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Effects of mycorrhizal fungi application on some growth parameters of Monterey strawberry cultivars under different salt stress conditions

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Abstract
Salinity is one of the most important environmental problems for agricultural production. In recent years, some studies revealed that arbuscular mycorrhizal fungi positively influenced plant growth and development and increased the uptake of nutrients under saline conditions. This study was carried out to investigate the response of the Monterey strawberry cultivar to mycorrhizal fungi (*Glomus spp.*) root inoculations during salinity stress under greenhouse conditions. In the present study, four different salt concentrations (0, 20, 40, and 80 mM NaCl) were applied to growing media with and without mycorrhiza conditions. The parameters such as leaf number, leaf area, petiole length, root length, dry matter contents in leaves, crowns, and roots, fruit weight, fruit yield, and Na, P, and K accumulation in leaves, crowns, and roots were determined. It was determined that increasing the amount of salt negatively affected all parameters in the control treatment. Leaf area significantly decreased with increasing concentration of NaCl treatment with and without mycorrhiza conditions. High salinity caused an increase in the Na content, but K and P contents decreased with salinity. Finally, it is suggested that the application of mycorrhizae generally positively affected examined parameters in strawberries under salinity conditions.
Keywords: Strawberry, Salt stress, Arbuscular Mycorrhizal Fungi, Growth parameters, Yield

INTRODUCTION

Strawberries (*Fragaria ananassa*), belonging to the Rosaceae family, are sweet-scented, fleshy, and juicy false fruits (Zhang et al., 2011). Strawberries are considered a functional food due to their biological activities and potential health benefits, and they are widely consumed (Siebeneichler et al., 2022).

In recent years, strawberry cultivation has spread to almost all regions of Turkey. The total annual production has now reached 728.112 tons (TUIK, 2023). With the increase in strawberry production, stress factors such as salinity, which limit cultivation, have emerged. In recent years, researchers have been focusing on the selection of salt-resistant or salt-tolerant varieties since the problem of soil salinity is difficult and expensive to eliminate (Kamar et al., 2023).

Strawberry plants are considered to be a salt-sensitive crop and it was reported that salt stress conditions negatively affect plant growth and yield (Saied et al., 2005; Karlıdağ et al., 2009; Yıldırım et al., 2009). In strawberry cultivation, using poor-quality water for fertilization and irrigation purposes also causes a gradual accumulation of salt in the soil (Jamalian et al., 2013).

Plants are frequently exposed to adverse environmental conditions such as drought, salinity, and cold stress during their growth and development (Gómez-del-Campo 2015; Azizinya 2005). It is estimated that about one-third of the world's cultivated land is affected by salinity (Kaya et al., 2002). In Turkey, these conditions adversely affect approximately 1.5 million hectares (Dinc et al., 1993). Salinity has complex effects on plants, and the adverse effects of salinity are associated with water deficit, ionic imbalance, mineral nutrition, stomatal behavior, photosynthetic efficiency, carbon allocation, and utilization (Bohnert et al., 1996; Moghaieb et al., 2001). Salinity stress negatively affects plant physiology both the whole plant and at cellular levels through osmotic and ionic stress. High salt concentrations in the soil can negatively affect seed germination, growth, flowering, and fruit set, leading to decreased crop yield and quality (Arora et al. 2008).

About a century ago, Frank, a German scientist (forest phytopathologist), made a major discovery regarding plant-fungal interactions. He identified fungi that were abundant in the roots of some plants but did not cause infection. In 1885, he named these fungi "mycorrhiza" (myko+rhiza), a combination of the words "fungus" and "root". Although this symbiotic relationship between plants and soil microorganisms is the most common, most important, and most interesting one of all symbiotic relationships (Allen, 1991), it recently began to gain importance, and the number of studies on it has been increasing (Allen, 1991; Gai et al., 2006; Martin and Slater, 2007).

The most effective mycorrhizal fungi in horticultural crops are vesicular-arbuscular mycorrhizas (VAM) (Rouphael et al., 2015). The utilization of symbiotic microorganisms that promote plant growth, especially arbuscular mycorrhizal (AM) fungi, can be useful in the development of strategies to facilitate plant growth in saline soils (Younesi and Moradi, 2014). The benefits that mycorrhizal fungi offer to plants include the provision of growth-promoting substances (auxin, cytokinin, and gibberellin, etc.), increased resistance to toxic substances left by heavy metals, increased resistance of seedlings to drought, and contribution to the control of root diseases in plants (Palta et al., 2010).

