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Growth, Biochemical, Physiological, Yield and Quality Traits Responses of Ten Tomato Varieties to Soil Salinity Stress

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SALINITY stress is one of the extreme major ecological challenges as abiotic stress for crop production sustainability during all stages in most farmlands worldwide especially in arid and semi-arid environments. So, this experiment was comprised ten tomato varieties (1F_1, 4 F_1, 33 F_1, 35 F_1, 023 F_1, o44 F_1, 085 F_1, G15, Novi and Nancy) to choice the salinity tolerance variety under saline-affected soil (EC 8.1 dS m^{-1}). All the used varieties have differential responses to salinity stress. Therefore, all varieties, the high salinity stress shown a great reduction in most morphological and physiological traits; however, an intermediate decrease was obtained in some varieties in most studied traits. In this experiment, morphological, physiological and biochemical attributes are varied under saline affected soil for the ten varieties. Nevertheless, this work the varieties of (023 F_1, o44 F_1, G15, Novi and Nancy) were the most tolerant to soil salinity stress, compared to other ten varieties, especially 1F_1 and 4F_1 were more susceptible to soil salinity stress. The 023 F1, Nancy, Novi, 35 and G15 varieties, produced the highest values of plant height and leaf area (dm^2/ plant) and flowering attributes. Also, 023 F1 hybrid had the highest value in proline content and POD enzyme activity in comparing to other tomato varieties in most cases. Moreover, both of 023 F_1 and 044 F_1 hybrids had the highest total fruit yield and more acceptable for fruit quality parameters. Therefore, more research to find solutions to select the tolerant tomato varieties to salinity stress is needed and producing the new resistant tomato hybrids against salinity conditions by breeders.

Keywords: Tomato hybrids, salt stress, physiological, Biochemical aspects,enzymes activity.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most highly consumed and widely grown vegetables worldwide **(Campestrini et al., 2019; Li et al., 2021)** ranking the second most important vegetable crop following potato (*Solanum tuberosum* L.), from approximately harvested area 4.92 million ha produced annually 186.11 million tons of tomato yield **(FAOSTAT, 2024)**. China is the largest producer of tomatoes, while Egypt ranks 5th, producing about 6.28 million tons from a cultivated area of 143,618 ha and an average yield of 43.7 tons ha^{-1} **(FAOSTAT, 2024)**. Total yield of tomato are highly changeable, ranging from more than 423 tons per ha in the Holland to less than 1.45 tons per ha in Somalia in 2022 (**FAOSTAT, 2024**), while in Egypt it was 43.7 tons per ha, with average yield of 37.84 tons per ha worldwide. Tomato fruits are rich in nutrients, phenolic compounds, carotenoids, lycopene, ascorbic acid and total antioxidants (**Ali et al., 2021**) that are useful for human health and may reduce or prevent different human chronic diseases (**Stoleru et al., 2020; Murariu et al., 2021;** and **Ali et al., 2021**). Numerous factors can reduce tomato yield and fruit quality yearly, specially caused by climate change as heat or cold stress, flooding, drought and salinity stresses (**Inculet et al., 2019** and **Sharaf-Eldin et al., 2024).** So, Climate change is deliberated a global hazard that affects crop production and food security **(Munns et al., 2008;** and **Bacha et al., 2018)**. Soil salinity is considered a serious problem in various countries worldwide, mostly with arid and semi-arid environments. Also, it can damagingly affect physiological, biochemical, and genetic aspects of cultivated crops as well as soil fertility (**El-Ramady et al., 2024**) and also, human health (**El-Ramady et al., 2020**). FAO reported that salt-affected soil area annually alters 1.5 million ha from farmland to non-farmland and decreases the total production by up to 46 million ha per year which led to worldwide worry reducing the total agricultural productivity (**FAO, 2022**). So, tomato cultivation is progressively threatened by various environmental stresses, among which soil

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salinity is a major concern. Salinity affects over 20% of irrigated lands globally, reducing the productivity of sensitive crops as tomatoes due to osmotic stress, ion toxicity, and nutrient imbalances of soil salinization, exacerbated by climate change and poor irrigation practices, necessitates the development of salt-tolerant tomato varieties to ensure sustainable production in affected areas **(Bogoutdinova et al., 2024; Yahyaoui et al., 2024).**

Tomatoes are sensitive to moderately influenced by salinity stress during germination, plant growth and fruit maturity stages particularly with the high salinity rates (**Zaki and Yokoi, 2016;** and **El-Daej. 2018**). In this concern, **Zaki and Yokoi (2016)** cleared that the response to salinity mostly depends on the tomato genotype. Additionally, the salinity tolerance has been controlled by numerous genes in many plants (**Ali et al., 2021**). **Adilu and Gebre (2021)** studied the effect of salinity on germination rate, speed and energy of seeds in different tomato varieties. They stated that seed germination parameters were significantly affected by the combined effect of variety and salinity. Also, the highest level of salinity (4 dS m^{-1}) reduced the germination of different tomato varieties, among the four tested tomato varieties, ARP D2 and Roma VF were tolerant to salinity. Furthermore, there are many impacts on all tomato growth traits due to salinity stress, making changes in several morphological aspects in all growing phases of plant growth, i.e., plant height, root/shoot ratio, leaf area, number of branches and the number of leaves/flowers per plant (**Roșca et al., 2023**). So, salinity persuades many harmful effects on plants which are forced to react. Moreover, each plant variety or hybrid differently responds to salinity stress. **Assimakopoulou et al. (2015)** evaluated the reactions of tomato cultivars and hybrids (Santorini Authentic, Santorini Kaisia, Chios, Cherelino F1, Scintilla F1, Delicassi F1, and Zucchero F1) at three NaCl levels (0, 75 and 150 mM). They revealed that Chios cultivar was the most influenced at 150 mM and a high decreasing in its total plant dry weight occurred by 65.37% in compared to other varieties/hybrids, growth inhibition was due to the toxicity of Cl^- and Na^+ ions and to the nutritional imbalance induced by salinity. In the same line, S**amarah et al. (2021)** assessed the effect of different salinity levels (0, 5, 10, and 15 dS m^{-1}) on tomato seedling growth. They showed that the seedlings grown at 15 dS m^{-1} had the lower length and dry weights compared to other saline levels (0, 5, 10 dS m^{-1}).

