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Research Paper

Effects of mycorrhizal seeding substrate on salinity and biomass allocation of processing tomatoes in salinized soil

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Abstract. In combination with mild (S), moderate (M) and severe (H) salinized soils, two different seedling substrates were set up, namely: non-mycorrhized seedling substrate (n) and mycorrhizal seedling substrate (m), and a total of six treatments were used to study the photosynthetic characteristics and biomass allocation of processed tomato during the whole growth period. The results showed that the mycorrhizal treatment increased the yield, photosynthetic parameters, root morphology, and configuration and mycorrhizal infection rate of processed tomato in different salinized soils, which increased the dry weight of aboveground and underground parts by 6.7-202.0% and 0.3-150.0% respectively. The root-to-shoot ratio increased by 4.3 to 32.3%. The mycorrhizal seedling substrate can improve the plant biomass and yield by promoting the photosynthesis, root growth and root-shoot ratio of processed tomato under salt stress, and finally improve the salt tolerance of processed tomato.

Keywords: Salinized soil, seedling substrate, mycorrhiza, photosynthetic parameters, biomass.

INTRODUCTION

Plants synthesize carbohydrates through photosynthesis, and obtain the energy and carbon necessary for biosynthesis and cellular maintenance through respiration (Yasuaki *et al.*, 2019). In the process of plant growth and development, photosynthesis is the basic life activity of plants, and it is also one of the most sensitive physiological processes for stresses such as salt stress. Improvement of photosynthetic capacity could increase plant dry mass, allocation to reproductive organs and is a major target for ensuring food security (Chen *et al.*, 2017; Carmo-Silva *et al*., 2017). Soil salinization is one of the most serious abiotic stress factors affecting plant productivity through reduction of soil water potential, decreasing the absorptive capacity of the roots for water and nutrients (Murugesan *et al*., 2019). It hinders the growth and development of crops and the sustainable development of agriculture, and over 800 millions ha of soil resources worldwide are affected by soil salinity or alkalinity, representing 70% of the total agricultural land (Ye *et al*., 2019). Salt stress causes physiological drought to plants, imbalance in nutrient composition and excessive toxicity due to Na^+ and Cl^- ions thereby leading to reduction in osmotic potential of plants, disruption of cell organelles and their metabolism. These ultimately affect plant growth and reduce the yield (Langeroodi *et al.*, 2017). In addition, salinity is one of the most severe environmental stresses limiting agricultural crop production worldwide. Photosynthesis is one of the main biochemical processes getting affected by such stress conditions, and also the largest organic synthesis on Earth. The mechanism by which photosynthetic apparatus responds to salt stress is extremely complex and varies with plant genotype, developmental stage, history of the plant cell and duration of stress imposed (Behrooz *et al*., 2019; Huang *et al*., 2019).

Reduced photosynthesis under salinity is not only

attributed to stomatal closure leading to a reduction of intercellular CO_2 concentration, but also to no stomatal factors. When Na^+ and Cl^- ions reach high concentrations in leaves, they cause impairment in both biochemical and photo chemical processes of photosynthesis. Tomato (*S. lycopersicum* L.) is the most cultivated and most important vegetable in the world, and is adapted to a variety of climates, from temperate to tropical and from arid to humid areas. However, salt stress is a main factor that limits the fruit yields of tomato, because salinity seriously disrupts tomato plant growth at all stages of growth, thus reducing fruit production (Martínez-Gutiérrez *et al.*, 2016). Therefore, studying how to improve the salt tolerance of crops and photosynthetic characteristics under salt stress is indispensable for improving tomato yield. Arbuscular mycorrhizal fungi can mitigate salt stress in host plants. It can also alleviate the net photosynthetic rate, stomatal conductance and relative water content of plants under salt stress (Munns and Tester, 2008; Chen *et al.*, 2017). Mycorrhizal inoculation significantly increased plant biomass while slightly increased shoot phosphorus and potassium concentrations, and reduced shoot sodium concentrations (Liu *et al.*, 2018). Therefore, the aim of this study was to determine whether the mycorrhizal seedling substrate can improve the photosynthesis of processed tomato under salt stress and increase the final biomass and yield of the crop through mycorrhizal infection. The purpose is to (1) characterize the effects and differences of photosynthetic characteristics on the photosynthetic characteristics of different salt concentrations; (2) analyze the physiological mechanisms and biomass accumulation leading to differences in photosynthetic characteristics.

MATERLALS AND METHODS

Experimental design

The experiment was conducted in the net room of Xinjiang Agricultural University in Urumqi, Xinjiang from April to September 2018. Set up lightly salinized soil (salt content less than (3 g kg^{-1}) 0.3%, control), moderately salinized soil (salt content (6 g kg^{-1}) 0.3 to 0.6%) and severe salinized Soil (salt content (10 g kg^{-1}) 0.6 to 1.0%) was used as research material. The basic physical and chemical properties of the soil are as follows: Organic matter (11.24 g kg^{-1}), Olsen-P (5.0 mg kg^{-1}), available potassium (121 mg kg^{-1}), pH (7.79), total salt (1.7 g kg^{-1}), conductance (300 μs cm^{-1}), Treatment of supplemented mycorrhizal seedling substrate and non-mycorrhizal seedling substrate, Treatments were mild salinized soil + non-mycorrhizal seedlings (S-n), mildly salinized soil + mycorrhizalized seedlings (S-m), moderately salinized soils + non-mycorrhizalized seedlings (M-n), Moderately salinized soil + mycorrhizalized seedlings (M-m), severely salinized soils + non-mycorrhizalized seedlings (H-n), severely salinized soils + mycorrhizalized seedlings (H-m), each treatment was repeated seven times. The test carrier was a plastic pot (62 × 21 × 21 cm), and the soil volume in each pot was 24 kg. The amount of nitrogen fertilizer (pure N) used was 300 kg ha^{-1}, the amount of phosphate fertilizer (P_2O_5) was 150 kg ha^{-1}, and the amount of potassium fertilizer (K_2O) was 75 kg ha^{-1}. Phosphate fertilizer and potash fertilizer were applied as base fertilizers at one time. The application rate of nitrogen fertilizer was 40% as base fertilizer and 60% as top dressing, and 30% were applied in flowering and fruit expansion periods, respectively.

