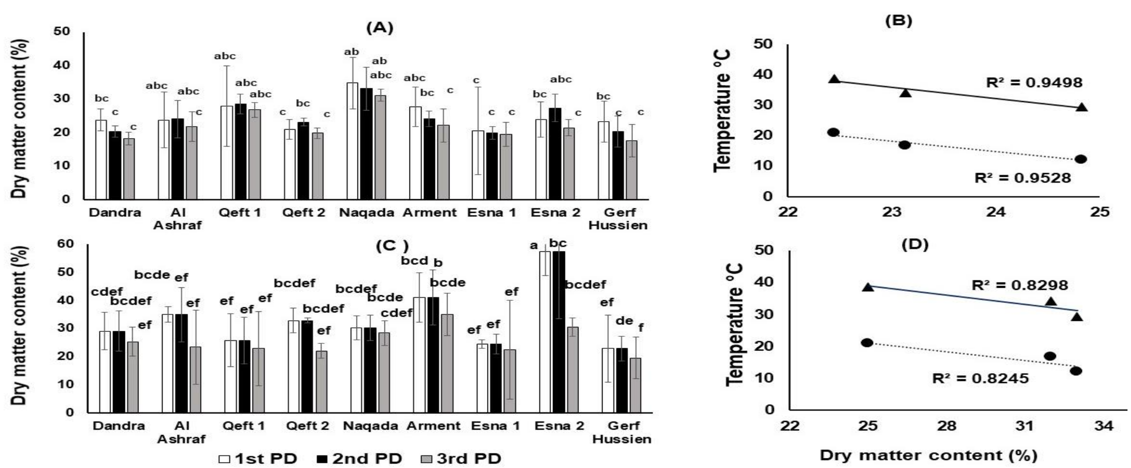


Figure 13. The Impact of planting dates on dry matter content of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent dry matter content values in 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between dry matter content and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

3.3. The Impact of planting dates on No. of days to 50 % flowering, No.of fruits per plant, fruit weight (g), weight of fruits per plant (Kg) and total yield (ton/fed) of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes.

Our results showed that all the flowering, yield and yield components traits were highly affected by heat stress on the second and third planting dates. The data revealed significant differences among pepper genotypes in No. of days to 50 % flowering, No. of fruits per plant, fruit weight, weight of fruits per plant and total yield per feddan in both seasons and planting dates. There was a high negative correlation between the traits studied and the prevailing temperature reflecting the negative impact of heat stress.

Data in Figure 14 showed the significant differences observed among genotypes in the days to 50 % flowering in all planting dates in both seasons. Gerf Hussien showed the earliest flowering genotypes. It flowered earlier than the Dandra by 2.8 and 2.5 days in both seasons. While Arment delayed in flowering by 10.8 and 2.8 days compared to the control Dandra in the both seasons.

Data presented in Figure 15 demonstrates that genotypes significantly varied in the No. of fruits≠ per plant in all planting dates. Dandra and Al-Ashraf gave the highest No. of fruits per plant. The lowest No. of fruits per plant was obtained from Arment which decreased by 12.86 % and 19.74 % in the first season and second season compared to the control.

Data in Figure 16 showed the significant differences observed among genotypes in the fruit weight in all planting dates in both seasons

Significant differences among genotypes in the fruit weight were observed in both seasons. Qeft-1 gave the highest fruit weight. It exceeded the (control) Dandra by 2.33 % and10.87 % in the first and second seasons, respectively. The lowest fruit weight was obtained from Esna 2 which decreased by 45.81 % in the first season and by 40.12 % in the second season compared to the control (Figure 16).

Data presented in Figure 17 demonstrate that there are significant differences among the weight of fruits per plant values in both seasons. Dandra gave the highest weight of fruits per plant in both seasons. The lowest weight of fruits/plant was obtained from Esna1 which decreased by 15.72 % and 12.37 % in both seasons compared to the control.

