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Impact of Planting Dates on Tomato (*Solanum lycopersicon L.*) Hybrid Performance under Heat and Cold Stress in Sohag, Egypt

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Abstract

Tomatoes are a warm-season crop grown year-round in Egypt. However, prices tend to spike during certain periods, particularly in the summer and autumn. In the Sohag governorate, farmers typically plant tomatoes from mid-August to the end of November to take advantage of higher prices in late autumn and early winter. However, tomatoes planted very early in August or very late in November experience heat and cold stress, respectively. This experiment was conducted to assess the impact of planting dates (September, October and November) on the performance of seven tomato hybrids. Our results showed that vegetative growth attributes such as leaf area, leaf area index, and plant fresh weight decreased under heat and cold stress, except for some genotypes. Plant length was affected by cold stress but not by heat stress. Plant survival decreased under both heat and cold stress. Conversely, dry matter content, TSS, vitamin C, total acidity, and fruit firmness increased as temperatures decreased. Fruit weight, fruit diameter, early fruit yield per plant, and total yield per feddan were negatively affected by the first and third planting dates, which were exposed to heat and cold stress, respectively. Both heat and cold stress adversely impacted all plant attributes, although heat stress in the first planting date was less severe than cold stress in the third planting date. The optimal planting date was found to be the second planting date in October, with the best varieties being 9090 and Super gold across the three planting dates

Key words: Genotypes, heat tolerance, cold tolerance, fruit

INTRODUCTION

Tomato is a warm season crop and it is highly sensitive to both heat and cold stress, which significantly impacts their growth, yield, and market prices. These temperature stresses lead to fluctuations in tomato production, causing supply shortages that result in spiked market prices (Camejo et al., 2005). For instance, extreme weather conditions have been linked to significant price increases in tomato markets due to reduced yields and fruit quality (Yuan and Yang, 2018). Consequently, both cold and heat stress in tomatoes not only threaten food security but also contribute to economic instability in the agricultural sector (Kaushal et al., 2016). Exposure of tomato plants to temperatures below 10-15°C can inhibit seed germination, disrupt vegetative growth, and cause chilling injuries in mature fruits (Weiss and Egea-Cortines, 2009). Conversely, temperatures above 35°C can impair seed germination, vegetative development, and reproductive processes, leading to reduced fruit set and lower yields (Wahid and Close, 2007). Heat stress highly affects plant performance and yield, leading to substantial declines in its productivity. Heat stress can cause leaf burn, wilting, and reduced leaf area, which further limits photosynthetic capacity and transpiration rates (Wahid et al., 2007). The reproductive stages are particularly sensitive, with heat stress leading to poor pollen viability, reduced fertilization rates, and increased flower and fruit abortion (Zinn et al., 2010). Consequently, these physiological and morphological disruptions translate into lower yields, as seen in crops like wheat and rice, where heat stress during critical growth periods can reduce grain filling and spikelet fertility, ultimately diminishing grain yield (Lobell & Gourdji, 2012). High temperatures disrupt cellular functions, impairing photosynthesis by damaging the photosynthetic apparatus and reducing chlorophyll content (Sharma *et al*., 2014). This results in decreased photosynthetic efficiency and impaired energy production Cold stress, also, significantly impacts plant physiology, morphology, and yield, posing a challenge for crop productivity. Cold stress often results in stunted growth, leaf chlorosis, and wilting, as well as a reduction in leaf area and biomass (Atayee & Noori, 2020). These morphological changes are accompanied by a delay in flowering and fruit set, and consequently reduce plant yield. For instance, in crops like tomatoes and rice, cold stress during critical developmental stages can significantly reduce fruit set and grain filling, leading to lower overall yields (Venema et al., 2005; Prasad et al., 2006). Low temperatures disrupt cellular processes by causing changes in membrane fluidity and function, leading to decreased metabolic activities and impaired photosynthesis due to the inhibition of enzyme activities (Theocharis et al., 2012; Ruelland et al., 2009). Cold stress also induces the production of reactive oxygen species (ROS), which can damage cellular structures (Krasensky & Jonak, 2012) Therefore, mitigating cold stress through breeding and management practices is essential to sustain crop productivity in cooler climates. Tomato varieties exhibit varying levels of tolerance to cold and heat stress, which is crucial for maintaining productivity under extreme weather conditions. Cold-tolerant tomato varieties have been developed through breeding programs that select for traits such as enhanced membrane stability and efficient antioxidant systems, enabling them to maintain metabolic functions and photosynthesis at lower temperatures (Venema et al., 2005). For instance, certain wild tomato species have been used to introduce cold tolerance traits into commercial varieties, improving their ability to germinate and grow in cooler climates (Foolad et al., 1998). Conversely, heat-tolerant tomato varieties have been bred to withstand high temperatures by enhancing traits like heat shock protein production, which helps in protecting cellular structures from thermal damage (Camejo et al., 2005). These varieties can sustain photosynthesis and reproductive development even at temperatures above 35°C, reducing the risk of yield losses due to heat stress (Wahid et al., 2007). The development and use of such stress-tolerant varieties are essential strategies for ensuring tomato crop resilience in the face of climate change. The objectives of this study are to identify relatively heat and cold tolerant tomato genotypes grown under Sohag conditions and to determine the best planting date suitable for the tested genotypes.