Plant culture

The mycorrhiza substrate and the non-mycorrhized substrate were used for seedling. The mycorrhizal substrate seedling is sterilized by treating the substrate of licorice residue: corn stover: peat: vermiculite=4:5:1:5 at 121°C for one hour, and then according to the microbial agent: the substrate is 150 g: 1.18 kg. The proportion is fully mixed and spared, and the non-mycorrhitic matrix component is the matrix without mycorrhizal agent. Mixed bacteria: *Acaulospora foveata, Acaulospora morrowiae, Acaulospora spinosa, Gigaspora albida, Gigaspora gigantean, Gigaspora margarita, Glomus claroideum, Glomus clarum, Glomus diaphanum, Glomus etunicatum, Glomus mosseae, Glomus intraradices, Glomus versiforme* and *Scutellospora erythropa.* The tomato seeds were soaked in tap water for six hours, placed in a shaker, and shaken at "200-250" for 32 hours. When the seeds emerged from the white tip, seeds of the same size were selected and placed in the breeding tray for cultivation. The seedlings were transplanted into the pot when they grow to two leaves and one heart.

Determination method

Samples were collected at 45, 65, 85, 105 and 125 days after tomato planting. Six plants were divided into aerial and underground parts. They were killed at 10°C for 15 min and dried at 80°C to weigh dry matter. Thirty root segments of each plant were examined by staining microscopy with toluene blue. Mycorrhizal infection rate was calculated by frequency standard method (Phillips and Hayman, 1970). Formula for calculating mycorrhizal dependence degree (Hetrick *et al.*, 1992): mycorrhizal dependence degree = (dry matter quantity of inoculation treatment - dry matter quantity of non-inoculation treatment) / dry matter quantity of inoculation treatment×100%.

Dry mass (DM) production, root parameters and root/shoot ratio

A total of six tomato plants were selected from each treatment and cut at the cotyledonary node after the

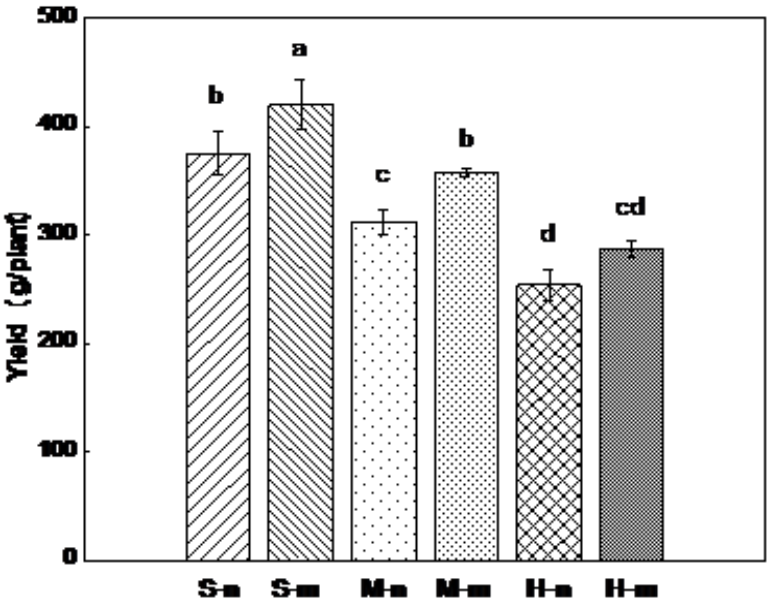

Figure 1. The effects of various treatments on tomato yield. Means with different letters in a row are significantly different (LSD, P≤0.05).
S-n mild soils- non-mycorrhized seedling substrate
S-m mild soils- mycorrhized seedling substrate
M-n moderate soils- non-mycorrhized seedling substrate
M-m moderate soils-mycorrhized seedling substrate
H-n severe salinized- non-mycorrhized seedling substrate
Hm severe salinized-mycorrhized seedling substrate

measurement of photosynthesis. Plants were uprooted from the soil and were separated into leaves, stems and roots. DM was obtained from samples oven-dried at 80°C. Root morphology: Analyze the digitized image obtained by scanning with WinRHIZOron MF 2011, a software to obtain root length and root surface area.

Determination of photosynthetic parameters and SPAD

Between 10:00 and 12:00 in the morning, the functional leaves of tomato were selected, and the net photosynthetic rate, stomatal conductance, transpiration rate and intercellular CO_2 concentration were determined by CIRAS-2 photosynthetic apparatus. A chlorophyll meter (SPAD-502 type) measures the SPAD value of functional leaves.

Statistical analysis

Analysis of variance (ANOVA) was performed using SPSS software v. 20.0. Differences between treatments were considered significant at P≤0.05 according to least significant difference (LSD) tests. The Figures were plotted using software origin 8.0. The data were presented as means ± SD.

RESULTS

The yield of processed tomato with mycorrhizal seedling culture was higher than that of non-mycorrhizal seedling treatment under the salt stress. With the increase of salt concentration, the yield of each treatment decreased gradually (Figure 1). Moreover, the difference between different seedling substrates in lightly salinized soil is more significant.

