Journal of Plant Process and Function, Vol. 13, No. 61, Year 2024 **page: 15-33**
https://doi.org/10.22034/13.61.15

Research Article

Pistachio waste compost and mycorrhiza effect on nutrient concentrations and pistachio leaves development (*Pistacia vera* L.)

Mehrnoush Eskandari Torbaghan[1*] and Abdolhamid Sherafati[2]

[1] Instructor, Soil and Water Department, Khorasan Razavi Agricultural and Natural Resources Research and Education Center, AREEO, Mashhad, Iran
[2] Instructor, Horticulture Crops Research Department, Khorasan Razavi Agricultural and Natural Resources Research and Education Center, AREEO, Mashhad, Iran
(Received: 2023/06/10-Accepted: 2023/09/19)

Abstract

No study has been reported on the effect of organic and biological fertilizers on the leaf type and development of pistachio leaflets until now. A four-year field experiment was carried out to evaluate the pistachio leaflet development via nutritional status by pistachio waste compost (0, 10, 15 kg seedling^{-1}) and mycorrhizal fungi (0, 100, 200 g seedling^{-1}) consumption on two different pistachio salt-tolerant cultivars (Akbari and Badami Zarand) grown in saline-alkaline soil. Calcium, iron, manganese, and biological nitrogen fixation by free-living diazotrophs were affected by the factor 'year'. The Akbari cultivar had the highest leaf area (428.4 cm^2) and micronutrient concentration. Akbari and Badami Zarand absorbed more micro and macronutrients, respectively. Leaves developed abnormally due to the high micronutrient concentration and larger leaf area. The pistachio waste compost had a greater impact on the nitrogen, iron, zinc, and manganese concentrations. Iron and zinc were only adequately supplied at the third level of the mycorrhizal fungus. Phosphorus, calcium, iron and manganese absorption in both levels fungi usage were affected by mycorrhizal dependency. Mycorrhizal dependency displayed a high positive effect on the number of 4 (41.8%) and 5 (40.6%) leaflets (developed leaves) in the 100g fungus application which was probably due to enhanced cellular differentiation in pistachio leaves. The leaf area and the number of leaflets were inversely related to each other. Alternatively, Badami Zarand which absorbed fewer micronutrients reduced the leaf area due to nutrient stress and produced 57.8% more normal leaves as a stress remedy. The seedlings of pistachio made less effort to develop normal leaves when their nutrition status was more appropriate.

Keywords: Leaf development, Leaflet number, Mycorrhizal dependency, Nutrient sufficiency ranges, Salinity and alkalinity stress

Introduction

The global harvested area of pistachios was 1,033,646 ha, and the total yield was 1,008,800 tons in 2020/2021. The Iranian share of fertile pistachio plantings was 411,432 ha (about 39%) and the total yield was 337,381 tons (Shahbandeh, 2021). Almost all pistachio orchards are mainly located in arid and semi-arid regions in Iran and have serious limitations such as water stress, soil and water salinity and alkalinity, nutrient uptake loss, and a low population of microorganisms and soil organic matter (Mehrnejad and Javanshah, 2010).

Thousands of tons of organic waste are produced by hundreds of pistachio processing factories. These wastes make up about 40% of the pistachio fresh weight harvested from the pistachio orchards (Sherafati *et al.*, 2013). If these wastes are not used properly, they can pollute the environment. Pistachio waste chemical analysis showed that it consists of about 11% protein, 15% fiber, 12% ash, and 33% dry matter, which are just some of the components (Forough Ameri, 1997). However, in recent years, the application of pistachio waste has been associated with serious concerns because of its high phenolic compounds, which destroyed soil aggregates (similar to that observed in sodic soils), and the unsuitable effect on the soil microbial community, especially bacteria (Mohajeryfar *et al.*, 2020).

Mycorrhizal fungi can enhance the tolerance of plants under salinity stress (Klinsukon *et al.*, 2021). Many primary non-living factors affect the distribution and abundance of Arbuscular mycorrhiza, for example, moderate salinity increases the percentage of

*Corresponding Author, Email: mehrnoosh.eskandary@gmail.com

[DOI: DOI: 10.22034/13.61.15]

colonization, but high salinity harms the percentage of mycorrhizal colonization. Root colonization percentages of pistachio were highest and lowest at 3 to 6 and 9 to 12 dS m^{-1} soil EC, respectively (Sanjari Nia *et al*., 2013). Arbuscular mycorrhizal fungi (AMF) can also operate over a wide pH range and tolerate acid stress. However, their activity decreases as soil pH increases (Sanjari Nia *et al*., 2013).

Pistachio (*Pistacia vera* L.) has compound leaves, and the number of leaflets per leaf depends on the genotype (Esmailpour, 2005) and climatic conditions, especially the chilling requirement (Hokmabadi and Javanshah, 2006). Studies have shown that the number of leaflets per leaf (1–5) varies in different years (Javanshah and Nazori, 2005; Asghari, 2002). Phenological characteristics, including leaf area and the number of normal (3 and 5 leaflets) and abnormal leaves (1, 2 and 4 leaflets), were different each year. The abnormal leaves showed a negative correlation with the average temperature of December in the early- and late-flowering varieties, and they also had a positive correlation with the average temperature of February in the middle-flowering varieties (Javanshah, 2008). This fact is probably the main reason for the plant hormone imbalance and growth retardation in the orchards of Kerman (Iran) (Lerner, 1999; Javanshah, 2008). Some researchers believe that a higher percentage of abnormal leaves is caused by a lack of chilling requirements. This means that the percentage of abnormal leaves increases in years when the chilling requirements are not met (Hokmabadi and Javanshah, 2006; Javanshah and Nazori, 2005). Neyshaburi *et al.* (2021) mentioned that the leaflet size and number can have a greater effect on the weight of pistachio fruit, and these traits can be used as a morphological marker for screening the superior pistachio genotypes. To date, there has been no report on the correlation between the number of leaflets per leaf and the concentration of leaf nutrients or other environmental factors.

This four-year research project included several innovative objectives. 1) Determining the effect of macro and micronutrient concentration on pistachio leaves development, leaf size, and evolution; 2) Revealing the correlation between soil salinity and alkalinity stress and pistachio leaf development; 3) Determining the developed leaves difference between the two different stress-tolerant cultivars in stress conditions; and 4) Investigating the effect of different factors such as mycorrhiza, pistachio waste compost usage, etc. on leaf normality and development and the compatibility of pistachios in very saline and alkaline soil and water conditions. The assessment consisted of measuring some growth characteristics, counting leaflets, analyzing micro- and macronutrients in leaves, and examining them together.

Materials and methods

Planning and implementation of the experiment: A field experiment was conducted on the seedlings of two pistachios (*Pistacia vera* L.) cultivars (Akbari and Badami Zarand). The experiment was laid out in a factorial split-plot arrangement based on a randomized complete block design (RCBD) for four years (2016–2019) with twelve replications in the Feyzabad pistachio research station of Khorasan Razavi, Iran. The research station is located at 34° 54′ 15″ N, 58° 45′ 37″ E with an altitude of 850 m. This research station was created in 1998 with an area of approximately 100 ha, and pistachio orchards have been gradually expanded. At the same time, different crops, such as cereals, were also grown, which were progressively eliminated from the production cycle due to increased soil and water salinity. Currently, approximately 20 hectares are dedicated to growing pistachios. The average rainfall, annual mean temperature, and climate type of the station are 110 mm, 19.1 ℃, and hot and dry climate, respectively. The water source used in the station is a deep well with a discharge of 30 l s^{-1}. Experimental factors include 1) two cultivars (Akbari (Ak) and Badami Zarand (Ba)) as main plots; 2) pistachio waste compost in three levels of zero, 10, and 15 kg $seedling^{-1}$ as sub-plots; 3) mycorrhizal fungi (belonging to four species, *Funneliformis mosseae*, *Rhizophahus intraradices*, *Glomus iranicus*, and *Rhizophahus irregularis* in equal proportions) in three levels of zero, 100, and 200 g $seedling^{-1}$ of soil containing fungal spores (one gram of soil containing 100 to 120 mixture propagules of four species fungi) obtained from Risheh Gostar Vira Compony as secondary sub-plots were applied in the first (Y1) and third (Y3) years of experiment. The investigated traits and factors were recorded and measured in the second (year 2=Y2) and fourth years (year 4 =Y4) of the experiment (biennial).

Land preparation and compost addition: The project implementation plan was performed on the mainland in April 2016. The distance between random experimental blocks, treatments and two adjacent seedlings in each plot was considered to be 6.0, 4.0 and 0.5 meters, respectively. Half-meter-wide and one-meter deep pits were dug at the planting site to remove the hardpan and provide appropriate space for adding pistachio waste compost. Chemical characteristics and nutrients in pistachio waste and compost are shown in the table (1) (Haydari, 2014). In the process of converting pistachio waste into compost (Table 1), the electrical conductivity (EC), organic matter content (OM%), as well as macronutrient concentration, have decreased, while the concentration of micronutrients (except copper) has increased significantly due to differences in the dynamic of elements in the composting process (Haydari, 2014). Some modeling studies of organic matter dynamics during the composting process have shown that the initial soluble fraction could contain some degradable and recalcitrant elements that are not easily accessible experimentally (Zhang *et al.*, 2012; 2014). This compost consisted of about 10–15% loamy-textured soil, 40% cow manure, and 45% pistachio waste, including 36% hull, 7%

[DOI: DOI: 10.22034/13.61.15]

Table 1. Comparison of some chemical characteristics and nutrients in the waste of pistachio processing with pistachio waste compost

Parameter	EC	pH	N	P	K	Ca^{+2}	Mg^{+2}	Na^{+}	Fe	Zn	Mn	Cu	OM	C/N
Unit	dS m^{-1}	-	%						mg kg^{-1}				%	-
[1]PW	7.8	6.3	1.2	0.33	2.4	0.8	0.32	0.33	250	12	29	33	44.8	21.6
[2]PWC	3.6	7.1	1.0	0.2	1.1	2.8	1.2	0.5	2215	24.5	385	11.7	9.2	5.33

[1]PW= Pistachio processing waste, [2]PWC= Pistachio waste compost

pistachio cluster wood, and 2.7% leaf. After complete mixing, these compounds accumulated approximately 170 cm high. Compost aeration was performed when the bed floor temperature reached about 70 ˚C. Aeration was performed three times until the bed temperature remained constant at about 25 ˚C. Then the compost was ready for use.

Two tolerant cultivars (Akbari and Badami Zarand) were selected based on the previous studies (Hokmabadi and Sherafati, 2015; Mohammadi Mohammad Abadi, 1998; Moein rad, 2000). Seedling cultivation was done indirectly on the mainland. To prepare pistachio seeds, they were immersed in water for 72 hours. Then, they were kept in cotton wool for one week at room temperature. Immediately at the onset of germination, they were planted in 45 cm (H) × 10 cm (W) plastic growth bags on March 5, 2016. The plastic growth bags were filled with sand, and the seedlings were irrigated with an average of water 3.6 dSm^{-1} EC before transferring to the mainland. Two months later, when the seedlings were about 15 cm high, they were transferred to the mainland. Before transplanting the seedlings from the plastic bags into the soil, pistachio waste compost (according to the implementation plan) was added to the soil to prevent soil subsidence from irrigation and root damage during planting. Then irrigation was performed once. The compost dosages used were chosen based on soil organic matter at the beginning of the experiment, reaching 0.5% in the volume of the rhizosphere. The pits were filled with different amounts of compost (0, 10 and 15 kg seed $ling^{-1}$) and remained soil.

Mycorrhizal inoculation and planting: After land preparation and compost addition, pits with 30 cm depth were dug again. Then mycorrhizal fungi doses were inoculated below the roots at this depth (30cm) (Shool *et al.*, 2014). Seedlings with 15 cm height and two months' age for both cultivars were planted in mid-May 2016. Due to the high salinity of water (12.2 dS m^{-1}) in the first year (Y1) of the experiment, the seedlings were irrigated with low water salinity about 4 dS m^{-1} by a pan to prevent seedling leaves from the damage of high water EC as the seedlings were very small and sensitive at the first time period. Pistachio waste compost addition and mycorrhizal inoculation were repeated in the third year (Y3) of the experiment. Further compost and mycorrhizae treatments were added, with pits 60 cm deep and 50 cm wide on one side of the seedlings.

Crop management: From the second year (Y2), the irrigation schedule was adjusted to a 15-day irrigation interval during the growing season (Hosseini fard *et al.*, 2017) with saline and alkaline water (Table 2). Spraying against pistachio psylla (*Agonoscena pistaciae*) was done as needed in the middle of the growing season (July) once a year. Spraying was carried out by the engine-powered hydraulic sprayer with a herbal composition (coconut vegetable oil extract) with the trading name "Palizin" (Kimia Sabz Avar Company) at a rate of 0.2% v/v. Weed control was done twice a year at the beginning of the growing season (May) and late growing season (October) by hand. No chemical fertilizers or organic manures were used to avoid interference with the treatment with mycorrhizal fertilizer and pistachio waste compost during the experiment.

Climate parameters measurement and assessment in four years of experiment: This study was conducted in 2016 on the mainland. The desired traits were recorded in 2017 (Y2) and then in 2019 (Y4). According to the data in Table 3, two important climatic parameters, including rainfall and temperature, have been completely variable in the years of this study. In the second year of implementation (2017), the amount of rainfall was 100.4 mm, while in the fourth year (2019), it was 214.1 mm. This means that the amount of rainfall in the fourth year (Y4) increased by more than 114% compared to the second year (Y2).

In the experimental years, there was a reduction trend in the average annual temperature (Table 3). It decreased to 20.15 and 19.46 ˚C in the second and fourth years of the experiment, respectively. Also, the suitable average temperature (25 ˚C) of the first three months of the growing season (April, May, and June), which is important for proper nutrient uptake and vegetative growth in pistachio, were equal to 25.71 and 21.86 ˚C for the second (Y2) and fourth (Y4) years of the experiment, respectively (Table 3). It should be noted that the main growth of the pistachio shoot begins in early April and continues until mid-May (Ferguson *et al.*, 2005). Shoot growth also follows root growth. Root growth begins about 2 to 6 weeks earlier than shoot growth. It reaches maximum growth in mid-April to mid-May; after that, the shoot growth begins and reaches its maximum in June. Young, white roots in the regions of elongation and maturation absorb most of the water and mineral nutrients utilized by the tree (Ryugo, 1988).

Measurement of vegetative parameters: During the second (year 2= Y2) and fourth years (year 4= Y4) of the experiment, parameters were measured since the seedlings' growth was limited due to undesirable growth conditions in the first year (Y1) of the experiment, so it

[DOI: DOI: 10.22034/13.61.15]

Table 2. Some chemical properties of the irrigation water used in the experiment

Parameter	[1]EC	pH	CO_3^{-2}	HCO_3^-	Cl^-	$(Ca+Mg)^{2+}$	Ca^{+2}	Mg^{+2}	Na^+	[2]SAR
Unit	dS m^{-1}	-	meq l^{-1}							-
Y1	12.2	7.3	0.00	3.2	91.5	40	25.6	14.4	78.6	17.6
Y4	14.1	7.5	0.00	1.8	135.5	56	36	20	85.1	16.1

Y1 = first year (2016), Y4 = fourth year (2019)
[1]EC= Electrical conductivity, [2] SAR= Sodium adsorption ratio.

