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ORIGINAL PAPER

Effect of olive mill wastewater enriched with vermicompost and pomace on the mineral content of onion, garlic and spinach*

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Abstract

Olive mill wastewater (OMW) obtained in olive oil production contains substances that are harmful to the soil. It is ecologically and economically important to convert OMW and olive mill waste (olive pomace), applied together with organic materials such as vermicompost, into a useful form. In this study, the effects of OMW enriched vermicompost and pomace on the mineral content of onion, garlic and spinach, and the possibilities of reducing the negative effects of olive mill wastewater were investigated. The study concluded that vermicompost and pomace added to OMW reduced its negative effects on plants. For example, the highest copper value (1.54 mg kg^{-1}) in onion was obtained from OMW-V2 treatment, and the highest sodium value (280.06 mg kg^{-1}) was obtained from OMW-V1 treatment. In cv. Matador spinach, the highest nitrogen value (2.72%) was received from OMW2 treatment, while the highest values of phosphorus (245.51 g 100 g^{-1}), sodium (39.69 mg kg^{-1}), and iron (51.52 mg kg^{-1}) were obtained from the P1 treatment; the highest potassium (1592.22 mg kg^{-1}) and copper (1.98 mg kg^{-1}) values were obtained from OMW-P2 treatment. A two-way hierarchical cluster analysis (HCA) revealed that a high degree of similarity based on the mineral content was observed between treatments: OMW-V3 and V1, V1 and OMW-P1 and OMW-V3 and OMW-V4 in the Uzunbacak local spring onion variety, Kirmizibacak local garlic variety and cv. Matador spinach, respectively. The results are valuable in revealing the possibilities of economic use of pomace and olive mill wastewater.

Keywords: garlic, olive mill wastewater, onion, pomace, spinach

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INTRODUCTION

Ecological and organic farming practices are the right approaches in agricultural areas that are gradually decreasing and losing quality as a result of intensive and incorrect agricultural practices. Soil organic matter is an important source of nutrients and energy for the activity of beneficial bacteria, and an important factor for soil quality (Voltr et al. 2021). There is a direct connection between the soil organic matter content and soil health. Agricultural practices that ignore the vital activity of soil lead to slow damage not only of the soil but also of all living organisms. One of the methods that cannot solve these problems but can cure them is an attempt to restore the vital potential lost in soils by treating them with organic matter. Any agricultural activity with increased use of organic matter extends the use of soils and saves us time by extending the life of our soils and thus developing better agricultural activities (Lal 2020).

Vermicompost is a soil conditioner and organic fertilizer created by earthworms converting various organic waste into humus and humus-like substances, which are rich in enzymes, humic acid and fulvic acid (Mustafayeva et al. 2022, Bayyigit et al. 2023). In addition to its positive effects on plant growth and soil improvement, vermicompost is also known to enhance plants' stress tolerance by reducing the negative effects of toxic elements under salt stress conditions (Ayyobi et al. 2014, Celikcan et al. 2021). It is known that chemical fertilizers and pesticides used uncontrollably to obtain the maximum yield per unit area cause environmental pollution; in turn, contaminated groundwater resources and chemical residues, which can be detected analytically in agricultural products, seriously affect human and animal health. In this context, vermicomposts provide significant economic benefits and have a positive impact on human health by ensuring the sustainability of organic farming and the disposal of solid waste from consumption (Çiçek 2021).

While olive oil is an important source of nutrition, its production creates such by-products as OMW and pomace. Pomace is a by-product that can be recycled in various ways, but OMW, which currently has no commercial recycling, is a waste product and causes environmental pollution in areas where olive oil production is predominant (Sumer et al. 2016). OMW resulting from olive oil production contains various polyphenols and phenolic compounds with phytotoxic properties, hence the wastewater from the olive oil production sector has a significant pollution potential. Due to the pollutants it contains, direct contamination of the soil with OMW is dangerous and harmful. Converting wastewater and pomace from olive mills into a useful compost fertilizer applied in combination with organic nutrients such as vermicompost is known to have many enviromental and economic benefits (Hassen et al. 2023).

Onion (*Allium cepa* L.) and garlic (*Allium sativum* L.) are economically important *Allium* species worlwide. Garlic in particular has been cultivated all over the world since ancient times as a vegetable, spice and medicinal plant, and it is known that garlic is nowadays called "functional food" (Besirli et al. 2022, Yarali Karakan 2022). These species are not only used as table food but are also recognized as spices and in traditional medicine (Akan 2014, Yarali Karakan et al. 2024). Spinach (*Spinacia oleracea* L.), an annual plant native to Asia, is a preferred vegetable because of its the rich nutrient content in its leaves. Spinach is particularly rich in nitrogen, starch and iron. It is more nutrient-dense than other green vegetables, and is very important in a diet owing to its anemia-relieving effect (Impa et al. 2023).