The increase of SPAD with the increase of the number of days shows a trend of increasing first and then decreasing SPAD. Between 45 and 85 d, the SPAD value of each treatment increased with the increase of the number of days, and the tomato had the highest SPAD value under S-m treatment. At 105 d, except for M-m treatment, the SPAD values of the other treatments began to decrease, and the SPAD values under mycorrhizal treatment were higher than the non-mycorrhizal treatment, which were 1.9, 8.9 and 4.3% higher, respectively. At 105-125 d, the treatments showed a downward trend. In the heavily salinized soil, the SPAD value of processed tomato treated with mycorrhizal seedling substrate was higher than that of non-mycorrhizal seedling substrate (Figure 2).

It can be seen from the Figure 3 that the gas exchange parameters Tr, Pn and gs tend to increase first and then decrease during the whole growth period, but Ci is opposite. As the growth period increases, the Ci of each

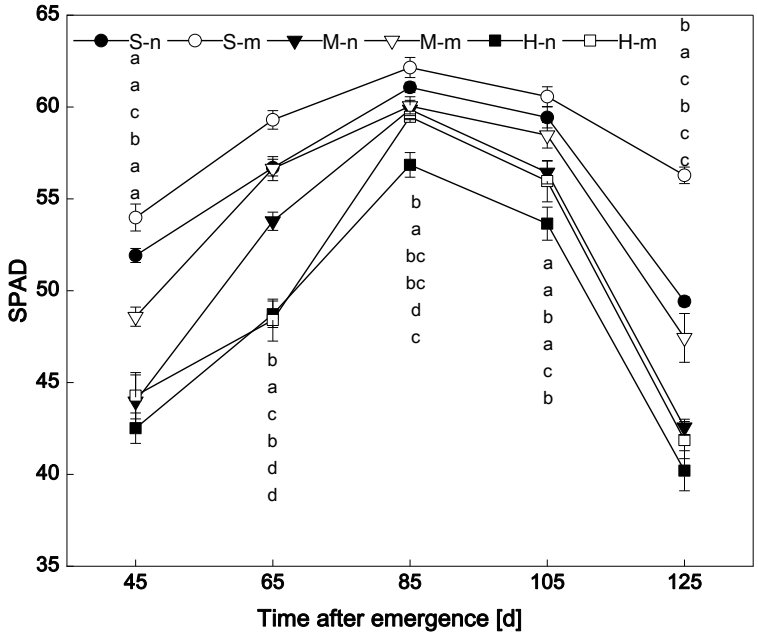

Figure 2. The effects of various treatments on tomato SPAD. Means with different letters in a row are significantly different (LSD, $P \leq 0.05$).
S-n mild soils- non-mycorrhized seedling substrate
S-m mild soils- mycorrhized seedling substrate
M-n moderate soils- non-mycorrhized seedling substrate
M-m moderate soils-mycorrhized seedling substrate
H-n severe salinized- non-mycorrhized seedling substrate
Hm severe salinized-mycorrhized seedling substrate

treatment shows a tendency to decrease first and then rise. At 45 to 65 d, Pn, Tr and gs continued to increase, and each treatment reached the maximum at 65 d. The performance was S>M>H, n>m, as Ci showed a downward trend, and H treatment was higher than M and S treatment. n is higher than m treatment. At 65 to 125 d, except for the increase of Ci and the peak at 125 d, the other parameters showed a gradual decline trend and the lowest at 125 d (Figure 3).

With the increase of growth days, the roots, stems and leaf organs of each treatment increased to different extents, and in the three salinized soils, the overall biomass showed higher mycorrhizal treatment than non-mycorrhizal treatment. The stems and leaves showed a rapid increase trend between 105-125 d, and the root biomass increased more gently. In mildly salinized soil, the DM of S-m treated stems was 15.5% higher than that of S-n, but the DM performance of roots and leaves was opposite. In moderate and severe salinization soil, the DM of roots, stems and leaves of M-m was 0.3-92.0, 23.6-207.8, and 16.7-203.1% higher than that of m-n. DM of H-m was 7.1-76.4, 31.9-114.9 and 28.2-67.2% higher than that of H-n. In the non-mycorrhizal treatment, the DM of each organ in the highly salinized soil was the lowest. In the mycorrhizal treatment, the DM of each organ of H-m was slightly lower than M-m, but the DM of stems and leaves did not differ significantly between the two treatments, which may be related to the effects of mycorrhiza on the rhizosphere growth and physiological growth of crops (Figure 4).

With the advancement of growth days, the root length gradually decreased in each treatment, and reached the maximum at 45 d. Under S, M, H treatment, m was increased by 4.5, 13.3 and 14.1%, respectively. The root surface area and total root length increased with the increase of plant growth days. The root surface area treated by S increased rapidly at 125 d, and the difference between S-n and S-m treatment was significant. The total root length increased significantly in the S and M treatments, and the H-treatment increased slowly. The total root length of the n-treatment was higher than the total root length of the m treatment at each stage (Figure 5).

At the growth stage, the root-shoot ratio showed a trend of increasing first and then decreasing. Compared with n, m had a higher root-shoot ratio, and showed S>Z>H in different salinized soils. The maximum is reached at 85 d and then gradually decreases (Figure 6).

