

## REDUCING THE SALINITY IMPACT ON SOILLESS CULTURE OF TOMATOES USING SUPPLEMENTAL CA AND FOLIAR MICRONUTRIENTS

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### ABSTRACT

Salt stress is known as one of the most severe abiotic factors limiting the plant production all over the world. In this study, three additives: (i) supplemental Ca (5 mmol L<sup>-1</sup>) to nutrient solution, (ii) foliar application of micronutrients (Fe, Mn and Zn at 60, 160 and 110 mg L<sup>-1</sup>, respectively), and (iii) combination of both of them were evaluated aiming to reduce the negative impact of salt stress on tomato plants cultivated in a soilless culture and improve the internal quality of fruits. The obtained results show that salinity reduced vegetative growth and physiological parameters, fruit yield and its components, and even more lowered fruit market classification of tomatoes. Salinity treatment reduced most of essential macro- and micronutrients in tomato fruit, whilst Na content was increased. Tomato productivity and fruit quality were ameliorated under saline conditions by increasing Ca into nutrient solution and applying a foliar application of micronutrients. A combination of both additives ranked the first to alleviate the adverse effects of salinity on tomatoes, followed by solo supplemental Ca into saline nutrient solution. On the other hand, the internal fruit quality of antioxidant compounds, such as vitamin C, lycopene,  $\alpha$ -carotene,  $\beta$ -carotene and lutein as well as acidity, total soluble solid and dry matter percent, were increased under saline conditions.

**Key words:** blossom-end-rot, EC-value of the nutrient solution, physiological parameters, tomato fruit quality, *Solanum lycopersicon* L., yield, vegetative growth

### INTRODUCTION

The world's population is expected to grow to nearly 10 billion by 2050 [Eigenbrod and Gruda 2015], boosting food demand by 50 percent compared to 2013 [FAO 2017]. Most of the predicted population growth will take place in the developing countries. In addition, developing countries, in particular, are and will be strongly confronted with severe food-se-

curity challenges. The agricultural sectors have been impacted by climate change and climate variability events [FAO 2016]. The impacts of climate change are caused by modifications in environment, e.g. rainfall patterns, increased temperature and sea level and reduced natural resource, etc. Therefore, food security is challenged by threatened climate change impacts. The

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environmental stress, e.g. water shortage and increasing salinity and temperature are major limiting factors in sustaining and increasing the plant productivity in many arid and semi-arid areas [Darwish et al. 2013, WWAP 2014, Zaki et al. 2015, Bisbis et al. 2018].

Declining water availability is one of the challenges facing Egypt for cultivation expansion to meet the needs of high population density [Darwish et al. 2013, Quda 2016]. Water share reached 860 m<sup>3</sup> capita<sup>-1</sup> and is expected to decrease to 582 m<sup>3</sup> by the year 2025 [Saleh et al. 2012], taking into account less water coming from Ethiopia and high population rate [Quda 2016]. The limited of both agricultural land and water resource motivated us to use modern cultivation techniques and increase the water use efficiency [Badr et al. 2010] and use of marginal waters [Saleh et al. 2012], without significant reduction in yield to satisfy the high rates of population growth.

Tomato (*Solanum lycopersicum*) is the most important vegetable crop in the world, that is cultivated in both greenhouses and open fields, with a global production of 177.042.359 tons [FAOSTAT 2016]. China is the leading producer country with 56.423.811 tons, while Egypt produced 7.943.285 tons in 2016 [FAOSTAT 2016]. Tomato is one of the great consumer of water [Al-Harbi et al. 2015], while water shortage of fresh water is becoming a serious problem in arid and semi-arid regions [WWAP 2014, Quda 2016], where rainfall is normally lower than evapotranspiration. In such regions, the competition for scarce water resources among users will inevitably reduce the supplies of fresh water available for crop irrigation. Consequently, agriculture will increasingly be forced to utilize marginal waters such as brackish water. However, tomatoes grown in some arid and semi-arid areas, such as e.g. in Egypt and some parts of China, are suffering from secondary salinization. Several studies were previously achieved on the effect of salinity on tomatoes. The most pronounced response of tomatoes to salinity is reduced plant growth and fruit yield as well as water uptake [Magan et al. 2008, Liu 2014, Zaki et al. 2015, Zhai et al. 2015, Zhang et al. 2017].

Many investigations have shown that using solutions with moderate electrical conductivity achieved by adding NaCl or nutrients, can limit the vegetative growth and accelerate the generative development,

improving the tomato fruit quality in terms of organic acidity [Gruda 2005, Gruda, 2009, Gruda et al. 2018]. On the other hand, advantages form moderate salinity on the antioxidant compounds into tomato fruits, were previously recorded [Kraus et al. 2007, Wu and Kubota 2008, Schnitzler and Kraus 2010, Liu 2014], irrespective of the reduction in plant growth and fruit yield. Therefore, salt added to nutrient solution is an easy way to improve the nutritional fruit quality of tomatoes. The beneficial effect of supplemental Ca to overcome salinity impact has been previously recognized [Navarro et al. 2000, Cramer 2002, Kaya et al. 2002, Tuzel et al. 2003, Bie et al. 2004, Saleh 2011]. The foliar application of micronutrients offers a method supplying nutrients to plants more rapidly than methods involving the root application [Marschner 1995], and seems to be an appropriate tool to circumvent the barrier at the soil and root level under stress conditions in order to maintain adequate nutrient levels in the leaves and shoots [Saleh 2009, Roosta and Hamidpour 2011, Abdelwanise et al. 2017, Shalaby et al. 2017]. These methods are easier to be applied in soilless culture systems.

Recently, soilless cultivation system has increased in greenhouses for intensive production of tomatoes and other important cash vegetable crops. This smart cultivation system has many advantages, e.g. maximum yield and most efficient nutrients and water use as well as avoiding the salt accumulation leading to sustainable agriculture, even under stress conditions [Meric et al. 2011, Savvas et al. 2013, Urrestarazu 2013].

Despite of the knowledge that has been gained through the previous studies on water management and salinity effect on tomatoes, studies are needed to collect and merge all advantages together as a model system, even in arid and semi-arid areas. In this study, three additives: supplemental Ca, foliar application of micronutrients and a combination of both of them were evaluated, aiming to reduce the negative impact of salinity on tomato plants cultivated in soilless system and improve the internal quality of fruits.

## MATERIALS AND METHODS

The experiment was conducted at the research station of Beijing Vegetable Research Center in Beijing, China during the cultivation season of 2016/2017.

We carried out this investigation in a greenhouse aiming to reduce the negative impact of salt stress on tomato plants cultivated in a soilless culture system and improve the internal quality of fruits. The maximum air temperature inside greenhouse was 24°C, with a minimum night temperature of 14°C during the cultivation period. Relative humidity ranged from 60 to 65%.

