Selcuk Journal of Agriculture and Food Sciences

https://dergipark.org.tr/tr/pub/selcukjafsci

Research Article

(2023) 37(2), 326-336 DOI:10.15316/SJAFS.2023.032 e-ISSN: 2458-8377 Selcuk J Agr Food Sci

The Effect of Mycorrhiza Applications on Growth and Yield in Some Strawberry Cultivars under Calcareous Soil Conditions

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HIGHLIGHTS

- *Glomus clorodum* alone and in combination, increases stem and root fresh weight.
- *Glomus etunicatum* + *Glomus clorodum* and *Glomus deserticola* + *Glomus etunicatum* applications had the best results.
- *Glomus etunicatum* and *Glomus clorodum* can be used to promote plant growth in strawberry calcareous soil conditions.

Abstract

This study was conducted in the research and practices of greenhouses at the University of Selçuk, Faculty of Agriculture and Horticulture Department. The effects of three different mycorrhiza species and combinations of strawberry plants on plant growth and nutrition were investigated in three different strawberries cultivars. According to the results, it was determined that *Glomus chlorodum* mycorrhiza alone and in combination increased stem fresh and root fresh weights, leaf relative water content, number of stems, and number of leaves compared to control plants. However, no significant changes could be obtained with mycorrhizal applications on membrane permeability and chlorophyll values in all strawberry varieties used. Nutrient analysis of nitrogen, magnesium, iron, manganese, and boron in the leaves of the application of mycorrhiza with significant increases has been achieved. *Glomus etunicatum* + *Glomus chlorodum* and *Glomus deserticola* + *Glomus etunicatum* applications had the best results. As a result of this study, it can be suggested that *Glomus etunicatum* and *Glomus chlorodum* can be used to promote plant growth in strawberry calcareous soil conditions.

Keywords: Calcareous; *Glomus* spp. Mycorrhiza; Plant Growth; Strawberry

1. Introduction

Strawberries are the most widely cultivated type of berry-like fruit. Due to their high adaptability to different climates and soil conditions, their cultivation has rapidly increased in our country (Paydaş and Kaşka 1989). Additionally, the suitability of strawberries for greenhouse and tunnel cultivation is an important factor in this growth. Alongside the rapid expansion of production areas, strawberry growers are increasingly facing problems. The most significant issues affecting strawberry cultivation in Turkey are alkaline and saline soils, as well as diseases and pests. As a result, stunted plant growth and reduced yields are the most commonly

Citation: Arıkan Ş, İpek M, Lütfi P, Eşitken A, Şahin M (2023). The Effect of Mycorrhiza Applications on Growth and Yield in Some Strawberry Cultivars under Calcareous Soil Conditions. *Selcuk Journal of Agriculture and Food Sciences*, 37(2), 326-336. https://doi.org/10.15316/SJAFS.2023.032

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Received date: 09/12/2022
Accepted date: 14/05/2023

encountered problems. A large portion of Turkish soils have formed under arid-semiarid climatic conditions and consist of alkaline soils with high pH levels. The most prominent issue resulting from the high lime content in the soil is leaf chlorosis. Therefore, iron deficiency is one of the most frequently encountered micronutrient deficiencies in our country. Lime-induced chlorosis is a term often used to describe chlorosis associated with impaired iron metabolism in soils with high calcium content (Faust 1989). While fruit species, in general, are quite sensitive to high lime content in the soil, strawberries, peaches, and pears exhibit an even greater sensitivity. As a result, significant yield losses occur in such areas due to ineffective photosynthesis. Rectifying iron deficiency is more challenging compared to other micronutrients. Currently, synthetic iron chelates are widely used commercially to prevent and alleviate lime-induced iron chlorosis in fruit trees. However, these applications are costly and have temporary effects, and the effectiveness of iron treatments can be low. This is because there are many factors that influence the availability of iron to plants. Obtaining positive results from every iron fertilization is not always possible. As a result, growers are compelled to implement an intensive fertilization program to solve the problem, leading to a significant increase in input costs.