MATERIALS AND METHODS

1. Plant material and experimental design

This experiment was carried out at the Experimental Farm of the Faculty of Agriculture, Sohag University, new campus, during two successive seasons of 2021/2022 and 2022/2023. The location of the site is 26°28'16.0 N latitude and 31°40'21.2 E longitude at an elevation of 100 m from the sea level. The soil texture of the experimental site was sandy loam. Physical and chemical properties of the soil of the experiment are shown in table 1and 2.

Table 1. physical analysis of the experimental soil.

Particle size distribution				Bulk density Mg m-3	Particle density Mg m-3	Total porosity %	Water holding capacity %	Field capacity%	Wilting percentage %	Available water %
Sand %	Silt %	Clay %	Texture grade							
78.2	7.3	14.5	Sandy loam	1.49	2.62	43.13	25.3	10.2	4.8	5.4

Table 2. Chemical analysis of the experimental soil.

Soil pH	EC (dS m-1)	Available N (mg kg-1)	NaHCO3- extractable P (mg kg-1)	NH4OAc- extractable K (mg kg-1)
8.55	0.69	17.8	3.21	98.7

Transplants of seven tomato genotypes (*Solanum lycopersicon* L.) hybrids were purchased from local nurseries and used in this experiment. 095, Dareen, 9090, Kabia and supergold originated from; 086 originated from China and 588 originated from India. Three planting dates were included in this experiment: the 1st planting date (15 September), the 2nd planting date (15 October), the 3rd planting date (15 November). The transplants were cultivated in a (12 m^2) plots. Each plot consisted of 10 m long and 1.2 m wide row with plants transplanted 50 cm apart within the row. Each plot contained 20 plants.

2. Measurements

1- Plant Length (cm).

The longest stem of each plant was measured from plant base to its top using a meter trip measuring tape after 3 months from transplanting. The following measurements were taken 70 days after transplanting by taking three plants/plot.

2- Total Leaf Area (LA)/Plant (cm^2):

A sample of ten discs of known area were taken from 10 leaves per plant and then the discs were weighed. The whole leaves of the plant were weighed, and the leaf area was determined as following:

$$\text{Total leaf area } (\text{cm}^3) = \frac{\text{Discs areas (cm3) x total leaf weight (g)}}{\text{Weight of discs (g)}}$$

3- Leaf Area Index (LAI):

Was measured as the following formula

$$\text{Leaf Area Index (LAI)} = \frac{\text{Leaf area (cm3)}}{\text{Plant area (cm3)}}$$

4- Plant Fresh Weight (kg):

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

5- Dry Matter Content (%):

Fresh plants were oven-dried at 65 ℃ for 48 h and then the dried plants were weighed to obtain the dry weight. The same three plants used for fresh weight trait used for this trait too**.**

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

$$\text{Dry Matter Content (\%)} = \frac{\text{Dry weight (g)}}{\text{Fresh weight (g)}} \text{X } 100$$

The following measurements were taken from a random sample of 10 fruits from each plot:

6- Fruit Weight (g):

Fruit weight was measured by digital scale.

7- Fruit Diameter (cm):

Fruits were measured at the middle of the fruit using the Vernier caliper.

8- Total Soluble Solids (TSS %)

Total soluble solids were determined by hand refractometer according to A.O.A.C., 2019. The amount of T.S.S was determined using a hand refractometer as follows:

Tomatoes fruit were blended for 2-5 minutes. Fruit juices were passed through double cheesecloth layers to remove hard particle. Few drops of the juice were placed on the clean prism and the reading was recorded.

9- Total Acidity (g citric/100 ml juice)

Total acidity was determined by titration with 0.01 N NaOH using phenolphthalein as an indicator according to A.O.A.C., 2019. A 5 ml of filtered tomato juice was transferred to a 50 ml conical flask. Two - three drops of phenolphthalein indicator (1.0 gram of the dye was dissolve in 5ml of 95% ethyl alcohol and diluted to 100 ml with distilled water) were added to the juice. Then the juice was titrated with 0.1N NaOH until the pink colour appeared. The volume of titration solution (0.1N NaOH) was recorded. Then the total acidity was calculated according to the following formula was used to calculate percent acid

$$\text{Total acidity (g citric /100ml juice)} = \frac{\text{ml.NaoH used X normality NaoH X M.E.citric acid (0.064)}}{\text{Volume of sample taken for estimation}} \text{X } 100$$

10- Ascorbic Acid (mg/100 ml juice):

Vitamin C was determined by titration with 2, 6-dichlorophenol indophenol according to A.O.A.C., 2019. To standardize the 2, 6-dichlorophenol indophenol dye a 5 ml of standard ascorbic acid (100mg of ascorbic acid in 100ml of 2 % oxalic acid solution) was transferred to 50 ml conical flask and titrated with dye. The dye factor was calculated as follows:

$$\text{Dye factor} = \frac{1}{\text{ml. dye (Titre)}}$$

A 5 ml of filtered tomato juice was transferred to a 50 ml conical flask. The juice was titrated with 2, 6-dichlorophenol indophenol until a stable pink color for 15 seconds was reached. The volume of 2, 6-dichlorophenol indophenol used was recorded. The ascorbic acid (mg per 100ml.) content was determined according to the following equation:

$$\text{vitamin C (mg Ascorbic /100ml juice)} = \frac{\text{ml. dye (Titre)X dye factor}}{\text{Volume of sample taken for estimation}} \text{X } 100$$

11- Early Yield/Plant (kg):

Early yield was calculated, by dividing the yield of the first harvest per plot, into the number of plants per plot.