In this study, we aimed to investigate for the first time the effect of olive mill wastewater enriched vermicompost and pomace on the mineral content of onion, garlic and spinach, as well as the possibilities of economic utilization of olive mill wastewater in crop production.

MATERIALS AND METHODS

Plant material

Information about the plant material used in the study is listed in Table 1.

Table 1

Plant material

Species	Name	Source
Onion	Uzunbacak local spring onion variety	Se-Ta Seed Company
Garlic	Kırmızıbacak local garlic variety	local producer in Kilis province
Spinach	standard variety (*Spinacia oleracea* L. cv. Matador)	Pinaper Seed Company

Onion and spinach seeds and garlic cloves were sown on 2 March 2022 into vials filled with peat, and kept in the research greenhouse of Kilis 7 Aralik University, Faculty of Agriculture. The seedlings were planted on 4 April 2022 in three-liter pots with three plants per pot, and then the treatments listed in Table 2 were carried out according to Barbera et al. (2013). Olive mill wastewater and pomace samples were collected from olive oil factories in Kilis province. After the treatments, three-month-old plants were harvested on 4 July 2022, and measurements and analyses were carried out.

Determination of mineral content

Garlic, onion and spinach samples were dried in a compressed air oven at 72°C, and the dried samples were pulverized in a mortar and pestle. Each 0.25 g sample was mixed with 9 mL of HNO_3 and 3 ml of H_2O_2 and burned in a Cem brand microwave oven, model Mars 6, at 200 W power for 30 minutes. The ashed samples were filtered on Whatman filter paper and diluted

Table 2

Treatments of olive mill wastewater, pomace and vermicompost

<table>
<tr><th>Control</th><th>Olive mill wastewater (OMW)</th><th>Vermicompost (V)</th><th>Pomace (P)</th><th>Olive mill wastewater (OMW) + vermicompost (V)</th><th>Olive mill wastewater (OMW) + Pomace (P)</th></tr>
<tr><td rowspan="4">Control (peat)</td><td>OMW1: 5 tons da^{-1} OMW</td><td rowspan="4">V1: 2 tons da^{-1} V</td><td rowspan="4">P1: 1 ton da^{-1} pomace P</td><td>OMW-V1: 5 ton da^{-1} OMW + 1 ton da^{-1} V</td><td>OMW-P1: 5 tons da^{-1} OMW + 1 ton da^{-1} P</td></tr>
<tr><td rowspan="3">OMW2: 10 tons da^{-1} OMW</td><td>OMW-V2: 5 tons da^{-1} OMW + 2 tons da^{-1} V</td><td rowspan="3">OMW-P2: 10 ton da^{-1} OMW + 1 ton da^{-1} P</td></tr>
<tr><td>OMW-V3: 10 tons da^{-1} OMW + 1 ton da^{-1} V</td></tr>
<tr><td>OMW-V4: 10 tons da^{-1} OMW + 2 tons da^{-1} V</td></tr>
</table>

to a final volume of 25 mL by adding distilled water. Calcium, magnesium, iron, manganese, zinc, and copper were determined with an atomic absorption spectrophotometer (Perkin Elmer brand, model 240 FS AA) using the flame ionization method; sodium and potassium were determined with a flame photometer (Jenway, model PFP 7) – Tefera, Chandravanshi 2018, Besirli et al. 2022. All analyses were performed in triplicate.

Statistical analysis

JMP Pro version 14 (SAS Institute, NC, USA) was used for all statistical analyses. Principal component analysis (PCA) and hierarchical cluster analysis (HCA) were performed to describe patterns of variation in OMW treatments and the mineral content of onion, garlic and spinach. The distribution of mineral content of onion, garlic and spinach was computed using the first two components (PC1 and PC2).

RESULTS AND DISCUSSION

Effect of olive mill wastewater on the mineral content of the Uzunbacak local spring onion variety

The effect of OMW treatments on the mineral content of the Uzunbacak spring onion variety is shown in Table 3. The highest nitrogen value (5.20%) was obtained from V1 (2 tons da^{-1} V) and the lowest nitrogen value was obtained from OMW-P2 (10 ton da^{-1} OMW +1 ton da^{-1} P). The phosphorus value varied between 0.36 and 0.52 mg kg^{-1}, the highest phosphorus value was obtained from V1 (2 tons da^{-1} V) and the lowest one was obtained from OMW-P2 (10 tons da^{-1} OMW +1 ton da^{-1} P). The highest values of potassium (5.02 mg kg^{-1}), magnesium (0.38 mg kg^{-1}), calcium (2.07 mg kg^{-1}), zinc (5.64 mg kg^{-1}), and iron (12.09 mg kg^{-1}) content were obtained from V1 (2 tons da^{-1} V) treatment, the highest copper value (1.54 mg kg^{-1}) was obtai-