Strawberries hold an important position among fruit species cultivated worldwide. In fact, they ranked 13th among the most produced fruits, with a production of 9.175.384 tons in 2021 (FAO 2023). Moreover, Turkey is the third-largest strawberry producer in the world, with a production of 669.195 tons. The major strawberry production in our country takes place in the provinces of Mersin, İzmir, Şanlıurfa, Aydın, and Çanakkale accounting for approximately 84% of our total production (TUIK 2023). However, in regions such as Central Anatolia where the soil is not suitable for strawberry production, cultivation can only be carried out in limited areas. Due to the delicate nature of strawberry fruits and their limited shelf life, production should ideally be conducted in proximity to the target markets (Suutarinen et al. 1998; Zhu and Zhou 2007). Nevertheless, economic strawberry production is not feasible everywhere due to varying soil and climate conditions.

Mycorrhizal fungi positively influence plant development and fruit yield by enhancing nutrient uptake in the plants they colonize (Marschner 1995; Bayözen 2007). Due to these benefits, profitable strawberry production can be achieved through mycorrhizal applications in calcareous and nutrient-deficient soils. Mycorrhizal fungi affect the uptake of water and dissolved minerals in inoculated plants, suppress soil-borne pathogens, reduce damage caused by diseases, positively influence plant root structure and chemistry, and increase yield and quality, providing opportunities for cultivation in challenging soil conditions. *Glomus deserticola*, *Glomus etunicatum*, and *Glomus chlorodum* are species of arbuscular mycorrhizal (AM) fungi that have been extensively studied for their positive effects on plant growth and development. These fungi form mutualistic symbiotic associations with the roots of various plant species, providing numerous benefits that contribute to enhanced plant performance. The use of these mycorrhizal species in agriculture and horticulture practices has gained considerable attention. Their ability to enhance nutrient uptake, improve plant resistance to environmental stresses, and promote sustainable farming methods makes them valuable tools for improving crop productivity and reducing reliance on chemical fertilizers. Further research is ongoing to better understand the mechanisms underlying their beneficial effects and optimize their application in various agricultural systems. Based on these considerations, this study aims to investigate the effects of three different mycorrhizal species (*G. deserticola, G. etunicatum,* and *G. chlorodum*) applied alone or in combination on plant characteristics and nutrient uptake in three strawberry varieties (Camorasa, Kabarla, and Rubygen) under calcareous soil conditions.

2. Materials and Methods

The research was conducted at the Research and Application Greenhouse of the Department of Horticulture, Faculty of Agriculture, Selçuk University. Three different strawberry varieties (Camorasa,

Kabarla, and Rubygem) propagated under *in vitro* conditions were used as plant materials in the experiment. Camorasa and Rubygem varieties exhibit short-day characteristics, while Kabarla strawberry varieties show a neutral-day response. The mycorrhizal strains *G. deserticola*, *G. etunicatum*, and *G. chlorodum* were employed in the study, both individually and in combination.

Glomus deserticola is known for its ability to thrive in arid and semiarid environments. This species of AM fungus has been found to improve plant growth under drought conditions by enhancing the plant's water uptake and drought tolerance. Additionally, *G. deserticola* aids in the absorption of phosphorus, which is often limited in dry soils, thereby improving nutrient acquisition and overall plant health (Ruiz-Lozano et al. 1995; Prisa 2021). *Glomus etunicatum* is one of the most widely studied AM fungi and has been shown to have beneficial effects on plant growth and nutrient uptake. It also contributes to improved resistance against various stresses, including drought, salinity, and heavy metal toxicity. Additionally, *G. etunicatum* has been reported to stimulate root development and enhance the production of plant growth-promoting hormones, further supporting plant growth and development (Ruiz-Lozano et al. 1995). *Glomus chlorodum* is another species of AM fungus that plays a significant role in plant growth and development. It forms symbiotic associations with plant roots, leading to improved nutrient uptake, particularly phosphorus. *G. chlorodum* has been found to enhance the plant's tolerance to abiotic stresses, such as drought and salinity, by improving water and nutrient availability. This species also aids in the establishment and maintenance of healthy soil microbial communities, contributing to overall soil fertility and ecosystem functioning (Bhattacharjya et al. 2018).