Under salt stress, mycorrhizal infection rate and mycorrhizal dependence increased first and then decreased with the increase of growth period. At 85d S-m, M-m, the mycorrhizal infection rate of H-m treatment reached the maximum and showed S-m > M-m > H-m, 63.48, 51.38 and 43.44% respectively. In the other

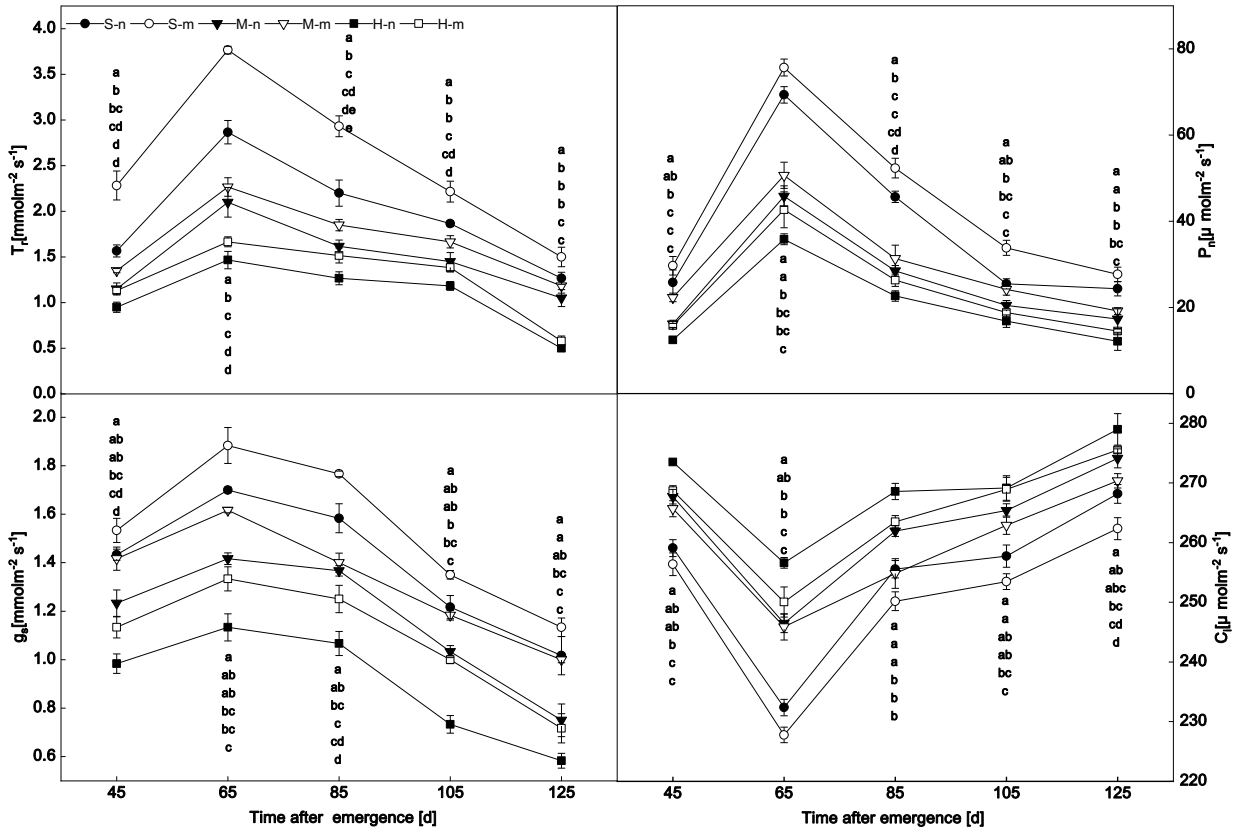

Figure 3. Effects of various treatments on photosynthetic parameters of tomato. Means with different letters in a row are significantly different (LSD, P≤0.05).
S-n mild soils- non-mycorrhized seedling substrate
S-m mild soils- mycorrhized seedling substrate
M-n moderate soils- non-mycorrhized seedling substrate
M-m moderate soils-mycorrhized seedling substrate
H-n severe salinized- non-mycorrhized seedling substrate
Hm severe salinized-mycorrhized seedling substrate

stages, the mycorrhizal infection rate of M-m and H-m treatment was 34.0, 89.9; 10.8, 31.6; 10.6, 36.4 and 19.9, 30.0% lower than that of S-m treatment (Table 1).

Principal component analysis for total root length (X1), root surface area (X2), specific root length (X3), Pn(X4), Tr(X5), gs(X6), Ci(X7), SPAD of processed tomatoes (X8) eight growth indicators were used for principal component extraction. Due to the dimensional difference between the indicators, the initial eigenvalue and the principal component factor variance contribution rate obtained by principal component analysis are normalized by the Z-score standardization method. It can see that the cumulative contribution rate of the first two extracted principal components is 83.945%, of which the contribution rate of PC1 is 56.400%, and the contribution rate of PC2 is 27.545% (Table 2).

Because the weights of the parameters of the indicators are different, the load of the principal components is different. In PC1, SPAD (X8), Pn (X4), Tr (X5), gs (X6) have higher load (weights are 0.663-0.956), total root length (X1), root surface area (X2). The root length (X3) has a lower load (weight is 0.077-0.421), and the total root length (X1) and root surface area (X2) of the second principal component have a higher load (weights are 0.863-0.915). Pn (X4) and Tr (X5) SPAD (X8) have a lower load (weights between 0.094 and 0.323). PC1 can separate mycorrhizal and non-mycorrhizal seedlings in moderately salinized soil, and PC2 can separate mild and severely saline soil. Therefore, it can be explained that in moderately salinized soil, different seedling substrate treatments affect the photosynthetic growth of processed tomato, and mild and severe salinized soil affects the growth of tomato underground roots (Figure 7).