In recent years, extensive research has been evaluating the salinity tolerance of different tomato varieties by studying their physiological and biochemical responses under stress conditions. These evaluations are serious for identifying salt varieties that can maintain higher growth rates, photosynthetic efficiency, and antioxidant activity as well as total yield under saline conditions. Therefore, this study aims to evaluate the performance of ten tomato varieties under salinity stress by analyzing main physiological traits such as growth parameters, water relations, and photosynthesis, as well as biochemical indicators like proline content, antioxidant enzyme activities, and ion accumulation.

2. Materials and Methods

2.1. Plant materials and site location

The field experiment was conducted at Horticultural farm, Faculty of Agriculture, Kafrelsheikh University, Kafr El-Sheikh Governorate, Egypt (N 31° 6' 22.752", E 30° 56' 31.11") during the summer season 2024 from 10th February to 9th May. The trial was included ten tomato varieties provided from different sources as shown in Table (1). Seeds of all varieties were sown in seedlings Styrofoam trays (209 cells) for 40 days in nursery of Kafrelsheikh University. All seedlings were daily irrigated and weekly fertilized until transplanting into the open field of experimental site after 40 days from sowing. Tomato seedlings of the ten varieties were transplanted in the open field (soil texture was clay, pH 7.55, and EC 8.1 (dS m^{-1}) as shown in Fig. (1). Salinity of irrigation water was as EC 0.492 (dS.m^{-1}). So, there is no tolerant tomato hybrid to salt stress, in this work we try to recommend if there is a tomato hybrid can be tolerant to salinity stress or not under Egyptian conditions.

2.2. Experimental site and growth conditions

Tomato seedlings of different varieties were transplanted in the experimental plots with an area of 9 m^2 (6 m in length × 1.5 m in width) with 15 plants for each plot (variety) for each replication. Plants were irrigated and fertilized twice a week using a drip irrigation system in accordance with the Egyptian Ministry of Agriculture and Land Reclamation's **(EMALR, 2022)** recommendations. The general agricultural practices, which are often conducted by the nearby tomato growers, were followed, including transplanting, irrigation, fertilization, pest control, etc., wherever necessary.

Table 1. Ten tomato varieties used in the experiment and sources.

Tomato varieties	Source
1 F_1	Tomato hybrid provided from Hungary
4 F_1	Tomato hybrid provided from Hungary
33 F_1	Champ 33 F_1 Hybrid Tomato, Nunhems Seeds Company, The Netherlands
35 F_1	Yogi-35 F_1 Hybrid Tomato Seed, Clause Vegetable Seeds Company, France
023 F_1	Gaara Seeds Company (Cairo, Egypt), which were exported from Sakata Vegetable Europe, Uchaud France https://sakata-vegetables.eu.
044	BB STM 0544 F_1, Tomato Determinate, Bakker Brothers Company, The Netherlands
085	BB STM 1085 F_1, Tomato Determinate, Bakker Brothers Company, The Netherlands
G15	GALAPAGOS Tomato, WWW.TOMATOENZADEN.NL, The Netherlands
Novi	New magic cv., Erasem Seeds d.o.o. Company Novi Sad - Republic of Serbia
Nancy	Nancy RZ F_1 hybrid, Rijk Zwaan, The Netherlands

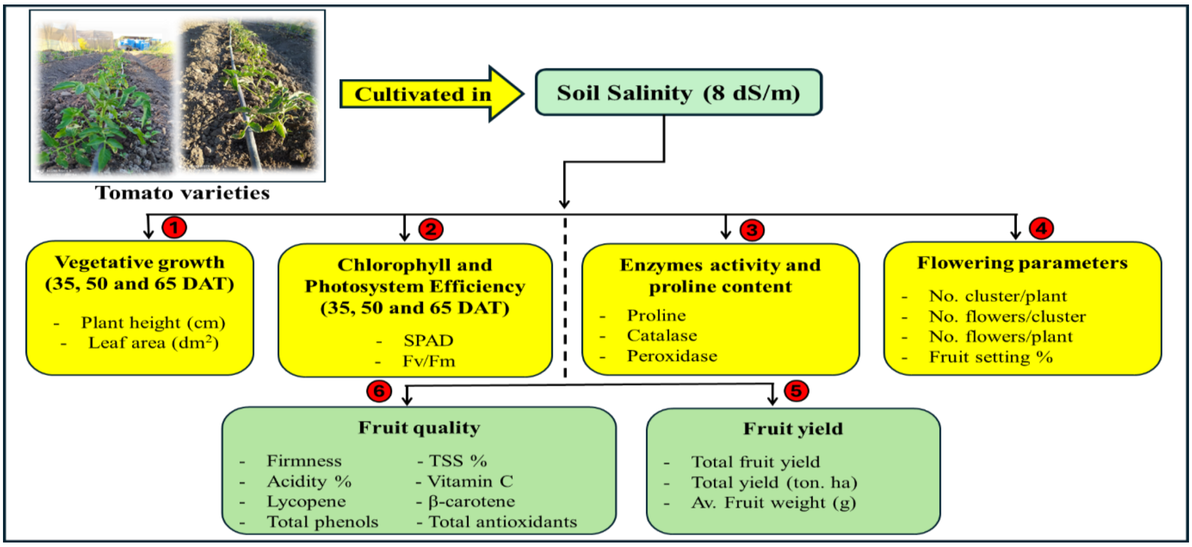

Fig. 1. General overview of the current experiment and studied parameters.

2.3 Data recorded

Five plants for each treatment were selected to assess vegetative growth traits at 35, 50 and 65 days after transplanting (DAT) and included plant height (cm), leaf area/plant (dm^2) using a portable leaf area meter (CI-202, Portable Laser, made in USA), the average leaf area of fifth 5^{th} true leaves from the growing tip was calculated. Chlorophyll content (SPAD) was measured by chlorophyll meter (Opti-Sciences, CCM-200 plus, USA), and the maximum efficiency of the photosystem (Fv/Fm) were determined using chlorophyll fluorescence (Opti-Sciences, Inc., Hudson, New Hampshire, USA), provided a portable Optic-Science OS-30p+ Fluorometer to test the features of at 35, 50 and 65 DAT, the maximal efficiency of the photosystem (Fv/Fm) was determined after adaptation in the dark in accordance to **Maxwell and Johnson, (2000).**

At 45 DAT, some physiological aspects were assessed, proline content (mg. g^{-1} fw) according to **Bates et al. (1973)**. Catalase enzyme activity (CAT) (Umg^{-1}fw min^{-1}), according to **Aebi (1984)** which used as the measurement method. Peroxidase enzyme activity (POD) (µg. g^{-1} fw min^{-1}) was evaluated in accordance to **Polle et al. (1994)** involved tracking the guaiacol oxidation-related shift in absorbance at 470 nm. Enzyme activity was determined by figuring out how much H_2O_2 was broken down in both enzymes. All physiological traits were measured in Plant Physiology and Breeding of Horticultural Crops Lab., Horticulture Department, Faculty of Agriculture, Kafrelsheikh University, Egypt (Accredited according to ISO/17025).