Table 3. Meteorological data in the four years of project implementation (2016-2019)

Year	Average of annual temperature (℃)	The average temperature of the first three months of the growing season (℃)	Annual rainfall (mm)
Y1	20	24.06	91.02
Y2	20.15	25.71	100.4
Y3	19.13	24.63	67.3
Y4	19.46	21.86	214.1

Y1 = first year (2016), Y2=Second year (2017), Y3=Third year (2018), and Y4 = fourth year (2019)

was impossible to measure the leaf sampling. No data were also collected in the third year (Y3). Data measurements in the third year (Y3) did not allow sufficient time for the fungal treatments to become effective because the treatments (pistachio waste compost and mycorrhiza) were added again in that period. The meteorological data for four years of the experiment were also reported in Table 3. At the end of the growing season of the second (Y2) and fourth (Y4) years of the experiment, the traits, including diameter, length, and width (crown), of seedlings were recorded. The diameter was measured at 10 cm above the soil surface with a caliper. About 30 leaves were harvested from the middle of the annual growth branches in mid-August to calculate leaf area and nutrient concentrations. The number of normal (3 and 5 leaflets) and abnormal (1, 2 and 4 leaflets) leaves was counted in the 30 sampling leaves of each tree. Leaf area was measured and recorded with a leaf area meter device (LI-3100C Area Meter, USA).

Determination of macro and micronutrients in soil and plants: Soil sampling was done at the beginning and end of the experiment. The physical and chemical properties of soil have been represented in tables (4) and (5). Sampling of tree leaves was performed in August of the Y2 and Y4 years of the experiment. Leaf samples were transferred to the soil and plant analysis Laboratory at the Khorasan Razavi Agriculture and Natural Resources Research and Education Center to measure the concentration of nutrients including nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), manganese (Mn), iron (Fe), and zinc (Zn). Leaf nitrogen was measured by the Kjeldahl method (Kalra, 1998). Leaf samples were burned in the electric furnaces for P, K, Mn, Fe and Zn measurements, and then they were prepared by the wet digestion method with hydrochloric acid for nutrient analysis (Ryan *et al.*, 2001). Phosphorus was determined by the ammonium molybdate method using a spectrophotometer (UV/VIS spectrophotometer, WPA-S2000 model) (Ryan *et al*., 2001). A flame photometer (Jenway - PFP7) was used to determine the amount of potassium (Rahi, 2013). Other elements were read by atomic absorption spectroscopy (Perkin Elmer, 2380 model).

The elemental composition of water was measured by the soil and water lab of the Khorasan Razavi Agricultural and Natural Resources Research Center each year (Table 2). Electrical conductivity (EC) and pH were measured by the EC and pH meter (EW-35414-00 model) (Ryan *et al*., 2001). The soluble calcium and magnesium were determined by the 0.01 normal titration method (Ryan *et al.*, 2001), soluble sodium by a Flame Photometer (JENWAY PFP 7 Model), carbonate and bicarbonate by 0.01 normal H_2SO_4 titration method (Klute, 1986), and soluble chloride by 0.01 normal $AgNO_3$ titration method (Klute, 1986). Some soil chemical properties were measured in the soil and water lab of the Khorasan Razavi Agricultural and Natural Resources Research Center (Table 4 and 5). The total neutralizing value was measured by normal titration with NaOH 1 (Klute, 1986). Other soil sample parameters were measured in the soil saturation extract (Aliehyaei and Behbahanizadeh, 1993). The methods for soil analysis were the same as previously described.

The mycorrhizal dependency (MGD) for nutrients was calculated using the following equation (Amanifar and Toghranegar, 2020).

MGD (%) = [(DW AM plants – DW NM plants) / DW AM plants] × 100

Where, MGD is mycorrhizal dependency, DW AM is the dry weight of the mycorrhizal plant and DW NM is the dry weight of the non-mycorrhizal plant.

Statistical analysis: The normality test was done by Excel before the data analysis via skewness and kurtosis measurement for each parameter (Results not shown). It showed a normal distribution. The data were statistically analyzed as a split-plot arrangement in time based on a randomized complete block design (combined analysis in RCBD) by MSTAT-C software and ANOVA tables were obtained. Then the means' comparison of data was performed by the Least Significant Difference (LSD) test (at a 5% probability level). The correlation

[DOI: DOI: 10.22034/13.61.15]

Table 4. Some soil properties at the first of experiment (2016)

Parameter	Unit	Amount		Parameter	Unit	Amount	
Depth		0-50 cm	50-100 cm	Depth		0-50 cm	50-100 cm
[1]EC	dS m^{-1}	8.9	9.1	K^+	mg kg^{-1}	172	238
pH	-	8.0	8.0	Ca^{2+}	meq l^{-1}	27.0	20.0
[2]Total neutralizing value (TNV)	%	16.7	16.2	Mg^{2+}	meq l^{-1}	19.0	10.0
[3]O.C	%	0.20	0.08	Fe^{2+}	mg kg^{-1}	2.23	2.20
Sand	%	23	41	Mn^{2+}	mg kg^{-1}	5.64	1.90
Silt	%	56	32	Zn^{2+}	mg kg^{-1}	0.44	0.48
Clay	%	21	27	Cu^{2+}	mg kg^{-1}	1.39	1.20
Soil Texture	-	silt loam	loam	Cl^-	meq l^{-1}	176.4	235.1
[4]Nt	%	0.040	0.023	Na^+	meq l^{-1}	72.9	84.1
P	mg kg^{-1}	12	14	[5]SAR	-	14.5	20.8

[1]EC= Electrical conductivity, [2] TNV is the percentage of the material that can neutralize acid expressed as the calcium carbonate equivalence (CCE) of the product, [3]O.C = Organic matter, [4] Nt= Total nitrogen, [5] SAR= Sodium adsorption ratio.

Table 5. Some soil properties at the end of experiment (2019)

Parameter	Unit	Amount		Parameter	Unit	Amount	
Depth		0-50 cm	50-100 cm	Depth		0-50 cm	50-100 cm
[1]EC	dS m^{-1}	36.0	32.7	K^+	mg kg^{-1}	321	212
pH	-	7.7	7.6	Ca^{2+}	meq l^{-1}	60.0	72.0
[2]Total neutralizing value (TNV)*	%	17.4	17.6	Mg^{2+}	meq l^{-1}	38.0	48.0
[3]O.C	%	0.26	0.20	Fe^{2+}	mg kg^{-1}	0.32	0.32
Sand	%	19	41	Mn^{2+}	mg kg^{-1}	1.66	1.16
Silt	%	54	36	Zn^{2+}	mg kg^{-1}	1.90	2.96
Clay	%	27	23	Cu^{2+}	mg kg^{-1}	1.32	0.74
Soil Texture	-	silt loam	loam	Cl^-	meq l^{-1}	255.0	260.0
[4]Nt	%	0.023	0.025	Na^+	meq l^{-1}	242.9	192.4
P	mg kg^{-1}	4.4	17.6	[5]SAR	-	34.7	24.8

EC= Electrical conductivity, [2] TNV is the percentage of the material that can neutralize acid expressed as the calcium carbonate equivalence (CCE) of the product, [3]O.C = Organic matter, [4] Nt= Total nitrogen, [5] SAR= Sodium adsorption ratio.

coefficients were calculated by MSTAT-C software too.

Results and discussion

Year effects on nutrient absorption: The concentration of N in leaves was higher than that in the first year (Y1) (Table 6). This higher nitrogen concentration can be mainly due to the increase in biological nitrogen fixation (BNF) by free-living diazotrophs due to increased rainfall (Table 3). During this process, molecular nitrogen is converted into nitrate and provided to the plant (Taiz *et al.*, 2014). Also, the reduction of temperature (Table 3) increased nitrogen accumulation in the plant (Table 7). The plant cannot utilize most of the absorbed nutrients at lower temperatures due to a reduction in metabolism and photosynthesis, resulting in an increase in their concentration in the shoots and roots (Hokmabadi *et al.*, 2015), as seen in the fourth year (Y4). It can be mentioned in Tables 4 and 5, the soil carbonic acid concentration increased due to rainfall doubling (+114%) (Table 3) and rising soil moisture. H_2CO_3 is a weak acid that affects the adsorbed calcium of soil particles and releases and activates a large amount of calcium from the soil (Arya and Khan, 2020). Maybe this can be the main reason for the significant difference in the leaf calcium concentration increase between the fourth year (Y4) (1.662%) and the first year (Y1) (1.499%) (Table 7). In addition, Ca and P have antagonistic interaction effects in soil (Mulder, 1954). Also, the primary soil calcium concentration was high (Tables 4 and 5), and the availability of calcium released into the soil increased by the calcium rising, so a large part of it led to the fixation of phosphorus as calcium phosphate and therefore reduced phosphorus uptake (Table 7). Among the macronutrients, only, the potassium concentration did not differ significantly in both years (Y1 and Y4) (Table 7). According to Mengel and Kirkby (2012), rainwater contains nutrients that can supply part of the plant's nutritional requirements . Among nutrients, potassium concentration was much lower in rainwater than other elements, especially sodium. In addition, the concentration of sodium was too high due to saline and alkaline irrigation water (Table 2) and soil (Tables 4 and 5) in this study. On the other hand, with decreasing soil acidity (pH) in rainy conditions (Arya and Khan, 2020; Foth, 1990), net potassium uptake decreases sharply (Marschner, 2011). Also, due to the high concentration of primary soil sodium (Table 4) and its dynamics in the soil, this element is activated by heavy rainfall and moves from the soil surface to the lower layers (Cui *et al.*, 2019). Due to the antagonistic interaction effect between the soil sodium and potassium concentration (Mulder, 1954), an increase in sodium concentration that is released into the soil could reduce the uptake and leaf potassium concentration in the second year (Y2). Of

[DOI: DOI: 10.22034/13.61.15]

Table 6. Analysis of variance of the investigated traits under different treatments of cultivars, pistachio waste compost and fungi

Treatment	df	Mean sum of squares					
		N	P	K	Ca	Fe	Zn
Year (A)	1	0.183^{ns}	0.002^{ns}	0.045^{ns}	0.719^{ns}	164268.00**	11521.669**
Block	4	0.056^{ns}	0.000^{ns}	0.382^{ns}	0.192^{ns}	81.519^{ns}	0.683^{ns}
Variety (B)	1	0.157^{ns}	0.000^{ns}	0.322^{ns}	0.044^{ns}	32378.70**	0.021^{ns}
(A) ×(B)	1	0.003^{ns}	0.000^{ns}	0.727^{ns}	0.167^{ns}	370.370^{ns}	123.521**
Error	4	0.040	0.0005	0.373	0.203	65.481	2.470
Compost (C)	2	0.060**	0.000^{ns}	0.048^{ns}	0.020^{ns}	3385.176**	36.613**
(A) × (C)	2	0.024^{ns}	0.001*	0.073^{ns}	0.039^{ns}	763.194**	4.280^{ns}
(C) ×(B)	2	0.020^{ns}	0.000^{ns}	0.064^{ns}	0.002^{ns}	3071.731**	42.799**
(A) × (C)× (B)	2	0.009^{ns}	0.000^{ns}	0.034^{ns}	0.027^{ns}	2413.898**	14.799**
Fungi (D)	2	0.005^{ns}	0.000^{ns}	0.057^{ns}	0.026^{ns}	8965.898**	47.600**
(A)× (D)	2	0.027^{ns}	0.000^{ns}	0.004^{ns}	0.011^{ns}	2606.861**	130.488**
(B)× (D)	2	0.002^{ns}	0.000^{ns}	0.026^{ns}	0.089**	1021.843**	104.090**
(A)× (B)× (D)	2	0.036^{ns}	0.000^{ns}	0.150^{ns}	0.165**	870.398**	57.924**
(C) ×(D)	4	0.029*	0.000^{ns}	0·037^{ns}	0.056**	1307.454**	21.322**
(A)× (C) × (D)	4	0.027^{ns}	0.001*	0.041^{ns}	0.009^{ns}	998.556**	15.725**
(B) ×(C)× (D)	4	0.024^{ns}	0.001*	0.061^{ns}	0.043*	713.787**	13.035**
(A) × (B) × (C)× (D)	4	0.006^{ns}	0.000^{ns}	0.023^{ns}	0.025^{ns}	5421.593**	20.826**
Error	32	0.011	0.0001	0.034	0.013	42.815	2.178
Error	32	0.007	0.000	0.014	0.009	36.414	3.110
CV (%)		3.90	12.29	9.15	6.16	3.18	8.52

^{ns}, * and ** are non-significant and significant respectively at the probability level of 5% and 1%

Continue of table 6.

Treatment	df	Mean sum of squares				
		Mn	Leaf area	Branch height	Branch diameter	Seedling width
Year (A)	1	1748.058**	7528.362**	6589.45**	602.083**	5410.253**
Block	4	88.822^{ns}	287.509^{ns}	16.131^{ns}	2.833^{ns}	0.697^{ns}
Variety (B)	1	3870.021**	83761.659**	32.013*	0.454^{ns}	33.779**
(A) ×(B)	1	7845.558**	3345.568*	116.979**	0.231^{ns}	19.935*
Error	4	25.64	211.97	3.585	2.352	1.100
Compost (C)	2	576.447**	29123.088**	414.006**	9.333**	43.623**
(A) × (C)	2	511.808**	1115.384**	217.334**	1.444^{ns}	36.442**
(C) ×(B)	2	47.632*	10446.727**	9.771^{ns}	6.704*	104.878**
(A) × (C)× (B)	2	620.141**	2439.694**	140.506**	0.593^{ns}	7.056^{ns}
Fungi (D)	2	366.252**	7385.530**	60.908**	0.194^{ns}	7.747^{ns}
(A)× (D)	2	192.586**	684.058*	211.524**	2.583^{ns}	4.344^{ns}
(B)× (D)	2	422.382**	11884.192**	138.374**	2.898^{ns}	15.293*
(A)× (B)× (D)	2	434.308**	506.678*	3.407**	0.843^{ns}	3.660^{ns}
(C) ×(D)	4	142.079**	3938.533**	123.439**	3.778^{ns}	89.744**
(A)× (C) × (D)	4	105.815**	1603.457**	40.289**	1.778^{ns}	6.932^{ns}
(B) ×(C)× (D)	4	412.639**	24166.901**	48.474**	0.481^{ns}	25.217**
(A) × (B) × (C)× (D)	4	208.662**	1845.844**	6.120**	1.370^{ns}	1.464^{ns}
Error	32	9.959	146.300	9.380	1.612	4.347
Error	32	21.395	174.932	8.949	0.512	3.331
CV (%)		7.43	3.30	6.88	7.09	9.52

^{ns}, * and ** are non-significant and significant respectively at the probability level of 5% and 1%

Continue of table 6.