2.1. Propagation of Plant Material

In the study, stolons from strawberry varieties were collected and subjected to *in vitro* clonal propagation through shoot tip culture under sterile conditions. After surface sterilization of the stolons, the MS (Murashige and Skoog 1962) medium was used as the basal nutrient medium in the tissue culture multiplication stage, supplemented with %3 sucrose, 1 mg l^{-1} BA, and 7 g l^{-1} agar to adjust the pH to 5.78. The obtained plantlets in the multiplication medium were transferred to MS nutrient medium containing 1 mg l^{-1} IBA for the rooting stage. The strawberry seedlings propagated under *in vitro* conditions were transferred to a medium containing peat and perlite in a 1:1 ratio to facilitate their adaptation to the external environment. After 45-60 days, the strawberry seedlings were ready for the planned study.

2.2. Application of Mycorrhizal Inoculation

Mycorrhizal inoculations were carried out by sprinkling an amount equivalent to 500 spores per plant, with half of the inoculum spread throughout the potting soil and the remaining half placed 4 cm below the soil surface in the pot (Altay 2017). This approach aimed to ensure dense mycorrhizal colonization both during the initial stages of seedling root development and in the later stages. The applied treatments in the experiment are as follows:

- Control
- *Glomus deserticola*
- *Glomus etunicatum*
- *Glomus chlorodum*
- *G. deserticola* + *G. etunicatum*
- *G. deserticola* + *G. chlorodum*
- *G. etunicatum* + *G. chlorodum*
- *G. deserticola* + *G. etunicatum* + *G. chlorodum*

2.3. Experimental Design

The experiment was set up according to a randomized complete block design with 3 replications, and each replication consisted of 5 plants. A mixture of soil, sand, and perlite in a ratio of 3:1:1 was used as the growing medium. The plants were planted in 5-liter pots. After the planting in mid-April, regular watering, weed control, and removal of flowers and side shoots until they reached sufficient size were carried out. Morphological measurements such as stem and root fresh weights, root length, leaf area, leaf number, and number of stem (Ipek et al. 2014), as well as physiological measurements including membrane permeability, leaf relative water content, chlorophyll value (Karlıdag et al. 2011), and nutrient element analysis in the leaves, were conducted in the experiment. Micro-Kjeldahl in N determination, vanado molybdic yellow color method in P analysis, Mohr's method in Cl analysis, and other nutrient elements (K, Ca, Mg, Mn, Fe, Zn, Cu, B, and Na) analyses were made using an ICP device (Soltanpour et al. 1979).

2.4. Statistical Analysis

The Duncan multiple comparison test was applied at a 5% significance level to compare the obtained data. The SPSS 23.0 program was used for statistical analysis.

3. Results and Discussion

Lime-rich soils are among the significant factors that limit strawberry cultivation. Plant species sensitive to alkalinity, such as strawberries, cannot be grown in soils with a high lime content. To address this issue, mycorrhizal applications, which enhance the uptake of plant nutrients from the soil, can provide a significant contribution to strawberry cultivation in these types of soils. When examining our results, it was determined that mycorrhizal applications to all varieties of strawberries under lime conditions significantly contributed to plant development.