Tomatoes, 'Jia Li No. 14', Seminis Vegetable Seeds Co. were sown on 1<sup>st</sup> July in trays with 5 × 10 cells using substrate of black peat and perlite (2 : 1). Uniform, six-week-old tomato seedlings with a good quality were transplanted into a hydroponic tube system, after washing the growing media from seedling roots. The seedling placed into a hole upper the tube and fixed by spongy piece above the roots, leading the roots free into the hydroponic system. The space between each two holes was 40 cm. For a good plant establishment, all tomato seedlings were exposed to a non-saline complete nutrient solution adjusted to approximately EC 2.3–2.4 dS m<sup>-1</sup> and pH 6.0–6.2 in a closed system, with re-circulating nutrient solution. The complete nutrient solution contained essential macronutrients as mg L<sup>-1</sup> of 143.5 N, 234 K, 120 Ca, 72 S and 24 Mg. Also, the essential micronutrients were added as mg L<sup>-1</sup> at 5 Fe, 0.5 Mn, 0.5 Zn, 0.02 Cu, 0.5 B and 0.01 Mo. H<sub>3</sub>PO<sub>4</sub> was applied to nutrient solution at 0.23 mL L<sup>-1</sup> as phosphorus source and to adjust pH of nutrient solution.

One month later, NaCl was added to the nutrient solution in saline treatments, resulting in a final EC value of 6.0 dS m<sup>-1</sup>. Three additives: (i) extra application of Ca to the saline nutrient solution, (ii) foliar application of micronutrients and (iii) combination of both of them were added to saline treatments and compared to non-saline and saline controls. The experiment contained five treatments as follows:

1. Nutrient solution only (non-saline control).
2. Salinity, by adding 50 mmol L<sup>-1</sup> NaCl to nutrient solution.
3. Salinity plus extra Ca, where Ca supplement was added at 5 mmol L<sup>-1</sup> of CaCl<sub>2</sub> to the saline nutrient solution.
4. Salinity plus foliar application of micronutrients (FAMN), e.g. Fe, Mn and Zn at 60, 160 and 110 mg L<sup>-1</sup>, respectively, as EDDHA-chelated Fe, manganese sulfate and zinc sulfate, respectively. The solution was

sprayed in two-week intervals three times, e.g. 50, 100 and 150 ml per plant, respectively.

5. Salinity plus extra Ca and foliar application of a mixture of micronutrients, as mentioned previously above.

The experimental was a complete randomized-block design with three replications. Each plot consisted of two hydroponic tubes containing 16 plants, with 40 cm space between each two plants. To maintain the adequate EC and pH of the nutrient solution, EC levels and pH were measured daily by EC meter and pH meter, and adjusted accordingly. Every three weeks, the entire nutrient solution was renewed for each treatment after having flushed pipe system and its tank (200 L), and washed by fresh water. Flower pollination was enhanced by bumblebees. The fruits were harvested manually when reached its marketing stage, four pickings. The other agricultural practices were applied wherever they were necessarily needed and as commonly recommended in the commercial production of tomatoes at the experimental station. The experiment ended at the end of January.

#### Evaluated parameters

1. Vegetative parameters: Representative sample of six plants from each plot was randomly selected to record plant height (cm), number of leaves per plant as well as total chlorophyll content (SPAD), using digital Minolta Chlorophyll Meter (SPAD-501).

2. Physiological parameters: The net photosynthesis rate, transpiration rate and stomatal conductance of fully expanded and well light exposed leaves were measured with a portable porometer (LCI4, ADC BioScientific Ltd. Hoddesdon, Herts, England).

3. Fruit yield: Fruit yield was calculated for each plant as the accumulated fruit weight and numbers during the four pickings, and then the average fruit weigh was calculated.

4. Fruit classification: Fruits were classified as percent of marketable fruits (Class A), soften and small fruits less than 40 mm diameter (Class B) and of blossom-end-rot fruits (BER).

5. Chemical contents: Representative fruit samples from each plot were selected for chemical analyses to determine macronutrients, e.g. N, P, K, Ca and Mg, as well as Na and micronutrients, e.g. Fe, Mn, Zn and Cu, as well as other chemical constitute related to fruit

quality, e.g. dry matter, protein, vitamin C, fiber, acidity, sugar, TSS, lycopene,  $\alpha$ -carotene,  $\beta$ -carotene and lutein according to Nielsen [2010].

### Statistical analysis

The treatment effects were evaluated by analysis of variances. The mean values were compared using Duncan's multiple range test at  $P < 5\%$  to determine the differences among treatment means, according to Gomez and Gomez [1984].

## RESULTS

### Vegetative growth and physiological parameters

The vegetative growth parameters of tomato plants represented by plant height, number of leaves per plants and chlorophyll content were reduced by salinity treatment compared to non-saline control (Fig. 1). Moreover, all physiological parameters, such as photosynthesis and transpiration rate and stomatal conductance were depressed by saline treatment (Fig. 2). The addition of supplemental Ca into nutrient solution and/or foliar application of micronutrients (FAMN) more or less decreased the adverse effects of salinity on vegetative growth and physiological parameters. The combination of both additives ranked the first to alleviate the adverse effects of salinity on tomato plants, followed by solo supplemental Ca into saline nutrient solution, while solo foliar application of micronutrients came the last. The solo supplemental Ca into saline nutrient solution enhanced only plant height and improved stomatal conductance, with a slight improvement on number of leaves per plant and chlorophyll content, whilst photosynthesis rate and transpiration were not statistically affected. The solo foliar application of micronutrients enhanced only the plant height under saline conditions, with a slight improvement on number of leaves per plant and chlorophyll content, while photosynthesis rate, transpiration and stomatal conductance were not statistically affected (Figs. 1 and 2).