Treatment	df	Mean sum of squares				
		Mn	Leaf area	Branch height	Branch diameter	Seedling width
Variety (A)	1	2037.498**	30.225^{ns}	1540.270*	0.107^{ns}	94.936*
Error	2	16.472	2.022	22.848	2.087	1.590
Compost (B)	2	754.865**	6.946**	651.672**	25.852**	282.821**
(B) ×(A)	2	1225.709**	91.162**	498.674**	28.047**	13.281**
Fungi (C)	2	721.400**	28.312**	60.412**	40.384**	156.839**
(A)× (C)	2	62.525*	6.358**	195.696**	10.754**	119.925**
(B) ×(C)	4	335.280**	26.237**	100.777**	26.508**	191.875**
(A) ×(B)× (C)	4	382.630**	40.462**	223.016**	36.487**	131.294**
Error	32	12.364	0.760	6.344	0.963	2.382
CV (%)		9.5	8.44	7.19	17.10	13.75

^{ns}, * and ** are non-significant and significant respectively at the probability level of 5% and 1%

[DOI: DOI: 10.22034/13.61.15]

Table 7. The effect of year on growth parameters and leaf nutrients of pistachios

Treatment	N	P	K	Ca	Fe	Zn	Mn	Leaf area	Branch height	Branch diameter	Seedling width
Unit	%	%	%	%	ppm	ppm	Ppm	cm^2	cm	mm	cm
Y2	2.029[b]	0.119[a]	1.293[a]	1.499[b]	150.981[b]	31.019[a]	58.204[b]	408.894[a]	35.659[b]	7.722[b]	12.093[b]
Y4	2.111[a]	0.111[b]	1.253[a]	1.662[a]	228.981[a]	10.361[b]	66.250[a]	392.196[b]	51.281[a]	12.444[a]	26.248[a]

Y2= 2017, Y4=2019

Means followed by the same letters are not significantly different (P ≤ 0.05) base on LSD test.

course, this difference was not significant (Table 7). In addition, the synergistic interaction effect of potassium with soil phosphorus was reported by Mulder (1954) too, which was consistent with the results of this study. Among the micronutrients, the concentration of zinc in leaves sharply decreased in the fourth year compared to the first year (Y1) (Table 7). This large difference could be due to a 114% increase in rainfall (Table 3) in the fourth year of the experiment, which affects lime in the soil (Tables 4 and 5) and increases soil bicarbonate (HCO_3^-). Zinc absorption decreases as soil bicarbonate increases (Acton, 2012). Increased rainfall probably caused changes in soil redox conditions (Table 3). Iron and manganese were reduced in the soil, and so their uptake increased by plants (Table 7) (Strawn *et al.*, 2015).

Pistachio cultivars (Akbari and Badami Zarand) effects: In studies conducted by Hokmabadi and Sherafati (2015); Hokmabadi *et al*. (2004); Moein rad (2000) and Mohammadi Mohammad Abadi (1998), it was found that the seedlings of Akbari and Badami Zarand cultivars had more ability to absorb nutrients from the soil compared to other cultivars of pistachio belonging *to Pistacia vera* L. in saline conditions and therefore, they were classified into relatively salt-tolerant pistachio cultivars with different degrees (Nilsen and Orcutt, 1996). The results presented in table (8) proved that there is no statistical difference between these two pistachio seedlings in nutrient uptake except for iron and manganese. However, Akbari and Badami Zarand cultivars absorbed more micro and macronutrients, respectively, but the concentration of micro and macro elements in the leaves of both cultivars was more and less than the sufficiency range (SR) of nutrients for pistachio (Table 9).

The results of this study showed that the concentration of iron and zinc in the seedlings of the Akbari cultivar was higher than the Badami Zarand cultivar but it was inverse between the two cultivars for manganese concentration (Table 8). Meanwhile, the Akbari and Badami Zarand cultivars had 58.5% and 42.2% abnormal leaves (the total number of 1, 2, and 4 leaflets), respectively (Table 8). In other words, the percentage of normal leaves (3 and 5 leaflets) decreased with the Fe, Zn and Mn concentration improved in the pistachio seedlings (Table 8), which indicates the influence of other factors such as genetics (cultivar) (Esmailpour, 2005) and environmental conditions (Hokmabadi and Javanshah, 2006; Javanshah and Nazori, 2005) in converting the leaves into normal leaves. Another hypothesis that can be stated is that the number of abnormal leaves in a micronutrient deficiency state increased. The highest reversed correlation coefficient was observed for manganese with leaf area (r=-0.46) and abnormal leaves (r=-0.53). At the molecular level, excessive Mn can prevent the uptake and translocation of other essential elements such as Ca, Mg, Fe and P, inhibit chlorophyll biosynthesis, cause a decline in the photosynthetic rate, reduce the meristematic cell division in roots by inhibiting auxin biosynthesis, and lead to an increase in the accumulation of oxidized Mn and oxidized phenolic compounds in the apoplast (Alejandro *et al.*, 2020). The results of Chou and Tan (1990) suggested the presence of a Mn (II)-sensitive mechanism for controlling cell division. The increase in the number of leaflets per leaf (normal leaflets) with a decrease in micronutrient deficiency is probably due to the prevention of photosynthesis reduction and the mitigation of nutritional stress (Javanshah and Nazori, 2005). However, the toxic Mn concentration causes abnormalities in cell division and abnormal leaf generation. Recent evidence suggests that the intracellular redox environment fluctuates during the cellular cycle, moving into a more oxidized state during mitosis (Sarsour *et al.*, 2014). Manganese superoxide dismutase (MnSOD) activity is higher in G0/G1 cells compared with S, G2 and M phases. After cell division, MnSOD activity increases in the G1 phase of the daughter generation. The periodic fluctuation in MnSOD activity during the cell cycle inversely correlates with cellular superoxide levels as well as glucose and oxygen consumption. Based on an inverse correlation between MnSOD activity and glucose consumption during the cell cycle, it is proposed that MnSOD is a central molecular player in the "Warburg effect. In general, loss of MnSOD activity results in "aberrant proliferation" (Sarsour *et al.*, 2014).

In the study of vegetative traits (Table 8), it was identified that the two important parameters (height and diameter of the seedlings) did not show any significant difference (P≤0.05) under the effect of a cultivar. The leaf area in the Akbari (428.4 cm^2) was higher than that in the Badami Zarand cultivar (372.7 cm^2) (Table 8). The relationship between leaf area and leaf macronutrient concentration was not very clear, but it was reversed. Thus, the Akbari cultivar had the highest leaf area and micronutrient concentration (Table 8). The results of studies on different plants showed that N, P, Zn and Ca played an important role in leaf size (Hasanuzzaman *et al.*, 2018). But in pistachio, the main cause of little leaf disease and leaf-area shrinkage has

[DOI: DOI: 10.22034/13.61.15]

Table 8. The effect of pistachio cultivars on growth parameters, leaf nutrients and leaflet number of pistachios

Treat.	N	P	K	Ca	Fe	Zn	Mn	Branch height
Unit	(%)	(%)	(%)	(%)	(ppm)	(ppm)	(ppm)	(cm)
Ak	2.031 [a]	0.114 [a]	1.218 [a]	1.601 [a]	207.296 [a]	20.704 [a]	56.241 [b]	42.926 [a]
Ba	2.108 [a]	0.116 [a]	1.328 [a]	1.560 [a]	172.667 [b]	20.676 [a]	68.213 [a]	44.015 [a]
Treat.	Leaf area	Branch diameter	Seedling width	1 leaflet	2 leaflets	3leaflets	4 leaflets	5 leaflets
Unit	(cm^2)	(mm)	(cm)	(%)	(%)	(%)	(%)	(%)
Ak	428.394 [a]	10.148 [a]	19.730 [a]	43.137 [a]	9.581 [b]	29.670 [b]	5.781 [a]	12.552 [a]
Ba	372.696 [b]	10.019 [a]	18.611 [b]	30.852 [b]	11.078 [a]	40.352 [a]	5.693 [a]	9.900 [b]

AK= Akbari var., Ba=Badami Zarand Var.
Means followed by the same letters are not significantly different (P ≤ 0.05) base on LSD test.

Table 9. Critical levels and sufficiency ranges for pistachio leaf nutrient (Ferguson, 2005)

Nutrient	Unit	Critical range	Sufficiency range
N	%	1.8	2.2 - 2.5
P	%	0.14	0.14 - 0.17
K	%	1.6	1.8 - 2.0
Ca	%	1.3	1.8 – 4.0
Fe	mg kg^{-1}	?	110.0
Zn	mg kg^{-1}	7.0	10 -15
Mn	mg kg^{-1}	3.0	30 - 80

been attributed to the deficiency of two micronutrients, copper and iron (Hokmabadi, 2011) and zinc and iron (Mehrnejad and Javanshah, 2010). For Fe and Mn concentrations, Table 8 confirms this point completely. Thus, the Fe concentration in the leaves of the Akbari cultivar was much higher than that of Badami Zarand, and the leaf area of Akbari had a higher significant difference from the Badami Zarand cultivar (P≤0.05). Each pistachio cultivar that can absorb more iron has a better reactive oxygen species (ROS) capturing system and has more leaf area and abnormal leaves (58.5%). Hilo *et al.* (2017) concluded that Fe acts locally by promoting cell division in the meristematic cells of adventitious root (AR) primordia. These results highlight a specific biological function of Fe in AR development. Iron cofactors such as heme and Fe-sulfur clusters function in all primary metabolic processes, including respiration, DNA synthesis and repair, and cell proliferation and differentiation (Camprubi *et al.*, 2017). In plants, iron is also essential for chlorophyll, hormone synthesis, and photosynthesis. Plants tightly regulate iron uptake, localization, transport, and storage, as iron overload can cause serious damage. This is because iron's potent electron chemistry also makes it dangerous when it is in physiological excess. Iron acts as a catalyst with hydrogen peroxide through the Fenton reaction, producing more dangerous reactive oxygen species (ROS), including the highly reactive hydroxide ion (Winterbourn, 1995). These potent oxidizers damage lipids, proteins, nucleic acids, and cell division disturbance (Becana *et al.*, 1998; Pinto *et al.*, 2016). When the damage becomes too severe, the cell cannot be saved and undergoes programmed cell death (Tsai and Huang, 2006). Iron is an absolute requirement for optimal cell proliferation (Le and Richardson, 2002).

Interacting effects of year and cultivar influenced micronutrients and growth parameters (Table 10). The concentration of Fe and Mn was higher in the fourth year and Akbari and Badami Zarand cultivars respectively, however, the zinc level was greater in the first year (Y1) and Badami Zarand (Table 10). Growth parameters were also improved in the fourth year and the Akbari cultivar.

Pistachio waste compost effects: The effect of pistachio waste compost was effective on the concentration of all leaf nutrients; it had a more significant effect on the concentration of N, Fe, Zn and Mn. In general, the 15 kg compost $seedling^{-1}$ had the greatest effect on the concentration of leaf nutrients. The control and the 10 kg $seedling^{-1}$ treatments did not differ from each other except for Fe and Mn (Table 11). It was found that the effect of pistachio waste compost on the concentration of macronutrients was almost below the critical levels (CL), and the concentration of three studied micronutrients (Fe, Mn and Zn) was even larger than the sufficiency range in pistachios (Table 9). Research conducted by Miri Dysfani and Sherafati (2013) on the effect of four organic fertilizers, including pistachio waste compost, manure, vermicompost, and municipal waste compost, on two pistachio seedlings of Akbari and Badami Sefid cultivars in greenhouse conditions presented that the effect of pistachio waste compost on the leaf's concentration of nutrients (N, P, K, Fe and Zn), as well as vegetative traits such as stem and root length and diameter, was greater than other organic fertilizers. In spite of the lower concentrations of microelements in pistachio waste compost (Table 1), the study suggests that the low EC and pH of pistachio compost compared to other organic fertilizers such as cattle, poultry, and sheep manure (FAO, 1982) may explain the higher microelement uptake in this study because microelements are more readily absorbed in soil with a low pH (Rengel, 2015). This study made it clear there is no need to use other fertilizer compounds (organic or chemical) to supply microelements in the sapling period of pistachios (before the fruiting age),

[DOI: DOI: 10.22034/13.61.15]

Table 10. The interaction effects of year and pistachio cultivars on growth parameters, leaf nutrients pistachios

Treatment	N	P	K	Ca	Fe	Zn	Mn	Leaf area	Branch height	Branch diameter	Seedling width
Unit	%	%	%	%	ppm	ppm	ppm	cm^2	cm	mm	cm
Y2×AK	1.995 ^{b}	0.1196 ^{a}	1.321 ^{a}	1.480 ^{a}	166.4 ^{c}	29.96 ^{b}	60.74 ^{b}	431.2 ^{a}	34.07 ^{c}	7.741 ^{b}	12.22 ^{c}
Y2×Ba	2.062 ^{ab}	0.1178 ^{a}	1.266 ^{a}	1.518 ^{a}	135.5 ^{d}	32.07 ^{a}	55.67 ^{c}	386.6 ^{b}	37.24 ^{b}	7.704 ^{b}	11.96 ^{c}
Y4×AK	2.068 ^{ab}	0.1074 ^{a}	1.116 ^{a}	1.721 ^{a}	248.1 ^{a}	11.44 ^{c}	51.74 ^{d}	425.6 ^{a}	51.78 ^{a}	12.56 ^{a}	27.24 ^{a}
Y4×Ba	2.154 ^{a}	0.1141 ^{a}	1.389 ^{a}	1.603 ^{a}	209.8 ^{b}	9.278 ^{d}	80.76 ^{a}	358.8 ^{c}	50.79 ^{a}	12.33 ^{a}	25.26 ^{b}

Y1= 2017, Y2=2019, AK= Akbari var., Ba=Badami Zarand Var.
Means followed by the same letters are not significantly different (P ≤ 0.05) based on the LSD test.

Table 11. The effect of pistachio waste compost on growth parameters, leaf nutrients and leaflet number of pistachios

Treat.	N	P	K	Ca	Fe	Zn	Mn	Branch height
Unit	(%)	(%)	(%)	(%)	(ppm)	(ppm)	(ppm)	(cm)
C0	2.034 ^{b}	0.1142 ^{a}	1.266 ^{a}	1.579 ^{a}	178.8 ^{b}	20.22 ^{b}	59.61 ^{b}	42.95 ^{b}
C10	2.061 ^{b}	0.1128 ^{a}	1.241 ^{a}	1.604 ^{a}	195.0 ^{a}	20.00 ^{b}	66.83 ^{a}	40.37 ^{c}
C15	2.114 ^{a}	0.1172 ^{a}	1.313 ^{a}	1.558 ^{a}	196.2 ^{a}	21.85 ^{a}	60.24 ^{b}	47.09 ^{a}
Treat.	Leaf area	Branch diameter	Seedling width	1 leaflet	2 leaflets	3leaflets	4 leaflets	5 leaflets
Unit	(cm^2)	(mm)	(cm)	(%)	(%)	(%)	(%)	(%)
C0	410.7 ^{b}	10.19 ^{a}	18.21 ^{b}	34.51 ^{b}	10.38 ^{a}	33.23 ^{b}	6.256 ^{a}	15.79 ^{a}
C10	386.4 ^{c}	9.528 ^{b}	18.94 ^{b}	44.34 ^{a}	9.683 ^{b}	30.08 ^{c}	4.367 ^{b}	9.256 ^{b}
C15	422.5 ^{a}	10.53 ^{a}	20.37 ^{a}	32.13 ^{b}	10.92 ^{a}	41.72 ^{a}	6.589 ^{a}	8.633 ^{b}

C0=control, C10=10 kg, C15=15 kg
Means followed by the same letters are not significantly different (P ≤ 0.05) base on LSD test.

with 15 kg seedling^{-1} of pistachio waste compost applied in such conditions. However, the 15 kg was insufficient to provide macronutrients and maximum vegetative growth; therefore, other organic manure, fertilizer, or pistachio compost should be used. The effect of treatments on leaflet number results was only affected by 10 kg seedling^{-1} of compost, which increased abnormal leaves (58.3%) compared to 39.3% of normal leaves (Table 11). This was probably caused by the low levels of all growth parameters at this compost level. The number of normal and abnormal leaves was the same in the other two treatments (Table 11).