Upon examining the stem and root fresh weights, the applications of *G. chlorodum* (32.41g), *G. etunicatum* + *G. chlorodum* (31.60g), and *G. deserticola* + *G. etunicatum* (29.68g) in the Rubygem strawberry variety, and the application of *G. deserticola* + *G. chlorodum* (29.42g) in the Kabarla strawberry variety yielded the best results in stem fresh weight compared to the control group (Table 1). In terms of root fresh weights, the highest increase was observed in the Rubygem strawberry variety with the applications of *G. etunicatum* + *G. chlorodum* (33.71g), *G. deserticola* + *G. etunicatum* + *G. chlorodum* (33.49g), and *G. deserticola* + *G. etunicatum* (32.86g). In the Camarosa strawberry variety, the highest increase was achieved with the application of *G. chlorodum* (38.05g). The application of *G. deserticola* + *G. etunicatum* + *G. chlorodum* in the Kabarla strawberry variety resulted in the highest number of stems (4.67 pcs per plant^{-1}) (Table 1). This was followed by the application of *G. etunicatum* + *G. chlorodum* (4.33 pcs per plant^{-1}) in the Rubygem strawberry variety and *G. chlorodum* (4.00 pcs per plant^{-1}) in the Camarosa strawberry variety. Similar studies to ours have also indicated the positive effects of mycorrhizal applications on plant growth under stress conditions. Abbaspour et al. (2006), Sinclair et al. (2014), and Elhindi et al. (2017) found that mycorrhizal applications in pistachio, strawberry, and sweet basil, respectively, were beneficial for plant growth under saline soil conditions. When examining the effects of mycorrhizal applications on leaf number, the application of *G. deserticola* + *G. chlorodum* provided the best results in terms of leaf number in the Kabarla (115.7 pcs per plant^{-1}) and Rubygem (100.7 pcs per plant^{-1}) varieties compared to other applications. Mycorrhizal fungi significantly enhance plant root and shoot development, fruit yield, and quality by increasing the uptake of water and dissolved nutrients from the soil. Studies conducted on different plant species and varieties such as peppers, eggplants, tomatoes, carrots, corn, apple-cherry-citrus rootstocks, citrus fruits, strawberries, and pomegranates support this (Araujo et al. 1997; Aguilera-Gomez et al. 1999; Kim et al. 2002; Ortas et al. 2003; Özkan et al. 2003; Ortaş et al. 2006; Ertan et al. 2007; Uçgun et al. 2009; Almaca et al. 2010; Akpınar 2011; Akay and Karaaslan 2012; Kiracı et al. 2014). According to the results obtained from leaf area measurements of plants, the application of *G. etunicatum* + *G. chlorodum* increased leaf area by 90.2% in the Camarosa strawberry variety compared to the control group, while in the Rubygem strawberry variety, the application of *G. chlorodum* increased leaf area by 58.3%, and the

application of *G. deserticola* + *G. chlorodum* increased leaf area by 52.7% compared to the control group (Table 1). A study reported positive results of mycorrhizal applications in pistachio plants grown under drought conditions (Abbaspour et al. 2012). In our study, it was found that the application of *G. chlorodum* mycorrhizal strains, either alone or in combination, increased stem and root fresh weights, sibling plant count, and leaf count compared to the control plants. Mycorrhizal application in carob trees grown in lime-rich soil conditions has been reported to result in significant increases in parameters such as shoot length, root collar diameter, leaf count, and leaf area (Davis et al. 1983).

Table 1. Effects of mycorrhizal applications on plant vegetative growth

Treatment	Variety	Stem Fresh Weights (g)	Root Fresh Weights (g)	Root Length (cm)	Number of Stems (per plant^{-1})	Leaf Area (cm^2)	Leaf Number (per plant^{-1})
Control	Camarosa	25.24 cdef	23.26 efgh	38.67 bcd	2.67 efg	31.14 m	57.0 n
Control	Kabarla	18.89 hıjk	25.45 def	31.67 ghı	3.00 def	47.07 de	65.0 l
Control	Rubygem	13.81 l	19.11 ghı	44.33 a	2.33 fg	36.53 k	46.0 r
G. deserticola	Camarosa	19.93 ghıj	21.25 fghı	34.33 efg	2.67 efg	43.93 g	54.0 o
G. deserticola	Kabarla	15.99 ıjkl	18.65 hı	28.67 ı	3.00 def	36.71 k	50.0 p
G. deserticola	Rubygem	27.13 bcd	27.24 de	29.33 ı	2.00 g	48.40 d	94.0 d
G. etunicatum	Camarosa	24.48 defg	26.44 def	34.67 efg	2.00 g	40.06 ıj	81.0 g
G. etunicatum	Kabarla	25.45 cdef	24.26 defg	32.00 ghı	2.67 efg	37.27 k	76.0 hı
G. etunicatum	Rubygem	23.86 defg	28.29 cde	28.67 ı	3.00 def	41.16 hı	60.0 m
G. chlorodum	Camarosa	26.30 cde	38.05 a	33.33 fgh	4.00 abc	45.72 ef	45.0 r
G. chlorodum	Kabarla	13.33 l	23.35 efgh	35.00 efg	2.00 g	34.79 l	91.0 e
G. chlorodum	Rubygem	32.41 a	29.82 bcd	33.33 fgh	3.33 cde	57.84 a	83.0 g
G. deserticola + *G. etunicatum*	Camarosa	24.48 defg	21.23 fghı	40.00 bc	3.33 cde	43.31 h	58.0 mn
G. deserticola + *G. etunicatum*	Kabarla	22.01 efgh	18.23 hı	29.00 ı	2.33 fg	34.04 l	64.0 l
G. deserticola + *G. etunicatum*	Rubygem	29.68 abc	32.86 abc	33.33 fgh	2.67 efg	41.09 ıj	74.0 ıj
G. deserticola + *G. chlorodum*	Camarosa	22.42 defgh	26.60 def	33.33 fgh	3.67 bcd	51.29 c	98.0 c
G. deserticola + *G. chlorodum*	Kabarla	29.42 abc	25.63 def	30.00 hı	3.00 def	35.28 l	100.7 b
G. deserticola + *G. chlorodum*	Rubygem	25.56 cdef	26.08 def	40.33 bc	2.33 fg	55.80 b	115.7 a
G. etunicatum + *G. chlorodum*	Camarosa	20.23 ghı	26.03 def	37.67 cde	2.33 fg	59.25 a	68.3 k
G. etunicatum + *G. chlorodum*	Kabarla	15.26 jkl	15.97 ı	36.33 def	3.00 def	34.17 l	72.0 j
G. etunicatum + *G. chlorodum*	Rubygem	31.60 ab	33.71 ab	42.00 ab	4.33 ab	44.51 fg	78.0 h
G. deserticola + *G. etunicatum* + *G. chlorodum*	Camarosa	19.93 ghıj	18.36 hı	34.33 efg	2.67 efg	48.40 d	86.0 f
G. deserticola + *G. etunicatum* + *G. chlorodum*	Kabarla	20.85 fgh	25.34 def	30.00 hı	4.67 a	39.64 j	69.0 k
G. deserticola + *G. etunicatum* + *G. chlorodum*	Rubygem	14.46 kl	33.49 abc	37.00 cdef	3.67 bcd	48.37 d	51.0 p