12- Total yield/ hectare (ton):

The total weight of ripe fruits will be collected in all harvests and weighed and summed up at the end of harvest.

3. Statistical Analysis

A split-plot layout was used with three replicates. The main plot was assigned to three planting dates and the subplot was assigned to the genotypes. Data were statically analyzed using the MSTAT package program. The mean for all the treatments was calculated and analyses of variances of all the characters were performed by F-variance test. Data obtained during the two seasons of the study were statistically analyzed and the treatments mean was compared using Duncan's multiple range tests (Gomez and Gomez, 1984).

RESULTS

This experiment was carried out in seasons of 2021-2022 and 2022-2023 in the Experimental Farm of Faculty of Agriculture, Sohag University new campus, New Sohag city, Sohag, Egypt to study the effects of cold and heat stress on six tomatoes plant performance.

1. Plant Length (cm).

Figure 1 illustrates the plant length of various tomato genotypes over two seasons (2021/2022 and 2022/2023), showing a general decrease in plant length with lower temperatures. Significant differences were observed among genotypes, with Kabia exhibiting the highest and Supergold the lowest plant lengths across both seasons. Planting dates also significantly influenced plant length; the first planting date yielded the tallest plants, while the third planting date resulted in the shortest, with decreases of 39% compared to the first date in both seasons. The second planting date produced plant lengths similar to the first one. The interaction between genotypes and planting dates was significant, with the shortest plants from Supergold on the third date (decreases of 42.1% and 40.9%) and the tallest from Kabia on the first planting date (increases of 19.6% and 21.4%) compared to the check genotype 086 in the first season.

2. Total Leaf Area /Plant (cm^2):

Figure 1 presents data on the total leaf area per plant of various tomato genotypes across two consecutive seasons (2021/2022 and 2022/2023), revealing a consistent decrease in leaf area with declining temperatures across all genotypes and planting dates. Significant differences were observed among genotypes, with genotype 9090 displaying the highest total leaf area, representing a substantial increase compared to the check genotype (086). Conversely, genotypes Kabia, 095, and 086 exhibited the lowest leaf areas. Planting dates also significantly influenced total leaf area, with the first date yielding the highest and the third date the lowest leaf area, showing a marked decrease compared to the control. Interactions between genotypes and planting dates further influenced total leaf area, with genotype 9090 showing the highest leaf area in the first planting date and Kabia the lowest in the third for both seasons.

3. Leaf Area Index (LAI):

Figure 2 illustrates the leaf area index (LAI) of various tomato genotypes over two seasons (2021/2022 and 2022/2023), showing a general decrease in LAI with declining temperatures. Genotype 9090 had the highest LAI, increasing by approximately 45% compared to the check genotype (086), while genotypes Kabia, 095, and 086 had the lowest LAI. Significant differences were observed among planting dates, with the first date producing the highest LAI and the third date producing the lowest, showing a decrease of over 61% compared to the control.

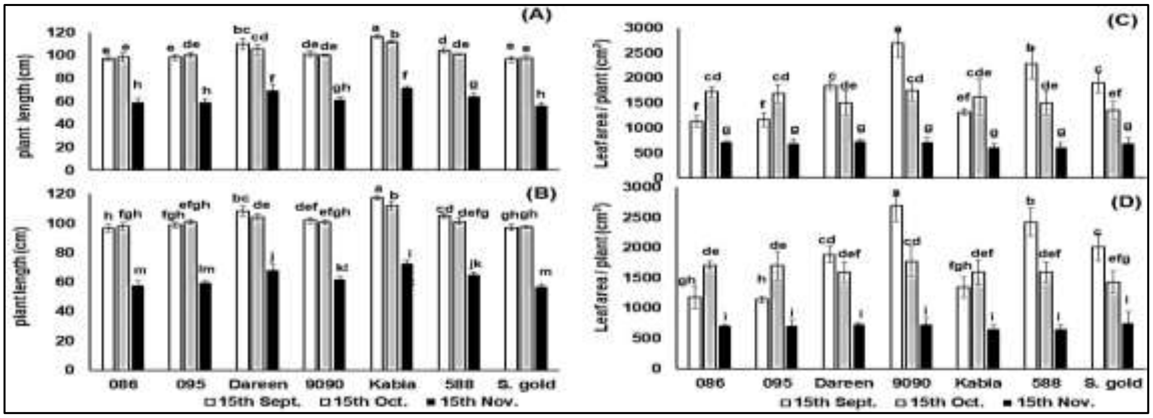

Figure 1. Impact of planting date on plant length (A and B) and leaf area (C and D) of tomato genotypes performance during seasons of 2021/2022 (A and C) and 2022/2023 (Band D) Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three biological replicates.