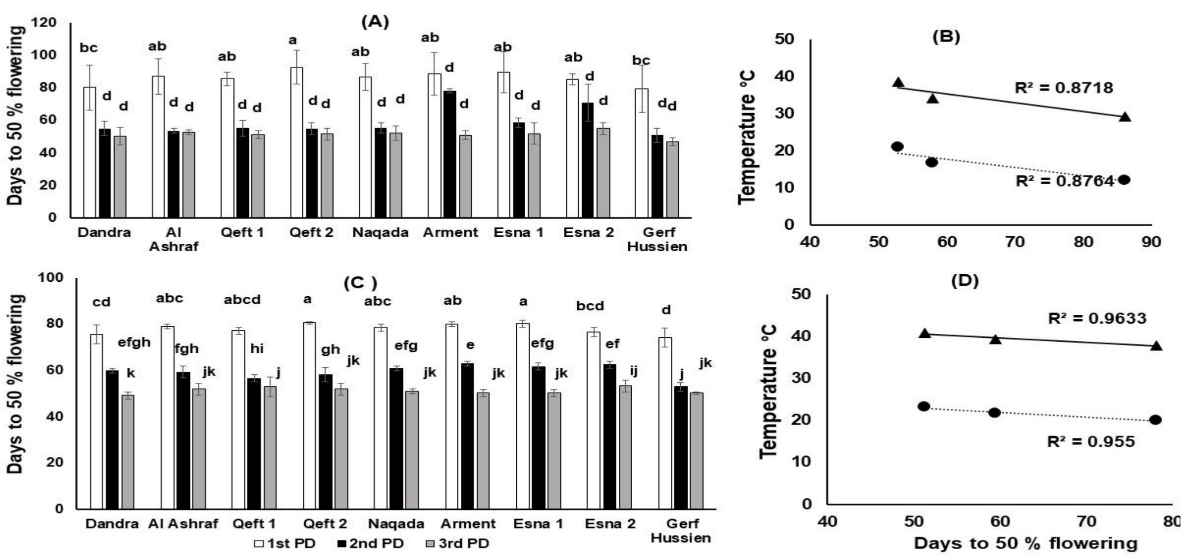


Figure 14. The Impact of planting dates on days to 50 % flowering of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent days to 50 % flowering values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between days to 50 % flowering and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