Mycorrhizal applications in strawberries under lime-rich soil conditions significantly influenced the leaf relative water content (LRWC) statistically. The lowest LRWC value was obtained from the leaves of plants in the *G. deserticola* + *G. chlorodum* treatment (39.42%) in the Camarosa strawberry variety, while the highest LRWC value was obtained from the *G. deserticola* + *G. etunicatum* + *G. chlorodum* treatment (58.50%) in the Rubygem strawberry variety. The LRWC values in the Kabarla strawberry variety fell within these ranges. Membrane permeability values showed variations among strawberry varieties depending on the applied mycorrhizal strains and combinations (Table 2). The lowest membrane damage was observed in the *G.*

etunicatum treatment (13.84%) in the Camarosa strawberry variety, while the highest membrane damage was observed in the *G. chlorodum* treatment (21.83%) in the Rubygem strawberry variety. In the Kabarla strawberry variety, the *G. etunicatum* treatment (16.40%) resulted in less membrane damage compared to the other treatments. When examining the effects of mycorrhizal applications on the chlorophyll value in strawberry leaves, the highest value was found in the control group of the Kabarla strawberry variety (40.00 SPAD). The *G. etunicatum* + *G. chlorodum* and *G. deserticola* + *G. etunicatum* + *G. chlorodum* treatments resulted in significant increases in leaf LRWC compared to the control plants (Table 2). Similarly, in their study, Davies et al. (2002) reported positive results of mycorrhizal applications on leaf water potential in pepper plants grown under drought conditions. Another study conducted on peppers also indicated that *G. intraradices* inoculation increased the plants' phosphorus content and positively affected their physiological performance (Demir 2004).

Table 2. Effects of mycorrhiza treatments on physiological parameters in strawberry