Many studies showed that inoculation with AM fungi improves the growth of plants under salt stress (Sharifi et al., 2007). The improved growth of AM plants was attributed to their enhanced ability to take up important nutrient elements such as N and P (Jeffries et al., 2003). However, in some cases, the plant's salt tolerance was not related to P concentration (Ruiz-Lozano and Azcón 2000). Thus, it was argued that salt-tolerance mechanisms, such as enhanced osmotic adjustment and reduced oxidative damage or improved nutritional status, can explain the contribution of AM symbioses to the salinity resistance of host plants (Augé 2001). The salt tolerance of plants may not be related to the amount of phosphorus (P) under certain conditions (Ruiz-Lozano and Azcón 2000). It was emphasized that arbuscular mycorrhizal (AM) symbioses increase the resistance of plants to salinity and that this is achieved by osmotic adjustment and reduced oxidative damage or improved nutritional status (Augé 2001).

The present study aims to investigate the effect of Mycorrhiza fungus on some growth and development parameters of Monterey strawberry cultivar grown at different salt concentrations.

MATERIALS AND METHODS

This study was carried out in a plastic greenhouse of the Department of Plant and Animal Production in the Suluova Vocational School of Amasya University in 2016. The 'Monterey', which is a neutral day strawberry variety, was used in this study. A commercial preparation containing Glomus spp. fungal species (*Glomus intraradices, Glomus aggregatum, Glomus mosseage, Glomus clarum, Glomus monosporus, Glomus deserticola, Glomus brasilianum, Glomus etunicatum, and Gigaspora margarita*) was used for mycorrhiza inoculation.

Trial Design and Method

The trial was set up in a randomized block design with 3 replications and 15 plants per replication. In the study, frigo strawberry seedlings were planted in plastic pots (22x40) on 04.15.2016. Two different media were used as growing media. The first consisted of 100% peat and the second consisted of a mixture of 50% garden soil and 50% peat. Mycorrhiza application was performed immediately before planting. The seedlings were dipped in a solution prepared by mixing 250 g of the powdered preparation with 10 liters of water for 30 seconds, thus ensuring the inoculation of the roots with the fungus.

The nutrient solution was not initially supplemented with salt (NaCl), but the salt treatment was started when the seedlings had 4-5 leaves old after a 40-day development period. Salt applications were applied weekly four times with 100 ml of nutrient solution containing a salt solution of 0, 20, 40, and 80 mM/L NaCl. Plants were irrigated periodically, and their nutrient requirements were met by making use of a nutrient solution (Hoagland and Arnon. 1938) at regular intervals. Control plants were given a normal nutrient solution without salt application. The growth of strawberry plants was monitored after salt application, and they were removed in October after 6 months. The applications were given in groups in the trial. The descriptions of the groups are given below (Table 1).

Table 1. NaCl doses, media conditions, and mycorrhiza inoculation applications

Groups	Description
S_0PNM	Nonmycorrhizal application in peat media without salt application
S_0PM	Mycorrhizal application in peat media without salt application
S_0PGNM	Nonmycorrhizal application in peat x garden soil media without salt application
S_0PGM	Mycorrhizal application in peat x garden soil media without salt application
S_{20}PNM	Nonmycorrhizal application in peat media with 20 mM/L salt application
S_{20}PM	Mycorrhizal application in peat media with 20 mM/L salt application
S_{20}PGNM	Nonmycorrhizal application in peat x garden soil media with 20 mM/L salt application
S_{20}PGM	Mycorrhizal application in peat x garden soil media with 20 mM/L salt application
S_{40}PNM	Nonmycorrhizal application in peat media with 40 mM/L salt application
S_{40}PM	Mycorrhizal application in peat media with 40 mM/L salt application
S_{40}PGNM	Nonmycorrhizal application in peat x garden soil media with 40 mM/L salt application
S_{40}PGM	Mycorrhizal application in peat x garden soil media with 40 mM/L salt application
S_{80}PNM	Nonmycorrhizal application in peat media with 80 mM/L salt application
S_{80}PM	Mycorrhizal application in peat media with 80 mM/L salt application
S_{80}PGNM	Nonmycorrhizal application in peat x garden soil media with 80 mM/L salt application
S_{80}PGM	Mycorrhizal application in peat x garden soil media with 80 mM/L salt application

Growth analysis

After harvesting, the plants were washed using plenty of water and passed through pure water. After the moisture was completely removed by using a drying paper, the root length (cm) and leaf petiole length (cm) were measured using a ruler. The number of developed leaves on each plant was counted individually. The surface areas of the leaves were determined using a planimeter (ADC BioScientific Area Meter AM300) with a measurement unit of cm^2 (Demirsoy et al., 2005). After harvesting, the plants were separated into roots, crowns, and leaves. They were then placed in paper bags and kept in an oven at 70°C until their weights did not change. Their dry weights (g) were then determined by weighing. The weighing process was carried out on a sensitive balance sensitive to 0.001 grams. The average fruit weight was determined by weighing the fruits in each treatment and dividing by the number of fruits. The fruits belonging to the plants in each treatment were harvested periodically, then they were weighed, and the yield amount (g/plant^{-1}) was determined by dividing by the number of plants. The harvested fruits were weighed on a balance sensitive with 0.1g sensitivity (Karaduva, 1992).