DISCUSSION

The results of this experiment show that in the three salinized soils, with the increase of salt concentration, the yield of tomato is gradually reduced, and the inoculation of mycorrhiza can increase the yield of crops to a certain extent. It shows that arbuscular mycorrhizal fungi (AMF)

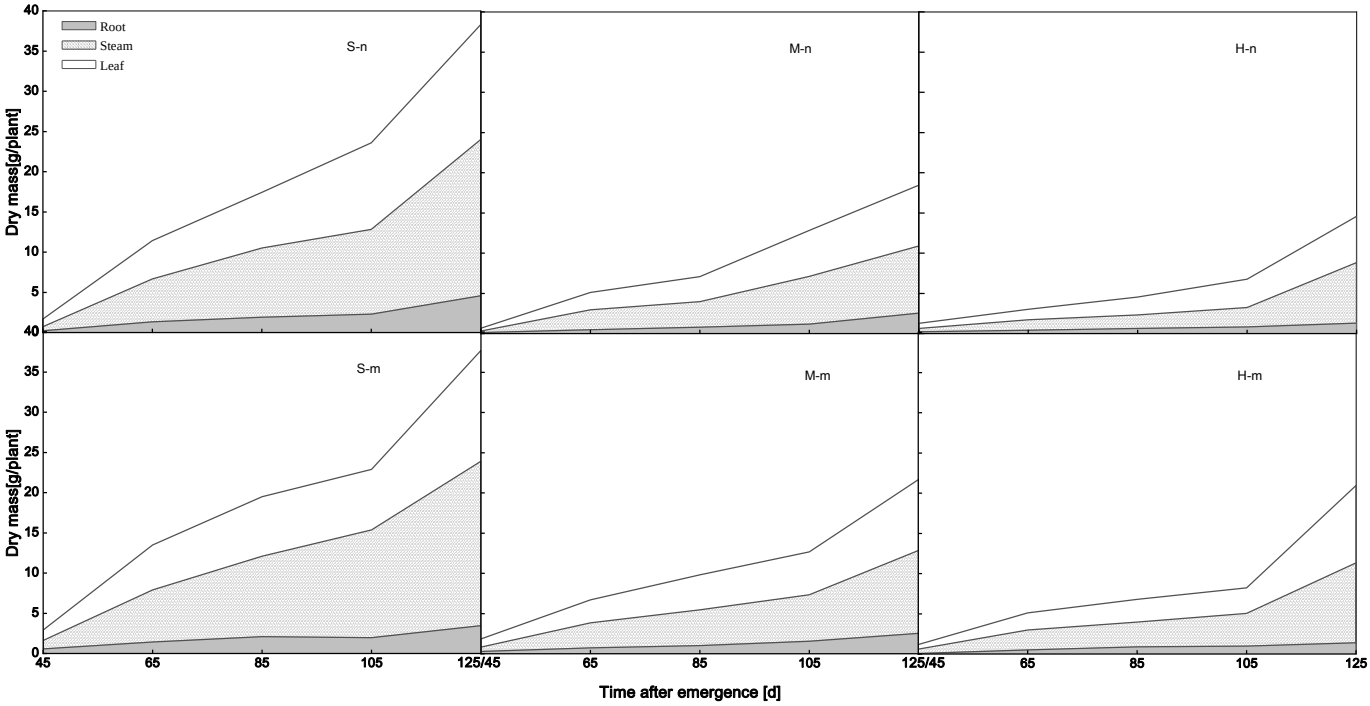

Figure 4. Effects of various treatments on dry matter distribution of tomatoes. Means with different letters in a row are significantly different (LSD, P≤0.05).
S-n mild soils- non-mycorrhized seedling substrate
S-m mild soils- mycorrhized seedling substrate
M-n moderate soils- non-mycorrhized seedling substrate
M-m moderate soils-mycorrhized seedling substrate
H-n severe salinized- non-mycorrhized seedling substrate
Hm severe salinized-mycorrhized seedling substrate

can increase crop yield by promoting the growth of crops under salt stress. It may be due to the development of extra-rooted mycelium after rooting and mycorrhiza symbiosis that help plants absorbs water and nutrients for plant growth (Bertolazi *et al.*, 2018).

When plants are exposed to salt stress, various physiological processes will be affected, directly or indirectly affecting chlorophyll content. The results of this experiment indicated that salt stress could reduce the SPAD value of processed tomato leaves, but inoculating mycorrhiza treatment could alleviate the salt stress on chlorophyll and increase the chlorophyll content. The chlorophyll content was highest at 85 d during the whole growth process, and others have the same conclusion in the study of black locust. It may be that the inoculation of AM fungi can increase the nitrogen content in plant leaves under salt stress, and then increase the chlorophyll content. It may also be that under the action of AM fungi, the inhibition of Na^+ on the absorption of Mg^{2+} and other mineral elements by plant leaves can be weakened or counteracted (Giri *et al.*, 2003), and salt stress may bring much negative effect on stomatal conductance then depressing photosynthesis (Elhindi *et al.*, 2017). Inoculation of mycorrhiza can also improve the photosynthesis parameters of plants under salt stress. In this study, Pn, Tr, and gs all showed higher mycorrhizal seedlings than non-mycorrhizal seedlings. AM fungi could increase the leaf gas exchanges under salt stresses, indicating AM fungi might improve leaf gas exchange in by increasing the stomatal conductance and transpiration in leaves, probably because this may be involved with hormonal and sugar regulation. Higher hormone content in mycorrhizal leaves might promote photosynthesis of plants under moderate salt stress. Enhanced accumulation of soluble sugars in mycorrhizal leaves augments water uptake for photosynthesis (Liu *et al.*, 2016), or because AM fungi reduce shoot Na content and increase K transport from root to shoot, along with alleviating oxidative damage, which promote photosynthesis and transpiration (Zhang *et al.*, 2018). In addition, with the increase of salt concentration, these three photosynthesis parameters decreased, but Ci showed the opposite trend. It indicated that under salt stress, in order to further promote the absorption and transportation of water and mineral nutrients in leaves, the transport rate of CO_2 to chloroplasts increased, which increased the concentration of intercellular carbon dioxide and promoted the increase of net photosynthetic rate (Xu *et al.*, 2018), which may be associated with osmotic effects of salts in the soil, the increase in sodium

