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ORIGINAL PAPER

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EFFECT OF EXOGENOUS SALICYLIC ACID ON THE RESPONSE OF SNAP BEAN (*Phaseolus vulgaris* L.) AND JERUSALEM ARTICHOKE (*Helianthus tuberosus* L.) TO DROUGHT STRESS

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ABSTRACT

Water shortage is a major problem that limits growth and productivity of plants in arid and semi-arid regions. Protecting plants from adverse environmental conditions by using simple methods could be of great value under these conditions. In the present study, we examined water status and drought tolerance of snap bean, a drought-sensitive plant, and Jerusalem artichoke, a relatively drought tolerant plant in response to the application of salicylic acid (SA). Different levels of SA were applied and several physiological, growth, productivity and quality parameters were recorded together with the relative water content. Foliar application of SA improved growth, productivity, quality as well as some physiological parameters of snap bean and Jerusalem artichoke plants exposed to drought stress. Total chlorophyll content and relative water content were higher in plants treated with SA compared to control plants when subjected to drought stress. The specific responses of snap bean and Jerusalem artichoke to SA under drought stress as well as the possible explanations of the effects of SA are discussed.

Key words: chlorophyll, plant growth regulator, relative water content, water relations, water status

INTRODUCTION

Arid and semi-arid conditions seriously affect growth and productivity of plants. Plants develop different strategies to avoid or tolerate the deleterious effects of drought stress. The success of such strategies depends – to some levels – on the genetic constitution of plants, enables them to tolerate these unfavorable conditions, as e.g. in xerophytes. Unfortunately, a majority of economical important plants are sensitive to drought and require special treatment to protect them from these conditions. In addition, the environmental stress impact agriculture production and climate change is expected to increase both the mean temperature and temperature extremes in the future, thereby changing the growing conditions for vegetables [Bisbis et al. 2018].

Snap bean plants are a very important protein source world-wide. However, bean plants (*Phaseolus vulgaris* L.) are injured by drought stress and are negatively affected regarding their growth, productivity and quality [El-Tohamy et al. 1999, 2013, Saleh et al. 2018].

Jerusalem artichoke has the ability to tolerate different environmental stress conditions including drought, frost as well as some pests and diseases [Slimestad et al. 2010]. This plant is native to north

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America and is considered to be an important source of inulin [Azis et al 1999, Muir et al. 2007] and a good source of alcohol production [Chekroun et al. 1996]. Also, Denoroy [1996] indicated that Jerusalem artichoke is a potential source of ethanol because of its high carbohydrate content of tubers and also may be used for inulin production and for energy production in the future [Kim et al. 2013, Li et al. 2013]. However, although Jerusalem artichoke is relatively adapted to unfavorable conditions such as drought, salt, cold and wind stress, which makes it suitable for a wide range of cultivation regions including arid and semi-arid conditions [Chen et al. 2013], drought can reduce the dry matter of tubers as well as growth and yield of this plant [Kocsis et al. 2007, 2008].

In previous studies on plant drought tolerance we investigated different subjects such as, e.g. modifying drip irrigation system [Badr et al. 2010], or using citric acid [El-Tohamy et al. 2013], brassinosteroids [El-Bassiony et al. 2012] and biofertilization [El-Tohamy et al. 2009]. In addition, Baum et al. [2015] reviewed the application of mycorrhiza, including its beneficial effects on drought tolerance of plants.

Salicylic acid (SA) could be a suitable plant growth regulator, or bioregulator, for reducing the negative effects of drought. Rao et al. [2012] indicated that foliar application of SA and L-tryptophan can play a role in reducing the effect of drought in maize. Anosheh et al. [2012] stated that the beneficial effects of SA and cycocel in reducing the drought stress injury could be related to improving stomatal regulation, maintaining leaf chlorophyll content, increasing water use efficiency, and stimulating root growth. SA also plays an important part in the responses of plants to environmental stresses including drought, low temperature and toxicity of heavy metals as found in mung bean plants [Roychoudhury et al. 2016]. Recently, Lakzayi et al. [2014] reported that SA is considered to be a potent signaling molecule in plants which is involved in eliciting specific responses to biotic and abiotic stresses including drought.