Determination of P, K, and Na (%)

In the laboratory, dried leaf, crown, and root samples were ground to pass through a 1-mm sieve and prepared for analysis. Phosphorus content was determined by using the vanadomolybdophosphoric yellow color method using a Thermo Scientific (Genesys 10S UV-VIS) spectrophotometer at a wavelength of 430 nm (Kacar, 1991). Potassium and sodium contents were determined by using atomic absorption spectrophotometry (Thermo Scientific (ICE 3000 Series)) in a solution obtained by wet ashing with a mixture of nitric and perchloric acids in root, crown, and leaf samples dried at 70°C in an oven (Kacar, 1972; 1991).

Statistical Analysis

The present study was carried out by using a randomized block design with 3 replications and 15 plants per replication. The statistical analyses of the results (SPSS 20.0) were conducted by performing a one-way analysis of variance. Multiple comparisons of the means were performed at the 5% significance level by using Duncan's multiple comparison method.

RESULTS AND DISCUSSION

The effects of four different concentrations of NaCl (0, 20, 40, and 80 mM/L), two different media (peat + garden soil), and mycorrhizal application on some growth parameters and yield of Monterey strawberries were investigated. The results obtained from this study are discussed below. The statistical analysis results of the data obtained in this study (root length, petiole length, leaf number, leaf area, dry weights, fruit weight, yield, and P, K, and Na contents) are given in Table 2.

Root Lenght

In this study, the highest root length (42.39 cm in S0PGM) was obtained from plants treated with mycorrhiza in a peat x garden soil medium without salt application (Table 2). The lowest root length value was 24.58 cm (S80PGNM), again obtained from plants treated with 80 mM/L salt without mycorrhiza in a peat x garden soil medium. The positive effect of mycorrhiza applications on root length was found to be statistically significant in both media. The results obtained show that root length decreases significantly with increasing salt concentration. Similarly to the present study, a study carried out in vitro on strawberries revealed that increasing salt concentration caused decreases in root length, root number, shoot number, and plant height (Erenoğlu et al., 2003). Another study was carried out on the effects of EC levels on yield and quality in the Camarosa strawberries by using different growing media (peat and coir) and it was determined that EC levels significantly affected plant growth and development when compared to growing media (Adak, 2010). In a study that compared the effects of bacterial and mycorrhizal applications under different salt stress conditions (0, 30, and 60 mM/L NaCl) on the San Andreas strawberry variety, the effects of salt concentrations and harvest days on root length were found to be statistically significant, whereas the effects of applications were found to be insignificant (Koç et al., 2015). Similarly to the present study, it was determined that increasing salt concentration caused a decrease in root length in Boysenberry plants to which only NaCl concentrations were applied (Kurt, 2021).

Leaf Petioles Length

In the experiment, examining the applications for petiole length, the highest value was determined to be 14.10 cm obtained from the S0SGM application, whereas the lowest value was found to be 8.55 cm obtained from the S80SNM application (Table 2). Petiole length decreased significantly with increasing salt concentrations. The effect of mycorrhiza application was generally evident in all applications. Comparing the mycorrhizal-applied media, it was determined that petiole length was higher in the peat x garden soil medium. Similar to the present study, Sönmez et al. (2013) found in their study investigating the effects of zinc, salt, and mycorrhiza on corn development that mycorrhizal application yielded the highest value in plant height and that plant height decreased under saline conditions. Pirlak and Eşitgen (2004) reported in their study that the length of strawberries' vegetative parts did not change with increasing salt application.

Leaf Number

In the present study, leaf numbers of the Monterey strawberry variety subjected to increasing NaCl applications are shown in Table 2. The highest leaf number was obtained with the S0PGM application with 12.99 leaves, whereas the lowest value was obtained with the S80PNM application with 8.87 leaves. The number of leaves decreased significantly with increasing salt concentration. The effect of mycorrhizal application on leaf number in peat media was found to be statistically significant as the salt concentration increased. Strawberries are known to be sensitive to salt stress and a study reported a decrease in stolon length, stolon number, leaf number, and fresh and dry root weights (Saied et al., 2005). In their study, Keutgen and Pawelzik (2009) found that the leaf numbers of the Korono and Elsanta strawberry varieties were 29.20 (control), 15.80 (40 mmolL^{-1}), and 11.90 (80 mmolL^{-1}) and 16.30 (control), 9.50 (40 mmolL^{-1}), and 8.20 (80 mmolL^{-1}), respectively. Similarly to the present study, it was found that the leaf number decreased significantly as the salt concentrations increased. Pirlak and Eşitgen (2004) applied three concentrations of salt (2.0, 5.0, and 7.5 mS cm^{-1} EC) to strawberries and reported that the leaf number of strawberries was negatively affected by salinity. In their study, the leaf number decreased from 37.74% to 29.79% as the salt level increased from 2.0 to 5.0 mS cm^{-1} EC.