The table (12) study showed that pistachio compost in the fourth year had the most significant effect on the concentration of most nutrients in leaves, which may be due to precipitation (Table 3) and increased soil moisture, which has increased nutrient availability. The vegetative growth parameters were maximum in 15 kg seedling^{-1} of pistachio waste compost (Table 12).

The effect of cultivar on macronutrient concentration was more remarkable than compost levels and Badami Zarand cultivar showed superiority in this respect. Inversely, micronutrient concentration and growth parameters were affected by pistachio waste compost levels (Table 13), which may be due to the higher concentration of microelements compared to their sufficiency level (Table 9) for pistachios. The pistachio cultivars and compost showed a significant and clear effect on leaflet number and the type of leaf (Tables 6 and 13).

The growth parameters and the nutrient concentration were most affected by the cultivar, compost level (15 kg seedling^{-1}), and year, respectively (Table 14). Phosphorous and potassium concentration and leaf area (465 cm^{-2}) were maximum in the Y2×Ak×C15 treatment. Calcium, iron, and seedling width were also maximum in the Y4×Ak×C15 treatment (Table 14).

Mycorrhizal fungus effects: In this study, the use of mycorrhizal fungi did not significantly affect the concentration of macronutrients, including N, P, K, and Ca in leaves (Table 15). The high pH, EC and low soil moisture and organic matter content can cause a mycorrhizal mycelium growth reduction (Sanjari Nia *et al.*, 2013; Mehrnejad and Javanshah, 2010). However, Fe and Zn concentrations were most affected by the third mycorrhizal application level (200 g), while Mn concentrations were most affected by the second level (100 g). The Mn concentration was 29 and 385 ppm in pistachio waste and compost, respectively (Table 1).

The diffusion rates of NO_3^-, NH_4^+, and PO_4^{-3} ions in the soil are 10^{-6}, 10^{-7}, and 10^{-8} cm^2sec^{-1}, respectively. NO_3^- is sufficient in most agricultural soils and due to its high diffusion coefficient and the extent of the NO_3^- depletion zone, the role of mycorrhiza in the nitrogen supply is low in plants (Dar, 2010). A study by Hayman (1987) showed that mycorrhizal plants were more likely to use non-fertilizer nitrogen sources than non-mycorrhizal plants. Most plants are non-mycorrhizal at high concentrations of nitrogen and phosphorus (Lambers *et al.*, 2018). In addition, extracellular phosphatase activity is high in mycorrhizal fungi. Although the activity of this enzyme is greatly reduced in saline and alkaline soils (Zhang *et al.*, 2011; Cao *et al.*, 2020), this may have been a reason for reducing the effect of mycorrhizal fungi on phosphorus uptake by the plant in this study (Table 15). Studies have shown that mycorrhizal fungi do not play a significant role in the uptake of potassium and calcium. Potassium has a high

[DOI: DOI: 10.22034/13.61.15]

Table 12. The interaction effects of year and pistachio waste compost on growth parameters, leaf nutrients and leaflet number of pistachios

Treatment	N	P	K	Ca	Fe	Zn	Mn	Leaf area	Branch height	Branch diameter	Seedling width
Unit	%	%	%	%	ppm	ppm	ppm	cm^2	cm	mm	cm
Y2×C0	2.011 ^{c}	0.1206^{ab}	1.277 ^{ab}	1.510 ^{bc}	144.9 ^{d}	30.17 ^{b}	59.11 ^{c}	419.8 ^{b}	35.76 ^{d}	7.667 ^{c}	12.06 ^{d}
Y2×C10	1.991 ^{c}	0.1111 ^{c}	1.221 ^{b}	1.548 ^{b}	152.2 ^{c}	30.61 ^{b}	58.83 ^{c}	370.9 ^{d}	34.64 ^{d}	7.389 ^{c}	12.00 ^{d}
Y2×C15	2.083 ^{ab}	0.1244 ^{a}	1.382 ^{a}	1.439 ^{c}	155.8 ^{c}	32.28 ^{a}	56.67 ^{d}	436.0 ^{a}	36.57 ^{d}	8.111 ^{c}	12.22 ^{d}
Y4×C0	2.056 ^{bc}	0.1078 ^{c}	1.254 ^{b}	1.648 ^{a}	212.7 ^{b}	10.28 ^{d}	60.11 ^{c}	401.5 ^{c}	50.14 ^{b}	12.72 ^{a}	24.36 ^{c}
Y4×C10	2.132 ^{a}	0.1144^{bc}	1.260 ^{ab}	1.661 ^{a}	237.7 ^{a}	9.389 ^{d}	74.83 ^{a}	366.0 ^{d}	46.09 ^{c}	11.67 ^{b}	25.87 ^{b}
Y4×C15	2.144 ^{a}	0.1100 ^{c}	1.243 ^{b}	1.677 ^{a}	236.6 ^{a}	11.42 ^{c}	63.81 ^{b}	409.1 ^{c}	57.61 ^{a}	12.94 ^{a}	28.52 ^{a}

Y2= 2017, Y4=2019, C0=control, C10=10 kg, C15=15 kg
Means followed by the same letters are not significantly different (P ≤ 0.05) base on LSD test.

Table 13. The interaction effects of pistachio cultivars and pistachio waste compost on growth parameters, leaf nutrients and leaflet number of pistachios

Treat.	N	P	K	Ca	Fe	Zn	Mn	Branch height
Unit	(%)	(%)	(%)	(%)	(ppm)	(ppm)	(ppm)	(cm)
Ak×C0	1.998 ^{b}	0.1133 ^{a}	1.173 ^{c}	1.606 ^{ab}	197.8 ^{c}	21.33 ^{b}	53.39 ^{d}	42.77 ^{c}
Ak×C10	1.998 ^{b}	0.1122 ^{a}	1.179 ^{bc}	1.625 ^{a}	202.3 ^{b}	20.00 ^{cd}	59.83 ^{c}	40.06 ^{d}
Ak×C15	2.098 ^{a}	0.1150 ^{a}	1.303 ^{ab}	1.571 ^{ab}	221.8 ^{a}	20.78 ^{bc}	55.50 ^{d}	45.95 ^{b}
Ba×C0	2.069 ^{ab}	0.1150 ^{a}	1.358 ^{a}	1.553 ^{ab}	159.8 ^{f}	19.11^{d}	65.83 ^{b}	43.13 ^{c}
Ba×C10	2.124 ^{a}	0.1133 ^{a}	1.302 ^{ab}	1.584 ^{ab}	187.6 ^{d}	20.00 ^{cd}	73.83 ^{a}	40.68 ^{d}
Ba×C15	2.130 ^{a}	0.1194 ^{a}	1.322 ^{a}	1.544 ^{b}	170.6 ^{e}	22.92 ^{a}	64.97 ^{b}	48.23 ^{a}
Treat.	Leaf area	Branch diameter	Seedling width	1 leaflet	2 leaflets	3leaflets	4 leaflets	5 leaflets
Unit	(cm^2)	(mm)	(cm)	(%)	(%)	(%)	(%)	(%)
Ak×C0	423.0 ^{b}	10.61 ^{ab}	19.65 ^{bc}	40.18 ^{b}	10.76 ^{c}	29.18 ^{c}	5.244 ^{b}	17.42 ^{a}
Ak×C10	414.5 ^{c}	9.111 ^{c}	17.53 ^{de}	58.97 ^{a}	6.344 ^{d}	18.96 ^{d}	4.089 ^{c}	11.24 ^{c}
Ak×C15	447.6 ^{a}	10.72 ^{a}	22.01 ^{a}	30.27 ^{d}	11.64 ^{b}	40.88 ^{a}	8.011 ^{a}	8.989 ^{d}
Ba×C0	398.3 ^{d}	9.778 ^{bc}	16.76 ^{e}	28.84 ^{d}	10.01 ^{c}	37.29 ^{b}	7.267 ^{a}	14.16 ^{b}
Ba×C10	322.3 ^{e}	9.944 ^{abc}	20.34 ^{b}	29.72 ^{d}	13.02 ^{a}	41.21 ^{a}	4.644 ^{bc}	7.267 ^{e}
Ba×C15	397.5 ^{d}	10.33 ^{ab}	18.73 ^{cd}	33.99 ^{c}	10.20 ^{c}	42.56 ^{a}	5.167 ^{b}	8.278 ^{de}

AK= Akbari var., Ba=Badami Zarand Var., C0=control, C10=10 kg, C15=15 kg
Means followed by the same letters are not significantly different (P ≤ 0.05) base on LSD test.

Table 14. The interaction effect of year, pistachio cultivars and pistachio waste compost on growth parameters and nutrients of pistachios

Treatment	N	P	K	Ca	Fe	Zn	Mn	Leaf area	Branch height	Branch diameter	Seedling width
Unit	%	%	%	%	ppm	ppm	ppm	cm^2	cm	mm	cm
Y2×Ak×C0	1.976^{cd}	0.1211 ^{ab}	1.294^{abc}	1.497 ^{e}	160.9^{f}	30.33^{bc}	59.56 ^{d}	422.6^{bc}	34.92 ^{f}	7.889 ^{de}	12.89 ^{ef}
Y2×Ak×C10	1.920 ^{d}	0.1133^{abc}	1.209^{bcd}	1.557 ^{de}	166.4^{ef}	30.11^{bc}	65.11 ^{c}	405.9 ^{d}	31.16 ^{g}	7.000 ^{e}	10.67 ^{g}
Y2×Ak×C15	2.090^{ab}	0.1244^{a}	1.459 ^{a}	1.386 ^{f}	172.0^{e}	29.44 ^{c}	57.56^{def}	465.0 ^{a}	36.14^{ef}	8.333 ^{d}	13.11 ^{ef}
Y2×Ba×C0	2.047^{bc}	0.1200 ^{ab}	1.259 ^{bc}	1.523 ^{de}	129.0^{h}	30.00^{bc}	58.67^{de}	417.0^{cd}	36.60^{ef}	7.444 ^{de}	11.22 ^{fg}
Y2×Ba×C10	2.062^{bc}	0.1089 ^{bc}	1.233 ^{bc}	1.539 ^{de}	138.0^{g}	31.11 ^{b}	52.56 ^{h}	335.8 ^{f}	38.13 ^{e}	7.778 ^{de}	13.33 ^{e}
Y2×Ba×C15	2.077 ^{b}	0.1244 ^{a}	1.306^{abc}	1.492 ^{ef}	139.6^{g}	35.11 ^{a}	55.78^{efg}	407.0 ^{d}	37.00^{ef}	7.889 ^{de}	11.33^{efg}
Y4×Ak×C0	2.021^{bc}	0.1056 ^{c}	1.051 ^{d}	1.714 ^{ab}	234.7^{b}	12.33 ^{d}	47.22 ^{i}	423.5^{bc}	50.61 ^{c}	13.33 ^{a}	26.41 ^{b}
Y4×Ak×C10	2.077 ^{b}	0.1111 ^{bc}	1.149 ^{cd}	1.693^{abc}	238.2^{b}	9.889^{fg}	54.56^{fgh}	423.1^{bc}	48.97 ^{c}	11.22 ^{c}	24.39 ^{c}
Y4×Ak×C15	2.106^{ab}	0.1056 ^{c}	1.148 ^{cd}	1.757 ^{a}	271.6^{a}	12.11^{de}	53.44^{gh}	430.2 ^{b}	55.76 ^{b}	13.11 ^{ab}	30.91 ^{a}
Y4×Ba×C0	2.091^{ab}	0.1100 ^{bc}	1.458 ^{a}	1.582 ^{de}	190.7^{d}	8.222 ^{h}	73.00 ^{b}	379.6 ^{e}	49.67 ^{c}	12.11 ^{bc}	22.30 ^{d}
Y4×Ba×C10	2.187 ^{a}	0.1178^{abc}	1.371 ^{ab}	1.629^{bcd}	237.2^{b}	8.889^{gh}	95.11 ^{a}	308.9 ^{g}	43.22 ^{d}	12.11 ^{bc}	27.36 ^{b}
Y4×Ba×C15	2.183 ^{a}	0.1144^{abc}	1.339 ^{ab}	1.597^{cde}	201.6^{c}	10.72^{ef}	74.17 ^{b}	387.9 ^{e}	59.47 ^{a}	12.78 ^{ab}	26.12 ^{bc}

Y2= 2017, Y4=2019, AK= Akbari var., Ba=Badami Zarand Var., C0=control, C10=10 kg, C15=15 kg
Means followed by the same letters are not significantly different (P ≤ 0.05) base on LSD test.

diffusion coefficient (2.1-9.5×10^{-7} cm^2sec^{-1}) similar to ammonium (Baligar and Fageria, 2001) and 88% of calcium uptake is also supplied by mass flow (Doshi, 2016). An antagonistic effect was observed between Zn consumption and Fe concentration in the study of drought stress, zinc application and mycorrhizal inoculation on the uptake of trace elements in maize (Sajedi and Rejali, 2011). Investigation of Fe and Zn concentrations during the experimental years (Tables 4 and 5) showed their inverse relationship and plant competition for the absorption of two elements. Moreover, the concentration of iron in pistachio waste

[DOI: DOI: 10.22034/13.61.15]

Table 15. The effect of mycorrhizal fungus on growth parameters, leaf nutrients and leaflet number of pistachios

Treat.	N	P	K	Ca	Fe	Zn	Mn	Branch height
Unit	(%)	(%)	(%)	(%)	(ppm)	(ppm)	(ppm)	(cm)
F0	2.082 [a]	0.1125 [a]	1.308 a	1.551 [a]	186.6 [b]	21.65 [a]	58.68 [c]	43.03 [b]
F100	2.058 [a]	0.1156 [a]	1.230 a	1.604 [a]	176.2 [c]	19.42 [b]	64.86 [a]	44.93 [a]
F200	2.069 [a]	0.1161 a	1.281 a	1.587 [a]	207.2 [a]	21.00 [a]	63.14 [b]	42.44 [b]
Treat.	Leaf area	Branch diameter	Seedling width	1 leaflet	2 leaflets	3leaflets	4 leaflets	5 leaflets
Unit	(cm^2)	(mm)	(cm)	(%)	(%)	(%)	(%)	(%)
F0	399.6 [b]	10.06 [a]	19.70 [a]	43.35 [a]	8.883 [b]	34.67 [b]	4.100 [c]	8.544 [c]
F100	415.3 [a]	10.03 [a]	18.84 [a]	30.69 [c]	10.99 [a]	36.99 [a]	7.039 [a]	14.39 [a]
F200	386.7 [c]	10.17 [a]	18.98 [a]	36.94 [b]	11.12 [a]	33.37 [b]	6.072 [b]	10.74 [b]

F0=control, F100= 100g, F200=200g

Means followed by the same letters are not significantly different (P ≤ 0.05) base on LSD test.

and compost was 21 and 90 times greater than the concentration of zinc, respectively (Table 1). Due to the high Fe concentration in pistachio compost and soil and the wide iron sufficiency range in pistachios (110.0 ppm, Table 9), mycorrhizal fungi did not help absorb Zn from the soil (Table 15). It is possible that the pistachio roots have better mechanisms for absorbing Fe. Numerous studies have demonstrated the positive effect of mycorrhizal fungi on manganese uptake in various pistachios cultivars too (Bagheri *et al.*, 2012; Safari Kamal Abadi, 2020). The increase in rainfall trends over the experimental years (Table 3) created reduction conditions in the soil and thus increased Mn^{+2} uptake. Moreover, the middle sufficiency range of Mn for pistachio (55.0 ppm, Table 9) caused the maximum leaf concentration of Mn, which was obtained at the second level of mycorrhizal usage (Table 15).