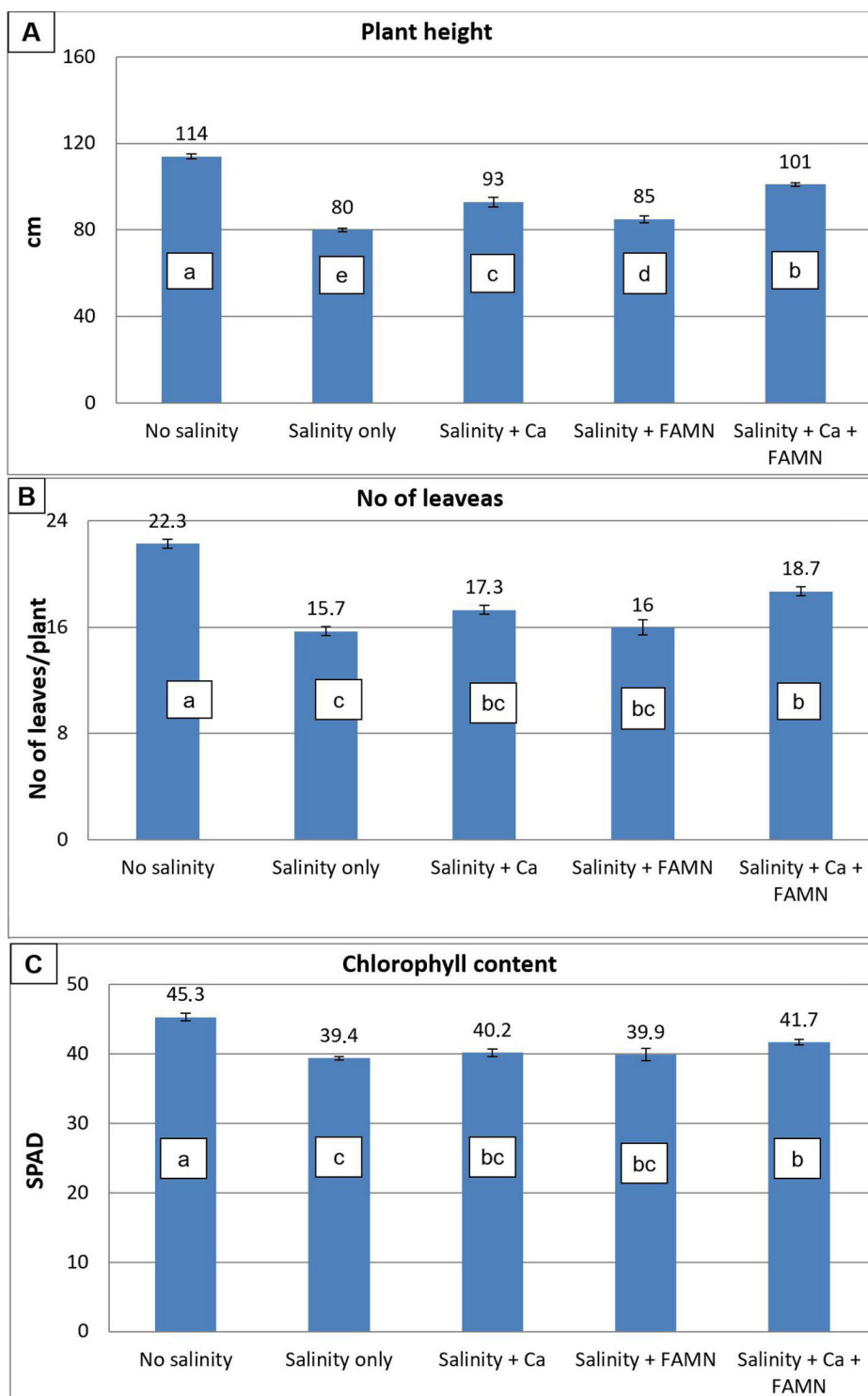
### Fruit yield and its components

The negative trend of salinity on vegetative growth and physiological parameters was reflected in fruit yield. For instance, saline nutrient solution depressed tomato fruit yield and its components as weight/plant

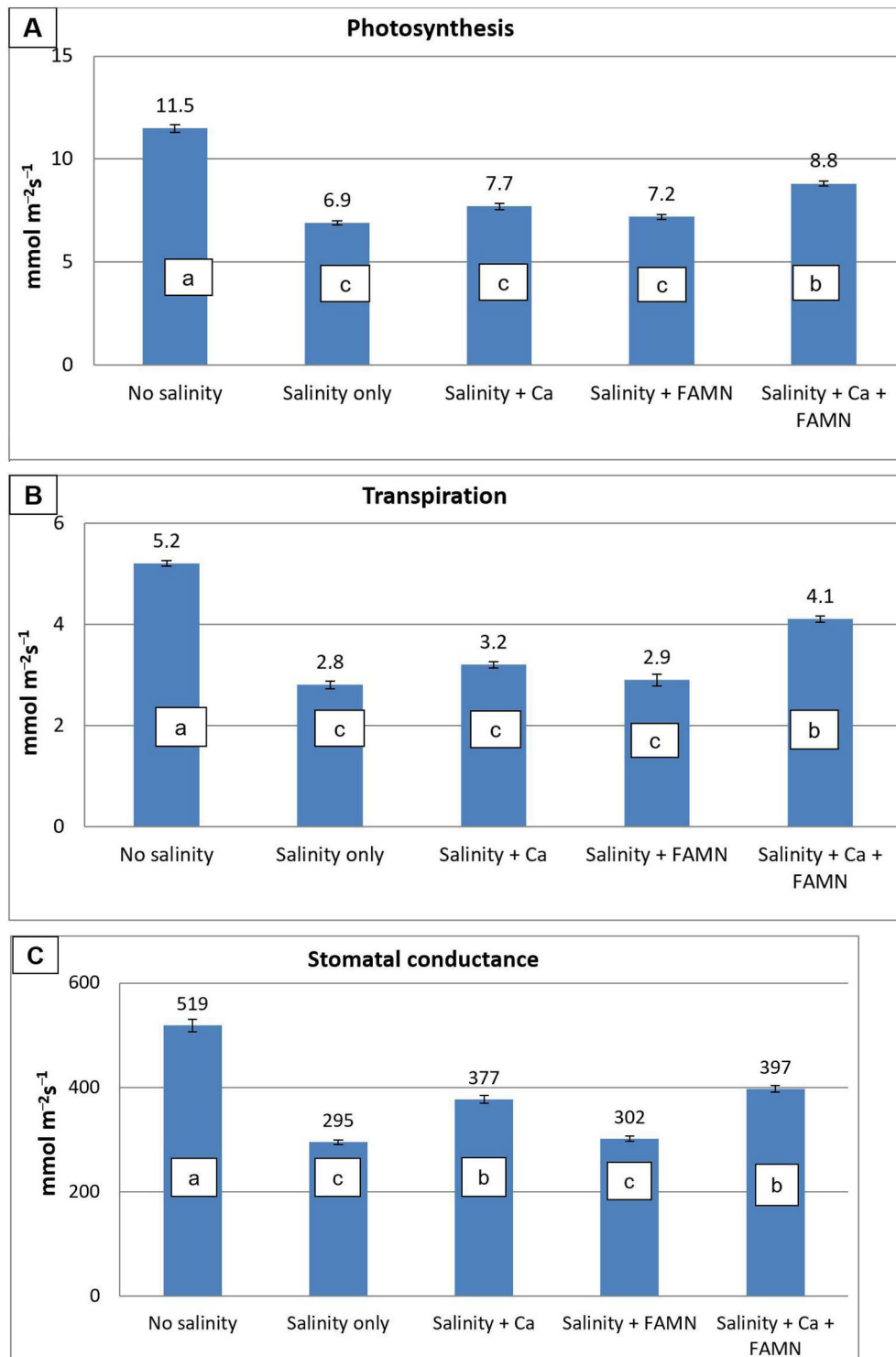
and number of fruits per plant (Fig. 3). Reduction in fruit yield reached to 39% compared to non-saline control. Moreover, much more negative effects were reflected on fruit weight and fruit market classification (Fig. 4). Salinity reduced the yield weight of fruit and Class A fruits, whilst Class B fruits and the appearance of blossom-end-rot (BER) fruits were increased compared to non-saline control. The addition of supplemental Ca into saline nutrient solution and/or foliar application of micronutrients more or less decreased the adverse effects of salinity on fruit yield and its components. An application with a combination of both additives together resulted in higher fruit yield (23%), followed by solo supplemental Ca into saline nutrient solution (17%), and solo foliar application of micronutrients (9%) compared to salinity control. In addition, the weight and number of fruits per plant as well as market classification were improved. The solo Ca supplementation into saline nutrient solution improved the fruit classification by increasing Class A fruits and decreasing BER fruits, with a slight enhancement on Class B fruits, fruit yield, weight and number of fruits per plant. The solo foliar application of micronutrients revealed a slight improvement on fruit yield and its components of salt-stressed plants by increasing Class A fruits and decreasing BER fruits, whilst the increases in fruit yield, weight and number of fruits per plant as well as Class B fruits, were not statistically significant.