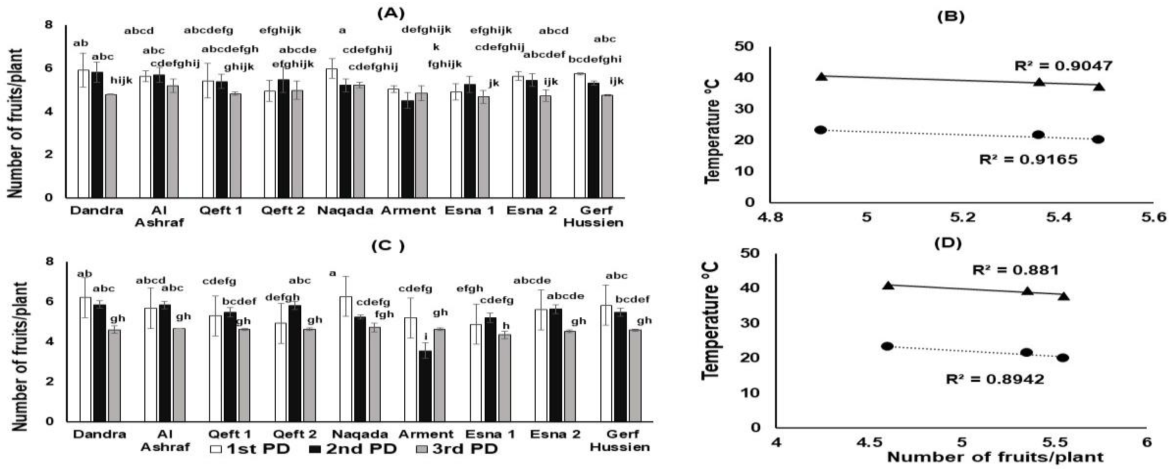
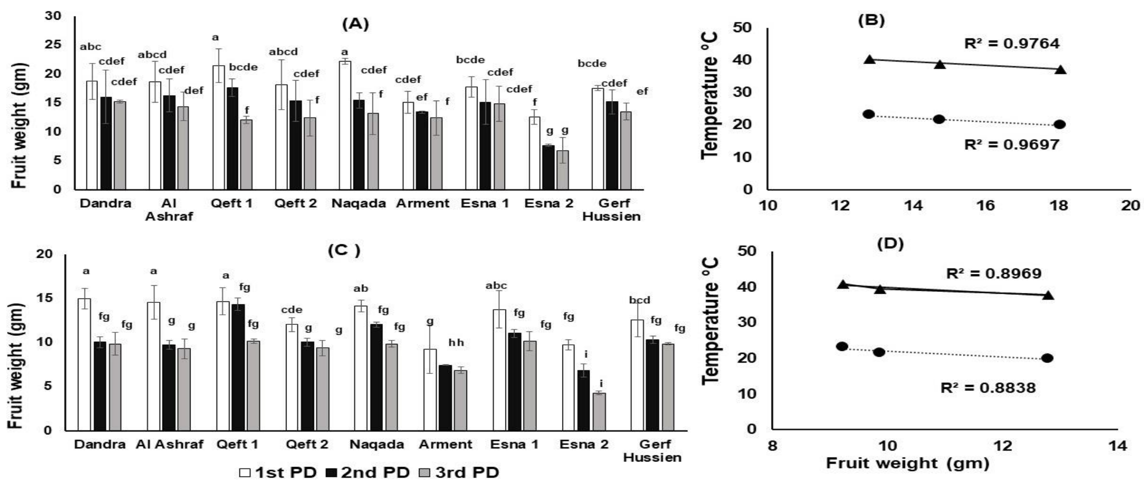


Figure 15. The Impact of planting dates on No. of fruits per plant of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent No of fruits per plant values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between No. of fruits per plant and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

Figure 16. The Impact of planting dates on fruit weight of pepper genotypes grown under Qena governorate conditions and mean of correlation



for genotypes. (A and C) represent fruit weight values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between fruit weight and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

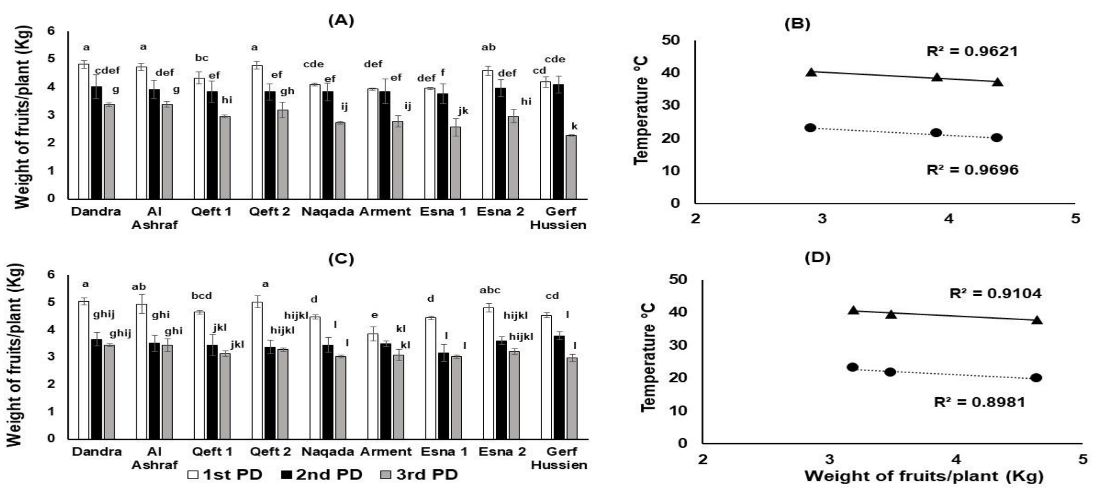


Figure 17. The Impact of planting dates on weight of fruits/plant of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent weight of fruits-per plant values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between weight of fruits per plant and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three technical replicates.