A few research works are done on water status and other responses of plants to SA application, especially under drought stress conditions. The aim of the present study is to examine drought tolerance, water status, growth, productivity and quality of snap bean, a drought-sensitive plant, and those of Jerusalem artichoke, a relatively drought-tolerant plant, in response to SA.

MATERIALS AND METHODS

The research work was conducted in the National Research Center of Egypt in 2014. Snap bean and Jerusalem artichoke were used in this study in separate experiments as follows.

Snap bean experiment. Seeds of snap bean (*Phaseolus vulgaris* L.) cv. 'Bronco' were sown in 5 Liter pots, filled with peat moss, on the first week of March in a greenhouse. When plants reached the 3rd leaf stage, they were sprayed with 0.1, 0.3, 0.5, 1 and 2 $g \cdot L^{-1}$ of SA. Four days after treatments, plants were subjected to drought stress by withholding water for 5 days. Tensiometers (Irrometer Company, Riverside, California, USA) were used for monitoring of soil water potential (soil water potential reached –40 centi-bar at the end of drought stress). Control plants were also subjected to drought, but were not sprayed with SA. All stressed plants were re-watered after the drought stress period and kept well-watered to follow post stress observations on vegetative growth parameters and yield as well as some quality parameters of pods.

The following parameters were recorded. Plant growth, quality and yield measurements, including plant height, number of leaves, number of pods, pod length, pod diameter and total yield were measured at the end of the experiments. The total soluble solids (T.S.S.) of pods was measured with a portable refractometer at the end of the experiments.

Physiological measurements, including total chlorophyll content of leaves, measured in the 2nd fully expanded leaves with TYS-A Chlorophyll Meter (Zhe Jang Top Instrument Co. LTD., China), and relative water content (RWC) of leaf discus of 14 mm diameter, punched from intact plants of the 2nd fully expanded leaves were measured, according to Turner [1981].

Jerusalem artichoke experiment. Tubers of Jerusalem artichoke (*Helianthus tuberosus L.*) cv. 'French' were cultivated in 5 Liter pots, filled with peat moss, on the first week of March in a greenhouse. Table 1 shows average of temperature and radiation during the year 2014.

Table 1. Average month-temperature and radiation during the year 2014

Month	Temperature average (°C)	Radiation average (MJ m^{-2})
1	12.5	12.6
2	13.6	15.3
3	16.5	19.7
4	19.9	22.9
5	23.1	26.1
6	26.1	29.1
7	26.6	28.9
8	26.7	26.3
9	25.0	22.9
10	22.5	18.0
11	18	13.6
12	14.2	11.8

The plants were treated with the same concentrations of SA as those used in snap bean experiment. Drought stress was applied as mentioned in bean experiment. Control plants were also subjected to drought, but were not sprayed with SA. After drought stress period, the plants were irrigated and kept at field capacity to follow post stress observations on vegetative growth parameters and yield as well as some quality parameters of pods.

The following parameters were recorded. Plant growth and yield measurements, including plant height, number of leaves, number of tubers and fresh weight of tubers were measured at the end of the experiments.

Physiological measurements, including total chlorophyll content of leaves, measured in the 2nd fully expanded leaves with TYS-A Chlorophyll Meter (Zhe Jang Top Instrument Co. LTD., China) and RWC according to Turner [1981]. The low moisture content of tubers made it difficult to take samples for T.S.S. measurement.

In both experiments, all plants were fertilized by using a full nutrient solution 15–5–25 (NPK). Plants were irrigated in a daily basis with the nutrient solution. Each pot received 250 ml of the nutrient solution.

Experimental design and statistical analysis. A complete randomized design was used and analysis of variance was calculated according to Snedecor and Cochran [1967]. The least significant difference (LSD) at 5% probability level was used to compare the means.