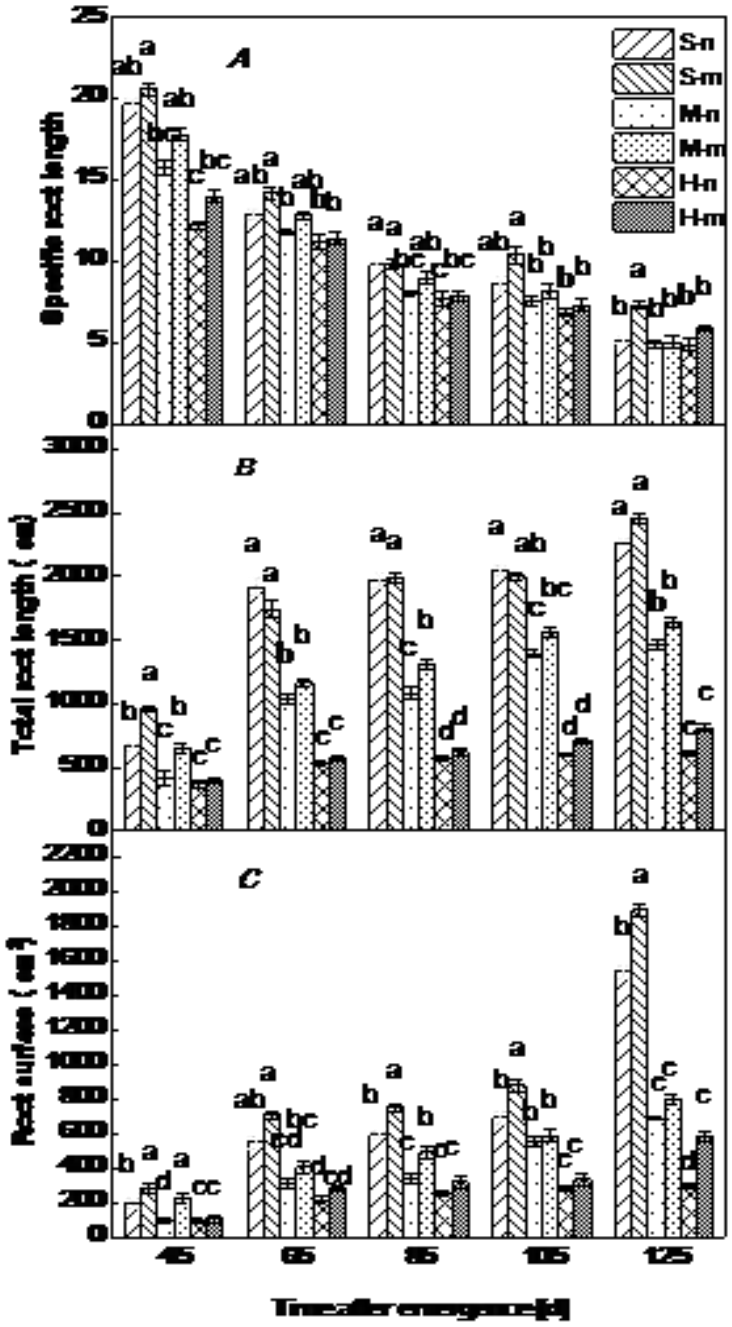

Figure 5. Effects of various treatments on tomato root parameters. Means with different letters in a row are significantly different (LSD, P ≤ 0.05).
S-n mild soils- non-mycorrhized seedling substrate
S-m mild soils- mycorrhized seedling substrate
M-n moderate soils- non-mycorrhized seedling substrate
M-m moderate soils-mycorrhized seedling substrate
H-n severe salinized- non-mycorrhized seedling substrate
Hm severe salinized-mycorrhized seedling substrate

and reduced levels of N in leaves (Aldênia *et al.*, 2016). In addition, at 65 d, the photosynthetic parameters of the leaves showed peak or minimum, indicating that the processed tomato was in the vigorous photosynthesis stage at 65 d, which may be related to the physiological characteristics of tomato. In this experiment, the biomass of the mycorrhizal seedling substrate was higher than that of the non-mycorrhizal seedling substrate in the three