Five plants were selected from each plot at 65 DAT, and five clusters from each plant were randomly designated and labelled for measure No. clusters/plant, No. flowers/clusters and No. flowers/plant and calculating the fruit setting percentage according to the following equation:

$$\text{Fruit setting } \% = \frac{\text{Number of successful fruit setting}}{\text{Total number of flowers}} \times 100$$

The total yield was included three harvests during the growing season starting 75 days DAT. Total fruit yield was calculated during growing season as number of fruits/plant and fruits weight (kg/plant), total yield (ton/ha) was calculated based on the yield per plant and average fruit weight (g) in each variety.

Fruit quality, five fruits were randomly chosen from each treatment of the second picking to measure some physical and chemical quality aspects of fruits including, fruit firmness (gcm^{-2}) according to **Radusin et al. (2013)**, using a hand penetrometer. Total soluble solids (TSS%), using a digital refractometer (model RFM 340 - T), it was determined in triplicate from the juice of fresh tomato fruits for each replication according to **Ilić et al. (2015)**. Titratable acidity (TA%), citric acid % was measured in fruit juice using automatic titration (model TTROLINEE®TL 5000/20M2 BASE UNIT, 20 ML TZ 3130) by 0.1N sodium hydroxide titration in accordance with **Tigchelaar. (1986)** instructions. Vitamin C (mg/100g fw) using titration with 2,6-dichlorophenol indophenol according to **A. O. A. C. (1990).** Lycopene and β-carotene contents (mg. g^{-1}fw) were determined by spectrophotometer at 663, 645, 505 and 453 nm according to **Nagata and Yamashita (1992)**. Total phenols (mg GAE/g fw) were estimated using the folin ciocalteau reagent as described by **Singleton and Rossi (1965)**. Total antioxidants capacity (μmolTE/10gfw) was measured by DPPH assay as described by **Binsan et al. (2008)**.

2.4 Experimental design and statistical analyses

There were ten treatments (varieties) in the trial and a randomized complete blocks design was used with three replications with randomly distribution of treatments in each replication. After confirming that the distribution of all the data was normal, **Snedecor and Cochran (1989)** recommended using one-way analysis of variance (ANOVA) for statistical analyses. Duncan's multiple range test **(Duncan, 1965)** was then used to compare the treatment means. The software package known as "CoStat program" (Version 6.311) was utilized to evaluate each statistical analyses.

3. Results

3.1. Vegetative growth traits

Vegetative growth traits, including plant height and leaf area/plant tomato varieties were significantly influenced by salinity stress after 35, 50 and 65 DAT as presented in Table 2 and Figs. 2 & 4. In general, it became clear that the different tomato varieties were shown two trends. The first included five varieties (023 F1, Nancy, Novi, 35 and G15), produced positive responses, these had highest values of plant height and leaf area (dm^2/ plant) without differences significantly in between. The other five varieties included (4, 085, 33, 1 and 044) showed the lowest values of vegetable growth without significant differences in between.

Table 2. Vegetative growth traits of tomato varieties during different growth stages under salinity stress.

Varieties	Plant height (cm)	Leaf area (dm^2) /Plant	Plant height (cm)	Leaf area (dm^2) /Plant	Plant height (cm)	Leaf area (dm^2) /Plant
	Days after transplanting (DAT)					
	35		**50**		**65**	
1 F_1	17.7cde	5.57bc	28.1bcd	11.63cd	33.4de	17.27de
4 F_1	14.4e	3.90c	24.0cd	10.49cd	30.1e	14.17e
33 F_1	18.0b-e	5.59bc	31.3abc	11.82cd	34.8cde	17.17de
35 F_1	21.2abc	6.46bc	31.4abc	13.33bcd	42.3abc	19.40cd
023 F_1	21.8a	7.51abc	37.0a	17.91ab	47.4a	24.27ab
044	17.7cde	7.57abc	36.4a	12.03bcd	46.7ab	25.73ab
085	15.6de	4.37c	22.4d	8.88d	29.0e	14.56e
G15	18.6a-d	10.22a	33.1ab	19.46a	38.9bcd	28.40a
Novi	21.5ab	9.17ab	36.7a	14.20a-d	44.0ab	22.09bc
Nancy	18.7a-d	10.31a	36.4a	16.52abc	42.6abc	25.83ab
F. test	**	**	**	*	**	**

* and **indicate significant differences at p values < 0.05 and < 0.01, respectively according to F. test. Different letters in the same column indicate significant differences among each group of treatments at p < 0.05 according to Duncan's multiple range test.

3.2 Total chlorophyll and photosystem efficiency

Total chlorophyll content (SPAD) and photosystem efficiency (Fv/Fm) in various tomato varieties under salinity stress at different growth stages (35, 50, and 65 DAT) were presented in Table (3). Results indicated that there were no significant differences for photosystem efficiency (Fv/Fm) across all growing stages (35, 50 and 65 DAT), while there were highly significant differences among tomato varieties in total chlorophyll content (SPAD) during all growing stages. For SPAD, Novi and 044 varieties had the highest content of total chlorophyll (SPAD), moreover (33, 085 and 4) varieties had the lowest values, while the rest of varieties showed an intermediate values without significant differences in between at growing tomato stages (35, 50 and 65 DAT).

Table 3. Total chlorophyll content (SPAD) and Maximum efficiency of the photosystem (Fv/Fm) in tomato varieties during different growth stages under salinity stress.

Varieties	SPAD	Fv/Fm	SPAD	Fv/Fm	SPAD	Fv/Fm
	Days after transplanting (DAT)					
	35		50		65	
1 F_1	40.8abc	0.706a	44.8a	0.708a	43.3ab	0.720a
4 F_1	32.1d	0.711a	40.0abc	0.717a	37.2cd	0.734a
33 F_1	30.9d	0.709a	35.3c	0.717a	34.5d	0.741a
35 F_1	36.5bcd	0.714a	40.1abc	0.718a	42.5ab	0.737a
023 F_1	34.7cd	0.721a	39.1bc	0.720a	38.5bcd	0.736a
044	42.0ab	0.710a	44.7a	0.714a	43.4ab	0.729a
085	30.9d	0.710a	40.4abc	0.708a	40.2bc	0.725a
G15	36.9bcd	0.697a	37.1c	0.709a	38.6bcd	0.722a
Novi	43.8a	0.718a	44.1ab	0.725a	46.8a	0.735a
Nancy	40.3abc	0.678a	40.1abc	0.680a	41.0bc	0.710a
F. test	**	ns	**	Ns	**	Ns

NS and ** indicate non-significant and significant differences at p values < 0.01, according to F. test. Different letters in the same column indicate significant differences among each group of treatments at p < 0.05 according to Duncan's multiple range test.