Vegetative traits, including leaf area and seedling height, were affected by the mycorrhizal fungi (Tables 6 and 15). The optimum and practical level of mycorrhizal fungi for growth parameters increase was 100 g $seedling^{-1}$. Since all rootstocks are heavily colonized in the field, Ferguson *et al.* (1998) proposed that pistachio rootstocks should be thought of as a pistachio-mycorrhizal symbiosis. The Arbuscular mycorrhiza (AM) inoculation caused higher pistachio growth (including plant shoot and root weights, leaf area, and total chlorophyll content) (Abbaspour *et al.*, 2012). The control and 200 g $seedling^{-1}$ mycorrhizal consumption caused abnormal leaves to increase by 56.3% and 54.13%, respectively (Table 15). However, pistachio growth parameters were maximum in 100 g $seedling^{-1}$, and at this level, the number of normal (51.38%) and abnormal (48.71%) were approximately equal (Table 15). It seems that better growing conditions and higher growth parameters have increased the number of abnormal leaves in pistachios (Tables 15 and 11). Under suitable growing conditions, the pistachio seedlings made less effort to produce developed (normal) leaves.

In the fourth year, mycorrhizal efficacy on the leaf concentration of N, Ca, and Fe was higher than in the first year (Y1) (Table 16). The influence of *Glomus etunicatum* colonization on plant growth and drought tolerance of 3-month-old *Pistacia vera* seedlings in potted culture in two different water treatments showed that the growth of AM-treated seedlings was higher than that of non-AM-treated seedlings, regardless of water status. P, K, Zn and Cu contents in (Arbuscular mycorrhizal) AM-treated shoots were greater than those in non-AM shoots under well-watered conditions and drought stress. N and Ca content were higher under drought stress, while AM symbiosis did not affect the Mg content (Abbaspour *et al.*, 2012). Totally, the growth parameters were higher in the fourth year and F100, except for the Leaf area index, which was high in the first year (Y1) and F100 (Table 16).

Table 17 showed that the cultivar factor (especially Badami Zarand) was stronger than the fungus level in the nutrient concentration and number of leaflets. Maximum leaf area was indicated in Akbari and 100 g $seedling^{-1}$ fungus with 458 cm^{-2} (Table 17). The results of Table 17 also showed that the abnormal leaves decreased with mycorrhizal consumption in the first year (Y1). In addition, the normal leaves were higher in the fourth year compared to abnormal leaves, unlike in the first year (Y1) (Table 17).

Phosphorous and potassium concentrations were maximum in the Y2×AK×F200 treatment. Calcium, iron, and branch diameter were also maximum in the Y4×Ak×F200 treatment (Table 18). The maximum leaf area was obtained in the Y2×Ak×F100 (459.7 cm^{-2}) and Y4×Ak×F100 (456.3 cm^{-2}) treatments. The smaller leaf area and other higher growth parameters were likely the result of higher humidity and a lower temperature (Table 5) in the second year (Y2) (Table 18). As a consequence, vegetative parameters were higher in the second year (Y2), so the leaves did not develop and reach their final growth, and the leaf area remained small (Table 18).

The amount of pistachio compost had a critical impact on the efficiency of mycorrhizal fungi (Table 19). As a consequence of the consumption of 15 kg $seedling^{-1}$ pistachio compost in combination with 200 g mycorrhizal fungi, the greatest effect on leaf nutrients, as well as seedling growth parameters such as seedling height, diameter, and width (Table 19) was found to be synergistic. The No. of abnormal and normal leaves was observed in the 200g fungi with 10 and 15 kg $seedling^{-1}$ of pistachio waste compost respectively (Table 19).

The 3-way interaction effect of the year, pistachio waste compost, and mycorrhizal fungus did not show

[DOI: DOI: 10.22034/13.61.15]

Table 16. The interaction effects of year and mycorrhizal fungus on growth parameters and leaf nutrients pistachio

Treatment	N	P	K	Ca	Fe	Zn	Mn	Leaf area	Branch height	Branch diameter	Seedling width
Unit	%	%	%	%	ppm	ppm	ppm	cm^2	Cm	mm	cm
Y2×F0	2.068 ab	0.1183 a	1.329 a	1.474 b	150.7 e	34.17 a	56.94 d	403.9 b	37.92 d	7.889 b	12.61 b
Y2×F100	1.989 c	0.1183 a	1.239 a	1.537 b	143.7 f	28.44 c	58.50 cd	423.1 a	35.13 e	7.778 b	12.11 b
Y2×F200	2.028 bc	0.1194 a	1.312 a	1.486 b	158.6 d	30.44 b	59.17 c	399.7 bc	33.92 e	7.500 b	11.56 b
Y4×F0	2.096 ab	0.1067 b	1.287 a	1.627 a	222.4 b	9.139 f	60.42 c	395.3 c	48.14 c	12.22 a	26.79 a
Y4×F100	2.126 a	0.1128 ab	1.221 a	1.671 a	208.7 c	10.39 e	71.22 a	407.5 b	54.73 a	12.28 a	25.56 a
Y4×F200	2.111 a	0.1128 ab	1.250 a	1.688 a	255.8 a	11.56 d	67.11 b	373.7 d	50.97 b	12.83 a	26.39 a

Y2= 2017, Y4=2019, F0=control, F100= 100g, F200=200g
Means followed by the same letters are not significantly different (P ≤ 0.05) base on LSD test.

Table 17. The interaction effect of pistachio cultivars and mycorrhizal fungus on growth parameters, nutrients and leaflet number of pistachios

Treat.	N	P	K	Ca	Fe	Zn	Mn	Branch height
Unit	(%)	(%)	(%)	(%)	(ppm)	(ppm)	(ppm)	(cm)
Ak × F0	2.038 bc	0.1117 a	1.268 ab	1.514 b	198.7 b	19.72 c	54.28 d	42.95 bc
Ak×F100	2.016 c	0.1128 a	1.144 b	1.657 a	199.0 b	20.17 c	61.22 c	42.24 bc
Ak×F200	2.041 bc	0.1161 a	1.243 ab	1.631 a	224.2 a	22.22 b	53.22 d	43.59 b
Ba × F0	2.126 a	0.1133 a	1.349 a	1.588 ab	174.4 d	23.58 a	63.08 c	43.12 bc
Ba×F100	2.099 ab	0.1183 a	1.316 a	1.551 b	153.4 e	18.67 d	68.50 b	47.63 a
Ba×F200	2.098 a	0.1161 a	1.318 a	1.643 b	190.2 c	19.78 c	73.06 a	41.30 c

Treat.	Leaf area	Branch diameter	Seedling width	1 leaflet	2 leaflets	3leaflets	4 leaflets	5 leaflets
Unit	(cm^2)	(mm)	(cm)	(%)	(%)	(%)	(%)	(%)
Ak × F0	432.9 b	10.00 a	20.98 a	51.60 a	7.500 c	25.89 e	4.744 c	9.622 c
Ak×F100	458.0 a	9.889 a	18.86 b	35.40 c	10.33 b	34.78 c	6.211 b	13.27 b
Ak×F200	394.3 c	10.56 a	19.35 b	42.41 b	10.91 ab	28.34 d	6.389 b	14.77 a
Ba × F0	366.4 e	10.11 a	18.42 b	35.10 c	10.27 b	43.46 a	3.456 d	7.467 d
Ba×F100	372.6 de	10.17 a	18.82 b	25.98 e	11.64 a	39.20 b	7.867 a	15.51 a
Ba×F200	379.1 d	9.778 a	18.60 b	31.48 d	11.32 a	38.40 b	5.756 b	6.722 d

AK= Akbari var., Ba=Badami Zarand Var., F0=control, F100= 100g, F200=200g
Means followed by the same letters are not significantly different (P ≤ 0.05) base on LSD test.

Table 18. The interaction effect of year, pistachio cultivars and mycorrhizal fungus on growth parameters, nutrients and leaflet number of pistachios

Treatment	N	P	K	Ca	Fe	Zn	Mn	Leaf area	Branch height	Branch diameter	Seedling width
Unit	%	%	%	%	ppm	ppm	ppm	cm^2	cm	mm	cm
Y2×Ak×F0	2.010 cd	0.1178abc	1.377 ab	1.442 fg	161.1 e	29.78 bc	57.11 f	435.6 b	36.91 de	7.889 c	13.67 d
Y2×Ak×F100	1.989 d	0.1189 ab	1.168 cde	1.584cde	159.7 e	29.22 c	64.78 d	459.7 a	31.63 f	7.667 c	11.33 e
Y2×Ak×F200	1.987 d	0.1222 a	1.418 a	1.412 g	178.6 d	30.89 b	60.33 e	398.2 c	33.68 f	7.667 c	11.67 de
Y2×Ba×F0	2.126 ab	0.1189 ab	1.282abcd	1.507defg	140.3 f	38.56 a	56.78 f	372.2 e	38.93 d	7.889 c	11.56 e
Y2×Ba×F100	1.990 d	0.1178abc	1.310 abc	1.489 efg	127.7 g	27.67 d	52.22 g	386.5 d	38.63 d	7.889 c	12.89 de
Y2×Ba×F200	2.070bcd	0.1167abc	1.206bcde	1.559 de	138.6 f	30.00 bc	58.00 ef	401.1 c	34.17 ef	7.333 c	11.44 e
Y4×Ak×F0	2.066bcd	0.1056 c	1.159 cde	1.586cde	236.3 b	9.667 g	51.44 g	430.2 b	48.99 c	12.11 b	28.30 a
Y4×Ak×F100	2.043bcd	0.1067 bc	1.120 de	1.730 b	238.3 b	11.11 f	57.67 ef	456.3 a	52.84 b	12.11 b	26.38 abc
Y4×Ak×F200	2.094 bc	0.1100abc	1.069 e	1.849 a	269.8 a	13.56 e	46.11 h	390.4 cd	53.50 b	13.44 a	27.03 ab
Y4×Ba×F0	2.126 ab	0.1078 bc	1.416 a	1.669 bc	208.4 c	8.611 g	69.39 c	360.5 f	47.30 c	12.33 ab	25.28 bc
Y4×Ba×F100	2.209 a	0.1189 ab	1.321 abc	1.612 cd	179.1 d	9.667 g	84.78 b	358.7 f	56.62 a	12.44 ab	24.74 c
Y4×Ba×F200	2.127 ab	0.1156abc	1.431 a	1.527 def	241.9 b	9.556 g	88.11 a	357.1 f	48.43 c	12.22 b	25.76 bc

Y2= 2017, Y4=2019, AK= Akbari var., Ba=Badami Zarand Var., F0=control, F100= 100g, F200=200g
Means followed by the same letters are not significantly different (P ≤ 0.05) base on LSD test.

any special impact on macro and micronutrient concentration (Table 20), but growth parameters including branch height and diameter and seedling width were maximum in the Y4× C15×F200 treatment. The leaf area was maximum in the Y2× C15×200 treatment (Table 20).

There was no special trend in the table (21) for nutrient concentrations, growth parameters, and number of leaflets. The most of mean growth parameters including branch height and diameter and seedling width were greater in the Ak×C15×F200 treatment (Table 21). Also, the maximum of abnormal (85.13%) and normal (56.13%) leaves were observed in the Ak×C10×F200 and Ba×C15×F0 treatments respectively

[DOI: DOI: 10.22034/13.61.15]

Table 19. The interaction effects of pistachio waste compost and mycorrhizal fungus on growth parameters, leaf nutrients and leaflet number of pistachios

Treat.	N	P	K	Ca	Fe	Zn	Mn	Branch height
Unit	(%)	(%)	(%)	(%)	(ppm)	(ppm)	(ppm)	(cm)
C0 × F0	2.058 bc	01083 b	1.278 ab	1.582 abc	184.1 d	20.83 bc	56.42 e	41.83 b
C0 × F100	1.980 c	0.1183 ab	1.262 ab	1.617 abc	165.8 f	18.83 d	58.50 de	48.27 a
C0 ×F200	2.063 abc	0.1158 ab	1.257 ab	1.538 cd	186.5 cd	21.00 bc	63.92 b	38.75 c
C10 × F0	2.041 bc	0.1092 ab	1.244 b	1.596 abc	184.1 d	19.83 cd	62.67 bc	41.13 bc
C10×F100	2.113 ab	0.1158 ab	1.227 b	1.553 bcd	176.1 e	18.83 d	73.00 a	39.93 bc
C10×F200	2.030 bc	0.1133 ab	1.250 ab	1.664 a	224.8 a	21.33 b	64.83 b	40.04 bc
C15 × F0	2.146 a	0.1200 a	1.403 a	1.475 d	191.5 c	24.29 a	56.96 e	46.13 a
C15×F100	2.080 ab	0.1125 ab	1.200 e	1.461 ab	186.7 cd	20.58 bc	63.08 bc	46.60 a
C15×F200	2.116 ab	0.1192 ab	1.336 ab	1.558 bcd	210.3 b	20.67 bc	60.67 cd	48.54 a
Treat.	Leaf area	Branch diameter	Seedling width	1 leaflet	2 leaflets	3leaflets	4 leaflets	5 leaflets
Unit	(cm^2)	(mm)	(cm)	(%)	(%)	(%)	(%)	(%)
C0 × F0	394.1 de	10.33 abc	21.19 ab	42.03 b	9.433 cd	34.33 cd	4.217 cd	9.750 d
C0 ×F100	439.9 a	10.25 abcd	15.68 d	35.03 c	10.00 cd	33.50 cd	6.300 b	14.92 b
C0 ×F200	397.9 cd	10.00 bcd	17.74 c	26.47 e	11.72 b	31.87 de	8.250 a	22.70 a
C10 × F0	386.6 e	10.00 bcd	20.13 b	51.28 a	6.767 e	29.72 e	3.350 d	8.167 de
C10×F100	362.4 f	9.250 d	19.58 b	30.45 de	9.850 cd	36.38 c	7.700 a	15.55 b
C10×F200	356.3 f	9.333 cd	17.09 cd	51.30 a	12.43 ab	24.15 f	2.050 e	4.050 f
C15 × F0	418.2 b	9.833 bcd	17.77 c	36.73 c	10.45 c	39.97 b	4.733 c	7.717 e
C15×F100	443.5 a	10.58 ab	21.24 ab	26.58 e	13.12 a	41.08 b	7.117 ab	12.70 c
C15×F200	405.9 c	11.17 a	22.09 a	33.07 cd	9.200 d	44.10 a	7.917 a	5.483 f

C0=control, C10=10 kg, C15=15 kg, F0=control, F100= 100g, F200=200g
Means followed by the same letters are not significantly different (P ≤ 0.05) base on LSD test.