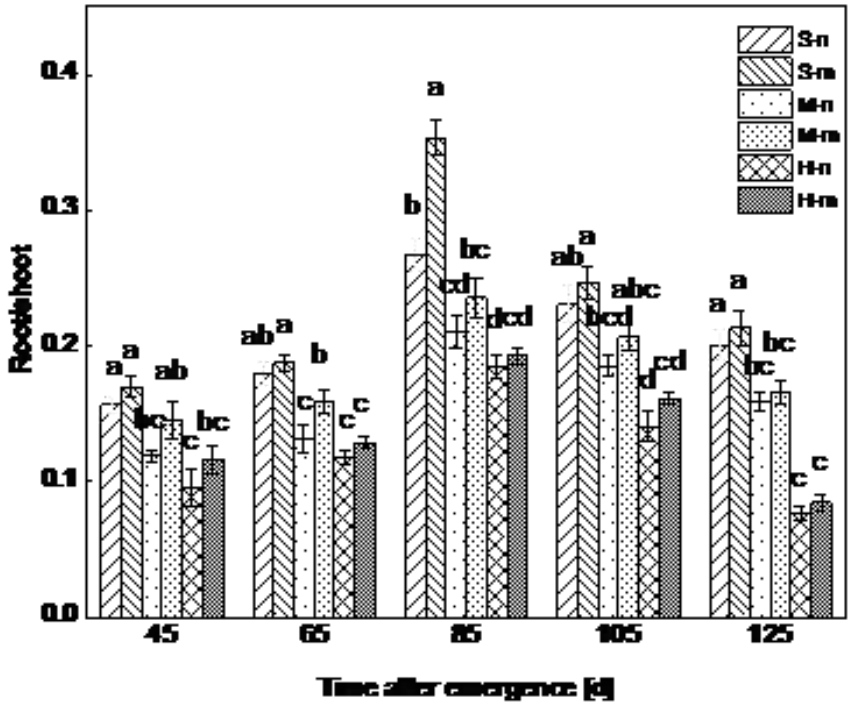

Figure 6. Effects of various treatments on root/shoot ratio of tomato. Means with different letters in a row are significantly different (LSD, P ≤ 0.05).
S-n mild soils- non-mycorrhized seedling substrate
S-m mild soils- mycorrhized seedling substrate
M-n moderate soils- non-mycorrhized seedling substrate
M-m moderate soils-mycorrhized seedling substrate
H-n severe salinized- non-mycorrhized seedling substrate
Hm severe salinized-mycorrhized seedling substrate

salinized soils. This indicates that AM fungi can significantly alleviate the negative effects of salt stress and increase plant biomass (Demir *et al.*, 2011). It may be through a series of physiological effects such as increasing chlorophyll content, light energy utilization efficiency, gas exchange and enzyme activity under salt stress to improve physiological mechanism and promote biomass accumulation (Xu *et al.*, 2018). In addition, as the salt concentration increases, the biomass of processed tomatoes decreases. The lower production of dry weight, in function of salinity, is probably because of the physiological drought due to the reduction of the osmotic potential of the soil solution, since the roots were the most affected. The difficulty of water absorption also affects the nutrient uptake, which compromises seedling development (Maia *et al.*, 2014).

Roots as organs that directly sense changes in salinity and their response to salt conditions are important for studying plant survival and soil improvement. The results of this experiment indicated that the total root length and root surface area of processed tomato roots under mycorrhizal treatment were higher than that of non-mycorrhizal seedling treatment, and gradually decreased with the increase of salt concentration, but increased with the increase of growth days. The roots are used as the gateway to the nutrients and water in the soil. The morphological composition of the roots is directly related to the absorption and utilization of nutrients and water in different soil layers. Under the condition of salt stress, the AM fungi in the soil establish a symbiotic relationship with the roots of the plants. Its root growth produces a significant boost. This may be due to the absorption of water by mycelium outside the mycorrhizal root after AMF inoculation, and AMF can promote water transport and hydrogen peroxide distribution in root tip cells, thereby promoting root growth (Ding *et al.*, 2020). In addition, the root length of processed tomato roots showed the opposite trend. The root length of mycorrhizal seedling treatment was lower than that of non-mycorrhizal seedling substrate treatment at 45-105 d, but the difference was not significant, with salt concentration. The increase in the root length of each treatment gradually decreases. It shows that salt and mycorrhiza treatment will reduce the specific root length of plants. Predecessors have also reached the same conclusion in the study of tomato and corn roots (Ghazanfar *et al.*, 2015; Sheng *et al*., 2009). This is because AMF provides more nutrients for plants, and plant roots also produce corresponding positive effects. At the same time, AMF hyphae replaces plant roots for absorption function, and

Table 1. Effects of various treatments on the colonization-rate and dependence of tomato mycorrhiza.

Treatment	Seeding stage		Flowering stage		Fruit development stage		Fruit expanding		Picking harvest	
	AMF colonization rate (%)	AMF dependence (%)	AMF colonization rate (%)	AMF dependence (%)	AMF colonization rate (%)	AMF dependence (%)	AMF colonization rate (%)	AMF dependence (%)	AMF colonization rate (%)	AMF Dependence (%)
S-n	0	0	0	0	0	0	0	0	0	0
S-m	11.9 ± 0.50^{a}	26.3 ± 0.02^{b}	48.4 ± 2.10^{a}	14.9 ± 0.04^{b}	63.5 ± 1.32^{a}	9.0 ± 0.01^{c}	40.7 ± 0.99^{a}	6.4 ± 0.02^{b}	24.7 ± 0.98^{a}	4.1 ± 0.01c
M-n	0	0	0	0	0	0	0	0	0	0
M-m	8.8 ± 0.31^{b}	27.7 ± 0.02^{b}	43.6 ± 1.37^{b}	22.3 ± 0.05^{a}	51.4 ± 1.36^{b}	22.1 ± 0.04^{b}	36.4 ± 1.21^{b}	10.5 ± 0.02^{a}	19.8 ± 0.44^{b}	7.5 ± 0.01 b
H-n	0	0	0	0	0	0	0	0	0	0
H-m	6.3 ± 0.28^{c}	28.6 ± 0.02^{a}	36.8 ± 0.75^{c}	40.9 ± 0.04^{a}	43.4 ± 1.15^{c}	32.6 ± 0.04^{a}	29.9 ± 0.54^{c}	17.5 ± 0.02^{a}	19.0 ± 0.40^{b}	10.1 ± 0.01 a

Means with different letters in a row are significantly different (LSD, $P \leq 0.05$).
Treatment: (S-n) mild salinized soil - non-mycorrhizal seedlings, (S-m) mildly salinized soil - mycorrhizalized seedlings, (M-n) moderately salinized soils - non-mycorrhizalized seedlings, (M-m) moderately salinized soil - mycorrhizalized seedlings, (H-n) severely salinized soils - non-mycorrhizalized seedlings, (H-m) severely salinized soils - mycorrhizalized seedlings.