Figure 18 illustrates the differences among the total yield values in both seasons. Dandra gave the highest total yield in both seasons. The lowest total yield was obtained from Esna 1 and Arment which decreased by 15.59 % and 14.13 % in the first and second seasons, respectively compared to the control.

3.4. Stability analysis

The analysis of variance for total yield in pepper cultivars (Table 5) revealed highly significant differences between environments (E), genotypes (G), and their interactions (G × E), indicating the presence of substantial variability in both the growing conditions and the performance of genotypes across different environments. The significant interaction between genotypes and environments (G × E) suggests that genotypes responded differently to the environmental conditions, emphasizing the need to evaluate the stability of each genotype under varying conditions.

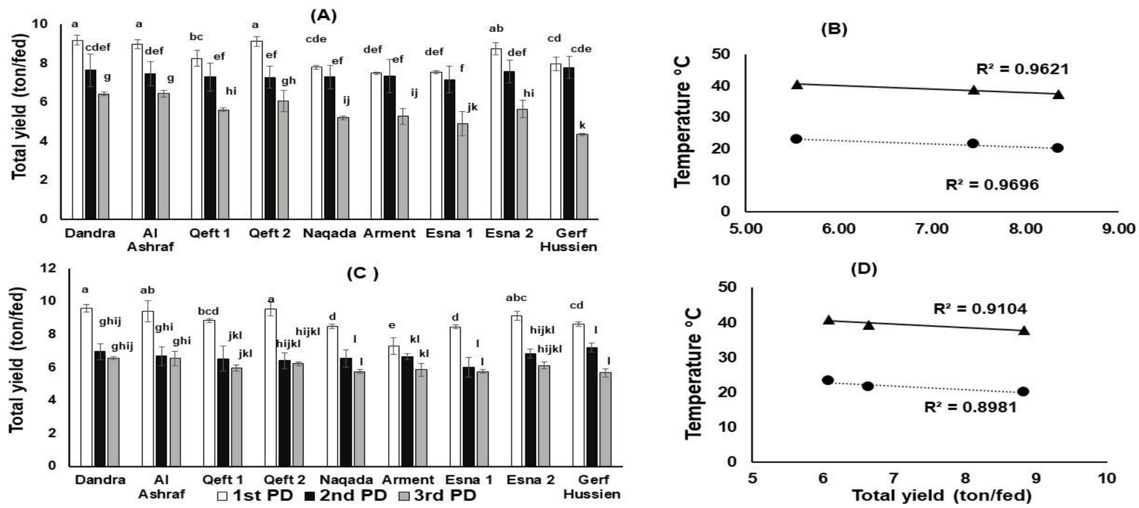


Figure 18. The Impact of planting dates on the total yield of pepper genotypes grown under Qena governorate conditions and mean of correlation for genotypes. (A and C) represent total yield values in seasons 2020 and 2021 respectively for the genotypes. (B and D) represent the correlations between total yield and prevailing temperature. Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three techenical replicates.

Stability Analysis

The stability analysis of variance (Table 6) further supports the presence of significant variation among genotypes for total yield, as indicated by the significant mean squares for genotypes (M.S. = 2.92 **, P < 0.01). Additionally, the interaction between environments and genotypes, as well as the linear component of the environment (E) and G × E interaction, was significant. This suggests that the environmental conditions exerted both linear and non-linear effects on genotype performance.

The stability of individual genotypes was assessed using the regression coefficient (bi) and the deviation from regression (s²d), based on the **(Eberhart and Russell, 1966)** model. Genotypes with a regression coefficient close to 1 and a non-significant deviation from regression are considered stable. Among the genotypes, Qeft 2 and Gerf Hussien had significant deviations from regression (s²d = 0.76 and 1.30, respectively), indicating poor stability. In contrast, Dandara, Qeft-1, and Esna-1 exhibited non-significant deviations, implying greater stability across environments.