3.3 Enzymes activity and proline content

Data presented in figure (3) show that tomato varieties cultivated under salinity stress conditions had significant differences in terms of proline content and catalase activity (CAT). In contrast there were no significant differences among varieties for peroxidase activity (POD) as shown in Fig. (3). The 023 F1 hybrid had the highest value in proline content (0.764 mg g^{-1} fw) in comparing to other tomato varieties. In contrary, the "1" and "Nancy" varieties had the lowest proline content (0.562 and 0.566 mg g^{-1} fw, respectively), while the other rest tomato varieties came in the middle without significant differences in between. For POD activity, Nancy, Novi, 33 and 023 varieties were had the highest values compared to other varieties. There were no significant differences among all varieties for catalase activity except for 085 variety which achieved the lowest value (33.9 U g^{-1} fw min^{-1}).

3.4 Flowering parameters

Data presented in Table (4) and Fig. (4) show that the flowering attributes (No. clusters/p, No. flowers/cluster, No. flowers/plant and fruit setting %) of different tomato varieties ware significantly affected by salinity stress conditions. Varieties of Nancy, G15 and 023 F1 hybrid had the highest values in all flowering attributes respectively, however the variety of 085 had the lowest values in this concern, while the rest of varieties had the middle position without significantly differences among them in most cases. For number of clusters/plant, the variety "Nancy" exhibited the highest number of clusters (13.03/plant). This variety's ability to produce more clusters may lead to increased fruiting opportunities. On the other hand, variety "085" produced the lowest cluster count (6.11/plant), which may limit its overall yield potential. Number of flowers/cluster, the "Nancy" variety also stood out with the highest number of flowers (8.7/cluster), further enhancing its potential for fruit set. Conversely, varieties of "33" and "085" had the lowest flowers /cluster (3.3). Total number of flowers/plant, the total flowers count/plant follows had a similar trend, with "Nancy" variety which produced 113.0 flowers. In contrast, variety "085" had the fewest flowers numbers/plant (20.2), indicating a significant disadvantage in reproductive capacity. Fruit setting percentage, the fruit setting % is a critical parameter and factor of the efficiency of the flowering process in producing viable fruit. "Nancy" variety again outperforms other varieties with a fruit setting percentage of 72.2% in comparing with the variety "33" which gave the lowest fruit setting percentage (59.9%).

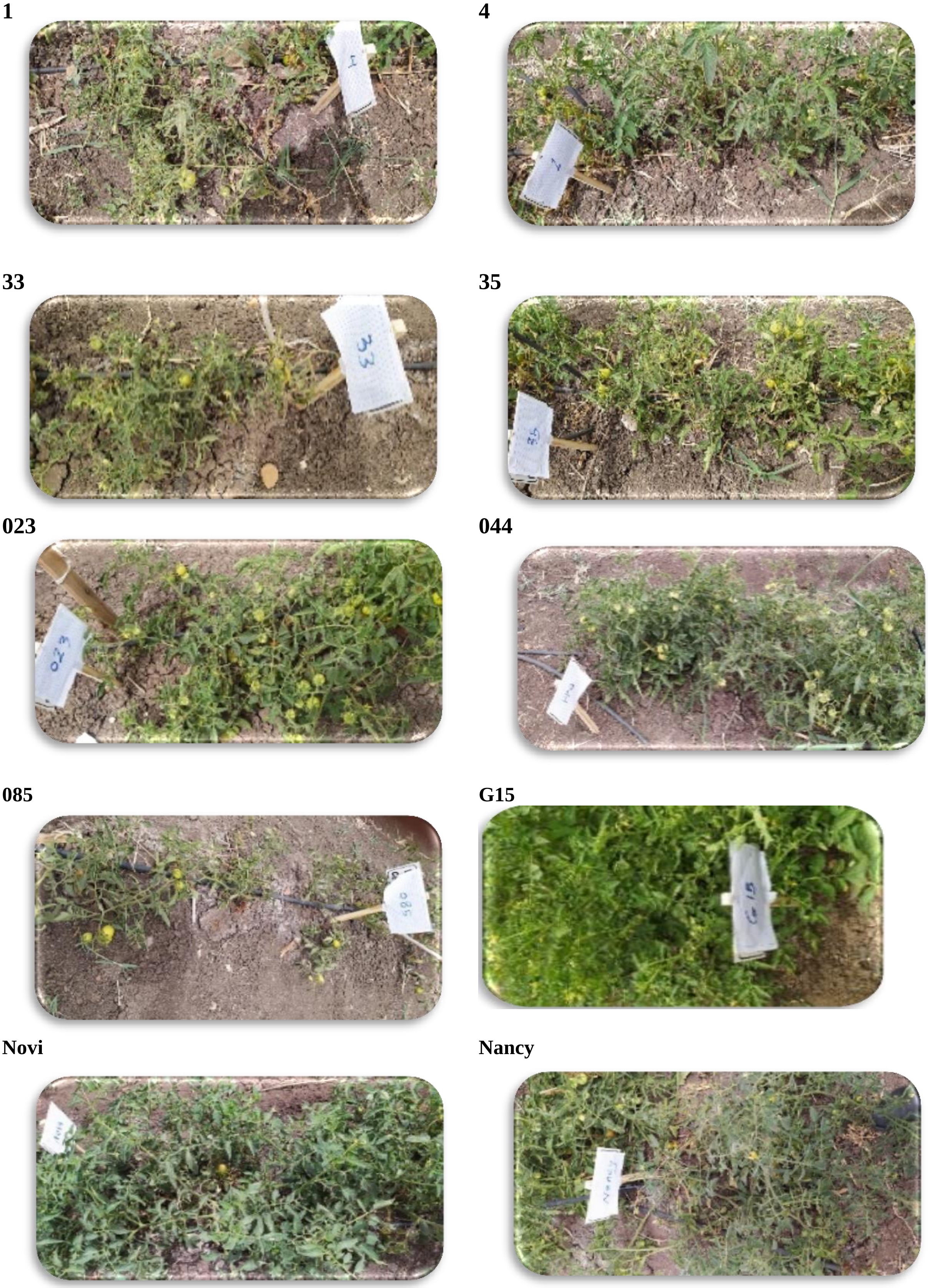

Fig. 2.Vegetative growth of tomato varieties at 50 DAT under salinity stress.