Leaf Area

The results of the statistical analysis conducted to determine the effect of different salt doses and mycorrhizal application on the leaf area of strawberries grown in different media are shown in Table 2. In the experiment, the highest leaf area was obtained from the control applications of 42.00 cm^2 (S0PM) and 41.65 cm^2 (S0PGM), while the lowest values were obtained from the applications where the salt concentration was 80 mM/L, with values of 26.61 cm^2 (S80PNM), 24.94 cm^2 (S80PM), and 25.48 cm^2 (S80PGM). In the experiment, it was determined that the leaf area decreased significantly as the salt concentrations increased. In addition, it was found that the leaf area in mycorrhizal application was generally higher than others.

In their study, Keutgen and Pawelzik (2009) found that the leaf area of the Elsanta strawberry variety decreased due to the increase in salinity. They reported that this was due to the increase in Na^+ and Cl^- ions in the root region and the appearance of typical symptoms on strawberry leaves. They also stated that necroses, which turn from red to brown starting from the leaf tips and spreading to the edges, occur at advanced stages of salinity and even lead to death. Similarly, in the experiments conducted with the Monterey strawberry variety in the present study, the necrosis caused by the increase in Na^+ and Cl^- concentrations in the root region covered the entire leaf surface and resulted in a significant decrease in leaf area. Üzal and Yıldız (2014) found that the effect of high salt concentrations on strawberry plants is first seen as symptoms such as yellowing and necrosis of old leaves. Over time, this effect manifests itself as decreases in biomass weight and leaf area, particularly in the leaves of the plants. Keutgen and Pawelzik (2009) stated that the decrease in leaf area in both strawberry varieties they used was due to a decrease in the number of leaves. In their study with the Albion, Benicia, Monterey, San Andreas, and Ventana strawberry varieties, Ferreira et al. (2019) applied salt at doses of 0.7 (control), 1.0, 1.5, and 2.5 dS m^{-1} for 240 days and determined the survival rates of the varieties. Albion had the highest survival rate (94%) at the highest salt concentration (2.5 dS/m), followed by San Andreas (77%), Benicia (75%), and Ventana (67%). Monterey had the lowest survival rate (53%) at the 2.5 dS m^{-1} salt application.

Dry Weights

In the Monterey strawberry variety subjected to NaCl stress, the dry weights measured at the end of the 6-month growing period are given in Table 2. The difference between the salt and control applications was found to be significant in terms of the dry leaf, dry crown, and dry root weights measured in the experiment.

In the experiment, the highest dry leaf weight was obtained from the control group without salt application, 19.08 g/ plant (S0PGM). The lowest dry leaf weight in the experiment was determined in the applications where the salt dose was 80 mM/L, 8.81 g/plant (S80PNM). Leaf dry weights decreased significantly as salt concentrations increased. The positive effect of mycorrhiza was statistically significant in the applications where the salt dose was 40 and 80 mM/L.

In the experiment, the S0PM application with mycorrhiza inoculation yielded the highest crown dry matter content, with an average value of 4.21 g/plant, whereas the S0PGM application with mycorrhiza application had an average of 4.24 g/plant. The S80PNM application without mycorrhiza had the lowest crown dry matter content, with an average of 1.96 g/plant, and the S80PGNM application without mycorrhiza had an average value of 2.18 g/plant. Examining the dry crown weights, the effect of mycorrhiza application was found to be statistically significant at high salt concentrations.

The root weights of the plants in peat x soil medium without salt stress and with mycorrhiza inoculation reached the highest dry matter ratio with 4.29 g/plant and 4.27 g/plant in peat medium, while the plants in peat medium containing 80 mMol salt without mycorrhiza were determined to have the lowest values with an average of 2.00 g/ plant. It was found statistically significant that root dry weights decreased with increasing salt levels like other growth parameters. The positive effect of mycorrhiza on root dry weights was statistically significant at 40 and 80 mM/L salt doses.

Üzal and Yıldız (2014) reported that leaves were affected the most by increasing salt stress on strawberries. They found that leaf weight and leaf area decreased significantly when compared to other parameters in the experiment and that the level of decrease increased as the application duration increased. It was reported that this decrease varies depending on the variety. It was concluded that the entire plant was not negatively affected as a result of accumulating Cl^- ions in the root region in some varieties (Saied et al., 2003). In another study, it was determined that the dry leaf weight of the Camarosa and Tioga strawberry varieties decreased with increasing salt concentration (Turhan and Eriş, 2005). It was determined that the effects that started with necrosis on grape leaves continued to increase as the salt concentrations increased (Sivritepe, 1995).