Table 5: Pooled analysis of variance for total yield (ton /fed.) in nine pepper genotypes grown under six environments (3 planting dates X two years).

Source of variance	d.f	M.S
Environments (E)	(e-1) 5	1.23**
Replication/ E	12	2.51
Genotypes (G)	(g-1) 8	23.79**
G × E	(g-1) (e-1) 40	1.77**
Error	96	0.13

Table 6: Mean squares from stability analysis of variance for total yield (ton /fed.) of 9 pepper cultivars.

Source of variance	d.f	M.S
Genotypes (G)	(g-1) 8	2.92**
E + (G×E)	(E+(g x e)-1) 45	5.41**
E (linear)	1	224.58**
G×E (linear)	8	0.58**
Pooled deviation	36	0.40**
Dandara	4	0.29NS
Al-Ashraf	4	0.43*
Qeft 1	4	0.02NS
Qeft 2	4	0.76**
Naqada	4	0.10NS
Arment	4	0.50**
Esna 1	4	0.17NS
Esna 2	4	0.02NS
Gerf Hussien	4	1.30**
Pooled error	96	0.133

Yield and Adaptation

The total yield of the nine pepper genotypes across six environments varied considerably (Table 7). The average total yield ranged from 6.65 tons per fed. for Esna-1 to 7.74 tons per fed. for Dandara. Genotypes such as Dandara (7.74 tons/fed.), Al-Ashraf (7.60 tons/fed.), and Qeft-2 (7.46 tons/fed.) exhibited the highest average yields, demonstrating strong overall performance.

The regression coefficient (bi) values provide insights into the adaptability of genotypes to varying environments. Genotypes with bi values close to 1 are considered to have average responsiveness to environmental changes. For instance, Dandara (bi = 1.03), Al-Ashraf (bi = 0.98), and Qeft-1 (bi = 0.99) showed moderate responsiveness, indicating good adaptability across diverse environments. In contrast, G6 Arment (bi = 0.64) showed a significantly lower regression coefficient, suggesting this genotype performs better in less favorable environments and may lack adaptability to high-yield environments.

Notably, Qeft-2 (bi = 1.14) and Gerf Hussien (bi = 1.17) had regression coefficients greater than 1, indicating a tendency for better performance in more favorable environments, although their significant deviations from regression suggest less stability. G6 Arment, while yielding lower overall, also exhibited significant deviation from regression (s^2d = 0.50), signaling poor stability despite its relatively low adaptation to favorable environments.

DISCUSSION

In Egypt, sweet pepper is a favorite vegetable grown year-round. Pepper is a tropical plant that grows well in the summer. The yield is abundant during summer and prices are fair at this time of year. Since the pepper requires moderate to high temperatures for each step of its life cycle, it is sensitive to low temperatures and cannot tolerate frost. In the winter, sweet pepper is grown in greenhouses. The ideal temperature is from 21 to 30 °C. Lower temperatures cause juvenile portions to wither, germination rates to drop, and growth to slow down. Consequently, it's critical to find either somewhat or completely tolerant of heat stress genotypes.

The effects of heat stress on plant growth and performance are well-known. Based on our results, it is clear that high temperatures had an impact on all genotypes that were investigated for every genotype of sweet pepper cultivated in an open field under heat stress conditions during two consecutive seasons in 2020–2021 and 2021–2022. Heat stress decreased plant height, fresh weight, dry weight, total leaf area and leaf area index. High negative correlations were observed between the prevailing temperature and plant fresh weight, dry weight, total leaf area and dry matter. (Figures 1, 4.5,6 and 7).