### Chemical contents

Presented data in Tables 1, 2, 3 and 4 show fruits chemical contents of tomato plants exposed to salinity. The obtained results illustrated that the essential macronutrients, such as N, K, Ca and Mg (Tab. 1) as well as the contents of protein and fiber (Tab. 3) were decreased in tomato fruits under saline conditions compared to non-saline control. Moreover, the same reduction trend was observed in the contents of essential micronutrients, such as Fe, Mn and Zn in tomato fruits under saline conditions compared to non-saline control (Tab. 2). Conversely, the content of Na was increased by salinity treatment (Tab. 1). Also, the percent of dry matter (Tab. 2), total soluble solid (TSS) and acidity (Tab. 3) were increased in tomato fruits under saline conditions compared to non-saline control. Moreover, saline nutrient solution increased the contents of lycopene

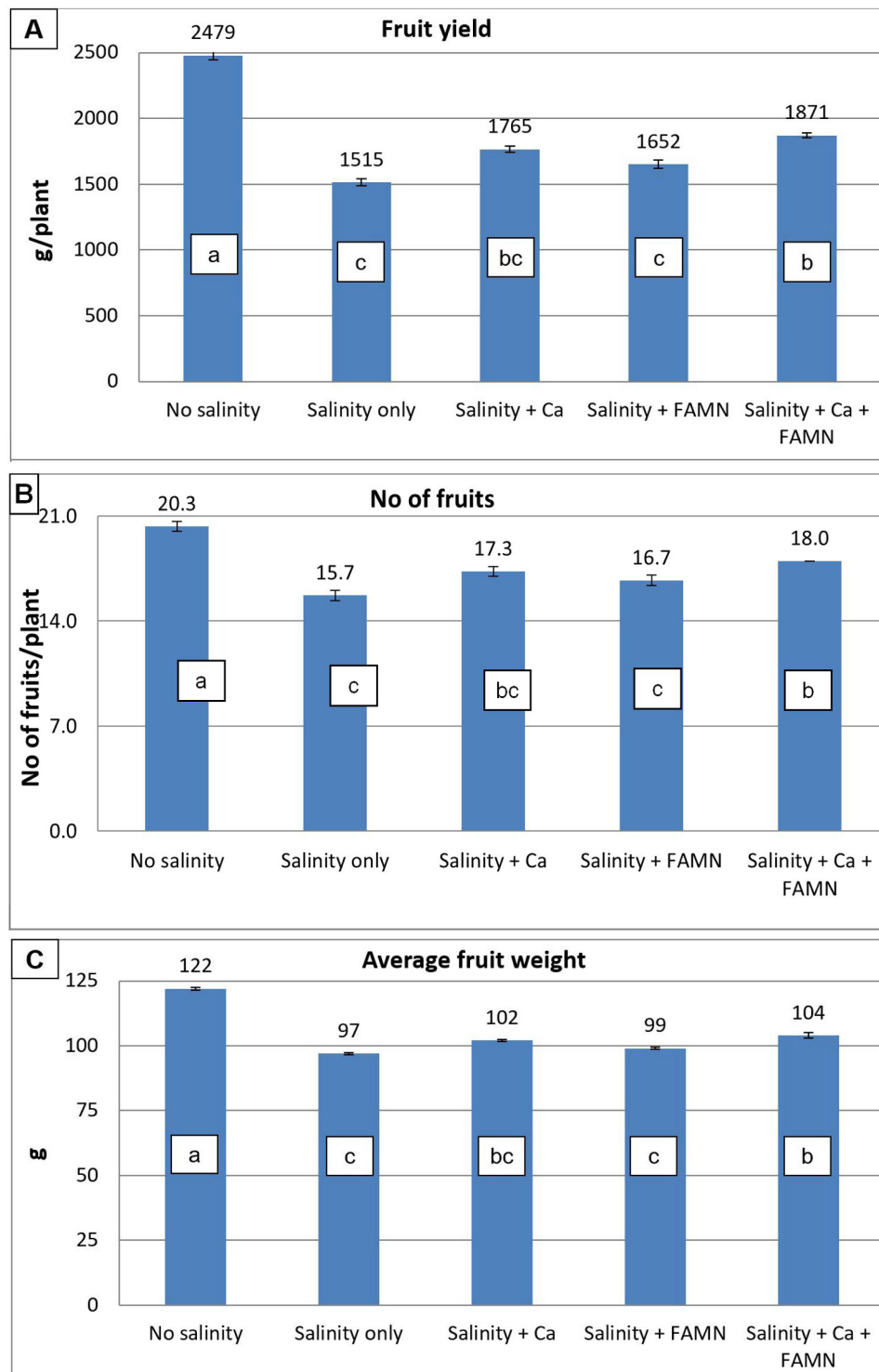


**Fig. 1.** Effect of Ca and foliar application of micronutrients (FAMN) on vegetative characters of salt-stressed tomato plants

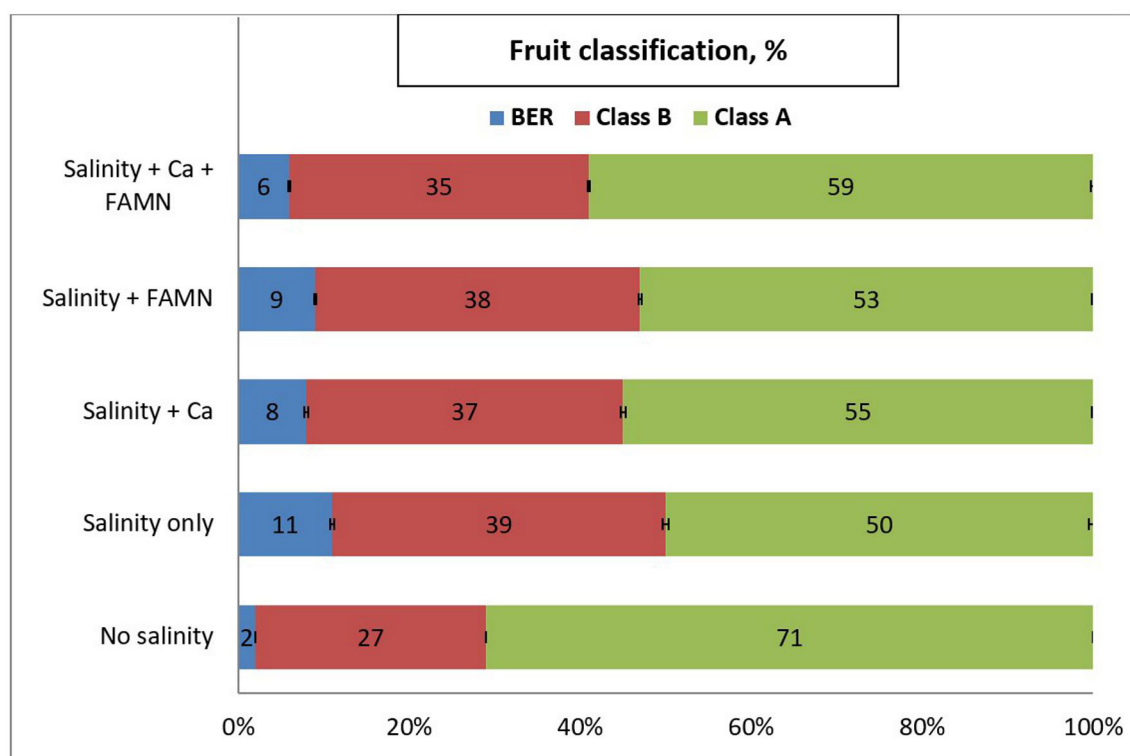


**Fig. 2.** Effect of Ca and foliar application of micronutrients (FAMN) on physiological characters of salt-stressed tomato plants