RESULTS AND DISCUSSION

Effects of salicylic acid on some physiological parameters of snap bean and Jerusalem artichoke plants

Relative water content (RWC) is an effective parameter which reflects plant water status. The plants treated by SA tended to have significantly higher RWC compared to control plants (fig. 1), indicating that SA could improve the water status of snap bean and Jerusalem artichoke plants under drought stress. Thus, SA-treated plants could overcome the negative effects of drought conditions and recover from drought stress. Moreover, the results of RWC also indicated the drought sensitivity of snap bean plants compared to Jerusalem artichoke (fig. 1).

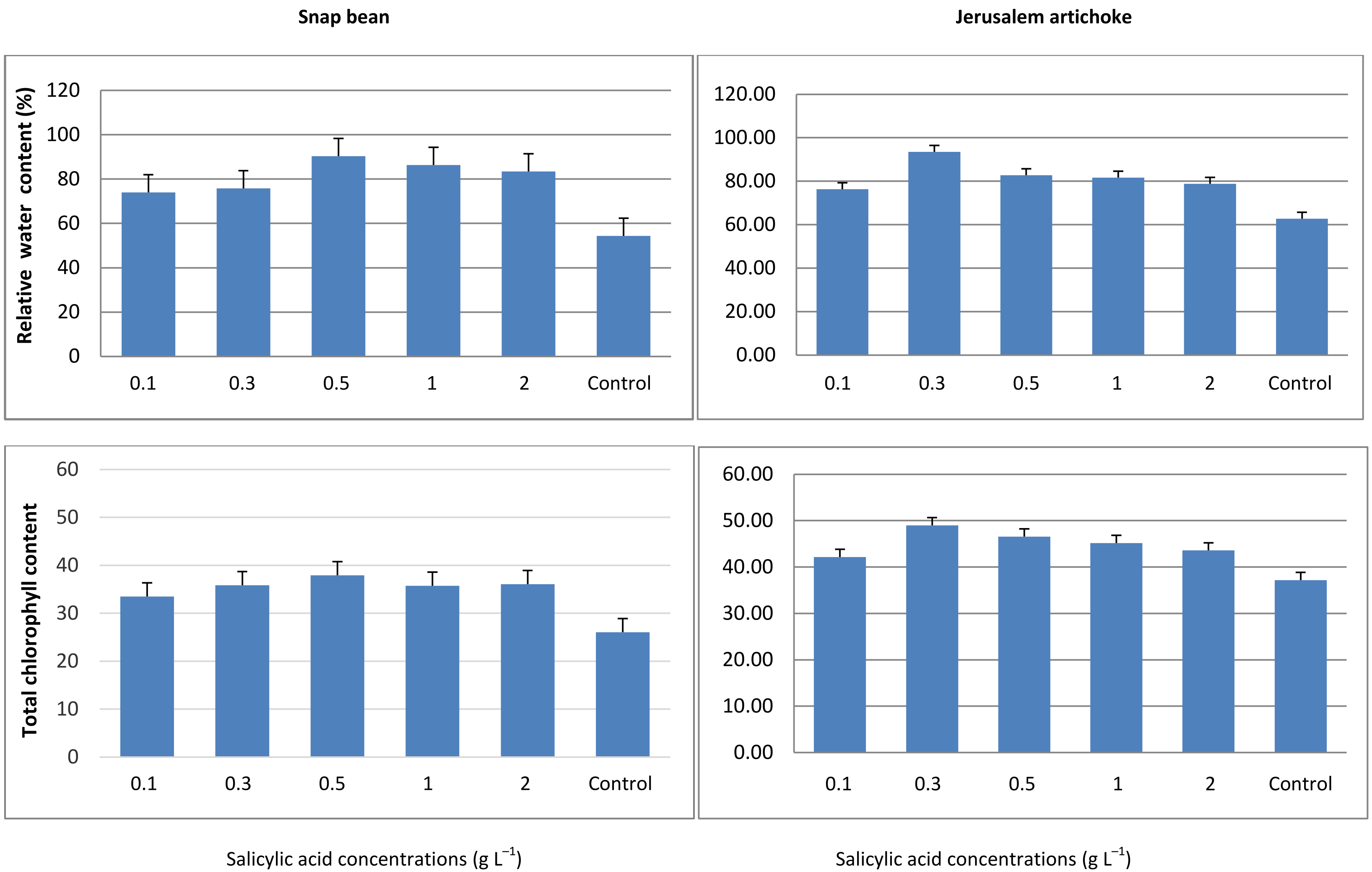

Fig. 1. The influence of salicylic acid on relative water content and total chlorophyll of snap bean and Jerusalem artichoke leaves (vertical bars present LSD value at 5%)

Pasala et al. [2016] discussed the important impact of using plant growth regulators to minimize the harmful effects of environmental stresses, including water deficit. Rao et al. [2012] indicated the efficiency of SA in maintaining higher relative water content of maize plants during drought. Also, Latif et al. [2015] found that foliar application of SA improved drought tolerance, relative water content of leaves, total soluble solids and enhanced growth of *Zea mays* plants. Moreover, the significance of SA to water relations of soybean plants [Barkosky and Einhelling 1993] and water use efficiency of wheat [Anosheh et al. 2012] was evident. Ansari et al. [2016] stated that SA was very efficient in protecting flaxseed plants from drought stress and found that SA increased relative water content and P content even when plants were not inoculated with mycorrhiza. On the other hand, the RWC decreased when mycorrhiza was inoculated, indicating an antagonistic action between mycorrhiza and SA. El-Tayeb and Ahmed [2010] described SA as an important signal molecule affecting plant responses to stress and possibly improving drought tolerance of plants. Under salinity stress conditions, SA significantly reduced transpiration rate of rosemary plants [Najafian et al. 2009]. This may also explain the improvement in water status and relative water content in plants in our experiment in response to SA application under drought stress conditions.