Table 20. The interaction effect of year, pistachio waste compost and mycorrhizal fungus on growth parameters, nutrients and leaflet number of pistachios

Treatment	N	P	K	Ca	Fe	Zn	Mn	Leaf area	Branch height	Branch diameter	Seedling width
Unit	%	%	%	%	ppm	ppm	ppm	cm^2	cm	mm	cm
Y2×C0×F0	2.042 bcd	0.1183abcd	1.270abc	1.513 ef	134.0hi	33.83 b	57.67 hi	393.9 fg	36.30 gh	8.500 e	14.83 g
Y2×C0×F100	1.910 e	0.1183abcd	1.242 bc	1.535 de	141.2 ij	27.17 g	55.17 ij	445.5 ab	39.85 fg	7.667 efg	9.833 k
Y2×C0×F200	2.082abcd	0.1250 ab	1.318abc	1.482 efg	150.7gh	29.50ef	64.50 cd	420.0 de	31.13 ij	6.833 g	11.50 hijk
Y2×C10×F0	2.035 d	0.1033 de	1.233 bc	1.540 de	149.2gh	31.33cd	55.33 ij	396.1 f	39.73 fg	7.833 efg	12.67 ghij
Y2×C10×F100	2.040 cd	0.1217 abc	1.258 bc	1.523 def	134.5 j	28.17fg	61.50defg	367.9 hij	29.95 j	7.333 efg	12.83 ghi
Y2×C10×F200	1.898 e	0.1083 cde	1.172 c	1.580 cde	173.0 e	32.33bc	59.67efgh	348.6 k	34.25 hi	7.000 fg	10.50 ijk
Y2×C15×F0	2.127abcd	0.1333 a	1.485 a	1.370 g	160.0 f	37.33 a	57.83 ghi	423.8cde	37.73 gh	7.333 efg	10.33 jk
Y2×C15×F100	2.018 de	0.1150 bcd	1.217 c	1.552 de	155.3fg	30.00de	58.83fghi	456.0 a	35.60 h	8.333 ef	13.67 gh
Y2×C15×F200	2.105abcd	0.1250 ab	1.445 ab	1.395 fg	152.0 g	29.50ef	53.33 j	430.4 cd	36.38 gh	8.667 e	12.67 ghij
Y4×C0×F0	2.075abcd	0.09833 e	1.287abc	1.650abcd	225.2 c	7.833 k	55.17 ij	394.4 fg	47.37 cd	12.17 bcd	27.55 bc
Y4×C0×F100	2.050 bcd	0.1183abcd	1.282abc	1.700 abc	190.5 d	10.50 ij	61.83 def	434.4 bc	56.68 b	12.83 abc	21.53 f
Y4×C0×F200	2.043 bcd	0.1067 cde	1.195 c	1.595bcde	222.3 c	12.50 h	63.33 de	375.9 hi	46.37 cd	13.17 ab	23.98 def
Y4×C10×F0	2.047 bcd	0.1150 bcd	1.255 bc	1.652abcd	219.0 c	8.333 k	70.00 b	377.1 hi	42.53 ef	12.17 bcd	27.60 bc
Y4×C10×F100	2.187 a	0.1100bcde	1.197 c	1.583 cde	217.7 c	9.500jk	84.50 a	357.0 jk	49.92 c	11.17 d	26.33 cd
Y4×C10×F200	2.162 abc	0.1183abcd	1.328abc	1.748 a	276.5 a	10.33 ij	70.00 b	363.9 ij	45.83 de	11.67 cd	23.68 ef
Y4× C15×F0	2.165 ab	0.1067 cde	1.320abc	1.580 cde	223.0 c	11.25hi	56.08 hij	414.6 e	54.53 b	12.33abcd	25.22 cde
Y4×C15×F100	2.142abcd	0.1100bcde	1.183 c	1.730 a	218.0 c	11.17hij	76.33 bc	431.1 cd	57.60 ab	12.83 abc	28.82 b
Y4×C15×F200	2.127abcd	0.1133bcde	1.227 c	1.720 ab	268.7 b	11.83hi	68.00 bc	381.5 gh	60.70 a	13.67 a	31.52 a

Y2= 2017, Y4=2019, C0=control, C10=10 kg, C15=15 kg, F0=control, F100= 100g, F200=200g
Means followed by the same letters are not significantly different (P ≤ 0.05) base on LSD test.

(Table 21). The average of Ca, Fe and Zn concentrations in the Akbari cultivar were higher. Whereas, the mean of N, P, K, Zn and Mn concentrations was greater in Badami Zarand cultivar (Table 21). There may be an antagonistic interaction between free-living diazotrophs increasing because of increased rainfall with mycorrhiza, resulting in more normal leaves affected by F0 (control) than by F100 and F200 (Table 21). The Y4×Ak×C15×F200 treatment displayed maximum growth parameters, calcium and iron concentration (Table 23).

Mycorrhizal dependency (MD) effects: One of the important indications of mycorrhizal inoculation on plant growth and nutrient uptake is mycorrhizal dependency (MD) (Plenchette *et al.*, 1983; Ortas *et al.*, 1996). Mycorrhizal fungi form an association with plant

[DOI: DOI: 10.22034/13.61.15]

Table 21. The interaction effect of pistachio cultivars, pistachio waste compost and mycorrhizal fungus on growth parameters, nutrients and leaflet number of pistachios

Treat.	N	P	K	Ca	Fe	Zn	Mn	Branch height
Unit	(%)	(%)	(%)	(%)	(ppm)	(ppm)	(ppm)	(cm)
Ak×C0×F0	2.032 abcd	0.1017 d	1.163 cde	1.568bcdefg	193.2 e	20.33 cd	55.17 i	43.50 de
Ak ×C0×F100	1.945 e	0.1150 abcd	1.173 cde	1.627 abcd	193.7 e	20.00cde	56.33 hi	43.47 de
Ak ×C0×F200	2.018 bcde	0.1233 a	1.182 bcde	1.620 abcd	206.5 d	23.67 b	48.67 j	41.33 def
Ak ×C10×F0	1.937 e	0.1133 abcd	1.235 abcde	1.498 defg	196.3 e	18.67 def	60.00 fgh	41.15 def
Ak×C10×F100	2.093 abc	0.1167 abcd	1.168 cde	1.645 abc	182.0 fg	19.83 cde	63.17 cdef	39.03 fg
Ak×C10×F200	1.965 de	0.1067 bcd	1.133 de	1.732 a	228.7 b	21.50 c	56.33 hi	40.00 ef
Ak × C15×F0	2.145 a	0.1200 abc	1.405 a	1.475 efg	206.7 d	20.17 cd	47.67 j	44.20 cd
Ak×C15×F100	2.010 cde	0.1067 bcd	1.090 e	1.698 ab	221.3 bc	20.67 c	64.17 cde	44.22 cd
Ak×C15×F200	2.138 ab	0.1183 abc	1.415 a	1.540cdefg	237.3 a	21.50 c	54.67 i	49.43 b
Ba×C0×F0	2.085abcd	0.1150 abcd	1.393 ab	1.595bcdef	175.0 gh	21.33 c	57.67 ghi	40.17 ef
Ba×C0×F100	2.015bcde	0.1217 ab	1.350 abcd	1.607abcde	138.0 k	17.67 f	60.67 efg	53.07 a
Ba×C0×F200	2.107 abc	0.1083 abcd	1.332 abcd	1.457 g	166.5 i	18.33 ef	79.17 a	36.17 g
Ba×C10×F0	2.145 a	0.1050 cd	1.253 abcde	1.693 ab	171.8 hi	21.00 c	65.33 cd	41.12 def
Ba×C10×F100	2.133 abc	0.1150 abcd	1.287 abcde	1.462 fg	170.2 hi	17.83 f	82.83 a	40.83 def
Ba×C10×F200	2.095 abc	0.1200 abc	1.367 abc	1.597 bcde	220.8 c	21.17 c	73.33 b	40.08 ef
Ba×C15×F0	2.147 a	0.1200 abc	1.400 a	1.475 efg	176.3 fgh	28.42 a	66.25 c	48.7 b
Ba×C15×F100	2.150 a	0.1183 abc	1.310 abcd	1.583bcdefg	152.0 j	20.50 c	62.00 def	48.98 b
Ba×C15×F200	2.093 abc	0.1200 abc	1.257 abcde	1.575bcdefg	183.3 f	19.83 cde	66.67 c	47.65 bc

Treat.	Leaf area	Branch diameter	Seedling width	1 leaflet	2 leaflets	3leaflets	4 leaflets	5 leaflets
Unit	(cm^2)	(mm)	(cm)	(%)	(%)	(%)	(%)	(%)
Ak×C0×F0	368.1 g	10.67 ab	25.28 a	50.70 c	6.933 i	30.53 gh	3.867 ghij	7.733 fg
Ak ×C0×F100	490.5 b	10.67 ab	15.48 k	37.40 ef	9.933 fg	33.47 fg	6.667 de	12.27 cd
Ak×C0×F200	410.4 e	10.50 ab	18.18 fghij	32.43 fgh	15.40 b	23.53 j	5.200 efg	32.27 a
Ak ×C10×F0	424.7 d	9.500 bc	18.42 fghi	61.60 b	4.700 j	18.93 k	3.500 hij	10.10 def
Ak×C10×F100	429.6 d	8.500 c	18.27 fghij	41.63 de	7.667 hi	25.00 ij	6.967 cd	18.83 b
Ak×C10×F200	389.2 f	9.333 bc	15.90 jk	73.67 a	6.667 i	12.93 l	1.800 k	4.800 hij
Ak ×C15×F0	505.9 a	9.833 bc	19.25 efgh	42.50 de	10.87 ef	28.20 hi	6.867 cd	11.03 cde
Ak×C15×F100	453.8 c	10.50 ab	22.82 bc	27.17 hi	13.40 c	45.87 b	5.000 fgh	8.700 efg
Ak×C15×F200	383.2 f	11.83 a	23.97 ab	21.13 jk	10.67 ef	48.57 ab	12.17 a	7.233 gh
Ba×C0×F0	420.1 de	10.00 b	17.10 hijk	33.37 fg	11.93 de	38.13 cde	4.567 fghi	11.77 cd
Ba×C0×F100	389.3 f	9.833 bc	15.88 jk	32.67 fgh	10.07 fg	33.53 fg	5.933 def	17.57 b
Ba×C0×F200	385.4 f	9.500 bc	17.30 ghijk	20.50 jk	8.033 hi	40.20 cd	11.30 a	13.13 c
Ba×C10×F0	348.5 h	10.50 ab	21.85 bcd	40.97 de	8.833 gh	40.50 c	3.200 ijk	6.233 ghi
Ba×C10×F100	295.3 j	10.00 b	20.90 cde	19.27 k	12.03 cde	47.77 ab	8.433 bc	12.27 cd
Ba×C10×F200	323.3 i	9.333 bc	18.28 fghij	28.93 ghi	18.20 a	35.37 ef	2.300 jk	3.300 j
Ba×C15×F0	330.5 i	9.833 bc	16.30 ijk	30.97.ghi	10.03 fg	51.73 a	2.600 jk	4.400 ij
Ba×C15×F100	433.2 d	10.67 ab	19.67 defg	26.00 ij	12.83 cd	36.30 def	9.233 b	16.70 b
Ba×C15×F200	428.6 d	10.50 ab	20.22 def	45.00 cd	7.733 hi	39.63 cd	3.667 ghij	3.733 ij

AK= Akbari var., Ba=Badami Zarand Var., C0=control, C10=10 kg, C15=15 kg, F0=control, F100= 100g, F200=200g
Means followed by the same letters are not significantly different (P ≤ 0.05) base on LSD test.

Table 22. The effect of mycorrhizal dependency on growth parameters, leaf nutrients and leaflet number of pistachios

Treat.	N	P	K	Ca	Fe	Zn	Mn	Leaf area	Branch height	Branch diameter	Seedling width	1 leaflet	2 leaflets	3 leaflets	4 leaflets	5 leaflets
Unit	%															
MD_{F100}	-1.2	2.7	-6.3	3.3	5.9	-11.5	9.5	3.8	4.2	-0.3	-4.6	-41.3	19.2	6.3	41.8	40.6
MD_{F200}	-0.6	3.1	-2.1	2.3	9.9	-3.1	7.1	-3.3	-1.4	1.1	-3.8	-17.4	20.1	-3.9	32.5	20.4

MD_{F100} and MD_{F200} are mycorrhizal dependence to 100 and 200 grams of mycorrhizal fungi, respectively.

roots, which enhances plant nutrient uptake, especially of P, Zn, Cu, K, and partly ammonium-nitrogen (NH_4^+) in soils with low fertilization (Ortas, 2003). A comparison of mycorrhizal dependency results (Table 22) showed P, Ca, Fe and Mn responded positively to MGD at both levels of fungi consumption (100 and 200 g). The highest percent of mycorrhizal dependency was found in the Fe_{200} and Mn_{100} treatments among the

[DOI: DOI: 10.22034/13.61.15]

Table 23. The interaction effect of year, pistachio cultivars, pistachio waste compost and mycorrhizal fungus on growth parameters and nutrients of pistachios