4. Plant Fresh Weight (kg):

Figure 2 shows the fresh weight of various tomato genotypes over two seasons (2021/2022 and 2022/2023), indicating that plant fresh weight generally decreases with lower temperatures. Plant fresh weight increased moderately in the second planting date compared to the first planting date, then decreased significantly in the third planting date. Although differences among genotypes were non-significant, genotype 9090 had the highest fresh weight and genotype 588 had the lowest fresh weight. Significant differences among planting dates were observed, with the second planting date yielding the highest fresh weight, followed by the first, and the third planting dates showing the lowest fresh weight, decreasing by about 49.9 and 50.6% compared to the first planting date in both seasons. The interaction between genotypes and planting dates varied significantly, with Kabia showing the highest fresh weight on the second planting date and genotype 588 the lowest on the third planting date.

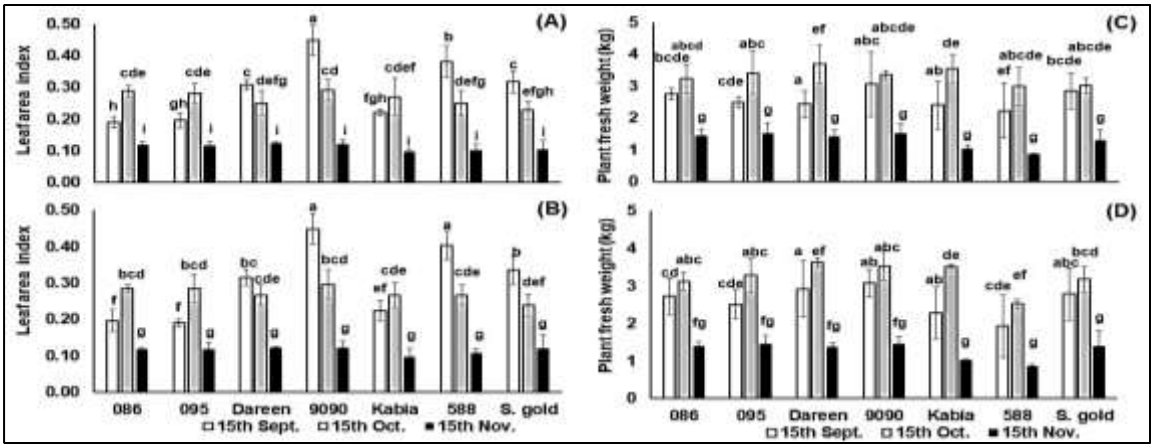

Figure 2. Impact of planting date on leaf area index (A and B) and plant fresh weight (C and D) of tomato genotypes performance during seasons of 2021/2022 (A and C) and 2022/2023 (B and D) Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three biological replicates.

5. Dry Matter Content (%):

Figure 3 presents data on the dry matter content of tomato genotypes across two consecutive seasons (2021/2022 and 2022/2023), revealing an increase in dry matter content with decreasing optimal temperatures across all planting dates. Significant differences were noted among genotypes, with Kabia and genotype 588 exhibiting the highest dry matter content in both seasons, while genotypes 9090, Super gold and dareen showed the lowest, decreasing by approximately 10-14% compared to the check genotype 086. Planting dates significantly influenced dry matter content, with the third date yielding the highest content, followed by the second, and the first date showing the lowest. Interactions between genotypes and planting dates varied significantly, with genotype 588 showing the highest dry matter content on the third planting date, while genotype 9090 had the lowest on the first date in both seasons.

6. Total soluble solids (TSS %)

Figure 3 illustrates the total soluble solids of tomato genotypes across two consecutive seasons (2021/2022 and 2022/2023), indicating that decreased temperatures increased the total soluble solids for all genotypes across all planting dates in both seasons. Significant variations were observed among genotypes, with Dareen exhibiting the highest values, surpassing the check genotype 086 by approximately 20-18% in both seasons, while genotype 588 had the lowest. Planting dates significantly influenced total soluble solids, with the highest values obtained from the third date, followed by the second, and the lowest from the control. Interaction effects between genotypes and planting dates were significant, with genotype 095 showing the highest total soluble solids on the third date, outperforming the check genotype by over 140% in both seasons, while genotype 588 had the lowest in the control for both seasons.

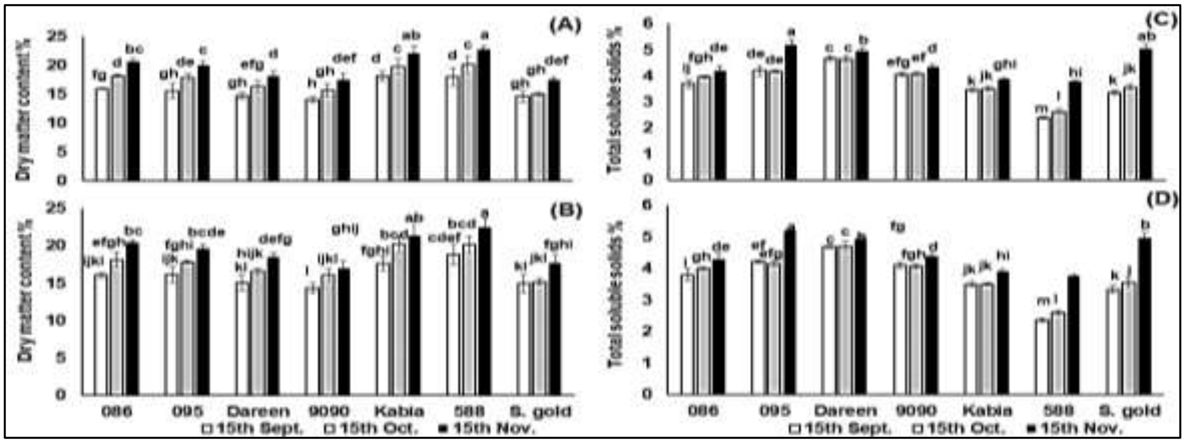

Figure 3. Impact of planting date on dry matter content (A and B) and total soluble solids (C and D) of tomato genotypes performance during seasons of 2021/2022 (A and C) and 2022/2023 (B and D) Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three biological replicates.