Yılmaz and Kına (2008) showed in their studies that the dry crown weights of the Gloria variety exhibited a general increasing trend, unlike the present study. Kına (2008) reported that the fresh and dry root weights of the Kabarla variety increased with increasing salt applications, but there was a slight decrease in the Gloria variety. Turhan and Eriş (2005) found an increase in the early stages of salt applications in the Camarosa variety, followed by a decrease. Chartzoulakis and Klapaki (2000) reported a significant decrease in leaf, crown, and root dry weights of pepper as salt stress increased. In a study carried out on Kent, Jewel, and Saint-Pierre strawberry varieties, three different salt doses were applied (0, 30, and 60 mM/L), and it was determined that the fresh weight of leaves and roots decreased as the salt doses increased, whereas both leaf and root fresh weights were higher in mycorrhizal-inoculated plants. Keutgen and Pawelzik (2009) found a decrease in the growth of the Camarosa strawberry variety in the application where the salt was 40 mg NaCl.

Fruit Weight

The effects of mycorrhiza on the average fruit weight per plant in this study, where different salt doses were applied to two different environments, are given in Table 2. In the experiments, it was found that the effect of mycorrhiza application on the average fruit weight per plant was significant at the $p < 0.05$ level under increasing salt stress. In this study, the highest average fruit weight was obtained from the S0PNM application (4.72 g), whereas the lowest average fruit weight was obtained from the S80PNM application (2.52 g). The effect of mycorrhiza on the average fruit weight is significantly evident, especially in applications with 80 mM/L concentration. The increase in salt concentrations caused statistically significant decreases in the average fruit weight. The effect of the environmental difference on the average fruit weight was unclear.

Keutgen and Pawelzik (2008) found that salt application reduced the average fruit weight of the Elsanta strawberry variety. At the 80 mM/L NaCl concentration, 26% and 46% decreases in fruit weights were found in Korona and Elsanta varieties, respectively. Sato et al. (2006) related the decrease in fruit size in environments with increasing salt concentrations to the inhibition of water uptake and the decrease in water transport to the fruit. In parallel with the present study, Kamar et al. (2023) determined the highest fruit weight value in the control group in their study with 4 different salt concentrations (1 dS/m, 1.5 dS/m, 2 dS/m, and 2.5 dS/m) and 3 strawberry genotypes, and they found that the average fruit weight values decreased with increasing salt dose.

Yield

The effects of mycorrhiza application on average fruit yield per plant in different environments under long-term salt stress are presented in Table 2. In this study, it was found that the effect of mycorrhiza application on the average fruit yield of strawberries under increasing salt stress was statistically significant. The lowest average fruit yield per plant was obtained from the S80PNM application (61.20 g) with a salt dose of 80 mM/L, whereas the highest value was obtained from the S0PM and S20PGM applications with 99.63 g and 99.17 g, respectively. In general, the mycorrhiza application yielded positive results in the fruit yield of the Monterey strawberry variety under salt stress conditions.

As a result of the studies on salt stress, it was determined that root, crown, and shoot development and fruit weights and yields of plants decreased and fruit quality was also negatively affected (Abbas et al., 1991; Franco et al., 1993). In a study carried out with Elsanta and Korono strawberry varieties, it was found that fruit yield and number of fruits per plant were not affected by salinity in the first year but decreased significantly in the second year (Saied et al., 2005). Ferreira et al. (2019) carried out a study with Albion, Benicia, Monterey, San Andreas, and Ventana strawberry varieties by using a salt tolerance modeling approach based on all reductions in dry weight and fruit yield, and they determined that Albion was the most tolerant, whereas San Andreas and Ventana were sensitive, and Benicia and Monterey were moderately tolerant. Kamar et al. (2023) observed that different salt concentrations negatively affected yield in the No. 112 and No. 36 strawberry genotypes, with the greatest yield reductions occurring in the Fortuna strawberry variety.

Table 2. Effect of inoculation with mycorrhizal fungi on root length, petiole length. leaf number, leaf area, dry weights, fruit weight, and yield of Monterey strawberry grown in two media at four salinity levels.