Treatment	N	P	K	Ca	Fe	Zn	Mn
Unit	%	%	%	%	ppm	ppm	ppm
Y2×Ak×C0×F0	1.997 efgh	0.1067 defg	1.273 bcdefghij	1.510 fghij	146.3 mno	30.33 ef	56.00 klmno
Y2×Ak ×C0×F100	1.893 hi	0.1167 bcdefg	1.237 defghij	1.537 defghij	154.3 m	28.33 fg	62.33 ghij
Y2×Ak ×C0×F200	2.037 cdefgh	0.1400 a	1.373 bcdefgh	1.443 hijk	182.0 l	32.33 cde	60.33 hijk
Y2×Ak ×C10×F0	1.893 hi	01100 cdefg	1.300 bcdefghi	1.497 ghijk	151.7 mn	29.67 f	59.67 hijkl
Y2×Ak×C10×F100	2.050 cdefgh	0.1267 abcd	1.167 efghij	1.587 cdefghi	142.3 nop	30.00 ef	68.33 def
Y2×Ak×C10×F200	1.817 i	0.1033 efg	1.160 efghij	1.587 cdefghi	205.3 jk	30.67 def	67.33 efg
Y2×Ak ×C15×F0	2.140 abcdef	0.1367 ab	1.557 ab	1.320 kl	185.3 l	29.33 f	55.67 klmno
Y2×Ak×C15×F100	2.023 defgh	0.1133 cdefg	1.100ghij	1.630 bcdefgh	182.3 l	29.33 f	63.67 fghi
Y2×Ak×C15×F200	2.107 bcdef	0.1233 abcde	1.720 a	1.207 l	148.3 mno	29.67 f	53.33 nop
Y2×Ba×C0×F0	2.087 bcdefg	0.1300 abc	1.267 bcdefghij	1.517 efghij	139.7 op	37.33 b	59.33 ijklm
Y2×Ba×C0×F100	1.927 ghi	0.1200 abcdef	1.247 cdefghij	1.533 defghij	128.0 qr	26.00 g	48.00 qr
Y2×Ba×C0×F200	2.127 abcdef	0.1100 cdefg	1.263 bcdefghij	1.520 efghij	119.3 r	26.67 g	68.67 def
Y2×Ba×C10×F0	2.177 abcd	0.09667 g	1.167 efghij	1.583 cdefghi	146.7 mno	33.00 cd	51.00 opq
Y2×Ba×C10×F100	2.030 defgh	0.1167 bcdefg	1.350 bcdefghi	1.460 hijk	126.7 qr	26.33 g	54.67 lmnop
Y2×Ba×C10×F200	1.980 fghi	0.1133 cdefg	1.183 efghij	1.573 defghij	140.7 op	34.00 c	52.00 opq
Y2×Ba×C15×F0	2.113abcdef	0.1300 abc	1.413 abcdef	1.420 ijk	134.7 pq	45.33 a	60.00 hijk
Y2×Ba×C15×F100	2.013defgh	0.1167 bcdefg	1.333 bcdefghi	1.473hijk	128.3 qr	30.67 def	54.00 nop
Y2×Ba×C15×F200	2.103bcdef	0.1267 abcd	1.170 efghij	1.583 cdefghi	155.7 m	29.33 f	53.33 nop
Y4×Ak×C0×F0	2.067 bcdefgh	0.09667 g	1.053 ij	1.627 bcdefgh	240.0 d	10.33 jklmn	54.33 mnop
Y4×Ak ×C0×F100	1.997efgh	0.1133 cdefg	1.110 fghij	1.720 abcd	233.0 de	11.67 ijkl	50.33 pqr
Y4×Ak ×C0×F200	2.000 efgh	0.1067 defg	09900 j	1.797 ab	231.0 def	15.00 h	37.00 s
Y4×Ak ×C10×F0	1.980 fghi	0.1167bcdefg	1.170 efghij	1.500 ghijk	241.0 d	7.667 op	60.33 hijk
Y4×Ak×C10×F100	2.137 abcdef	0.1067 defg	1.170 efghij	1.703 abcde	221.7 fgh	9.667 klmno	58.00 jklmn
Y4×Ak×C10×F200	2.113 abcdef	0.1100 cdefg	1.107 fghij	1.877 a	252.0 c	12.33 ij	45.33 r
Y4×Ak ×C15×F0	2.150 abcdef	0.1033 efg	1.253 bcdefghij	1.630 bcdefgh	228.0 efg	11.00 ijklm	39.67 s
Y4×Ak×C15×F100	1.997 efgh	0.1000 fg	1.080 hij	1.767 abc	260.3 c	12.00 ijk	64.67 fgh
Y4×Ak×C15×F200	2.170abcde	0.1133 cdefg	1.110 fghij	1.873 a	326.3 a	13.33 hi	56.00 klmno
Y4×Ba×C0×F0	2.083 bcdefg	0.1000 fg	1.520 abcd	1.673 bcdefg	210.3 ij	5.333 p	56.00 klmno
Y4×Ba×C0×F100	2.103 bcdef	0.1233 abcde	1.453 abcde	1.680 bcdefg	148.0 mno	9.333 lmno	73.33 d
Y4×Ba×C0×F200	2.087 bcdefg	0.1067 defg	1.400 bcdefg	1.393 jkl	213.7 hij	10.00 jklmno	89.67 b
Y4×Ba×C10×F0	2.113 abcdef	0.1133 cdefg	1.340 bcdefghi	1.803 ab	197.0 k	9.000 mno	79.67 c
Y4×Ba×C10×F100	2.237 ab	0.1133 cdefg	1.223 defghij	1.463 hijk	213.7 hij	9.333 lmno	111.0 a
Y4×Ba×C10×F200	2.210 abc	0.1267 abcd	1.550 abc	1.620 bcdefgh	301.0 b	8.333 no	94.67 b
Y4×Ba×C15×F0	2.180 abcd	0.1100 cdefg	1.387 bcdefgh	1.530 efghij	218.0 ghi	11.50 ijkl	72.50 de
Y4×Ba×C15×F100	2.287 a	0.1200 abcdef	1.287 bcdefghij	1.693 abcdef	175.7 l	10.33 jklmn	70.00 de
Y4×Ba×C15×F200	2.083 bcdefg	0.1133 cdefg	1.343 bcdefghi	1.567 defghij	211.0 hij	10.33 jklmn	80.00 c

Y2= 2017, Y4=2019, AK= Akbari var., Ba=Badami Zarand Var., C0=control, C10=10 kg, C15=15 kg, F0=control, F100= 100g, F200=200g

Means followed by the same letters are not significantly different (P ≤ 0.05) based on the LSD test.

nutrients, with 9.9% and 9.5, respectively, compared to the control (Table 22). Mycorrhizal dependency was observed at both levels of fungal consumption on plant calcium and manganese content, but it was higher at the 100 g level (Table 22).

The higher number of 4 and 5 leaflets (developed leaves) per leaf was affected by mycorrhizal dependency (Table 22). The high number of leaflets per leaf indicates more differentiation in pistachio leaves. Therefore, this study indicated that mycorrhizal consumption, particularly at the second level (100 g), caused more cellular differentiation in pistachio leaves under saline-alkaline conditions. At the highest level of mycorrhizal symbiosis (MDF_{200}), nutrient concentrations, especially iron, were highest, which had a reversed relationship with normal leaf production (Table 22).

Conclusions

Under soil salinity and alkalinity stress conditions, we can conclude two different explanations for leaf pistachio development; 1) As compared to the highest levels (15 kg seedling^{-1} pistachio waste compost and 200 g mycorrhizal fungi), the synergistic effect of 10 kg seedling^{-1} pistachio waste compost and 100 g mycorrhizal consumption produced a smaller effect on micronutrient absorption. Consequently, micronutrient uptake was lower in both cultivars at lower levels, particularly in Badami Zarand. Also, the less salt-tolerant cultivar (Badami Zarand) decreased leaf area and iron concentration. Therefore, photosynthesis decreased and nutritional stress increased, resulting in a

[DOI: DOI: 10.22034/13.61.15]

Continue of table 23.

Treatment	Leaf area	Branch height	Branch diameter	Seedling width
Unit	cm^2	cm	mm	cm
Y2×Ak×C0×F0	368.4 ^{k}	37.93 ^{hijk}	8.667 ^{efg}	18.67 ^{j}
Y2×Ak ×C0×F100	480.2 ^{bc}	35.00 ^{jklmn}	7.667 ^{fgh}	8.667 ^{n}
Y2×Ak ×C0×F200	419.1 ^{hij}	31.83 ^{lmn}	7.333 ^{fgh}	11.33 ^{klmn}
Y2×Ak ×C10×F0	426.5 ^{fghi}	36.73 ^{jkl}	7.333 ^{fgh}	11.00 ^{lmn}
Y2×Ak×C10×F100	436.3 ^{efgh}	25.73 ^{o}	7.000 ^{fgh}	11.00 ^{lmn}
Y2×Ak×C10×F200	355.0 ^{klm}	31.00 ^{mn}	6.667 ^{gh}	10.00 ^{mn}
Y2×Ak ×C15×F0	511.9 ^{a}	36.07 ^{jklmn}	7.667 ^{fgh}	11.33 ^{klmn}
Y2×Ak×C15×F100	462.6 ^{cd}	34.17 ^{klmn}	8.333 ^{efgh}	14.33 ^{kl}
Y2×Ak×C15×F200	420.6 ^{ghij}	38.20 ^{hijk}	9.000 ^{ef}	13.67 ^{kl}
Y2×Ba×C0×F0	419.3 ^{hij}	34.67 ^{jklmn}	8.333 ^{efgh}	11.00 ^{lmn}
Y2×Ba×C0×F100	410.7 ^{ij}	44.70 ^{efg}	7.667 ^{fgh}	11.00 ^{lmn}
Y2×Ba×C0×F200	421.0 ^{ghij}	30.43 ^{no}	6.333 ^{h}	11.67 ^{klmn}
Y2×Ba×C10×F0	365.7 ^{kl}	42.73 ^{fgh}	8.333 ^{efgh}	14.33 ^{kl}
Y2×Ba×C10×F100	299.5 ^{p}	34.17 ^{klmn}	7.667 ^{fgh}	14.67 ^{k}
Y2×Ba×C10×F200	342.2 ^{mno}	37.50 ^{ijk}	7.333 ^{fgh}	11.00 ^{lmn}
Y2×Ba×C15×F0	331.7 ^{no}	39.40 ^{hij}	7.000 ^{fgh}	9.333 ^{n}
Y2×Ba×C15×F100	449.3 ^{de}	37.03 ^{ijk}	8.333 ^{efgh}	13.00 ^{klm}
Y2×Ba×C15×F200	440.1 ^{efg}	34.57 ^{jklmn}	8.333 ^{efgh}	11.67 ^{klmn}
Y4×Ak×C0×F0	367.8 ^{k}	49.07 ^{de}	12.67 ^{abc}	31.90 ^{ab}
Y4×Ak ×C0×F100	500.9 ^{a}	51.93 ^{bcd}	13.67 ^{ab}	22.30 ^{jhi}
Y4×Ak ×C0×F200	401.8 ^{j}	50.83 ^{cd}	13.67 ^{ab}	25.03 ^{efgh}
Y4×Ak ×C10×F0	423.0 ^{ghi}	45.57 ^{efg}	11.67 ^{bcd}	25.83 ^{def}
Y4×Ak×C10×F100	422.9 ^{ghi}	52.33 ^{bcd}	10.00 ^{de}	25.53 ^{defg}
Y4×Ak×C10×F200	423.4 ^{ghi}	49.00 ^{de}	12.00 ^{bcd}	21.80 ^{hij}
Y4×Ak ×C15×F0	499.8 ^{ab}	52.33 ^{bcd}	12.00 ^{bcd}	27.17 ^{cde}
Y4×Ak×C15×F100	445.0 ^{def}	54.27 ^{bc}	12.67 ^{abc}	31.30 ^{ab}
Y4×Ak×C15×F200	345.9 ^{lmno}	60.67 ^{a}	14.67 ^{a}	34.27 ^{a}
Y4×Ba×C0×F0	420.9 ^{ghij}	45.67 ^{efg}	11.67 ^{bcd}	23.20 ^{fghi}
Y4×Ba×C0×F100	368.0 ^{k}	61.43 ^{a}	12.00 ^{bcd}	20.77 ^{ij}
Y4×Ba×C0×F200	349.9 ^{klmn}	41.90 ^{ghi}	12.67 ^{abc}	22.93 ^{fghi}
Y4×Ba×C10×F0	331.2 ^{no}	39.50 ^{hij}	12.67 ^{abc}	29.37 ^{bc}
Y4×Ba×C10×F100	291.0 ^{p}	47.50 ^{def}	12.33 ^{bc}	27.13 ^{cde}
Y4×Ba×C10×F200	304.4 ^{p}	42.67 ^{fgh}	11.33 ^{cd}	25.57 ^{defg}
Y4×Ba×C15×F0	329.4 ^{o}	56.73 ^{ab}	12.67 ^{abc}	23.27 ^{fghi}
Y4×Ba×C15×F100	417.1 ^{hij}	60.93 ^{a}	13.00 ^{abc}	26.33 ^{cdef}
Y4×Ba×C15×F200	417.1 ^{hij}	60.73 ^{a}	12.67 ^{abc}	28.77 ^{bcd}

Y2= 2017, Y4=2019, AK= Akbari var., Ba=Badami Zarand Var., C0=control, C10=10 kg, C15=15 kg, F0=control, F100= 100g, F200=200g

Means followed by the same letters are not significantly different (P ≤ 0.05) based on the LSD test.

greater number of normal leaves (3 and 5 leaflets per leaf) and possibly more cellular differentiation.

2) The trend of two climatic parameters, including precipitation (more than +114% increase) and the temperature of the first three months (April, May, and June) of the growing season (nearly 4 ˚C decrease), was improved during the experimental years, so the nutrient status, particularly iron (78 ppm increase) and Mn (8 ppm increase), increased. There was a significant increase in the number of leaves as a result of the increased vegetative growth, including branch height, diameter, and seedling width; consequently, leaf area decreased. Leaf area reduction was not affected by micronutrient stress, but it was decreased by the number of leaves rising and so the abnormal leaves (1, 2 and 4 leaflets) increased.

Pistachio leaf area and number of leaflets per leaf, two factors that contribute to salinity resistance, were found to be inversely related in this study. The leaf area reduction in the first hypothesis is caused by the natural growth inhibitors due to the increase in nutrient stress, while the leaf area reduction in the second hypothesis is caused by the increase in the number of leaves. In addition, this study displayed that the concentration and status of micronutrients (Fe) and (Mn) are very important factors in the normality of leaf status, along with the other environmental factors. In the presence of high concentrations of Mn and Fe, abnormal leaves were produced for different reasons. A high concentration of Mn disrupts cell division, and a great Fe concentration produces more abnormal leaves, probably due to potent oxidizer production in physiological excess concentration and so cell division disturbance. However, these results require further

[DOI: DOI: 10.22034/13.61.15]

studies and evidence to confirm them due to their enormous complexity.

Under none non-environmental stress conditions, the plant makes more abnormal leaves. While under nutritional stress conditions especially micronutrients, the plant produces more normal leaves to compensate for the stress condition. However, as the number of normal leaves increases, their size and area decrease.

References

Abbaspour, H., Saeidi-Sar, S., Afshari, H., & Abdel-Wahhab, M. (2012). Tolerance of Mycorrhiza infected Pistachio (*Pistacia vera* L.) seedling to drought stress under glasshouse conditions. *Journal of Plant Physiology*, *169*(7), 704-9. https://doi.org/10.1016/j.jplph.2012.01.014

Acton, Q. A. (2012). Carbonates—Advances in Research and Application. Atlanta, Georgia, USA, Scholarly Editions.

Alejandro, S., Holler, S., Meier, B., & Peiter, E. (2020). Manganese in plants: From acquisition to subcellular allocation. *Frontiers in Plant Science*, *11*, 300. https://doi.org/10.3389/fpls.2020.00300

Aliehyaei, M. & Behbahanizadeh, A. A. (1993). Descriptions of Methods for Soil Chemical Analysis No. 893. Soil and Water Research Institute. Agricultural Research, Extension and Education Organization. Ministry of Agriculture.

Amanifar, S. & Toghranegar, Z. (2020). The efficiency of Arbuscular mycorrhiza for improving tolerance of *Valeriana officinalis* L. and enhancing valerenic acid accumulation under salinity stress. *Industrial Crops and Products*, *147*, 112234. https://doi.org/10.1016/j.indcrop.2020.112234

Arya, R. L. & Khan, K. (2020). Fundamentals of Soil Science. Scientific Publishers, India.

Asghari, H. (2002). The effect of dormex, volk oil and nitrate potassium on remove bud pistachio dormancy (*Pistacia vera* L.) in the tropic. M. Sc. Thesis, College of Agriculture, Shiraz University.