7. Total Acidity (g citric/100 ml juice)

Figure 4 presents the total acidity of tomato genotypes across two consecutive seasons (2021/2022 and 2022/2023), indicating that decreased temperatures increased the total acidity for all genotypes across all planting dates in both seasons. Significant differences were observed among genotypes, with genotype 086 exhibiting the highest acidity values in the first season, while genotypes 086 and Super gold showed the highest in the second season, and Kabia had the lowest in both seasons. Planting dates significantly influenced total acidity, with the highest values obtained from the third date, followed by the second, and the lowest from the control. Interaction effects between genotypes and planting dates were significant, with genotype 588 showing the highest acidity on the third date and genotype 086 on the second, both outperforming the check genotype by over 120% in both seasons, while Kabia had the lowest acidity in the control.

8. Vitamin C (mg ascorbic /100 ml juice):

Figure 4 depicts the vitamin C concentration in tomato genotypes across two consecutive seasons (2021/2022 and 2022/2023), showing an increase as temperatures decrease. Significant differences were observed among genotypes, with genotype 095 exhibiting the highest values, surpassing the check genotype by approximately 24-17% in both seasons, while Dareen and Supergold had the lowest. Planting dates significantly influenced vitamin C levels, with the highest values obtained from the third date, followed by the second, and the lowest from the first. Interaction effects between genotypes and planting dates were significant, with genotype 095 showing the highest vitamin C on the third date, exceeding the check genotype by over 200% in both seasons, while Dareen and Supergold had the lowest in both seasons.

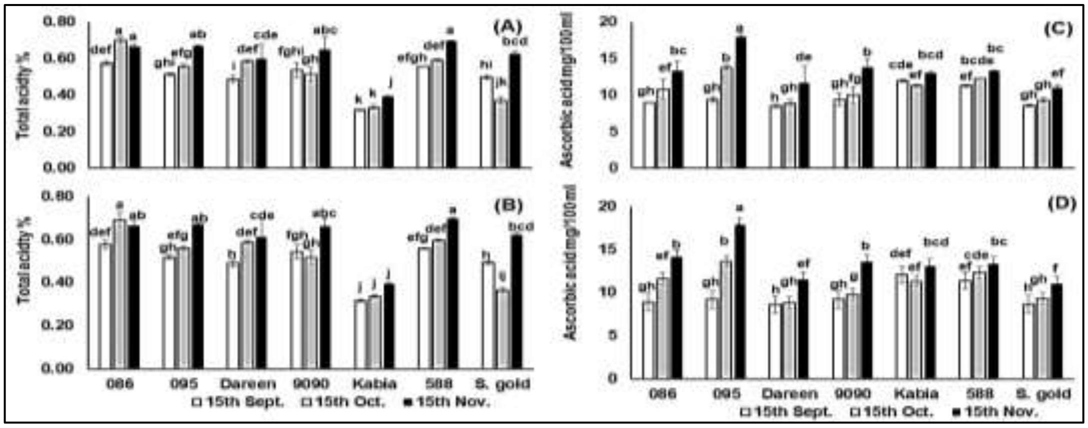

Figure 4. Impact of planting date on total acidity % (A and B) ascorbic acid mg/100 ml (C and D) of tomato genotypes performance during seasons of 2021/2022 (A and C) and 2022/2023 (B and D) Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three biological replicates

9. Fruit Weight (g):

Figure 5 depicts fruit weight data of tomato genotypes across two consecutive seasons (2021/2022 and 2022/2023), showing a trend of decreased fruit weight with exposure to lower temperatures across all planting dates. Significant differences were observed among genotypes, with genotype 095 consistently displaying the highest fruit weight in both seasons, while genotype 588 consistently had the lowest. Planting dates also significantly influenced fruit weight, with the second date yielding the highest weight, followed by the first, and the third date showing the lowest, resulting in approximately a 48% decrease compared to the control in both seasons. Interaction effects between genotypes and planting dates were significant, with genotypes 095 and Supergold performing the best on the second planting date in both seasons, outperforming the check genotype 086 by over 115%, while genotypes 9090 and 588 exhibited the lowest fruit weight on the third planting date in both seasons.

10. **Fruit diameter (cm):**

Figure 5 illustrates fruit diameter data of tomato genotypes across two consecutive seasons (2021/2022 and 2022/2023), indicating that both cold and heat stress reduced fruit diameter for all genotypes across all planting dates in both seasons. Significant variations were observed among genotypes, with genotype 095 consistently yielding the highest fruit diameter, exceeding the check genotype 086 by approximately 8-9% in both seasons, while genotype 9090 consistently had the lowest. Planting dates significantly influenced fruit diameter, with the highest diameters observed on the second date, followed by the first, and the lowest on the third, showing decreases of about 10-35% compared to the control in both seasons. Interaction effects between genotypes and planting dates were significant, with genotypes 095 and Super gold performing the best on the second planting date, exhibiting increases of around 6-12% compared to the check genotype 086, while genotypes 9090 and 588 had the lowest fruit diameter on the third planting date in both seasons.