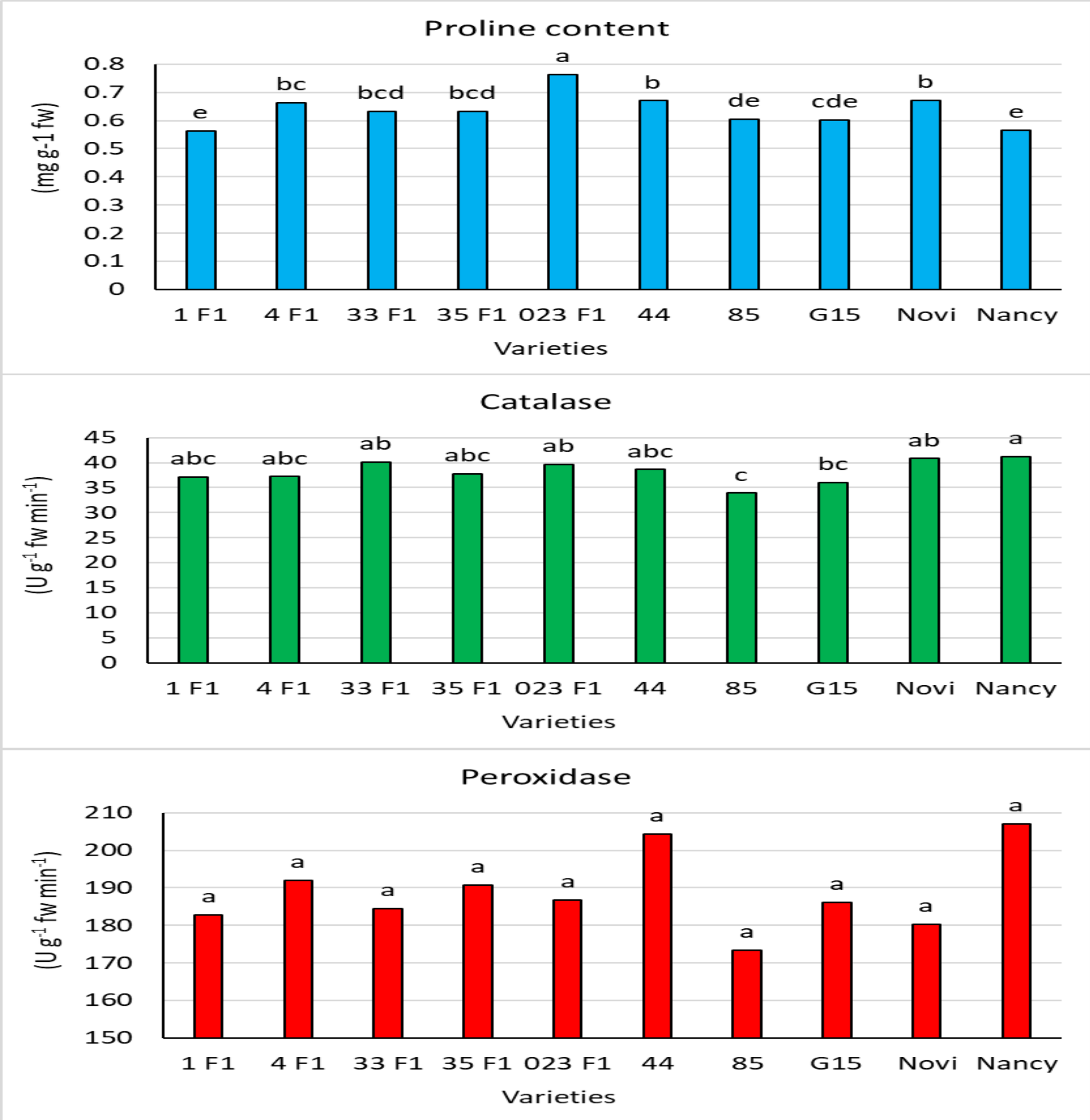

Fig. 3. Proline content, catalase (CAT) and peroxidase (POD) enzyme activities in leaves of different tomato varieties as affected by salinity stress at 45 days after transplanting. Different letters indicate significant differences among treatments at $p < 0.05$ according to Duncan's multiple rang test.

TABLE 4. Flowering attributes of different tomato varieties as affected by salinity stress at 60 days after transplanting.

Varieties	No. clusters/plant	No. flowers/cluster	No. flowers/plant	Fruit setting (%)
1 F_1	7.33de	4.0cd	29.3ef	63.6bcd
4 F_1	9.46c	3.7d	34.4e	62.3bcd
33 F_1	8.62cd	3.3d	28.5ef	59.9cd
35 F_1	7.36de	3.7d	26.7ef	70.1ab
023 F_1	11.30b	4.7c	52.4c	67.0abc
044	11.77ab	4cd	47.1cd	68.5ab
085	6.11e	3.3d	20.2f	57.8d
G15	12.53ab	7.7b	96.3b	68.0abc
Novi	9.51c	4.0cd	38.1de	63.3bcd
Nancy	13.03a	8.7a	113.0a	72.2a
F. test	**	**	**	*

* and ** indicate significant differences at p values < 0.05 and < 0.01, respectively according to F. test. Different letters in the same column indicate significant differences among each group of treatments at $p < 0.05$ according to Duncan's multiple range test.