Application	Root length (cm)	Petiole length (cm)	Leaf number (number)	Leaf area (cm^2)	Dry leaf weight (g)	Dry crown weight (g)	Dry root weight (g)	Fruit weight (g)	Yield (g)
S_0PNM	39.90 abc	12.37 c	12.02 abcd	40.08 ab	18.46 a	4.14ab	3.94 ab	4.72 a	87.10 abc
S_0PM	42.02 ab	13.57 ab	12.33 abc	42.00 a	18.97 a	4.21 a	4.27 a	4.43 ab	99.63 a
S_0PGNM	38.98 bc	12.49 bc	12.55 ab	39.6 4abc	18.22 a	3.94 abc	3.97 ab	4.25 abc	89.13 abc
S_0PGM	42.39 a	14.10 a	12.9 9a	41.6 5a	19.08 a	4.24 a	4.29 a	4.50 ab	92.66 ab
S_{20}PNM	37.42 cd	11.61 cde	11.56 bcde	36.99 bc	15.95 b	3.42 d	3.89 ab	3.45 abcd	75.33 abc
S_{20}PM	37.75 cd	11.88 cd	11.00 defg	37.99 bc	16.59 b	3.61 cd	3.76 b	4.51 ab	85.57 abc
S_{20}PGNM	34.92 de	12.04 cd	12.04 abcd	36.63 c	15.98 b	3.29 de	3.80 b	4.34 ab	82.08 abc
S_{20}PGM	38.05 cd	12.31 c	11.35 cdef	38.09 bc	18.13 a	3.70 bcd	3.94 ab	4.44 ab	99.17 a
S_{40}PNM	37.34 cd	10.51 efg	10.60 efgh	30.72 de	12.09 d	2.87 e	2.69 d	3.63 abcde	71.40 abc
S_{40}PM	36.70 cd	10.01 fg	11.11 defg	30.01 de	13.78 c	3.54 cd	3.37 c	3.61 abcde	74.80 abc
S_{40}PGNM	28.23 ef	11.51 cde	11.02 defg	30.17 de	12.24 d	2.88 e	2.77 d	4.04 abc	65.27 bc
S_{40}PGM	36.48 de	10.94 def	10.92 efgh	32.72 d	14.06 c	3.34 d	3.75 b	3.68 abcd	71.97 abc
S_{80}PNM	27.99 f	8.55 gh	8.87 hı	26.61 f	8.81 f	1.96 f	2.00 f	2.52 ef	61.20 c
S_{80}PM	33.80 e	9.69 fg	9.80 h	24.94 f	10.33 ef	2.88 e	2.39 de	3.09 cd	68.17 bc
S_{80}PGNM	24.58 g	9.27 g	10.30 fgh	27.47 ef	9.06 f	2.18 f	2.14 ef	2.75 e	66.05 bc
S_{80}PGM	36.52 de	9.98 fg	10.05 gh	25.48 f	11.12 de	2.85 e	2.73 d	3.14 bcd	71.86 abc

$p<0.005$

% P content

The effects of mycorrhiza inoculation on strawberry plants on P contents of the roots, crowns, and leaves under different salt treatments and media are illustrated in Figure 1. Increasing salt levels significantly reduced the average P accumulation in strawberries. In the present study, the highest average P accumulations in leaves, crowns, and roots were determined to be 0.52% (S0PGM), 0.44% (S0PGM), and 0.31 % (S0PM), respectively, whereas the lowest values were found to be 0.14% (S80PGNM), 0.14% (S80PM), and 0.11% (S80PM). The effect of the media on P concentration was found to be not significantly observed, whereas the average P content of roots, crowns, and leaves was statistically significantly lower at high salt levels than in the control. Comparing the P contents of plant parts at the same salt concentrations, the effect of mycorrhiza inoculation was found to be significant.

In parallel with the present study, Pirlak and Eşitgen (2004) reported that N, P, K, Na, and Cl ions were significantly affected by salt applications. They also found that K and P contents in plant leaves were higher at low salt levels than at high salt levels. Moreover, Erdal et al. (2000) examining cucumber seedlings and Alpaslan et al. (1998) examining wheat found that P uptake was negatively affected under increasing salt conditions and P content in the plant decreased. Sönmez et al. (2013) applied two different salt doses (0 and 100 mg Na Cl/kg) to maize plants and reported a 29% increase in P content. Similarly, Güneş et al. (1999) reported that P uptake increased with increasing salt concentration. They stated that this may be due to the increase in the available P content of the soil in saline environments and the synergistic effect of Na. In another study, it was reported that salinity limited the uptake of P and other elements in particular (Evelin et al., 2009).

% K content

The changes in K content in roots, crowns, and leaves of strawberries after mycorrhiza application at different salt levels and in different media are given in Figure 2. In this study, the highest and lowest K accumulation values were determined to be 3.24% (S0PGM), 1.15% (S80PGNM), and 1.18% (S80PNM) in leaves, 2.89% (S0PNM), 1.15% (S80PNM), and 1.17% (S80PGNM) in crowns, and 3.03% (S0PGM) and 0.52% (S80PNM) in roots. It was found that the K content decreased significantly with increasing salt doses applied to leaves, crowns, and roots. Additionally, the effect of mycorrhiza resulted in increased K accumulation in all organs.