It is worth mentioning that the optimum concentrations of SA necessary to improve water status and drought tolerance of plants under study were 0.5 g L^{-1} and 0.3 g L^{-1} for snap bean and Jerusalem artichoke, respectively. The effect of SA on protecting bean plants from drought was more evident than that in Jerusalem artichoke as Jerusalem artichoke is relatively tolerant to drought compared to snap bean plants. Slimestad et al. [2010] indicated that Jerusalem artichoke can tolerate different environmental stress conditions, including drought, better than other plants. As indicated in Figure 1, the values of relative water content and chlorophyll content were relatively higher in Jerusalem artichoke than in snap bean plants, indicating that Jerusalem artichoke plants could maintain a better water status and thus be more tolerant to drought stress compared to snap bean plants. According to Chen et al. [2013], Jerusalem artichoke is suitable for a wide range of cultivation regions including arid and semi-arid conditions. This is not the case with snap bean plants. Growth and productivity of bean plants are significantly affected by water stress [Millar and Gardner 1972]. Also in the previous study we found that water stress resulted in a decline of leaf water potential, stomatal conductance, photosynthesis rate and growth, productivity and quality parameters of snap bean plants [El-Tohamy et al. 1999]. The ability of Jerusalem artichoke to tolerate drought seems to be very much related to accumulation of free proline as Zhang et al. [2011] stated. They studied the drought tolerance of two Jerusalem artichoke cultivars and found that the higher drought-tolerant cultivar had more accumulation of free proline during drought and had better maintenance of water status than the other cultivar. Latif et al. [2015] suggested that SA could ameliorate drought stress through accumulation of both soluble and cell wall-bound phenolics. On the other hand, the findings of Kurepin et al. [2015] indicated that under drought stress conditions, endogenous SA could promote glycinebetaine biosynthesis in chloroplasts, which had an osmoregulation effect as a proposed role of SA on improving drought tolerance of plants.