The high temperature in this experiment had a significant impact on both fresh and dried weight. On the third planting date, there was a significant decrease in plant fresh and dry weight. These characteristics and the current temperature have an important negative correlation that we have seen, which is consistent with their function in plant growth and development. One limiting component is growth temperature. Plant height, root weight, and fresh and dry weight are all considerably reduced when chili pepper seedlings are cultivated at 42 °C (Prasad *et al.,* 2006; Hasanuzzaman *et al.*, 2013; Saqib and Anjum 2021; Rajametov *et al.*, 2021), in tomato and other crops (Kumar *et al.,* 2011; Bikash 2012),in maize(Hussain *et al*., 2019), in rice(Gray *et al*., 2016), in sorghum bicolor at seedling stage (Gosavi *et al.,* 2014). Heat stress decreased plant height, tillers number and total biomass in the rice cultivar (Mitra *et al.*, 2008).

One of the main effects of heat stress on chili peppers is thought to be the creation of reactive oxygen species (ROS), which causes oxidative stress, antioxidant production, accumulation, and adjustment of suitable solutes (Ghai *et al.*, 2016; Hasanuzzaman *et al.*, 2012; Hasanuzzaman *et al.*, 2013) and in maize (Hussain *et al.*, 2019). Heat negatively affects chlorophyll and photosynthesis, resulting in the production of injurious reactive oxygen species (ROSs) (Camejo *et al.*, 2006; Guo *et al.*, 2007).

When exposed to high temperatures, photosynthetic pigments may be reduced due to suppression of production, changes in chloroplast ultrastructure, particularly the membrane, and photo-deterioration (Reda and Mandoura 2011). Heat stress in peppers had a detrimental impact on dry matter, leaf area, net rate of assimilation, and relative growth rate (Lopez *et al.,* 2011; Gisbert-Mullor *et al.,* 2021), in maize and millet (Wahid, 2007) and sugarcane (Srivastava *et al.*, 2012). Also, there was a significant reduction in leaf area index because of the high temperature and low humidity, which limited plant vegetative growth in sweet pepper (Koner *et al.*, 2015), in potatoes, as well as improper vegetative growth due to high temperature (Bustan *et al.*, 2004).

Heat stress decreased relative water content, crop growth rate, relative growth rate and net assimilation rate, negative correlations were observed between the prevailing temperature and relative water content, crop growth rate, relative growth rate and net assimilation rate, Figures (9, 10, 11 and 12). Heat stress affects sensitive plants' physiological processes at every growth stage. Proline, total soluble carbohydrates, photosynthetic rate, ion leakage, antioxidant activity, reactive oxygen species (ROS), total soluble protein, leaf area, leaf area index, net assimilation, relative growth rate, and fresh and dry weight are all impacted by these changes (Bhandari *et al.*, 2018; Weng and Lai., 2005; Partelli *et al.*, 2009; Zribi *et al.*, 2009; Yang *et al.*, 2011; Olvera-Gonzalez *et al.*, 2013; Feng *et al.*, 2014).

Heat stress, on the other hand, decreased the dry matter content. Therefore, dry matter content negatively correlated with the average high and low temperature (Figure 13). Heat stress had a detrimental impact on dry matter, leaf area, the net rate of assimilation, relative growth rate, and maize and millet (Wahid *et al*, 2007); sugarcane (Srivastava *et al.*, 2012); and peppers (Lopez *et al.*, 2011; Gisbert-Mullor *et al.,* 2021). High temperature had a huge effect on pepper plants grown on the third planting date in regard to 50 % flowering. The time required for flowering is the least compared to the first and the second planting date. The first planting date had the longest No. of days to 50 % flowering in the second season and had longer flowering time because of the prevailing temperature was colder than the third planting date (Figure 14). It is clear that the more the plant is exposed to high temperatures, the faster flowering occurs. (Korkmaz and Dufault, 2001; Korkmaz and Dufault, 2004).