**Fig. 3.** Effect of Ca and foliar application of micronutrients (FAMN) on fruit yield of salt-stressed tomato plants



**Fig. 4.** Effect of Ca and foliar application of micronutrients (FAMN) on tomato fruit classification: Class A, Class B and Blossom-end-rot (BER) fruits

pene,  $\alpha$ -carotene,  $\beta$ -carotene and lutein in tomato fruits compared to non-saline control (Tab. 4). However, the increases in lycopene,  $\alpha$ -carotene, and  $\beta$ -carotene in tomato fruit were not statistically significant when the extra Ca was applied to saline nutrient solution and/or salt-stressed plants foliar sprayed by micronutrients. On the other hand, the application of a combination of both additives, extra Ca and foliar application of micronutrients decreased the content of Na in tomato fruits. Moreover, the addition of supplemental Ca into saline nutrient solution and/or foliar application of micronutrients, positively affected the contents of essential nutrients, such as N, K, Ca, Mg, Fe, Mn and Zn as well as protein content in tomato fruits under saline condition. Also, the solo supplementation with Ca into saline nutrient solution enhanced N, K, Ca, Mg, Fe, Mn, Zn and protein content, while solo foliar application of micronutrients enhanced the contents Fe, Mn and Zn in tomato fruits under saline conditions. On the other

hand, vitamin C content in tomato fruits was not significantly affected by salinity compared to non-saline control. Meanwhile, addition of solo supplemental Ca into saline nutrient solution or plus foliar application of micronutrients increased vitamin C content in tomato fruits (Tab. 3). However, variation among all five studied treatments on their effects on the contents of P (Tab. 1), Cu (Tab. 2) and sugar (Tab. 3) of tomato fruits were not statistically significant.

## DISCUSSION

It is well known that salinity is a limiting factor for plant growth and its productivity. The clarity of morphological effects and physiological processes due to salinity can lead to a better management of plant productivity under salt stress. Basically, salinity adversely affects the plant growth through three main interrelated ways, e.g. water deficit, nutrient imbalance,



**Table 1.** Effect of Ca and foliar application of micronutrients (FAMN) on fruit chemical contents (macroelements and Na) of salt-stressed tomato plants

Treatments	N	P	K	Ca	Mg	Na
	% DW					
No salinity	3.87 a	0.64 a	4.99 a	0.17 a	0.26 a	0.12 b
Salinity only	2.15 c	0.41 a	3.06 c	0.09 c	0.15 c	0.14 a
Salinity + Ca	2.83 b	0.51 a	3.73 b	0.11 b	0.18 bc	0.14 a
Salinity + FAMN	2.45 bc	0.45 a	3.35 c	0.10 bc	0.17 bc	0.14 a
Salinity + Ca + FAMN	2.89 b	0.50 a	3.48 bc	0.10 bc	0.19 b	0.13 ab

Means within each column followed by the same letter are not significantly different at  $P < 5\%$

**Table 2.** Effect of Ca and foliar application of micronutrients (FAMN) on fruit chemical contents (microelements and dry matter) of salt-stressed tomato plants

Treatments	Fe	Mn	Zn	Cu	Dry matter
	mg kg <sup>-1</sup> DW (ppm)				(%)
No salinity	71.36 a	14.97 a	23.15 a	6.09 a	5.03 c
Salinity only	42.52 c	9.07 c	13.10 c	4.03 b	6.42 a
Salinity + Ca	52.76 b	11.37 b	16.54 bc	4.42 b	5.64 b
Salinity + FAMN	53.72 b	11.01 b	15.14 bc	3.71 b	6.05 ab
Salinity + Ca + FAMN	56.77 b	11.73 b	18.10 b	4.00 b	5.89 ab

Means within each column followed by the same letter are not significantly different at  $P < 5\%$

**Table 3.** Effect of Ca and foliar application of micronutrients (FAMN) on fruit chemical contents (vitamin C, protein, fiber, acidity, sugar and TSS) of salt-stressed tomato plants

Treatments	Vitamin C	Protein	Fiber	Acidity	Sugar	TSS
	Mg 100 g <sup>-1</sup> FW	% DW	% DW	(%)	(%)	(%)
No salinity	17.9 c	24.21 a	12.61 a	0.59 b	2.37 a	4.90 b
Salinity only	18.2 c	13.44 c	7.78 b	0.68 a	2.51 a	5.73 a
Salinity + Ca	19.2 b	17.71 b	9.21 b	0.64 a	2.71 a	5.77 a
Salinity + FAMN	18.5 c	15.33 bc	7.81 b	0.67 a	2.57 a	5.50 a
Salinity + Ca + FAMN	20.2 a	18.07 b	8.61 b	0.65 a	2.84 a	5.80 a

Means within each column followed by the same letter are not significantly different at  $P < 5\%$

**Table 4.** Effect of Ca and foliar application of micronutrients (FAMN) on fruit chemical contents (lycopene, carotenes and lutein) of salt-stressed tomato plants

Treatments	Lycopene	$\alpha$ -Carotene	$\beta$ -Carotene	Lutein
	g 100 g <sup>-1</sup> FW			
No salinity	4.86 b	0.0234 b	0.625 b	0.0599 b
Salinity only	5.66 a	0.0305 a	0.728 a	0.0707 a
Salinity + Ca	5.09 b	0.0258 b	0.655 b	0.0636 a
Salinity + FAMN	4.96 b	0.0236 b	0.639 b	0.0620 a
Salinity + Ca + FAMN	5.14 b	0.0253 b	0.642 b	0.0677 ab

Means within each column followed by the same letter are not significantly different at  $P < 5\%$

ance and ion toxicity [Munns 2002, Gama et al. 2007, Munns and Tester 2008]. The observed reduction in vegetative growth and fruit yield of tomatoes under our experiment were most likely the result of the effect of salinity through those basic ways. NaCl application into nutrient solution caused 30% reduction in tomato growth representative by plant height and number of leaves per plant, whilst the content of chlorophyll was reduced by 13% under our experimental conditions. Initially, Na and Cl salts induced the osmotic stress in the nutrient solution leading to water deficit in plant organs due to water-uptake restriction by plant roots, then an imbalance in nutrient uptake and a specific ion toxicity of N and Cl were observed. Even in soilless culture systems, high salinity levels can be detrimental to plant growth [Gruda and Tanny 2014, Gruda and Tanny 2015]. Bustomi et al. [2014] reported that plant height of tomatoes started to decrease at 3.0 dS m<sup>-2</sup>. Albacete et al. [2008] recorded reduction in shoot biomass by 50–60% and root fresh weight by 30% of tomato plants exposed to salinity at 100 mM NaCl. Plant water status was not directly measured under our experiment. However, water deficit of plants reduces the cell turgor pressure, cell enlargement and cell wall expansion, which should also have contributed to decrease the plant growth [Munns 2002, Shimul et al. 2014, Zhang et al. 2017].