A similar trend was observed in the total chlorophyll content of leaves (fig. 1) in plants treated with SA. Lakzayi et al. [2014] reported that drought stress resulted in reducing chlorophyll content of plants due to oxidative stress. In addition, Anosheh et al. [2012] stated that the improvement in drought tolerance of wheat plants in response to SA application may be due to its effect on maintaining higher chlorophyll content of leaves and enhancing water use efficiency. Moreover, the most effective level of SA in drought-sensitive snap bean plant was almost twice as higher as that in drought-resistant Jerusalem artichoke plant.

Effects of salicylic acid on growth, productivity and some quality parameters of snap bean and Jerusalem artichoke plants

Salicylic acid improved drought tolerance and consequently resulted in more vigorous plants that recovered rapidly from drought stress as indicated by higher growth and productivity after drought stress period. This result was evident in both snap bean and Jerusa-

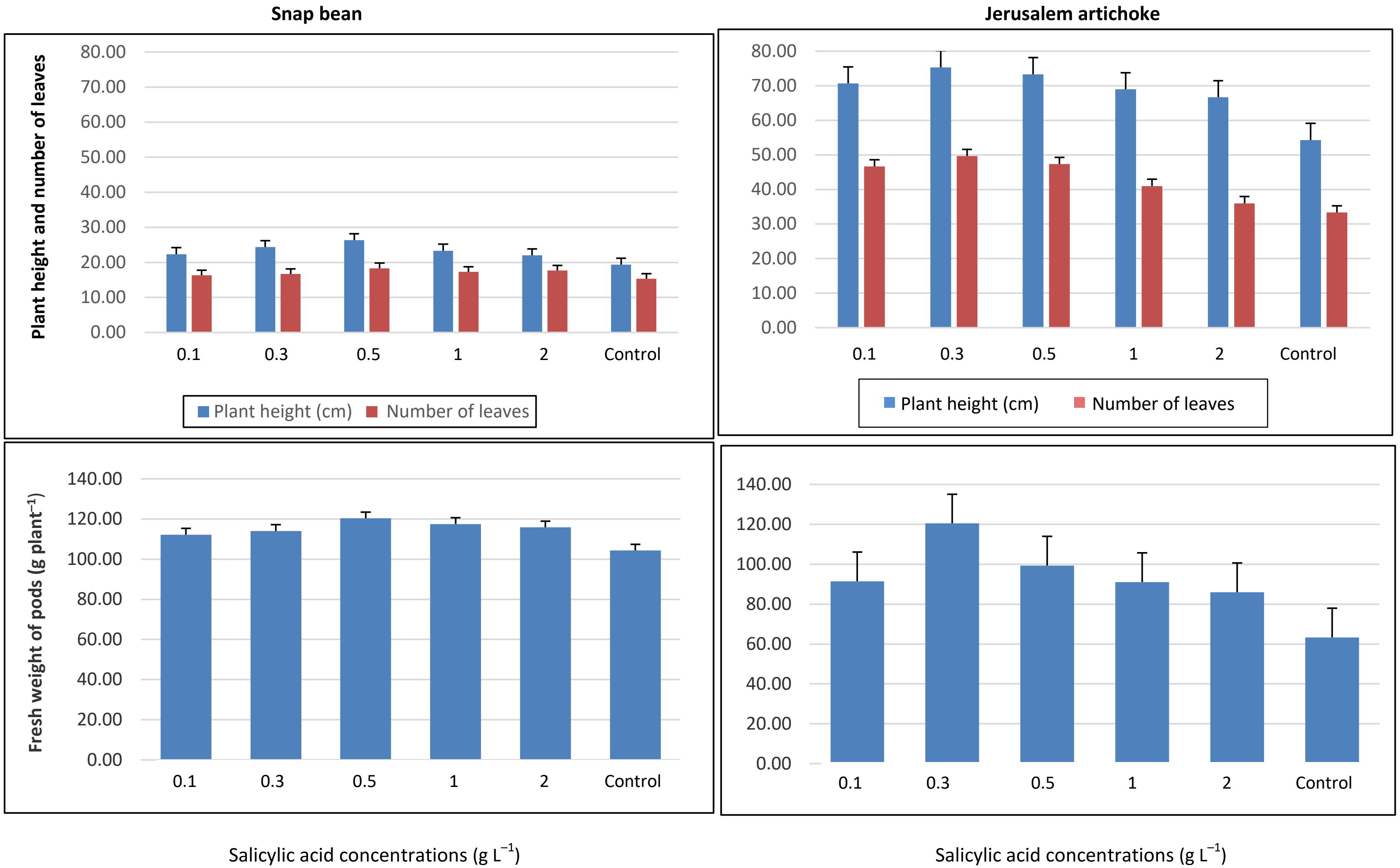

Fig. 2. The influence of salicylic acid on plant height, number of leaves and fresh weight of snap bean pods and of Jerusalem artichoke tubers (vertical bars present LSD value at 5%)

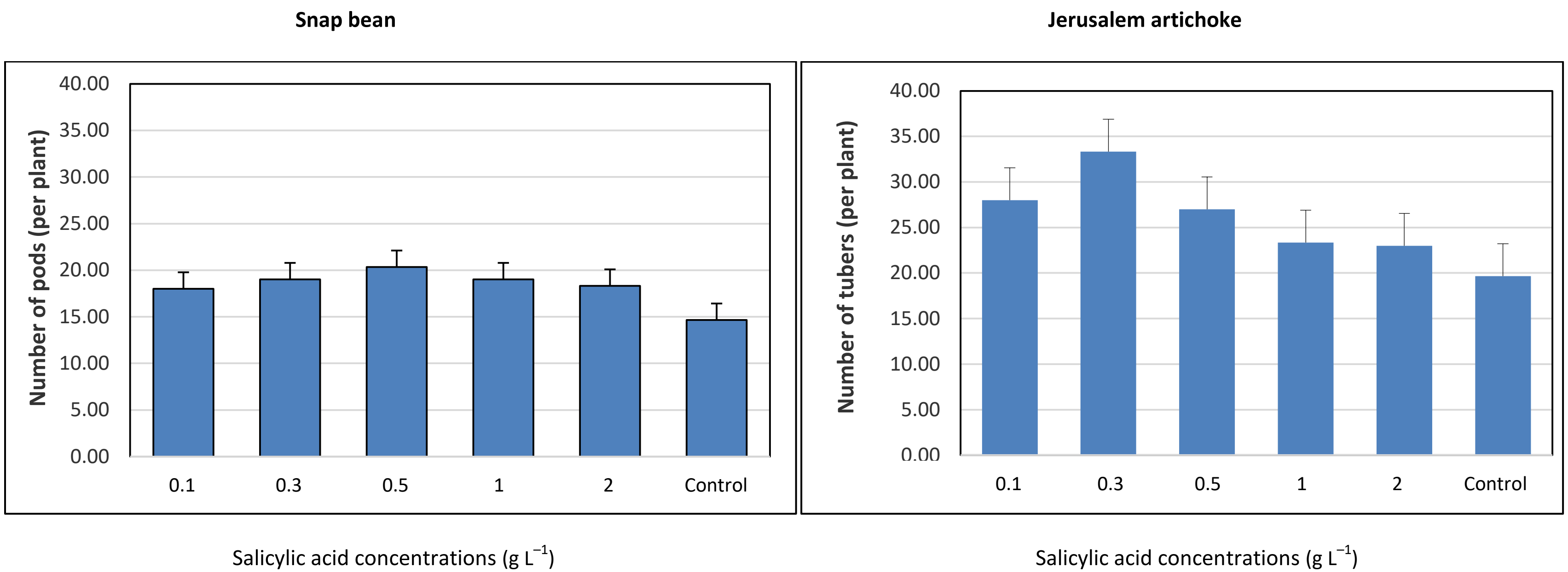

Fig. 3. The influence of number of pods and number of tubers of both snap bean pods and tuber of Jerusalem artichoke, respectively (vertical bars present LSD value at 5%)