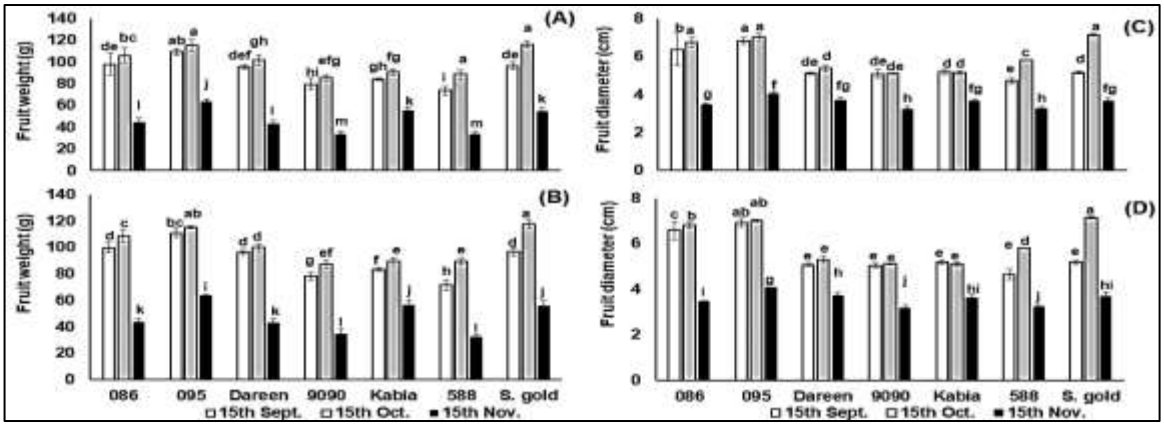

Figure 5. Impact of planting date on fruit weight (g) (A and B) fruit diameter (cm) (C and D) of tomato genotypes performance during seasons of 2021/2022 (A and C) and 2022/2023 (B and D) Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three biological replicates

11. Early yield /plant (kg)

Figure 6 presents the early yield per plant of tomato genotypes across the 2021/2022 and 2022/2023 seasons, revealing a decrease in yield with decreasing temperatures. Significant variations were observed among genotypes, with 9090 and Supergold yielding the highest early yield per plant, showing increases of approximately 38.20% and 40.75% respectively in both seasons, while genotype 588 exhibited the lowest yield. Planting dates significantly influenced early yield per plant, with the highest obtained from the second planting date followed by the first, and the lowest from the third, showing decreases of about 75.41% and 75.33% compared to the control in both seasons, respectively. Interaction effects between genotypes and planting dates were significant, with Dareen yielding the highest early yield per plant in the second planting date in the first season, and Supergold in the second season, while 095 and Supergold had the lowest in the third planting date in both seasons.

12. Total yield/hectare. (ton)

Figure 6 illustrates the total yield per feddan (ton) of tomato genotypes across the 2021/2022 and 2022/2023 seasons, revealing significant variations influenced by planting dates and genotypes. Genotypes 9090 and Supergold demonstrated the highest total yield, with 9090 achieving 25.38 tons/fed and 24.72 tons/fed, and Supergold yielding 24.52 tons/fed and 23.24 tons/fed, representing increases of approximately 18.26% to 14.25% compared to the genotype 086 in both seasons. Conversely, genotype 588 exhibited the lowest total yield at 17.08 tons/fed and 17.33 tons/fed in both seasons. Planting dates significantly affected total yield, with the second planting date yielding the highest totals (32.81 tons/fed in the first season and 33.18 tons/fed in the second), followed by the first planting date, while the third planting date resulted in the lowest yields, declining by approximately 81% to 80% compared to the control in both seasons. Interaction effects between genotypes and planting dates were significant, with genotype 9090 yielding the highest total yield in the second planting date, showing increases of 53.4% to 57.73% compared to the first season.

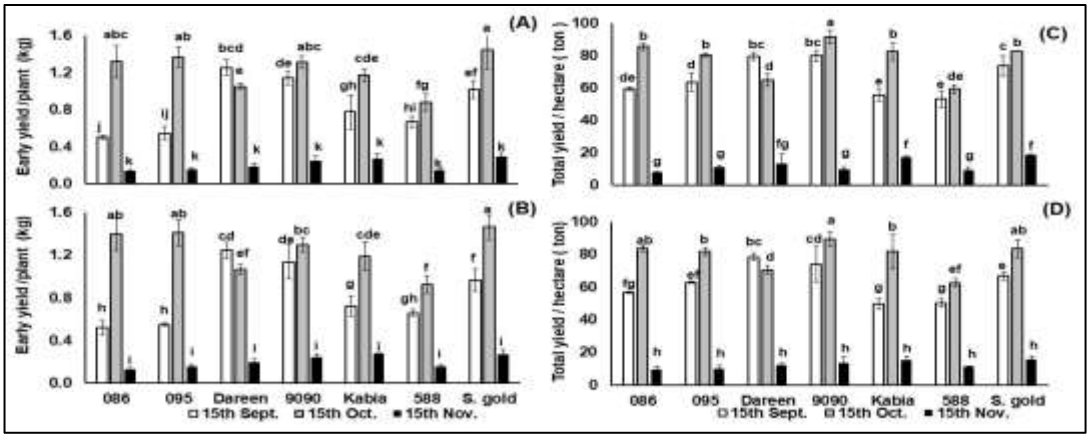

Figure 6. Impact of planting date on early yield /plant (kg) (A and B) total yield/ hectare. (ton) (C and D) of tomato genotypes performance during seasons of 2021/2022 (A and C) and 2022/2023 (B and D) Means followed by the same letter (s) are not significantly different at level 5 %. Error bars are the ± SD of three biological replicates