Tomatoes react to water deficit with increased stomatal resistance, in order to minimize transpiration, resulting in a lower net photosynthetic rate [Gama et al. 2007, Wu and Kubota 2008, Shimul et al. 2014]. We recorded a reduction in the physiological parameters, such as photosynthesis rate, transpiration and stomatal conductance, which reached to 40, 46 and 43%, respectively due to salinity at our study conditions. Shimul et al. [2014] reported similar reduction in stomatal resistance and photosynthetic activities as well as chlorophyll content of tomatoes. According to Shimul et al. [2014] and Zhang et al. [2017], this is possibly caused by malfunction of the photosystem and related processes due to nutrient imbalance and/or ion toxicity of Na and Cl.

Reduction in net photosynthesis rate by salinity has contributed to produce smaller fruits and less fruit numbers leading to a reduction in total fruit yield. Fruit yield per plant was 39% more affected by saline nutrient solution than vegetative growth in our

study. Compared to non-saline control, tomato plants produced 77% and 80% lower number of fruits and weight per plant, respectively. This may be explained as a main result of adverse effects on plant growth and net assimilation rate, accordingly decreasing dry matter accumulation. A similar magnitude for the decrease of fruit yield under saline conditions was previously obtained by several scientists [Qaryouti et al. 2007, Liu 2014, Zaki et al. 2015, Zhai et al. 2015].

Fruit market classification was more deteriorated by saline nutrient solution than vegetative growth and even fruit yield. This classification recorded 50, 39 and 11%, respectively for Class A fruits, Class B fruits and BER fruits, respectively due to salinity treatment under the present experiment. BER is a typical calcium-physiological disorder [Schnitzler and Gruda 2002, 2003]. Tuzel [2003] reported that fruit yield and water consumption decreased dramatically with the increase of salinity, while the incidence of BER fruits and non-marketable yield increased. Magan et al. [2008] found that marketable fruits revealed more reduction by salinity above 4.4 dS m<sup>-1</sup>. Qaryouti et al. [2007] estimated 7.2% reduction in fruit yield at 5.0 dS m<sup>-1</sup>. However, other experiments have shown that salinity alone does not seem to cause BER, when NaCl is used to increase salinity. However, salinity is a prime cause of BER when combined with other stress factors [Schnitzler and Gruda 2002, 2003]. Therefore, increasing of salt concentration in the nutrient solution has to be associated with other environmental and cultural practices measurements that secure a stress-free cultivation.

Several properties of the nutrient solution can effectively modify produced quality, for instance, EC or nutrient concentration, chemical forms of the elements, nutrient management, temperature of the nutrient solution, pH, etc. [Gruda 2009]. According to Gruda [2009], the proper management of the salt concentration of the nutrient solution can provide an effective tool to improve the vegetable quality. Moderate salinity can improve the quality of vegetables, due to changes in two classes of phytochemicals: compatible osmolytes and antioxidants [Grieve 2010].

The striking result from our study is that the contents of the inner chemical quality measurements of antioxidant compounds, e.g. vitamin C, lycopene,  $\alpha$ -carotene,  $\beta$ -carotene and lutein as well as acidity,

TSS and dry matter percent, were increased under saline conditions. Thus, salt added to nutrient solution can improve the inner fruit quality of tomatoes. It seems that it is normal attitude and not surprise, where the same trend was previously obtained. The advantage for moderate salinity on the antioxidant compounds into tomato fruits was previously recorded by several scientists [Kraus et al. 2007, Wu and Kubota 2008, Schnitzler and Kraus 2010, Liu 2014], irrespective of the reduction in plant growth and fruit yield. Small fruits having less water under salinity could have caused greater concentrations of these compounds. The increases in such compounds may be due to osmotic adjustment by plants to avoid the harmful osmotic effect of salinity and to avoid the dehydration [Verslues et al. 2006]. Comparing with non-saline control, Qaryouti et al. [2007] found that inner parameters of fruit quality increased by increasing salinity up to 5.0 dS m<sup>-1</sup>. Schnitzler and Kraus [2010] reported that increasing EC levels in the nutrient solution had no negative influence on tomato fruits, where level of aroma and health promoting compounds, such as lycopene, carotenoids, phenols, vitamin E, TSS and organic acids were higher for tomatoes grown under increased EC than in the control. Liu et al. [2014] found higher TSS and titratable acid by 150 mM NaCl compared to non-saline control. Zhang et al. [2017] mentioned that the contents of sugar and acid were increased by increased nutrient solution salinity.

NaCl application into nutrient solution caused general reduction of most essential macro- and micronutrients in tomato fruits, while the content of Na reached 156% higher compared to non-saline control. This common effect derives from the uptake competition between Na and nutrient cations at the roots zone due to nutrient imbalance [Munns and Tester 2008, Zhang et al. 2017]. Also, increasing Na as a harmful element led to nutrient imbalance for other essential elements. Grattan and Grieve [1999] found that the presence of high levels of Na in the root zone caused nutrient imbalance and altered the permeability of membranes and its selectivity. Moreover, Grattan and Grieve [1999] reported that salinity dominated by Na salts not only reduces the Ca availability but reduces Ca transport and mobility to growing regions, which affects the quality of both vegetative and productive organs. Salinity can also cause a combination of com-

plex interactions that affect the plant metabolism, susceptibility to internal injury nutrient requirement. It is well known that Ca moves through the xylem following transpiration system, which was reduced by osmotic effect of salinity on root zone. Therefore, application of extra Ca to nutrient solution corrected the nutrient imbalance. The level of Ca in the external solution needed for maximal growth in saline conditions is usually between 5 and 10 mmol L<sup>-1</sup>, depending on the salinity level [Cramer 2002]. Likewise, the optimal Na : Ca ratio is somewhere between 10 and 20 for most plants.

As mentioned previously above, the adverse effects of salinity on plants were through water deficit and nutrient imbalance. Therefore, the clarity of physiological processes due to salinity can lead to a better management for plant productivity even under salt stress and overcome the adverse effect on growth and yield. Plant ability against salinity can be improved by restricting the salt entry into plants and minimizing the salt concentration in cytoplasm and cell wall [Munns 2002]. Supplemented addition of essential nutrients, such as Ca and K to saline nutrient solution contributed to a decrease in Na and promote mutual competition between those essential nutrients and Na on membrane-binding and transport sites and improved cell-wall integrity [Cramer 2002]. Additional Ca can protect cell membrane from the adverse effect of salinity [Grattan and Grieve 1999, Cramer 2002]. In the present study, tomato productivity and fruit quality were ameliorated under saline conditions by adding extra Ca into nutrient solution at 5 mmol L<sup>-1</sup> and/or foliar application of micronutrients as a mixture of micronutrients, e.g. Fe, Mn and Zn at 60, 160 and 110 mg L<sup>-1</sup>, respectively. Lopez and Satti [1996] found that addition of 20 mM Ca(NO<sub>3</sub>)<sub>2</sub> and 2 mM KNO<sub>3</sub> to saline nutrient solution increased the root volume of tomatoes. Bia et al. [2001] reported that Ca improved the shoot growth, photosynthetic rate and gas exchange as well as increased the content Ca and decreased the content of Na in lettuce plants exposed to salinity. Likewise, Ca supplemented into saline nutrient solution alleviated the negative effects of salinity on strawberry [Kaye et al. 2002]. For good management to reduce salinity effects on artichokes, Saleh et al. 2005 recommended to increase Ca into saline nutrient solution to correct nutrient imbalance. Also,

the foliar application of Ca reduced the incidence of tipburn in lettuce grown under different stress conditions [Saleh 2009].