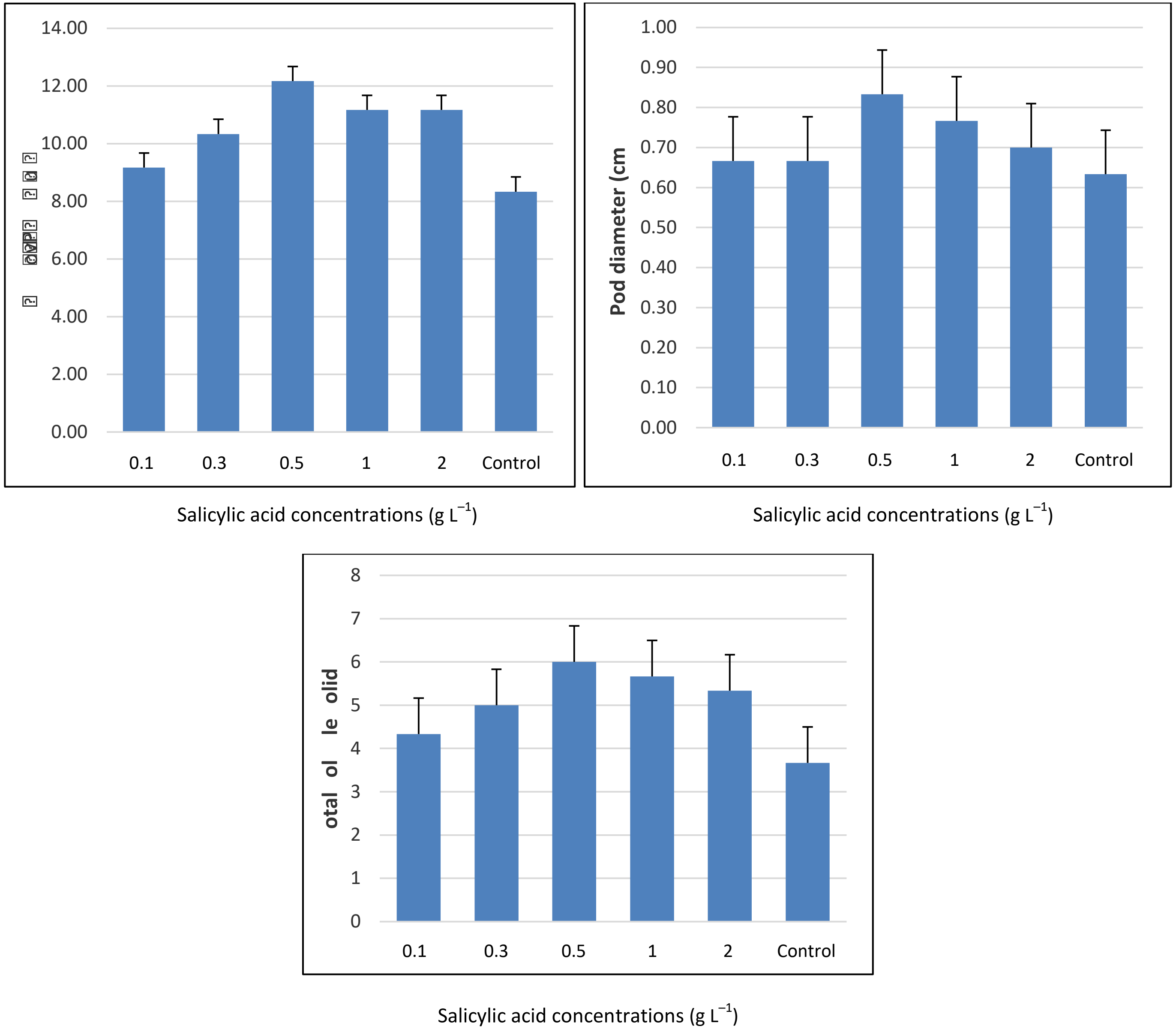

Fig. 4. The influence of salicylic acid on pod length, pod diameter and total soluble solids of snap bean pods (vertical bars present LSD value at 5%)