Our results revealed that heat stress affected yield and yield components. Heat stress decreased the No. of fruits per plant, fruit weight, weight of fruits per plant and total yield, in all pepper genotypes. There was a high negative correlation among the prevailing temperature and No. of fruits per plant, fruit weight, weight of fruits per plant and total yield (Figures 15, 16, 17 and 18). High temperature reduces the percentage of fruit set, individual fruit weight, length, Fruit diameter and number of fruits per plant in sweet pepper (Saha *et al.*, 2010; Lopez *et al.*, 2011; Das *et al.*, 2014; Kumari *et al.*, 2021; Saqib and Anjum 2021: Taskovics *et al.*, 2010; Lopez-Marín *et al.*, 2013; Mends-Cole *et al.*, 2019). A higher percentage of fruit set under high temperature variables is a characteristic of heat-tolerant cultivars of *Capsicum annuum* L. (Scafaro *et al.*, 2010; Ghai *et al*., 2016), in chili pepper (Dahal *et al.*, 2006; Prasad *et al.*, 2008; Abdul Malik *et al.*, 2012; Thuy and Kenji 2015; Ghai *et al.*, 2016; Kaur *et al.*, 2016; Oh and Koh, 2019; Rajametov *et al.*, 2021). The temperature affects the reproductive potential, aesthetic, and commercial value of ornamental peppers (*Capsicum annuum L*.) (Gajanayake *et al.*, 2011).

Stability analysis

The results of the study provide valuable insights into the performance and stability of nine pepper genotypes grown under varying environmental conditions, emphasizing the importance of both yield and stability in the selection of cultivars suited to hot climate regions. The significant genotype (G) and environment (E) effects, as well as the genotype-by-environment (G×E) interactions, highlight the strong influence of environmental variability on the phenotypic performance of pepper genotypes, as shown by the pooled analysis of variance (Table 5). This finding aligns with previous research that suggests G ×E interactions are common in crop breeding trials conducted across diverse environments, especially under stress conditions like heat (Bita and Gerats, 2013; Yan)

Stability and Adaptability of Genotypes

The stability analysis revealed that genotypes exhibited varying degrees of adaptability and stability across the six environments, which were defined by different planting dates and years (Table 6). Genotypes like Dandara, Al-Ashraf, and Qeft1 showed non-significant deviations from regression, indicating their greater stability across environments. This is particularly important for farmers in hot climates, where temperature fluctuations can significantly affect plant growth and yield. Stable genotypes maintain consistent yields despite environmental variations, making them more reliable for cultivation under uncertain climate conditions (Becker and Léon, 1988).

On the other hand, genotypes such as Qeft 2 and Gerf Hussien demonstrated significant deviations from regression, indicating a lack of stability. While these genotypes may produce high yields in favorable environments, their performance is less predictable in less favorable conditions. This observation is consistent with the findings of other studies that suggest that genotypes with high sensitivity to environmental changes (bi > 1) tend to excel in optimal conditions but perform poorly in stressful environments **(Bilbro and Ray, 1976)**. In this study, Qeft 2 and Gerf Hussien showed better performance in favorable environments but lacked stability, making them less suitable for regions prone to unpredictable heat stress

Yield and Regression Coefficient (bi) as Indicators of Adaptation

The regression coefficient (bi) is an important parameter for evaluating the adaptability of genotypes to varying environments. Genotypes with bi values close to 1 are considered to have average adaptability, meaning they respond similarly to both favorable and unfavorable environments (Eberhart and Russell, 1966). In this study, Dandara (bi = 1.03) and Qeft1 (bi = 0.99) exhibited bi values close to 1, suggesting that they are well-adapted to a wide range of conditions, making them ideal for cultivation in hot climate regions where environmental conditions can vary.

Conversely, Arment (bi = 0.64) had a significantly lower regression coefficient, indicating that it is more suited to low-input or less favorable environments. This genotype may have mechanisms that allow it to maintain yield under heat stress, but it lacks the ability to take full advantage of more favorable conditions. Such genotypes are often considered stress-tolerant but may not be ideal for high-yield environments (Blum, 2014). On the other hand, Qeft 2 and Gerf Hussien had bi values above 1 (1.14 and 1.17, respectively), suggesting they perform well in high-yield environments but are less suited to harsh conditions, which is further supported by their significant deviations from regression.