Treatment	Variety	Membrane Permeability (%)	LRWC (%)	Chlorophyll Value (SPAD)
Control	Camarosa	18.61 de	40.04 mn	32.56 ef
Control	Kabarla	17.32 efg	56.39 bc	40.00 a
Control	Rubygem	17.53 efg	50.30 fg	36.52 bc
G. deserticola	Camarosa	17.22 fgh	49.83 gh	24.96 m
G. deserticola	Kabarla	16.99 fgh	57.21 bc	30.04 hı
G. deserticola	Rubygem	15.49 ı	51.07 e	35.32 c
G. etunicatum	Camarosa	13.84 j	46.47 j	31.38 fg
G. etunicatum	Kabarla	16.40 hı	42.27 l	36.34 bc
G. etunicatum	Rubygem	18.97 de	40.58 m	26.96 l
G. chlorodum	Camarosa	17.87 ef	52.88 d	26.10 l
G. chlorodum	Kabarla	20.36 bc	46.06 j	29.12 ıj
G. chlorodum	Rubygem	21.83 a	40.03 mn	26.72 l
G. deserticola + *G. etunicatum*	Camarosa	16.93 fgh	49.35 hı	27.14 l
G. deserticola + *G. etunicatum*	Kabarla	17.48 efg	53.43 d	23.32 n
G. deserticola + *G. etunicatum*	Rubygem	17.07 fgh	43.60 k	34.48 d
G. deserticola + *G. chlorodum*	Camarosa	19.51 cd	39.42 n	32.94 de
G. deserticola + *G. chlorodum*	Kabarla	21.65 ab	48.71 ı	28.28 jk
G. deserticola + *G. chlorodum*	Rubygem	18.11 ef	57.29 b	29.04 ıjk
G. etunicatum + *G. chlorodum*	Camarosa	16.50 ghı	49.36 ghı	31.14 gh
G. etunicatum + *G. chlorodum*	Kabarla	16.86 fghı	50.69 ef	27.96 k
G. etunicatum + *G. chlorodum*	Rubygem	17.99 ef	59.56 a	35.76 bc
G. deserticola + *G. etunicatum* + *G. chlorodum*	Camarosa	17.41 efg	55.20 c	20.04 o
G. deserticola + *G. etunicatum* + *G. chlorodum*	Kabarla	19.63 cd	48.74 hı	31.90 efg
G. deserticola + *G. etunicatum* + *G. chlorodum*	Rubygem	21.71 a	58.50 a	37.34 b

The effects of the applications on the macro- and micronutrient contents were found to be statistically significant based on the results of the nutrient element analysis in the leaves. When examining the nitrogen (N) content in the leaves, the highest value was obtained from the *G. deserticola* + *G. etunicatum* + *G. chlorodum* treatment (3.07%) in the Camarosa strawberry variety. In the Rubygem strawberry variety, the *G. deserticola* + *G. chlorodum* treatment followed with a nitrogen content of 3.03%. In terms of phosphorus content, the control (2969.7 mg kg^{-1}) and *G. deserticola* + *G. etunicatum* + *G. chlorodum* (2867.3 mg kg^{-1}) treatments in the Kabarla strawberry variety had the highest values. Similarly, in the Camarosa strawberry variety, the *G. deserticola* + *G. etunicatum* + *G. chlorodum* treatment resulted in a phosphorus content of 2846.7 mg kg^{-1}. The highest potassium content was obtained from the control group (21468.0 mg kg^{-1}) in the Kabarla strawberry variety, while in the Camarosa strawberry variety, the *G. deserticola* + *G. etunicatum* + *G. chlorodum* treatment followed with a potassium content of 20780.0 mg kg^{-1}.

Table 3. The effect of mycorrhiza treatments on the macronutrient content of strawberry leaves