lem artichoke plants as indicated in the present study. Hussain et al. [2008] stated that water stress could seriously reduce the production of sunflower plants and found that exogenous application of SA was effective in reducing drought stress in sunflower yield and quality. Kang et al. [2013] found that exogenous SA significantly reduced the negative effects of drought on growth and dry weight of wheat plants. Plants treated with SA had higher productivity, better plant growth, and even quality of pods. These results are manifested by higher growth indicated by higher plant height and number of leaves (fig. 2), productivity, indicated by higher number of bean pods and Jerusalem artichoke tubers (fig. 3) and fresh weight of pods and tubers (fig. 2) and quality, indicated by higher pod length and pod diameter (fig. 4). The optimum levels were at 0.5 g L^{-1} and 0.3 g L^{-1} for snap bean and Jerusalem artichoke respectively.

El-Tayeb and Ahmed [2010] reported that SA improved wheat growth under drought stress conditions, indicated by higher dry weight of seedlings compared to untreated seedlings. Our results are further in agreement with those of Lakzayi et al. [2014], who found that SA application improved growth of plants under drought stress conditions. Moreover, Bayat and Sepehr [2012] reported that foliar application of SA improved drought tolerance of maize plants, indicated by high growth and productivity under such conditions. Also, Askari and Ehsanzadeh [2015] found that foliar application of SA reduces the negative effects of drought on fennel plants by improving root growth and yield especially in tolerant genotypes. Even soaking seeds of common bean in SA could mitigate the harmful effects of drought stress, which was shown by plant height, leaf area and protein content [Sedeghipour and Aghaei 2012].

Consumer interest worldwide in the quality of vegetable products has increased in recent years. Product quality is a complex issue. As well as visual characteristics, properties such as texture, the content of minerals and vitamins, flavor and other organoleptic characteristics must be considered [Gruda 2005]. Total soluble solids belong to important quality parameters and, as indicated in Fig. 4, SA-treated snap bean plants maintained significantly higher total soluble solids of pods compared to control plants. The results of El-Tayeb and Ahmed [2010] showed that SA resulted in accumulation of sugars, proteins and minerals in wheat plants under drought stress. This is the most likely the reason why there was an improvement in total soluble solids of bean pods in response to SA application in our experiment, even though we did not investigate these parameters because they were not the focus of our work. The authors recommended to use SA in order to improve growth, yield and quality of bean plants under drought conditions. As previously discussed regarding RWC and chlorophyll content, there were differences in the behavior of snap bean and Jerusalem artichoke plants when subjected to drought as well as concerning their growth and productivity. These differences are based on the physiological reaction and plant tolerance to drought conditions.

CONCLUSION

In conclusion, the present study showed the effect of SA on improving water status, growth, yield and quality of snap bean and Jerusalem artichoke plants subjected to drought stress. The best results were achieved at the concentration of 0.5 g $L^{-1}$and 0.3 g L^{-1} for snap bean and Jerusalem artichoke, respectively. Such treatment can be used effectively during a shortage of water or before an expected drought situation. Jerusalem artichoke plants can be successfully grown in arid regions as they possess relatively high drought tolerance. Such crops have in addition, lower water requirements, compared to other crops and thus are able to be produced on a large scale in arid and semiarid lands.

To have a full understanding of mode of action of SA, further research is needed to explore the effects of SA on plant drought tolerance at the molecular and hormonal level. It is also important to study the interaction between SA and some microorganism application, such as mycorrhiza, in order to clarify whether they have synergistic or antagonistic effects when applied jointly under drought stress conditions.

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