Implications for Breeding and Cultivation in Hot Climates

The results of this study have important implications for breeding programs aimed at developing heat-tolerant pepper cultivars. In hot climates, stability is a critical trait, as fluctuating temperatures can lead to significant reductions in yield if the crop is not resilient to heat stress (Hill, 2001). Breeders should focus on selecting genotypes like Dandara and Qeft 1, which not only produce high yields but also exhibit stability across different planting dates and years

Moreover, the significant G X E interaction observed in this study suggests that environmental factors, particularly planting dates, play a crucial role in determining the performance of genotypes. By adjusting planting dates, farmers may be able to mitigate the impact of heat stress during critical growth stages such as flowering and fruit set, as suggested by several studies on planting strategies in hot climates (Craufurd and Wheeler, 2009).

Table 7: Average total yield (ton/fed.) of 9 genotypes growing under various Environmental conditions and the estimates of the different stability parameters in pepper cultivars.

Genotypes	Total yield (ton/fed.)							Regression coefficient (b)	Test of sig. For (b)		Deviation from regression (s2 d)
	E1	E2	E3	E4	E5	E6	Mean		b = 1	b = 0	
Dandara	9.19	7.66	6.44	9.59	6.97	6.56	7.74	1.03^{NS}	0.77	0.37	0.29NS
Al-Ashraf	8.99	7.49	6.46	9.43	6.69	6.56	7.60	0.98 NS	- 0.28	0.62	0.43*
Qeft-1	8.26	7.32	5.63	8.85	6.55	5.98	7.10	0.99 NS	-0.11	0.02	0.02NS
Qeft-2	9.13	7.30	6.09	9.58	6.24	6.43	7.46	1.14 NS	0.95	-0.66	0.76**
Naqada	7.81	7.32	5.21	8.51	6.56	5.76	6.86	0.96 NS	-0.46	-0.03	0.10 NS
Arment	7.50	7.35	5.29	7.32	6.65	5.88	6.67	0.64*	-3.57	2.07	0.50**
Esna-1	7.56	7.18	4.90	8.47	6.03	5.76	6.65	1.01 NS	0.12	-0.55	0.17 NS
Esna-2	8.75	7.58	5.66	9.16	6.86	6.12	7.36	1.09 NS	0.93	-0.44	0.02 NS
Gerf Hussien	7.99	7.80	4.36	8.64	7.21	5.68	6.95	1.17 NS	0.81	-1.39	1.30**
Mean	8.35	7.44	5.56	8.84	6.64	6.08	7.15	1			

L.S.D of genotypes means = 0.241 and L.S.D of environments means = 0.197
SE (Mean) = 0.104 S.E. (b)= 0.15

CONCLUSION

From our results, it could be concluded that heat stress severely affected all pepper genotypes. All studied traits decreased by increasing the prevailing temperature except chlorophyll content, number of days to 50 % flowering, and No. of branches per plant. In general, Dandra, Al-Ashraf, Qeft 2, and Esna 2 outperformed all pepper genotypes in most studied traits, especially the total yield components traits under normal and heat stress conditions. The results, also, demonstrate that while some pepper genotypes, like Qeft 2 and Gerf Hussien, may offer high yields in optimal conditions, they are less stable across varying environments, making them riskier choices for cultivation in hot climates. In contrast, genotypes like Dandara and Qeft 1 combine good yield performance with stability, making them better suited for consistent production in regions prone to heat stress. These findings underscore the importance of considering both yield and stability when selecting cultivars for breeding and agricultural production in challenging environments. So, our recommendations based on this study are. The genotypes Dandra, Al-Ashraf, Qeft 2, and Esna 2 are stable across the three planting dates, and they are considered relatively heat- tolerant and can be grown in the three planting dates. Dandra, Al-Ashraf, Qeft 2, and Esna 2 genotypes can be used as nuclear for breeding programs for heat stress. The best date for planting is February to get high yield from pepper in Qena governorate.

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