DISCUSSION

Tomato is a popular vegetable in Egypt grown year-round. It is cultivated in upper Egypt from autumn to early spring and in summer in the northern parts of Egypt. From autumn to early spring, the yield is usually plentiful, and prices are reasonable. During winter and summer, however, the prices are high to very high because of the scarcity of the commodity due to tomato intolerance to cold and heat stress. In winter tomato are produced in the warmer parts of the country such as Sohag governorate and Upper Egypt in general or it can be produced in a greenhouse. Although winter in Sohag is warm in most of the days, it has cold days and nights in January and February that highly affect the growth and development of tomato plants (Figure 7). Besides, there is a wide difference in the day and night temperatures. Farmers grow tomato in Sohag as early as mid of August to the end of November. Tomatoes planted early in mid of August to mid of September usually suffer transplant loss, plant death and yield reduction due to exposer to prevailing high temperature and the high incidence of white fly infestation and diseases. Tomatoes planted late in the end of November suffer slow growth and yield reduction. Thus, it is important to look for genotypes tolerant to cold and heat stress or relatively tolerant genotypes to start a breeding program. It is well-known that heat and cold stress affect plant performance and growth. From our results, it is evident that high and low temperatures affected all the studied traits in all tomato genotypes grown under cold and heat stress under the open field conditions in both seasons of the study. The effect of heat stress, however, was less pronounced than that of cold stress in this study. The reason for that is the period of heat stress the plant exposed to was short in the first planting date compared to the period of cold stress the plant exposed to during the third planting date. Figure 7 shows the records for average monthly and daily high and low temperature in the period of September 2021 to April 2022 and from September 2022 to April 2023. The average monthly high temperature in September was above 35 ◦C with some days exceed 45 ◦C. In October the temperature slightly dropped below 45 ◦C. in the period from November to March the average monthly high temperature, however, was nice and mild and suitable for tomato growth. The low temperature, on the other hand, started to drop below 10 ◦C from December and continued to Feb. Since the plants exposed to longer cold nights in third plants date that hot days in the first planting days, the effect of cold stress in the third planting dates was more severe the heat stress in the first planting date.

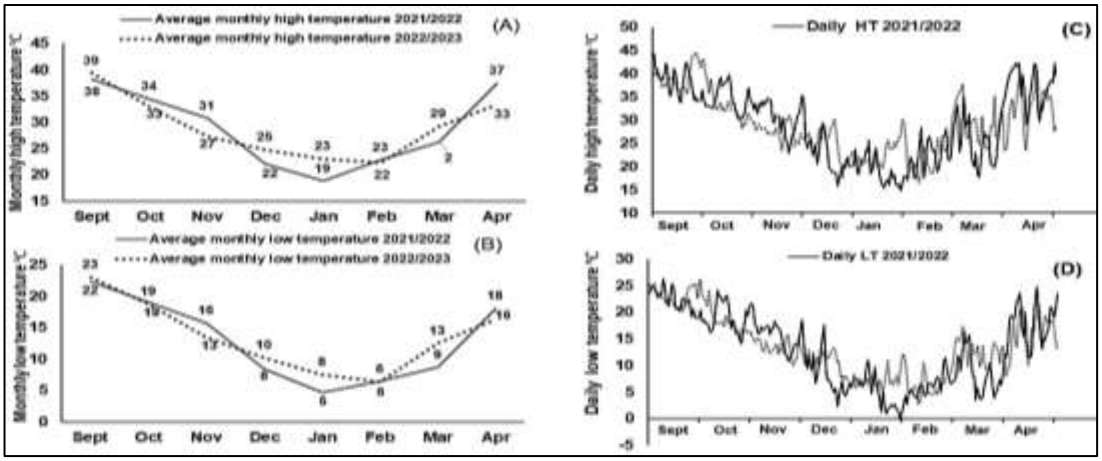

Figure 7. The average monthly high (A) and low (B) temperature and daily high (C) and low (D) temperature from September 2021 to April 2022 and from September 2022 to April 2023.