Bagheri, V., Shamshiri, M. H., Shirani, H., & Roosta, H. R. (2012). Nutrient uptake and distribution in Mycorrhizal Pistachio seedlings under drought stress. *Journal of Agriculture Science and Technology*, *14*, 1591-1604. 20.1001.1.16807073.2012.14.7.3.5

Baligar, V. C., Fageria, N. K., & He, Z. L. (2001). Nutrient use efficiency in plants. *Communications in Soil Science and Plant Analysis*, *32*(7-8), 921-950. https://doi.org/10.1081/CSS-100104098

Becana, M., Moran, J. F., & Iturbe-Ormaetxe, I. (1998). Iron-dependent oxygen free radical generation in plants subjected to environmental stress: Toxicity and antioxidant protection. *Plant and Soil*, *201*, 137-147. https://doi.org/10.1023/A:1004375732137

Cao, Y., Wu, X., Zhukova, A., Tang, Z., Weng, Y., Li, Z., & Yang, Y. (2020). *Arbuscular mycorrhizal* fungi (AMF) species and abundance exhibit different effects on saline-alkaline tolerance in *Leymus chinensis*. *Journal of Plant Interaction*, *15*(1), 266-279. DOI:10.1080/17429145.2020.1802524

Camprubi, E., Jordan, S. F., Vasiliadou, R., & Lane, N. (2017). Iron catalysis at the origin of life. *IUBMB Life*, *69* (6), 373-381. https://doi.org/10.1002/iub.1632

Chou, F. I. & Tan, S. T. (1990). Manganese (II) induces cell division and increases in superoxide dismutase and catalase activities in an aging deinococcal culture. *Journal of Bacteriology*, *172*(4), 2029-2035. doi: 10.1128/jb.172.4.2029-2035.1990

Cui, G., Lu, Y., Zheng, C., Liu, Z., & Sai, J. (2019). Relationship between soil salinization and groundwater hydration in Yaoba Oasis, Northwest China. *Water*, *11*(1), 175. https://doi.org/10.3390/w11010175

Dar, G. H. (2010). Soil Microbiology and Biochemistry. New India Publishing Agency, India.

Doshi, R. (2016). Soil Fertility and Nutrient Management. Scitus Academics, USA.

Esmailpour, A. (2005). Characteristics and special traits in the most important pistachio cultivars. Report No.27. Pistachio Research Institute, Rafsanjan, Iran.

FAO, (1982). Chemical and physical factors on the composting process and product quality. In: Organic materials on soil productivity in the Near East. Report No. 45.

Ferguson, L., Kaur, S., & Epstein, L. (1998). Arbuscular mycorrhizal fungi on pistachio rootstocks in California. *Acta Horticulture*, *470*, 211-218. 10.17660/ActaHortic.1998.470.29

Ferguson, L., Polito, V., & Kallsen, C. (2005). The pistachio tree; botany and physiology and factors that affect yield. Pistachio production manual, 4th Ed, Davis, CA, USA: University of California Fruit & Nut Research Information Center.

Forough Ameri, N. (1997). Determining the nutritional value and digestibility of dried and siloed pistachio hulls. M. Sc. thesis, Isfahan University of Technology.

Foth, H. D. (1990). Fundamentals of soil science. 8th Ed, Wiley Publication, USA.

Hasanuzzaman, M., Fujita, M., Oku, H., Nahar, K., & Hawrylak-Nowak, B. (2018). Plant Nutrients and Abiotic Stress Tolerance. Springer.

Haydari, M. (2014). Investigating the possibility of converting soft pistachio skin into compost and vermicompost. Report No. 45911. National Pistachio Research Institute. Rafsanjan, Iran.

Hayman, D. S. (1987). VA Mycorrhizas in Field Crop Systems. In: 'Ecophysiology of VA Mycorrhizal Plants' Ed. G.R Safir. CRC Press, Boca Raton, Florida, United States.

[DOI: DOI: 10.22034/13.61.15]

Hilo, A., Shahinnia, F., Druege, U., Franken, P., Melzer, M., Rutten, T., Wiren N. V., & Hajirezaei, M. R. (2017). A specific role of iron in promoting meristematic cell division during adventitious root formation. *Journal of Experimental Botany*, *68*(15), 4233-4247. DOI: 10.1093/jxb/erx248

Hokmabadi, H. & Sherafati, A. (2015). Effect of some pistachio rootstocks on nutrients element uptake of two Pistachio cultivars (Akbari and Bargsiyah). *Pistachio Science and Technology*, *1*, 32-43.

Hokmabadi, H., Rezaie, M., & Hokm Abadi, H. (2015). Investigation of the effect of ambient temperature on the uptake of phosphorus and nitrogen in several commercial pistachio rootstocks under controlled conditions. National Conferences on Scientific Approach in Green Gold Industry, Pistachio, Damghan, Iran.

Hokmabadi, H. (2011). Diagnostic of Environmental and Non environmental Damaging Factors Incoming to Pistachio Product. Education and Agricultural Promotion. Tehran, Iran.

Hokmabadi, H., Arzani, K., Dehghani-Shooraki, Y., & Panahi, B. (2004). Response of badami-zarand, sarakhs and ghazvini pistachio rootstocks to sodium chloride and boron excess in irrigation water. *Journal of Science and Technology of Agriculture and Natural Resources*, *7*(4), 11-24. https://sid.ir/paper/15017/en

Hokmabadi, H. & Javanshah, A. (2006). Meeting the chilling requirement and its importance in pistachios. Report No. 39. Pistachio Research Center. Rafsanjan, Iran.

Hosseini fard, J., Basirat, M., Sedaghati, N., & Akhiyani, A. (2017). Integrated management of soil fertility and plant nutrition in pistachio trees. Soil and Water Research Institute Press, Karaj, Iran.

Javanshah, A. (2008). Global warming affected some morphological characters of Pistachio trees (*Pistacia vera* L.). Nature Proceedings 3. https://doi.org/10.1038/npre.2008.2574.1

Javanshah, A. & Nazori, F. (2005). Global warming, dormancy and chilling requirement on temperate trees. Pistachio research institute Press. Rafsanjan, Iran.

Kalra, Y. P. (1998). Handbook of Reference Methods for Plant Analysis. CRC Press, Boca Raton, Florida, United States.

Klinsukon, C., Lumyong, S., Kuyper, T. W., & Boonlue, S. (2021). Colonization by Arbuscular mycorrhizal fungi improves salinity tolerance of eucalyptus (*Eucalyptus camaldulensis*) seedlings. *Scientific Reports*, *11*(1), 4362. https://doi.org/10.1038/s41598-021-84002-5

Klute, A. (1986). Method of soil analysis part l: Physical and mineralogical methods. 2nd ed. American Society of Agronomy and Soil Science Society of America, Madison, WI, USA.

Lambers, H., Albornoz, F., Kotula, L., Laliberte, E., Ranathunge, K., Teste F. P., & Zemunik, G. (2018). How belowground interactions contribute to the coexistence of mycorrhizal and non-mycorrhizal species in severely phosphorus-impoverished hyperdiverse ecosystems. *Plant and Soil*, *424*, 11-33. https://doi.org/10.1007/s11104-017-3427-2

Lerner, H. R. (1999). Plant Responses to Environmental Stresses: From Phytohormones to Genome Reorganization. 1st Ed, CRC Press, Boca Raton, Florida, United States.

Le, N. & Richardson, D. R. (2002). The role of iron in cell cycle progression and the proliferation of neoplastic cells. *Biochimica et Biophysica Acta*, *1603*(1), 31-46. DOI: 10.1016/s0304-419x (02)00068-9

Marschner, H. (2011). Marschner's Mineral Nutrition of Higher Plants. Academic Press, Cambridge, Massachusetts, United States.

Mehrnejad, M. R. & Javanshah, A. (2010). The strategic framework for developing and promoting pistachio research in Iran. Jomhori Publication, Tehran, Iran.

Mengel, K. & Kirkby, E. A. (2012). Principle of Plant Nutrition. 5th Ed, Berlin, Germany: Springer Science & Business Media.

Moein rad, H. (2000). Investigation of different varieties of pistachio to salinity stress. Ph.D. Thesis, Islamic Azad University Science and Research Branch, Tehran, Iran.

Miri Dysfani, M. & Sherafati, A. (2013). The effect of organic fertilizers on vegetative growth and nutrient uptake in two cultivars of pistachio Akbari & Badami Sefid Feyzabad. Abstract book of the 13th Iranian Soil Science Congress. Shahid Chamran University, Ahvaz, Iran.

Mohajeryfar, S., Khorasany, S., & Pakkish, Z. (2020). Investigation on the effect of preserving epi-carp during drying on physico-chemical and organoleptic properties of pistachio kernel (Ohadi cultivar). *Journal of Food Science and Technology*, *16*(96), 75-90.10.29252/fsct.16.96.75

Mohammadi Mohammad Abadi, A. (1998). The effect of soil and water salinity on pistachio rootstocks. Report No.13. Pistachio Research Institute, Rafsanjan, Iran.

Mulder, D. (1954). Les elements mineurs en culture fruitiere. *Convegno Nazionale Fruitticoltura, French Montana de Saint Vincent*, 98-118.

Neyshaburi, S., Rezaei, M., Movahednejad, M. H., Hokmabadi, H., & Heidari, P. (2021). Morphological and phenological characterizations of some male and female promising Pistachio genotypes from an open-pollinated population. *International Journal of Fruit Science*, *21*(1), 456-467. https://doi.org/10.1080/15538362.2021.1896982

Nilsen, E. T. & Orcutt, D. M. (1996). The Physiology of Plants under Stress, Abiotic Factors. 2nd Ed, Wiley, New York, United States.

[DOI: DOI: 10.22034/13.61.15]

Ortas, I. (2003). Effect of selected mycorrhizal inoculation on phosphorus sustainability in sterile and non-sterile soils in the Harran Plain in south Anatolia. *Journal of Plant Nutrition*, *26*(1), 1-17. https://doi.org/10.1081/PLN-120016494

Ortas, I., Harris, P. J., & Rowell, D. L. (1996). Enhanced uptake of phosphorus by mycorrhizal sorghum plants as influenced by forms of nitrogen. *Plant and Soil*, *184*, 255-264. https://doi.org/10.1007/BF00010454

Pinto, S. D. S., Souza, A. E. D., Oliva, M. A., & Pereira, E. G. (2016). Oxidative damage and photosynthetic impairment in tropical rice cultivars upon exposure to excess iron. *Scientia Agricola*, *73(3)*, 217-226. https://doi.org/10.1590/0103-9016-2015-0288

Plenchette, C., Fortin, J. A., & Furlan, V. (1983). Growth-responses of several plant-species to mycorrhizae in a soil of moderate P-fertility. 1. Mycorrhizal dependency under field conditions. *Plant and Soil*, *70*, 199-209. https://doi.org/10.1007/BF02374780

Rahi, A. R. (2013). Effect of nitroxin biofertilizer on morphological and physiological traits of *Amaranthus retroflexus*. *Iranian Journal of Plant Physiology*, *4*(1), 899-905.

Rengel, Z. (2015). Availability of Mn, Zn and Fe in the rhizosphere. *Journal of Soil Science and Plant Nutrition*, *15*(2), 397-409. http://dx.doi.org/10.4067/S0718-95162015005000036

Ryan, J., Estefan, G., & Rashid, A. (2001). Soil and Plant Analysis Laboratory Manual. 2nd Ed. International Center for Agriculture Research in the Dry Areas (ICARDA). Aleppo, Syria. National Agricultural Research Center, Islamabad, Pakistan.

Ryugo, K. (1988). Fruit Culture: Its Science and Art. John Wiley and Sons Press, New York, United States.

Safari Kamal Abadi, H. (2020). The effect of Arbuscular mycorrhizal fungi on nutrient concentrations in Ohadi (Fandoghi) and Kalleghouchi Pistachio seedlings in Kerman region. *Agricultural Marketing and Commercialization Journal*, *4*(2), 1-7.

Sajedi, N. A. & Rejali, F. (2011). The effect of drought stress, zinc application and mycorrhiza inoculation on the uptake of trace elements in maize. *International Journal of Science and Research*, *25(2)*, 83-92. 10.22092/IJSR.2011.126473

Sanjari Nia, M., Sarcheshmeh Pour, M., & Khezri, M. (2013). Overview of colonization percentage of Arbuscular mycorrhizal fungi in Pistachio orchards suburban areas of Kerman. Proceeding of the 8th Iranian horticultural Sciences congress. Bu-Ali Sina University, Hamedan, Iran.

Sarsour, E. H., Kalen, A. L., & Goswami, P. C. (2014). Manganese superoxide dismutase regulates a redox cycle within the cell cycle. *Antioxidants and Redox Signaling*, *20*(10), 1618-1627. DOI: 10.1089/ars.2013.5303

Shahbandeh, M. (2021). Pistachio Production Worldwide 2007-2021. Info Graphics. Statistica Publisher.

Sherafati, A., Arzani, K., & Ramzani Moghadam, M. R. (2013). Assessment of flowering and bearing of twelve Pistachio (*Pistacia vera* L.) cultivars under Khorasan environmental conditions. *Seed and Plant Improvement Journal*, *29*(2), 243-256. 10.22092/SPIJ.2017.111155

Shool, A., Shamshiri, M. H., Akhgar, A. R., & Esmaili Zadeh, M. (2014). The effect of Arbuscular mycorrhizal fungus (*Glomus mosseae*) and *Pseudomonas fluorescent* on nutrient uptake of pistachio seedlings of Qazvini cultivar in four irrigation regimes. *Journal of Child Psychology and Psychiatry*, *45(3)*, 297-307. 10.22059/IJHS.2014.52879

Strawn, D. G., Bohn, H. L., & O'Connor, G. A. (2015). Soil Chemistry. John Wiley & Sons, New York, United States.

Taiz, L., Zeiger, E., Moller, I. M., & Murphy, A. (2014). Physiology and Plant Development. Sinauer Publication.

Tsai, T. M. & Huang, H. J. (2006). Effects of iron excess on cell viability and mitogen-activated protein kinase activation in rice roots. *Physiologia Plantarum*, *127*(4), 583-592. https://doi.org/10.1111/j.1399-3054.2006.00696.x

Winterbourn, C. C. (1995). Toxicity of iron and hydrogen peroxide: The Fenton reaction. *Toxicology Letters*, *82-83*, 969-974. doi: 10.1016/0378-4274(95)03532-x

Zhang, Y., Lashermes, G., Houot, S., Doublet, J., Steyer, J. P., Zhu, Y. G., Barriuso, E., & Garnier, P. (2012). Modelling of organic matter dynamics during the composting process. *Waste Management*, *32*(1), 19-30. https://doi.org/10.1016/j.wasman.2011.09.008

Zhang, Y., Lashermes, G., Houot, S., Zhu, Y. G., Barriuso, E., & Garnier, P. (2014). COP-compost: A software to study the degradation of organic pollutants in composts. *Environmental Science and Pollution Research*, *21(4)*, 2761-76. https://doi.org/10.1007/s11356-013-2157-0

Zhang, H., Wu, X., Li, G., & Qin, P. (2011). Interactions between arbuscular mycorrhizal fungi and phosphate-solubilizing fungus (*Mortierella* sp.) and their effects on *Kostelelzkya virginica* growth and enzyme activities of rhizosphere and bulk soils at different salinities. *Biology and Fertility of Soils*, *47*, 543-554. https://doi.org/10.1007/s00374-011-0563-3

[DOI: DOI: 10.22034/13.61.15]