Treatment	Variety	N (%)	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})
Control	Camarosa	2.78 ıjk	2566.3 de	18690.3 bcde	6171.3 hıj	3307.3 bcde
Control	Kabarla	2.70 kl	2969.7 a	21468.0 a	8087.7 a	2821.7 h
Control	Rubygem	2.75 jk	2573.7 de	18272.0 bcde	6669.3 efg	2879.7 gh
G. deserticola	Camarosa	2.84 fghıj	2594.0 cde	19025.3 abcde	6181.3 hıj	3193.7 def
G. deserticola	Kabarla	2.78 ıjk	2572.3 de	18720.7 bcde	6258.3 hı	3606.7 a
G. deserticola	Rubygem	2.89 cdefg	2646.0 bcde	19013.3 abcde	6284.3 hı	3624.0 a
G. etunicatum	Camarosa	2.97 bc	2701.3 bcde	19669.0 abcde	7342.7 b	3131.0 efg
G. etunicatum	Kabarla	2.85 efghıj	2483.0 e	17544.7 cde	6071.0 ıj	3510.7 ab
G. etunicatum	Rubygem	2.89 cdefg	2729.3 bcd	19933.3 abcd	6452.3 gh	3420.7 abcd
G. chlorodum	Camarosa	2.78 ıjk	2746.0 bcd	18152.3 bcde	6207.7 hı	2982.7 fgh
G. chlorodum	Kabarla	2.86 defghı	2666.0 bcde	19244.7 abcde	6269.0 hı	3367.7 abcde
G. chlorodum	Rubygem	2.64 l	2723.0 bcd	20264.3 abc	8021.3 a	2835.3 h
G. deserticola + G. etunicatum	Camarosa	2.88 cdefgh	2724.3 bcd	19583.7 abcde	7248.7 bc	2915.3 gh
G. deserticola + G. etunicatum	Kabarla	2.94 bcde	2712.7 bcd	17346.7 de	7022.7 bcd	2803.3 hı
G. deserticola + G. etunicatum	Rubygem	2.75 jk	2721.0 bcd	18634.3 bcde	5885.7 j	3397.3 abcd
G. deserticola + G. chlorodum	Camarosa	2.80 ghıjk	2586.3 de	18464.7 bcde	6622.7 fg	2556.7 ı
G. deserticola + G. chlorodum	Kabarla	2.92 cdef	2684.7 bcde	18491.3 bcde	7215.7 bc	2919.0 gh
G. deserticola + G. chlorodum	Rubygem	3.03 ab	2815.3 abc	19913.3 abcd	7190.0 bc	3181.0 def
G. etunicatum + G. chlorodum	Camarosa	2.81 ghıj	2588.3 de	17114.3 e	6943.0 cde	2924.7 gh
G. etunicatum + G. chlorodum	Kabarla	2.79 hıjk	2604.0 cde	17318.3 de	5976.0 ıj	3200.7 cdef
G. etunicatum + G. chlorodum	Rubygem	2.84 efghıj	2750.0 bcd	19989.3 abcd	6428.0 gh	3457.7 abc
G. deserticola + G. etunicatum + G. chlorodum	Camarosa	3.07 a	2846.7 ab	20780.0 ab	7316.3 b	2732.3 hı
G. deserticola + G. etunicatum + G. chlorodum	Kabarla	2.95 bcd	2867.3 ab	19275.3 abcde	7304.7 b	2790.7 hı
G. deserticola + G. etunicatum + G. chlorodum	Rubygem	2.81 ghıj	2613.7 cde	18264.3 bcde	6854.3 def	2896.7 gh

Table 4. The effect of mycorrhiza treatments on the micronutrient content of strawberry leaves

Treatment	Variety	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})
Control	Camarosa	164.67 bcde	40.83 abcd	43.83 ab	16.77	12.76 abc
Control	Kabarla	151.00 cdef	35.33 bcd	45.79 a	15.46	12.57 abc
Control	Rubygem	136.33 efg	36.44 abcd	34.66 cde	14.72	14.52 ab
G. deserticola	Camarosa	174.00 abc	46.72 abc	43.73 ab	17.21	13.40 abc
G. deserticola	Kabarla	190.33 ab	43.94 abcd	39.76 abcde	16.63	12.96 abc
G. deserticola	Rubygem	176.00 abc	46.87 abc	41.64 abcd	16.79	12.67 abc
G. etunicatum	Camarosa	150.33 cdef	34.02 bcd	39.61 abcde	15.84	12.72 abc
G. etunicatum	Kabarla	182.00 ab	44.05 abcd	41.46 abcd	17.16	13.22 abc
G. etunicatum	Rubygem	177.67 abc	44.40 abcd	41.71 abcd	16.95	14.25 abc
G. chlorodum	Camarosa	181.00 ab	45.65 abcd	41.17 abcd	16.71	14.90 ab
G. chlorodum	Kabarla	192.67 ab	47.49 ab	43.37 ab	17.27	15.02 ab
G. chlorodum	Rubygem	138.67 defg	36.87 abcd	43.23 ab	14.80	11.98 bc
G. deserticola + G. etunicatum	Camarosa	134.67 fg	40.04 abcd	33.95 cde	15.33	12.90 abc
G. deserticola + G. etunicatum	Kabarla	144.33 defg	39.09 abcd	32.68 e	15.64	13.66 abc
G. deserticola + G. etunicatum	Rubygem	197.67 a	45.53 abcd	41.62 abcd	16.08	15.30 a
G. deserticola + G. chlorodum	Camarosa	117.00 g	33.43 cd	32.88 e	14.41	14.52 ab
G. deserticola + G. chlorodum	Kabarla	134.67 fg	38.30 abcd	33.48 de	15.67	13.09 abc
G. deserticola + G. chlorodum	Rubygem	133.00 fg	32.18 d	38.08 abcde	15.97	11.39 c
G. etunicatum + G. chlorodum	Camarosa	124.00 fg	35.06 bcd	41.92 abc	15.10	14.63 ab
G. etunicatum + G. chlorodum	Kabarla	165.67 bcd	42.87 abcd	43.73 ab	17.62	13.97 abc
G. etunicatum + G. chlorodum	Rubygem	201.00 a	49.37 a	44.27 ab	16.57	14.39 abc
G. deserticola + G. etunicatum + G. chlorodum	Camarosa	139.67 defg	38.61 abcd	35.93 bcde	15.98	13.92 abc
G. deserticola + G. etunicatum + G. chlorodum	Kabarla	124.00 fg	35.60 bcd	36.42 bcde	15.49	13.09 abc
G. deserticola + G. etunicatum + G. chlorodum	Rubygem	135.00 fg	33.63 cd	36.97 bcde	14.88	11.98 bc