Cold stress decreased plant length, leaf area, leaf area index and plant fresh weight, in all tomato genotypes, (Figures 1 and 2). Heat stress on the other hand decreased plant fresh weight for all genotypes. However, it had varied responses in plant length, leaf area and leaf area index where some genotypes produced taller plants, denser leaf area and bigger leaf area index under heat stress. Thus, the varied response in the genotypes may be due to the variation in genetic makeup. So, the genotype that gave higher plant length, leaf area and leaf area index could be considered relatively heat tolerant. Cold stress decreases the rate of cell division and elongation, and as a result, the plant fails to elongate leading to reduced plant growth. Plant growth is basically ensured by cell division, enlargement, and differentiation, as the increase in size and/or height of the plant is strongly connected with an increase in the number of cells and cell size. (Ben-Haj-Salah and Tardieu, 1995). Similarly, growth parameters in crop plants such as shoot and root length, and the associated fresh and dry weights showed a critical decrease in response to chilling (10 ◦C/3 ◦C, day/night) as reported in wheat (Zhang *et al.*, 2015) and tomato (Khan *et al.*, 2015). Cold stress negatively influenced height, in soybean (Staniak *et al.*, 2021). It is obvious that cold stress negatively influences photosynthesis and the process of dry matter accumulation (Aghaee *et al.*, 2011; Farooq *et al.*, 2009; Ramadan, 2021; Rodríguez *et al.*, 2015). Cold stress increased the dry matter content, total soluble solids, total acidity and vitamin C and in all genotypes. Heat stress, on the other hand, decreased the dry matter content, total soluble solids, total acidity and vitamin C in most genotypes (Figures 3 and 4). Surprisingly, the dry matter content significantly increased by decreasing the temperature. It was predicted that plants under cold stress would accumulate less dry matter since photosynthesis decreases. Interestingly, however, we have found opposite results where the dry matter accumulation increased by decreasing the temperature. the accumulation of dry matter content may be caused by cold stress which prevents the dry matter content in the leaf from transforming into new organs; The accumulation of dry matter in leaves inhibits photosynthesis as a result of negative feedback from the leaves. This phenomenon can be explained via plants fail to produce new organs or tissues when under cold stress hence, dry matter does not need to be allocated or translocated; it is preserved in leaves (Ramadan, 2021). Tobacco plants grown under 1mM nitrogen (N stress) accumulated more starch and sucrose compared with well-fed plants which received 5mM nitrogen (Mohmed 2014; Seger *et al* 2015). The previous three traits measured a group of compounds which are called osmo-protectants. These compounds accumulate in plants when exposed to stress conditions. When plants are exposed to any stress, plant tend to stabilize proteins and membranes as a first response to avoid damage by osmotic pressure, thereby accumulating higher amounts of different osmo-protectants. In addition, when plants are exposed to low temperatures (including freezing), water absorption by roots is suppressed and in order to protect the plant from dehydration, osmotic adjustment occurs which results in the production of a solute (substitute to water) consisting of sugars and its derivatives (Ito *et al.*, 2014). The content of vitamin C in fruits increased by up to 35 % at low temperatures (5–10 °C) compared to 20 °C (Schonhof *et al.*, 2007). Furthermore, Steindal *et al.* (2013) reported 16% higher vitamin C levels in vegetables exposed to low temperatures (0–10 °C) for a shorter period before being harvested in a controlled environment. El-Shaieny *et al*, (2022) found that vitamin C content in okra pod decreased by increasing temperature and storing pods at 4 °C prevented degradation of vitamin C comparing to storing pods at 25 °C. Our data showed that both heat and cold stress decreased fruit weight, fruit diameter, early yield/plant and total yield (Figures 5 and 6). Yield and yield components such as fruit weight, fruit diameter, early yield/plant and total yield are decreased due to the decrease in temperatures. High temperatures can lead to reduced fruit set, smaller fruit size, and lower overall yield. Heat stress disrupts pollen viability and fertilization, causing flower drop and fruit abortion, which directly reduces fruit set and yield (Sato et al., 2006). Additionally, elevated temperatures can accelerate the degradation of photosynthetic pigments and impair photosynthesis, further diminishing plant growth and fruit production (Camejo et al., 2005). A decrease in the yield and fruit quality of tomato genotypes may be due to the accumulative effects of cold stress on different growth stages and physiological processes of tomato genotypes. Low temperatures during early development stages reduced seedling emergence percentage and plant biomass, indicating a reduction in photosynthesis. (Ramadan, 2021). Previous study reveals that low temperatures have a significant impact on yield (Fernandez-Munoz *et al.*, 1995; Lozano *et al.*, 1998). Cold stress can also severely impact tomato yield. Low temperatures can inhibit seed germination, delay plant development, and reduce flower and fruit formation. Cold stress can lead to chilling injury, which impairs cell function and reduces the efficiency of nutrient uptake and transport within the plant (Snyder & Melo-Abreu, 2005). This results in stunted growth and lower fruit quality and quantity. Furthermore, cold temperatures can affect enzyme activity involved in the ripening process, leading to irregular ripening and poor fruit quality (Saltveit, 2002).

CONCLUSION

In conclusion, high and low temperatures in the first and third planting dates beyond the optimum temperatures in the second planting date decreased most of the studied traits in most genotypes. Some traits such as plant length, plant survival %, plant fresh weight, leaf area, leaf area index, fruit weight, fruit diameter, early yield/plant and total yield decreased when exposed to low and high temperatures. Traits such as dry matter content, total acidity, total soluble solids, ascorbic acid and fruit firmness increased by decreasing temperature. Some genotypes showed heat stress tolerance in leaf area and leaf area index traits such as 9090, 588 and Super gold although it was reflected in higher yields compared to other genotypes. The genotypes showed varied performance when exposed to high and low stress on the different planting dates. So, it is recommended to obtain high yields of tomato plants under Sohag conditions; The mid of October is the best planting date unless the high prices from plants cultivated in the mid of September will compensate for the reduction in the yield; genotypes such as 9090, 588 and Super gold are recommended to be cultivated in the three planting dates.

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