The positive load of micronutrients is less soluble and have less competitive action to the uptake due to altered pH under saline conditions [Grattan and Grieve 1999]. Therefore, the foliar application offers a method supplying nutrients to plants more rapidly than methods involving the root application [Marschner 1995], and seems to be an appropriate tool to circumvent the barrier at the soil and root level in order to maintain adequate nutrient levels in the leaves and shoots under stress conditions [Saleh 2009]. In this concern, Roosta and Hamidpour [2011] reported that foliar application of macro- and micronutrients improved the plant growth and increased the fruit number and fruit yield of tomatoes in soilless culture. This is due to the role of micronutrients, which are involved in all metabolic and cellular functions and the integrated supply of those nutrients in adequate amount is one of the most important factors that control vegetable productivity. Although, not a direct role for foliar application of micronutrients against salinity, Saleh et al. [2005] used foliar application of micronutrients to prevent the incidence of black spots in artichokes grown under saline conditions. They improve the contents in artichoke heads, but their effect was almost not significant. Moreover, Shalaby et al. [2017] found that the foliar application of Fe-EDDHA 6% at 500 mg L<sup>-1</sup> in combination with silicon at 2 mmol L<sup>-1</sup> of K<sub>2</sub>SiO<sub>3</sub> improved tomato productivity and fruit quality even under salinity conditions. Also, Abdelwanise et al. [2017] reported that foliar application of macronutrients, such as N and K improved growth and sustained Moringa plants production even in calcareous soils, which suffer from the limitation of soil fertility, water availability and nutrient imbalance.

## CONCLUSION

Salinity negatively affected the tomato growth and its productivity. The essential nutrients in tomato fruit were decreased under saline conditions, while Na content was increased. Tomato productivity and fruit quality were ameliorated under saline conditions by increasing Ca into nutrient solution and foliar application of micronutrients.

On the other hand, the antioxidant compounds, such as vitamin C, lycopene,  $\alpha$ -carotene,  $\beta$ -carotene and lutein as well as acidity, TSS and dry matter percent were increased under saline conditions.

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## REFERENCES

- Abdelwanise, F.M., Saleh, S.A., Ezzo, M.I., Helmy, S.S., Abodahab, M.A. (2017). Response of Moringa plants to foliar application of Nitrogen and Potassium fertilizers. *Acta Hort.* 1158, 187–194.
- Albacete, A., Ghanem, M.E., Martinez-Andujar, C., Acosta, M., Sanchez-Bravo, J. (2008). Hormonal changes in relation to biomass partitioning and short growth impairment in salinized tomato (*Solanum lycopersicum* L.) plants. *J. Exp. Bot.* 59, 4119–4131.
- Al-Harbi, A.R., Al-Omran, A.M., Alenazi, M.M., Wahb-Allah, M.A. (2015). Salinity and deficit irrigation influence tomato growth, yield and water use efficiency at different developmental stages. *Int. J. Agric. Biol.* 17, 241–250.
- Badr, M.A., Abou Hussein, S.D., El-Tohamy, W.A., Gruda, N. (2010). Efficiency of subsurface drip irrigation for potato production under different dry stress conditions. *Gesunde Pflanzen* 62(2), 63–70.
- Bie, Z., Ito, T., Shinohara, Y. (2004). Sodium sulfate, sodium bicarbonate and supplemental calcium on the growth of lettuce. *Acta Hort.* 644, 433–440.
- Bisbis, M.B., Gruda, N., Blanke, M. (2018). Potential impacts of climate change on vegetable production and product quality – A review. *J. Clean. Prod.* 170(1), 1602–1620. doi.org/10.1016/j.jclepro.2017.09.224
- Bustomi, R.R., Senge, M.S., Suhandy, D., Tusi, A. (2014). The effect of EC levels of nutrient solution on growth, yield, quality of tomatoes (*Solanum lycopersicum*) under the hydroponics system. *J. Agricul. Eng. Biotechnol.* 2(1), 7–12.
- Cramer, G.R. (2002). Sodium-Calcium interactions under salinity stress. In: *Salinity: Environment-plants-*