Regarding calcium content in the leaves, the highest value of 8087.7 mg kg^{-1} was obtained from the control treatment in the Kabarla strawberry variety, and in the Rubygem strawberry variety, it was 8021.3 mg kg^{-1} from the *G. chlorodum* treatment (Table 3). The highest iron content of 201.00 mg kg^{-1} was obtained from the *G. etunicatum* + *G. chlorodum* treatment in the Rubygem strawberry variety. This value was followed by the *G. deserticola* + *G. etunicatum* treatment in the Rubygem strawberry variety, with an iron content of 197.67 mg kg^{-1}. The highest manganese content of 49.37 mg kg^{-1} was obtained from the *G. etunicatum* + *G. chlorodum* treatment in the Rubygem strawberry variety. There was not a significant difference in zinc content among the treatments, but the highest value was obtained from the control group (45.7937 mg kg^{-1}) in the Kabarla strawberry variety. When examining the microelement boron, the highest value was observed in the *G. deserticola* + *G. etunicatum* treatment in the Rubygem strawberry variety (Table 4). There was no statistically significant difference in copper content among the treatments. In many studies, it has been demonstrated that VAM fungi play a crucial role in nutrient uptake by plants, resulting in more efficient nutrient acquisition (Özkan et al. 2003; Korkmaz 2005; Ortaş et al. 2006; Yılmaz and Gül 2009; Özdemir et al. 2010). VAM fungi have been reported to be effective in the uptake of Zn, Cu, Mn, Fe, Ca, K, and N, in addition to playing a significant role in phosphorus uptake (Smith et al. 1992; Aguilera-Gomez et al. 1999; Davies et al. 2000).

4. Conclusions

Soil alkalinity, which is one of the significant stress factors affecting agriculture, also restricts strawberry cultivation. To be able to farm in such soils, growers resort to methods such as farm manure and chemical fertilization. However, these practices are often ineffective in soils with a high lime content. In addition to these practices, the use of certain soil-borne microorganisms (such as bacteria regulating plant growth and mycorrhizae) that enhance the uptake of nutrients and minerals like water from the soil can contribute to better plant growth under stressful conditions.

Mycorrhizae can be effective against stress factors such as drought, nutrient deficiency, and salinity due to their ability to enhance the uptake of plant nutrients and water from the soil and prevent the proliferation of soil-borne pathogens through their colonization. Taking these aspects into consideration, it is believed that mycorrhizae could have positive effects on strawberry cultivation in high lime alkaline soils.

Author Contributions: The authors have made an equal contribution. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the Scientific Research Projects Coordination Unit of S.U. under project number 16401016.

Conflicts of Interest: The authors declare no conflicts of interest.

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