Table 2. Principal component loading matrix.

Parameter	Component	
	1	2
x1	0.421	0.863
x2	0.077	0.915
x3	0.497	-0.694
x4	0.927	0.094
x5	0.974	0.11
x6	0.956	-0.121
x7	-0.959	-0.043
x8	0.663	0.323
Eigenvalue (λ)	4.574	2.142
Contribution (%)	56.400	27.545

Parameter: (x1) Total root length, (x2) root surface area, (x3) specific root length, (x4) Pn, (x5) Tr, (x6) gs, (x7) Ci, (x8) SPAD of processed tomatoes.

plant roots become thicker and smaller than roots (Brundrett, 2002). In this test, the root-shoot ratio decreases with increasing salt concentration. This is because salt stress has an adverse effect on the absorption of plant nutrients, especially the absorption of phosphorus and potassium in roots, resulting in a significant decrease in dry biomass in the shoots (Porcel *et al.*, 2016). In addition, the root-shoot ratio of processed tomato treated with mycorrhizal treatment was lower than that of non-mycorrhizal seedling treatment, and it showed a trend of increasing first and then decreasing during the whole growth process. At 85 d, the root-shoot ratio of each treatment peaked. It shows that the inoculum can increase the root-shoot

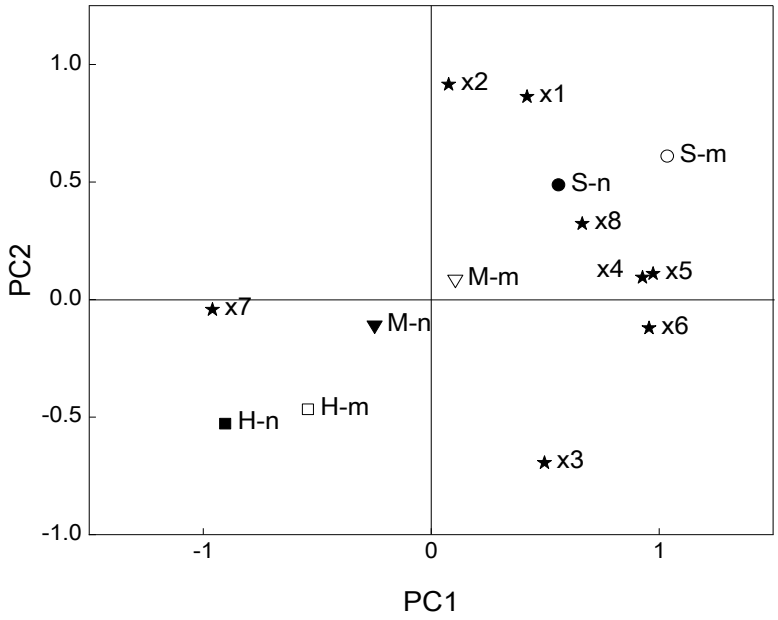

Figure 7. Principal component analysis of the effects of various treatments on tomato growth.
S-n mild soils- non-mycorrhized seedling substrate
S-m mild soils- mycorrhized seedling substrate
M-n moderate soils- non-mycorrhized seedling substrate
M-m moderate soils-mycorrhized seedling substrate
H-n severe salinized- non-mycorrhized seedling substrate
Hm severe salinized-mycorrhized seedling substrate

ratio of the plant (Xue *et al*., 2014). May be because the AM symbiosis favors Na^+ extrusion from the cytoplasm, its sequestration into the vacuole, the unloading of Na^+ from the xylem and its recirculation from photosynthetic organs to roots, there is a decrease of Na^+ root-to-shoot distribution and an increase of Na^+ accumulation in roots which seems to enhance the plant tolerance to salinity and allows AM plants to maintain their growing processes under salt conditions (Porcel *et al.*, 2016). Inoculation of AM can prevent a large increase in root respiration under salt stress, allowing trees to release more C assimilation to grow (Boris and Hans, 2015). Furthermore, the growth of roots is increased to promote the root-shoot ratio of the plants.

The rate of mycorrhizal infection represents the infection of the fungus and the amount of biomass in the root tissue (Koide and Mosse, 2014). In this experiment, with the increase of salt concentration, the mycorrhizal infection rate and mycorrhizal dependence decreased gradually, indicating that the growth of plants in salinized soil is closely related to the mycorrhiza development. It may be that salinity increases the production of hydrogen peroxide, and lipid peroxidation leads to loss of membrane integrity while reducing the absorption of essential nutrients (Ait-El-Mokhtar *et al.*, 2019). In turn, it affects the normal growth of the strain, and the mycorrhizal infection rate and mycorrhizal dependence are lower.

In this experiment, Principal Component Analysis showed that in the two treatments of the seedling substrate, the mycorrhizal seedling substrate can increase the root biomass and promote the aboveground photosynthesis of tomato plants, but in different degrees of salinized soil, that mainly rely on root growth. Because the mycelium can grow and stretch outside the rhizosphere, the roots are connected to the surrounding soil microhabitats, expanding the root area to absorb more nutrients. Therefore, water and nutrients can be absorbed by plants through a huge mycelial network (Liu *et al*., 2016).

CONCLUSION

The mycorrhizal seedling substrate can promote the photosynthesis of processed tomato under salt stress, thereby improving plant biomass and yield. In addition, it can promote root growth and increase plant root-shoot ratio to improve salt tolerance of processed tomato.

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