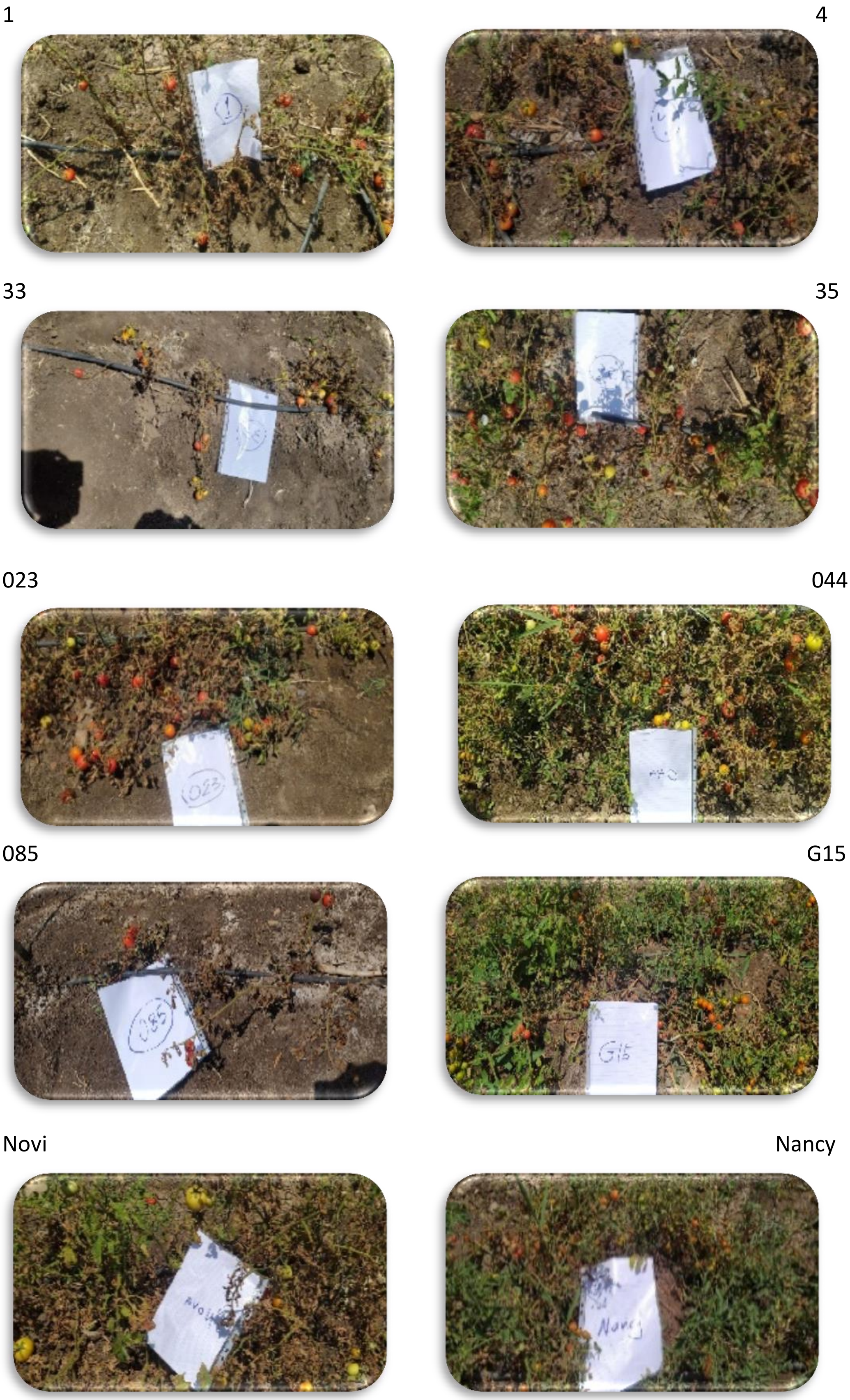

Fig. 4. Vegetative growth and fruit yield of tomato varieties at 65 DAT under salinity stress.

3.5 Fruit yield

Concerning to total fruit yield as no. fruits/plant, kg/plant and ton/ha as well as average fruit weight (g) were significantly differed by salinity stress in different varieties as shown in Table (5). The "Nancy" variety recorded the highest number of fruits/plant followed by G15, 023 F_1 and 044 varieties, respectively. In contrast 33 variety had the lowest no. of fruits/plant. Similarly, varieties of 044 and 023 F_1 had the highest weight of fruits with (2.30 and 2.22 kg/plant, respectively) and (30.61 and 29.54 ton/ha, respectively). However, both of 1 and 33 varieties had the lightest weight of fruits compared to other varieties. Consequently, the rest of varieties came in the middle position between the highest and lowest values. The "044" variety produced the heaviest fruits, followed with 023 F_1 hybrid, with an average fruit weight of 71.4 and 63.3 g, respectively. However, the "Nancy" variety, produced the lightest average fruit weight by 23.2 g in comparing to other varieties. It is noted that both varieties of Nancy and G15 had the largest number of fruits, but they achieved the lowest average fruit weight.

TABLE 5. Total fruit yield and average fruit weight of different tomato varieties as affected by salinity stress at the end of the experiment.

Varieties	Total fruit yield (No. of fruits /plant)	Total fruit yield (kg/plant)	Total yield (ton/ha)	Average fruit weight (g)
1 F_1	18.65de	0.857f	11.42f	46.0e
4 F_1	21.36de	1.22cd	16.22cd	57.1c
33 F_1	17.02e	0.910ef	12.13ef	53.5cd
35 F_1	18.70de	1.08de	14.44de	57.8bc
023 F_1	35.04c	2.22a	29.54a	63.3b
044	32.1c	2.30a	30.61a	71.4a
085	11.72f	0.583g	7.77g	50.0de
G15	65.17b	1.92b	25.54b	29.5f
Novi	24.10d	1.35c	17.99c	56.1c
Nancy	81.23a	1.88b	25.10b	23.2g
F. test	**	**	**	**

** indicate significant differences at p values < 0.01, according to F. test. Different letters in the same column indicate significant differences among each group of treatments at p < 0.05 according to Duncan's multiple range test.

3.6 Fruit quality

Tomato fruit quality aspects included, firmness, total soluble solids, titratable acidity and vitamin C, were highly significantly affected in different varieties due to salinity stress as shown in Table (6). The highest in firmness value was achieved by Novi variety, while both of 35 and 4 varieties had the lowest values, and the rest of varieties took a middle position. As for TSS %, Nancy and 085 varieties had resulted the maximum percentage, but, the minimum values of were obtained from 33, 35 and 4 varieties, respectively. G15 variety had the highest fruit acidity % followed by Nancy and 044 varieties, while 35 provided the lowest values. Regarding vitamin C content in fruits, 4 variety recorded the highest values followed by Novi, 35 and 023 F_1 without significant differences in between, whereas the rest varieties had the lowest values with non-significant differences between them especially, 1 and 085 varieties.

TABLE 6. Firmness, total soluble solids, titratable acidity and vitamin C of tomato fruits of the second picking in different varieties as affected by salinity stress.