Keutgen and Pawelzik (2009) reported that K content varies among the organs of strawberries. In their study, K content was determined to be the highest in the petiole and the lowest in the roots in both cultivars and treatments. In Elsanta, K levels increased in fruit and petioles, whereas Korono showed an increase in leaves and crowns. Essa (2002) reported that high Na uptake affects the uptake of elements such as K^+, Ca^{+2}, and Mg^+ in plants such as soybeans. Salt-tolerant cultivars had lower concentrations of Na^+ and Cl^- in their leaves, while K^+ concentrations were high. In contrast, Ferreira et al. (2019) did not observe an increase in Na^+ in leaves or competition between Na^+ and K^+ in cultivars. The high levels of Na and Cl in the soil can inhibit the uptake of K, Ca, and N ions in plants and also disrupt the ionic balance of plants (Güneş et al., 1999; Botella et al., 2005; Hong et al., 2009).

% Na content

The changes in Na ion accumulation percentages in root, crown, and leaf by different salt treatments are illustrated in Figure 3. In the present study, the highest and lowest Na accumulation levels were determined to be 4.01% in S80PGNM, 3.93% in S80PGM, and 0.79% in S0PNM in the leaves, 4.67% in S80PGM, 4.41% in S80PGNM, and 1.01% in S0PM in the crowns, and 5.01% in S80PGNM, 0.99% in S0PNM, and 1.04% in S0PM in the roots. In contrast to P and K levels, Na levels in leaves, crowns, and roots increased significantly with increasing salt doses. In general, Na content in leaves, crowns, and roots was lower in mycorrhiza treatments when compared to others.

Keutgen and Pawelzik (2009) reported that the presence of NaCl in the root zone of strawberries caused a decrease in N and Cl concentrations in all organs of strawberries. In their study, an increase in Na accumulation was observed in the fruit, leaves, petioles, crowns, and roots of the Korono and Elsanta strawberry varieties. Ferreira et al. (2019) reported in their study on 5 strawberry varieties that the salt did not affect the Na^+ concentration in the leaves of all varieties, but it affected both the roots and petioles, depending on the variety. Rahimi and Biglarifard (2011) stated that the high Na^+ level in the roots and crowns of the Camarosa variety was due to the higher proportion of dry weight of the roots and crowns. Pirlak and Eşitken (2004) found that the accumulation of Na and Cl in the leaves of both Camarosa and Fern varieties increased with increasing salinity. Marschner (1995) reported that plants take up more Na and Cl in saline environments. Again, Pirlak and Eşitken (2004) found that increasing the NaCl concentration in the nutrient solution increased the Na and Cl concentrations in the leaves. Moreover, Na and Cl ions accumulated more in both varieties at the 5.0 mS cm^{-1} EC salt level when compared to the 2.0 mS cm^{-1} EC level.