- Molecules, Läuchli, A., Lüttge, U. (eds.). Kluwer Academic Publishers, Netherlands, pp. 205–227.
- Darwish, K.H., Safaa, M., Momou, A., Saleh, S.A. (2013). Egypt: Land degradation issues with special reference to the impact of climate change. In: *Combating desertification in Asia, Africa and Middle East, Proven practices*, Heshmati, G.A. Squires, V.R. (eds.). Springer Science, Dordrecht, Chap. 6, 113–136.
- Eigenbrod, C., Gruda, N. (2015). Urban vegetable for food security in cities. A review. *Agron. Sustain. Dev.*, 35(2), 483–498. DOI:10.1007/s13593-014-0273-y
- FAO. (2016). *The state of food and agriculture. Climate change, agriculture and food security*. Rome, Italy.
- FAO. (2017). *The future of food and agriculture. Trends and challenges*. Rome, Italy.
- FAOSTAT. (2016). FAO statistics division. Major food and agricultural commodities producers – Countries by commodity. Available: [www.faostat.fao.org](http://www.faostat.fao.org) [date of access: 23.12.2017].
- Gama, P.B., Inanaga, S., Tanaka, K., Nakazawa, R. (2007). Physiological response of common bean (*Phaseolus vulgaris*) seedlings to salinity stress. *Afr. J. Biotechnol.* 6(2), 79–88.
- Gomez, K.A., Gomez, A.A. (1984). *Statistical Procedures for Agricultural Research*, 2<sup>nd</sup> ed. John Wiley & Sons, Inc., New York.
- Grattan, S.R., Grieve, G.M. (1999). Salinity-mineral nutrient relations in horticultural crops. *Sci. Hortic.* 78, 127–157.
- Grieve, C.M. (2010). Salinity-induced enhancement of horticultural crop quality. In: *Handbook of plant and crop stress*, Pessarakli, M. (ed.), 3<sup>rd</sup> ed. CRC Press, Florida, Chap. 47, 1173–1194.
- Gruda, N. (2009). Does soilless culture have an influence on product quality of vegetables? *J. Appl. Bot. Food Qual.* 82, 141–147.
- Gruda, N. (2005). Impact of environmental factors on product quality of greenhouse vegetables for fresh consumption. *Crit. Rev. Plant Sci.* 24(3), 227–247. <https://doi.org/10.1080/07352680591008628>
- Gruda, N., J. Tanny (2015). Protected crops – Recent advances, innovative technologies and future challenges. The 29th International Horticultural Congress in Brisbane, Australia, 17–22 August 2014. *Acta Hortic.* 1107, 271–277. DOI: 10.17660/ActaHortic.2015.1107.37
- Gruda, N., Savvas, D., Youssuf, R., Colla, G., 2018. Impact of modern cultivation technologies and practices on product quality of selected greenhouse vegetables – A review. *Eur. J. Hortic. Sci.* 83(5), 319–328. <https://doi.org/10.17660/eJHS.2018/83.5.5>
- Gruda, N., Tanny, J. (2014). Protected crops. In: *Horticulture: Plants for people and places*, Dixon, G.R., Aldous, D.E. (eds.). Springer Science+Business Media, Dordrecht, Vol. 1, Chap. 10, 327–405, DOI: 10.1007/978-94-017-8578-5\_10
- Kaya, C., Kirnak, H., Higgs, D., Saltali, K. (2002). Supplementary calcium enhances plant growth and fruit yield in strawberry cultivars grown at high (NaCl) salinity. *Sci. Hortic.* 93, 65–74.
- Krauss, S., Schnitzler, W.H., Grassmann, J., Voitke, M. (2007). Content and antioxidative capacity of carotenoids,  $\alpha$ -tocopherol and polyphenolics in compartments of tomatoes grown under saline conditions. *Acta Hortic.* 747, 563–569.
- Liu, F.Y., Li, K.T., Yang, W.J. (2014). Differential responses to short-term salinity stress of heat-tolerant cherry tomato cultivars grown at high temperature. *Hortic. Envir. Biotechnol.* 55(2), 79–90.
- Lopez, M.V., Satti, S.M.E., (1996). Calcium and potassium-enhanced growth and yield of tomato under sodium chloride stress. *Plant Sci.* 114, 19–27.
- Magan, J.J., Gallardo, M., Thompson, R.B., Lorenzo, P. (2008). Effects of salinity on fruit yield and quality of tomato grown in soil-less culture in greenhouses in Mediterranean climatic conditions. *Agric. Water Manag.* 95, 1041–1055.
- Marschner, H. (1995). *Mineral nutrition of higher plants*, 2<sup>nd</sup> ed. Academic Press, London.
- Meric, M.K., Tuzel, I.H., Tuzel, Y. Oztekin, G.B. (2011). Effects of nutrition systems and irrigation programs on tomato in soilless culture. *Agric. Water Manag.* 99, 19–25.
- Munns, R. (2002). Comparative physiology of salt and water stress. *Plant Cell Envir.* 25, 239–250.
- Munns, R., Tester, M. (2008). Mechanisms of salinity tolerance. *Ann. Rev. Plant Biol.* 59, 651–681.
- Navarro, J.M., Martinez, V., Carvajal, M. (2000). Ammonium, bicarbonate and calcium effects on tomato plants grown under saline conditions. *Plant Sci.* 157, 89–96.
- Nielsen, S. (2010). *Food Analysis. Laboratory Manual*. Springer US.
- Qaryouti, M.M., Qawasmi, W., Hamdan, H., Edwan, M. (2007). Influence of NaCl salinity stress on yield, plant water uptake and drainage water of tomato grown in soilless culture. *Acta Hortic.* 747, 539–544.
- Quda, S. (2016). *Major crops and water scarcity in Egypt. Irrigation water management under changing climate*. Springer Briefs in Water Science and Technology, eBook, ISBN 978-3-319-21771-0.



- Roosta, H.R., Hamidpour, M. (2011). Effects of foliar application of some macro- and micronutrients on tomato plants in aquaponic and hydroponic systems. *Sci. Hortic.* 129, 396–402.
- Saleh, S.A. (2009). Precision stressing by supplemental Ca and *Bacillus subtilis* FZB24 to improve quality of lettuce under protected cultivation. *Acta Hortic.* 824, 297–302.
- Saleh, S.A. (2011). Improvement of seed germination and stand establishment of globe artichoke under salt stress conditions. *Acta Hortic.* 898, 311–318.
- Saleh, S.A., El-Shal, Z.S., Fawzy, Z.S., El-Bassiony, A.M. (2012). Effect of water amounts on artichoke productivity irrigated with brackish water. *Austral. J. Basic Appl. Sci.* 6(5), 54–61.
- Saleh, S.A., Heuberger, H., Schnitzler, W.H. (2005). Alleviation of salinity effect on artichoke productivity by *Bacillus subtilis* FZB24, supplemental Ca and micronutrients. *J. Appl. Bot. Food Qual.* 79, 24–32.
- Savvas, D., Gianquinto, G., Tuzel, Y., Gruda, N. (2013). Soilless culture. FAO plant production and protection, paper No. 217, Good Agricultural practices for greenhouse vegetable crops, Rome.
- Schnitzler, W.H., Gruda, N., 2002. Hydroponics and product quality. In: *Hydroponic production of vegetables and ornamentals*, Savvas, D., Passam H.C. (eds.). Embrio Publications, Athens, Chap. 10, 373–411.
- Schnitzler, W.H., Gruda, N. (2003). Quality issues of greenhouse production. *Acta Hortic.*, 614, 663–674.
- Schnitzler, W.H., Krauss, S. (2010). Quality and health promoting compound of tomato fruit (*Solanum lycopersicum* Mill.) under salinity. *Acta Hortic.* 856, 21–30.
- Shalaby, O.A., Konopinski, M., Ramadan, M.E. (2017). Effect of chelated iron and silicon on the yield and quality of tomato plants grown under semi-arid conditions. *Acta Sci. Pol. Hortorum Cultus* 16(6), 29–40. DOI: 10.24326/asphc.2017.6.3
- Shimul, M.A., Ito, S.I., Sandia, S., Roni, M.Z., Jamal Uddin, A.F. (2014). Response of tomato (*Lycopersicon esculentum*) to salinity in hydroponic study. *Bangladesh J. Sci. Res.* 10(3), 249–254.
- Tuzel, Y., Tuzel, I.H., Ucer, F. (2003) Effects of salinity on tomato growing in substrate culture. *Acta Hortic.* 609, 329–335.
- Urrestarazu, M. (2013). State of the art and new trends of soilless culture in Spain and in emerging countries. *Acta Hortic.* 1013, 305–312.
- Veslues, P.E., Agarwal, M., Katiyar-Aarwal, S. (2006). Methods of concepts in quantifying resistance to drought, salt and freezing, abiotic stresses that affect plant water status. *The Plant J.* 45(4), 523–539.
- Wu, M., Kubota, C. (2008). Effect of electrical conductivity of hydroponic nutrient solution on leaf gas exchange of five greenhouse tomato cultivars. *Hortic. Tech.* 19, 271–277.
- WWAP. (2014). United Nations World Water Assessment Programme. The United Nations World Water Development Report: Water and energy. UNESCO, Paris.
- Zaki, M.E., Salem, A.A., Eid, S.M., Glala, A.A., Saleh, S.A. (2015). Improving production and quality of Tomato yield under saline conditions by using grafting technology. *Int. J. Chem. Tech. Res.* 8(12), 111–120.
- Zhai, Y., Yang, Q., Hou, M. (2015). The effects of saline water drip irrigation on tomato yield, quality and blossom-end rot incidence – A 3a case study in south of China. *PLoS One* 10(11), e0142204. DOI:10.1371/journal.pone.0142204
- Zhang, P., Senge, M., Dai, Y. (2017). Effects of salinity stress at different growth stages on tomato growth, yield and water use efficiency. *Commun. Soil Sci. Plant Anal.* 48(6), 624–634.