Varieties	Firmness (N)	TSS %	Acidity %	Vitamin C. (mg/100 g FW.)
1 F_1	653.3c	7.4de	0.077de	17.1d
4 F_1	603.3d	7.1ef	0.126bcd	36.8a
33 F_1	700.0b	6.7f	0.127bcd	24.9bcd
35 F_1	613.3d	7.0ef	0.0743e	31.4abc
023 F_1	696.7b	7.8cd	0.097cde	29.8abc
044	686.7bc	7.6de	0.159ab	30.1abc
085	653.3c	8.8ab	0.134bc	21.7d
G15	546.7e	8.3bc	0.201a	23.8cd
Novi	740.0a	5.3g	0.127bcd	32.7ab
Nancy	540.0e	9.3a	0.193a	24.8bcd
F. test	**	**	**	**

** indicate significant differences at p values < 0.01, according to F. test. Different letters in the same column indicate significant differences among each group of treatments at p < 0.05 according to Duncan's multiple range test.

3.7 Biochemical features

There were highly significant differences among different varieties in both of lycopene and total phenols due to salinity stress conditions, although the differences were not significant in both of β-carotene and total antioxidants values as shown in Fig. (5). The varieties of G15 and 4 significantly improved lycopene content in tomato fruits, whereas the lowest content of lycopene in tomato fruits was resulted in 044 and 1 varieties. For total phenols content, all tomato varieties under study were significantly differed from each other, Nancy, 044, 33 varieties were recorded the highest value in most cases.

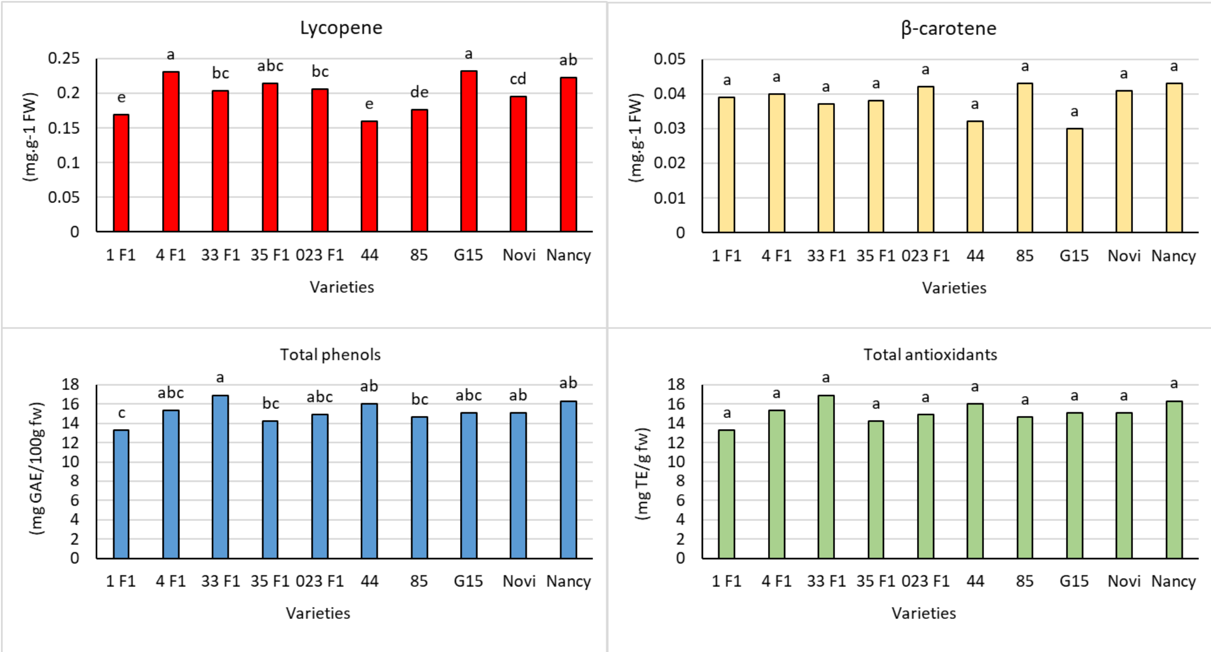

Fig. 5. Lycopene, β-carotene and total phenols contents and total antioxidants capacity of tomato fruits in different varieties as affected by salinity stress. Different letters indicate significant differences among treatments at $p < 0.05$ according to Duncan's multiple rang test.

4. Discussion

Tomato is an important annual vegetable crop of human food globally, it has been described before as moderately tolerant to salinity stress conditions **(Maas and Hoffman, 1977**) and changeable responses have been recorded in different genotypes under salinity stress conditions **(Sivakumar et al., 2020** and **Alam et al., 2021).** Generally, tomato responses to salinity is level and variety dependent, the salts accumulation in soil extremely affect plant physiological and biochemical processes as well as gene expression, with an impacts on plant growth, yield and fruit quality (**Roşca et al., 2023**). Likewise, in the current work, vegetative growth, physiological traits and yield of tomato varieties were significantly declined when grown in salinity conditions. In this concern, increasing salinity level, most plant traits i.e., height, fresh and dry weights of shoots, leaf area and yields were clearly declined (**Sivakumar et al., 2020** and **Alam et al., 2021**).

Salinity is one of the significant factors affecting tomato crop in all growing stages and development (**Roşca et al., 2023**). In this respect, sufficiently of researches are presented about the salinity stress impacts on various traits of tomato cultivars as growth, development, physiological, biochemical, productivity and fruit quality. Plant growth and development have a negative effects due to the exposure to salinity stress which may be causes plant death as a result to the toxicity of sodium ions after high accumulation in plant tissues which lead to weakness gradually and finally death (**Hasegawa, 2013**). Salinity causes osmotic stress, too much uptake of Na and Cl ions, and dysfunctions in nutrition system, lead to deteriorating the plant growth (**Zahra et al., 2020** and **Ludwiczak et al., 2021**). Also, there are an oxidative stress caused when the plants cultivated in saline soils due to the creation the reactive oxygen species (ROS) which causes plant senescence (**Isayenkov and Maathuis, 2019**). Likewise, **Zahra et al. (2020**) cleared that the high salinity level induced imbalance physiological processes like photosynthesis, respiration rates, and nitrogen fixation, which finally lead to crop yield reduction. Many negative alterations on plant development comprise morphological, physiological and biochemical traits as well crop yield due to high salts ions accumulation inside the plant tissues more than the tolerance limits of salinity (**Roşca et al., 2023**). Furthermore, salinity stress decreases the availability of water to uptake to use by plants which caused by the osmotic stress, thus plant roots are unable to absorb the water from the rhizosphere (**Shrivastava and Kumar, 2015**).