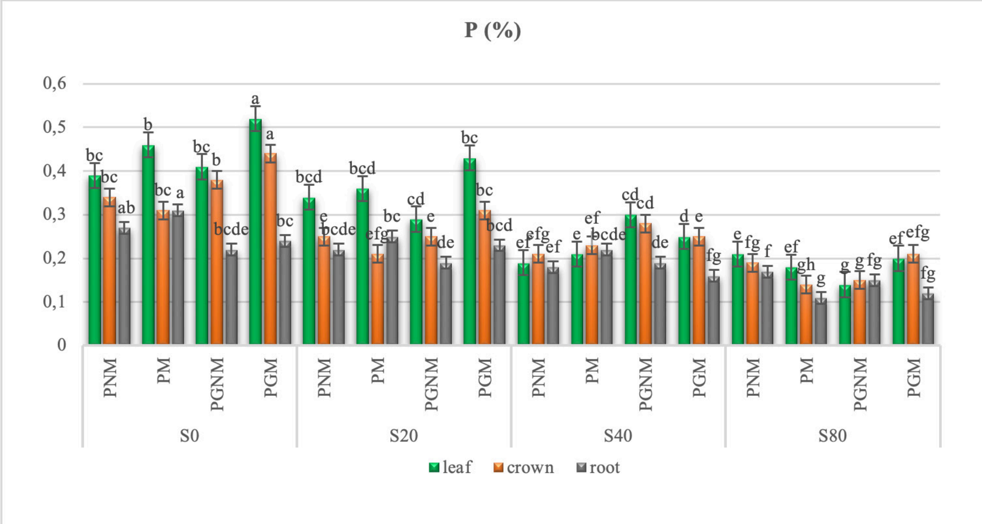

Figure 1. % P contents of the treatments

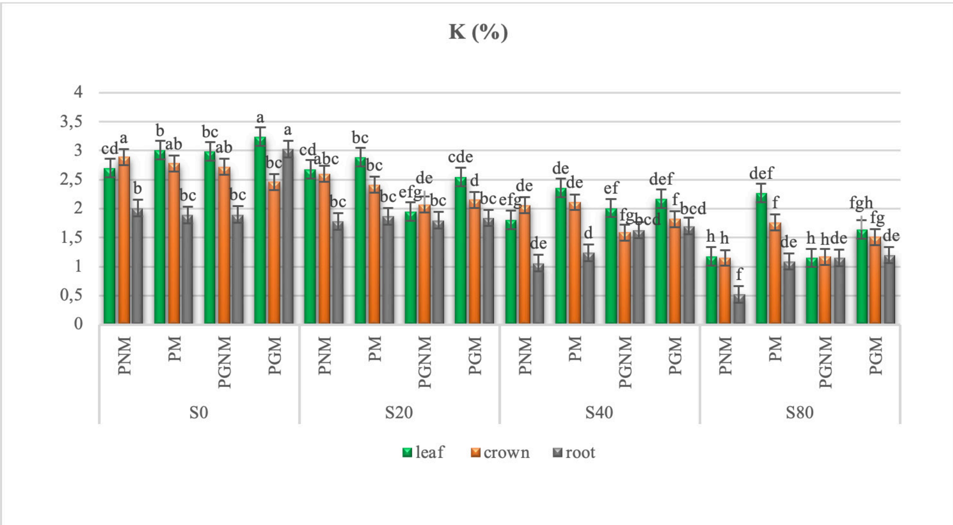

Figure 2. % K contents of the treatments

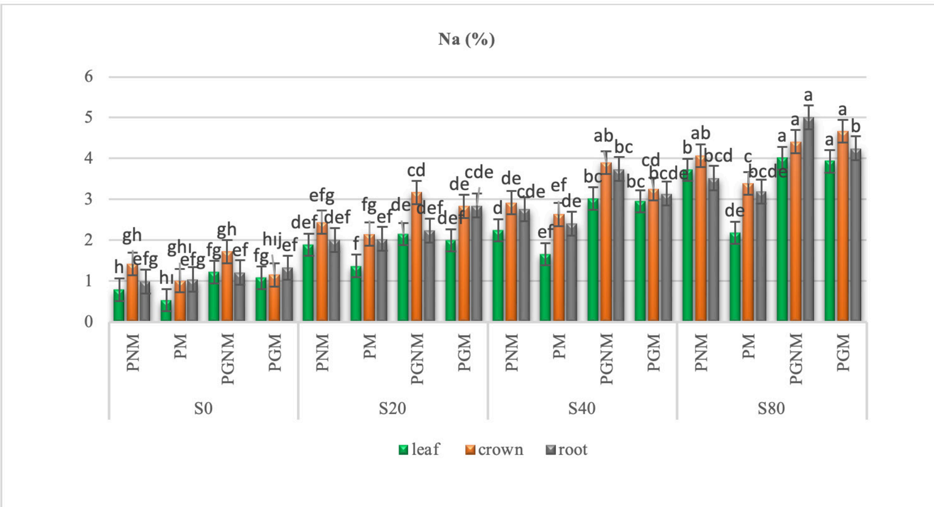

Figure 3. % Na contents of the treatments

CONCLUSION

Salinity is one of the most important factors that limit plant growth by negatively affecting soil fertility in agricultural production areas. Strawberries are among the plant species with the highest sensitivity to salt. In this study, it was determined that the application of mycorrhiza significantly affected the growth and development parameters of the Monterey strawberry variety under salt-stress conditions. It was concluded that the accumulation of Na^+ ions in the roots, crowns, and leaves should be considered in the resistance of strawberry plants under salty conditions. In the present study, it was observed that all values except the amount of Na decreased as salinity increased in all applications.

In conclusion, the use of mycorrhizal strains under stress conditions such as salinity had a significant effect on vegetative and generative growth in the Monterey strawberry variety. It was found that the use of mycorrhizal strains in strawberry cultivation significantly increased plant growth and development. Accordingly, it can be stated that the use of mycorrhizae to promote plant growth has more positive effects and is more beneficial to use in practice. In addition, it is important to determine the most suitable combinations by carrying out such studies on different varieties and species with different mycorrhizal strains, which will provide a source for field studies to be carried out in the future.

COMPLIANCE WITH ETHICAL STANDARDS

Peer-review

Externally peer-reviewed.

Conflict of interest

The authors declare that they have no competing, actual, potential or perceived conflict of interest.

Author contribution

Emrah BAĞ: Investigation, Project administration, Writing, Funding acquisition; Beril KOCAMAN: Supervisor, Editing.

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