Salinity in high level affects practically all plant growth parameters including, vegetative growth and subsequently the reproductive stage. Therefore, high salinity can create several negative effects on tomato plants due to the toxicity of both Na^+ and Cl^- in tomato tissues, i.e., replacement of nutrients with both Na and Cl ions, osmotic stress, photosynthetic declining, nutrients scarcity or imbalances, and adverse effects on alteration of vegetative growth as plant height and leaf area (Table 2), reducing flowering rates (Table 4), and lastly tomato yields were declined (Table 5 and Fig. 4). Tomato plants are commonly sensitive to salinity during all growing periods, and the extreme accumulation of Na ions in the cell cause rapidly osmotic inhibition and lead to cell death (**Shrivastava and Kumar, 2015**). Nevertheless, **El-Daej (2018)** and **Zaki and Yokoi (2016)** stated that tomato is a moderately tolerant plant to salinity, and both vegetative growth and fruit yield are just affected by high salinity levels.

Although, tomato plants response to salinity usually depends on its genotypes (**Zaki and Yokoi, 2016**) and it has been revealed that many plant genes can controlled salt tolerance for tomatoes (**Ali et al., 2021**) by inducing some changes in plant growth, physiology, and biochemical, with particularly on fruit yield. Various evidence indicates that, due to plant species and varieties, there is a major variability in tolerance to salinity stress (**Ashraf and Foolad, 2007**). In this investigation, high salinity stress (8 dS/m) was examined for commonly tomato plants are expected to survive within this salinity range which plays a vital role in the plant morphology. Results of plant height and leaf area traits, it can be stated that all tomato varieties under study were negatively influenced by salinity stress (8 dS/m) (Table, 2). Accordingly, salt stress caused a reduction in the growth traits of tomato as plant height and leaf area of all varieties at all growth stages (30, 50 and 65 DAT). Tomato varieties (023 F1, Nancy, Novi, 35 and G15) produced the highest values of plant height and leaf area (dm^2/plant) without significant differences in between comparing with the other five varieties (4, 085, 33, 1 and 044). Similar results have been described by, **Ors and Suarez (2017**), **Sahin et al. (2018**) and **Jameel et al. (2024)** that salinity conditions lead to inhibition in the plant growth of tomato. In this manner, **Alzahib et al. (2021)** reported that salts uptake caused metabolic imbalance in plants, ions toxic effect, and nutrients shortage, and all these troubles lead to oxidative stress. Also, saline condition cause water loss in plant cell, plasma membrane degradation and release of hydrolytic enzymes which led to the cytoplasmic halting that slowed down the development. Similar to our results, **El-Mageed and Semida (2015)** stated that salinity stress conditions lead to arrest in the growth and physiological aspects of all salt-sensitive plants. Salinity injuries plant growth, photosynthetic efficiency, nutrients and chlorophyll contents in tomato plants (**Ors et al., 2021**). In the current trial, Novi and 044 varieties had the highest content of total chlorophyll (SPAD), but (33, 085 and 4) varieties had the lowest values, at all growing tomato stages (Table, 3). This decreasing in chlorophyll content may be caused in deteriorating of photosynthesis rate in tomato plants as a result to disturbing in saline environs (**Parvin et al., 2019; Ors et al., 2021**).

There were highly significant differences among different varieties in both of lycopene and total phenols due to salinity conditions, some tomato varieties (G15, 4, Nancy, 044, 33) showed increased values of both lycopene and total phenols under salt stress (Fig., 5) which produced the highest vegetative growth (Table, 2) and subsequently the highest yield (Table, 5). Additionally, tomato varieties were not significantly differed in total antioxidants content (Fig. 5),

Plants create antioxidants in their tissue as proline, POD, and CAT (Fig, 3) for prevent oxidative stress and accumulation of ROS. Tomato varieties grown under salinity conditions had significant differences in proline content and CAT activity, while POD activity was not significantly differed among varieties. The 023 F_1 hybrid had the highest value in proline content (0.764 mg g^{-1} fw) compared to other tomato varieties, also 33, 023, Novi and Nancy varieties produced the highest values of CAT activity. This is similar to the findings of (**Jameel et al., 2024**) who stated increased contents of antioxidants in tomato plant varieties under salt stress. (**Lima et al., 2017**) noted that increased CAT activity help in reduction of H_2O_2 created under stress.

The effects on early growth stages of tomato finally produce some adverse results in total production. For example, average fruit weight was recorded a significant variation among different tomato varieties, (Table, 5). In this study, a significant decrease in tomato yield was found in (085) variety (7.7 ton/ha) due to salinity stress, while both of 023 and 044 varieties recorded the highest yield (29.54 and 30.61 ton/ha, respectively). So, the ionic imbalance in tomato tissues caused by excess salts may be reduced of growth traits of tomato varieties under salinity conditions (Table 2), however, the highest growth of some varieties may be related to its higher content from proline, CAT, POD, and antioxidants which reflected on flowering parameters as a positive effect. It is obvious from the results that there are significant differences among tomato genotypes due to salinity stress. In most cases, due to antioxidants content in some varieties, it reflects their ability for salt tolerance by preventing ROS damages as well as improves vegetative growth and finally produced the highest productivity under this stress. While there was an obvious reduction in total yield, tomato fruit quality was enhanced with salinity conditions. The TSS %, firmness, acidity %, and Vitamin C contents increased significantly with all varieties under the salinity stress (Table, 6) which is in agreement with those of **Agius et al., (2022**). These results were performed effectually to recognize salinity-tolerant variety next the same studies. Tomato production under salinity conditions faces numerous challenges, it may reduce the yield, which dependent on tomato genotype (varieties) in most cases.

5. Conclusions

As a result to climatic changes, salt stress is one of the major environmental challenges for tomato production and sustainability in arid and semi-arid areas such as Egypt. Therefore, in this trial we compare between ten tomato varieties to select the salinity tolerance variety under saline-affected soil. Accordingly, the high salinity stress shown a large reduction in most morphological and physiological traits in all varieties; however, an intermediate decrease was obtained in some varieties in most studied traits. However, the varieties of (023 F1, o44 F1, G15, Novi and Nancy) were the most tolerant to soil salinity stress, compared to other ten varieties, especially 1F1 and 4F1 were more susceptible to soil salinity stress. Also, 023 F1 hybrid had the highest value in antioxidant enzymes which reflected the highest total fruit yield and more acceptable for fruit quality parameters comparing with other varieties. So, more examinations are needed to find solutions to select the tolerant tomato varieties to salinity stress and producing the new resistant tomato hybrids against salinity conditions by breeders.

Declarations

Ethics approval and consent to participate

Consent for publication: The article contains no such material that may be unlawful, defamatory, or which would, if published, in any way whatsoever, violate the terms and conditions as laid down in the agreement.

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