Table 3

Effect of OMW treatments on the mineral content of the Uzunbacak local spring onion variety

Treat-ments	N (%)	P (mg kg-1)	K (mg kg-1)	Na (mg kg-1)	Mg (mg kg-1)	Ca (mg kg-1)	Zn (mg kg-1)	Fe (mg kg-1)	Cu (mg kg-1)
Control	4.83*bc**	0.43*c-e*	4.12*bc*	275.30*a*	0.35*b*	1.87*b*	5.02*b*	11.48*b*	1.48*b*
OMW1	4.71*e-g*	0.44*bc*	4.06*cd*	270.31*ab*	0.31*c*	1.80*c*	4.79*c-e*	10.83*c-e*	1.46*b*
OMW2	4.46*h*	0.37*h*	3.81*e*	255.31*ef*	0.29*d*	1.74*cd*	4.47*h*	10.26*gh*	1.36*e*
OMW-V1	4.87*b*	0.456*b*	4.19*b*	280.06*a*	0.34*b*	1.856*b*	4.93*bc*	11.26*b*	1.49*b*
OMW-V2	4.99*b*	0.455*b*	4.27*b*	278.22*a*	0.35*b*	1.89*b*	5.07*b*	11.82*a*	1.54*a*
OMW-V3	4.72*ef*	0.41*g*	4.08*cd*	265.72*bc*	0.32*c*	1.78*c*	4.78*d-f*	11.06*bc*	1.43*cd*
OMW-V4	4.79*cd*	0.452*b*	4.08*bc*	266.56*b*	0.31*c*	1.85*b*	4.89*cd*	11.18*b*	1.45*bc*
V1	5.20*a*	0.52*a*	5.02*a*	275.35*a*	0.38*a*	2.07*a*	5.64*a*	12.09*a*	1.48*b*
OMW-P1	4.54*h*	0.433*cd*	3.93*e*	259.09*c-e*	0.29*d*	1.72*d*	4.54*h*	10.57*ef*	1.35*e*
OMW-P2	4.44*h*	0.36*h*	3.90*e*	247.03*g*	0.28*d*	1.69*d*	4.46*h*	10.27*fg*	1.36*e*
P1	4.76*c-e*	0.43*c-f*	4.08*cd*	265.63*b-d*	0.340*b*	1.78*c*	4.71*e-g*	10.94*cd*	1.48*b*
LSD5%	0.131	0.0122	0.119	7.88	0.00942	0.053	0.131	0.316	0.053

* $P<0.05$, values shown with different letters are different from each other

ned from OMW-V2 (5 tons da^{-1} OMW+2 tons da^{-1} V) treatment, and the highest sodium value (280.06 mg kg^{-1}) was obtained from OMW-V1 (5 tons da^{-1} OMW+1 ton da^{-1} V) treatment. Compared to the control, vermicompost treatments increased N, P, K, Mg, Ca, Zn and Fe content by 8.33%, 20.93%, 21.84%, 8.57%, 10 .69%, 12.35% and 5.31%, respectively; the OMW-V1 treatment increased the Na content by 1.73%, and the OMW-V2 treatment increased the Cu content by 3.98%. According to the research, it can be said that olive pomace and vermicompost added to OMW have a positive effect on the mineral content of spring onion. Uluğ (2018), who evaluated vermicompost as an important source of organic fertilizer in organic and sustainable agriculture, found that vermicompost treatments positively influenced the mineral content of onion; Fe, Zn, Cu, P, Mg, Ca and K values were 504.78 - 599.10 ppm, 20.92 - 26.26 ppm, 13.48 - 17.87 ppm, 0.12 - 0.16%, 0.33 - 0.36%, 1.92 - 2.89%, K 1.44 - 2.20%. In a similar study, Srivastava et al. (2012) reported that increasing the amount of humus in the soil vermicompost treatment improved the mineral content of onion. Seferoglu (2011) reported that the content of potassium varied between 1.92% and 5.75%, calcium concentration ranged between 0.13% to 0.49% and magnesium concentration varied between 0.09% and 0.30% in onion plants submitted to OMW and pomace treatments, with the highest calcium and magnesium values being obtained after the 20% pomace treatment. Abou-El-Hassan et al. (2018) and Prusty (2019) found that vermicompost treatments had a positive effect on the N, P and K content of onion.

The relationships between the OMW treatments and the mineral content of the Uzunbacak local spring onion variety were calculated using the scatter

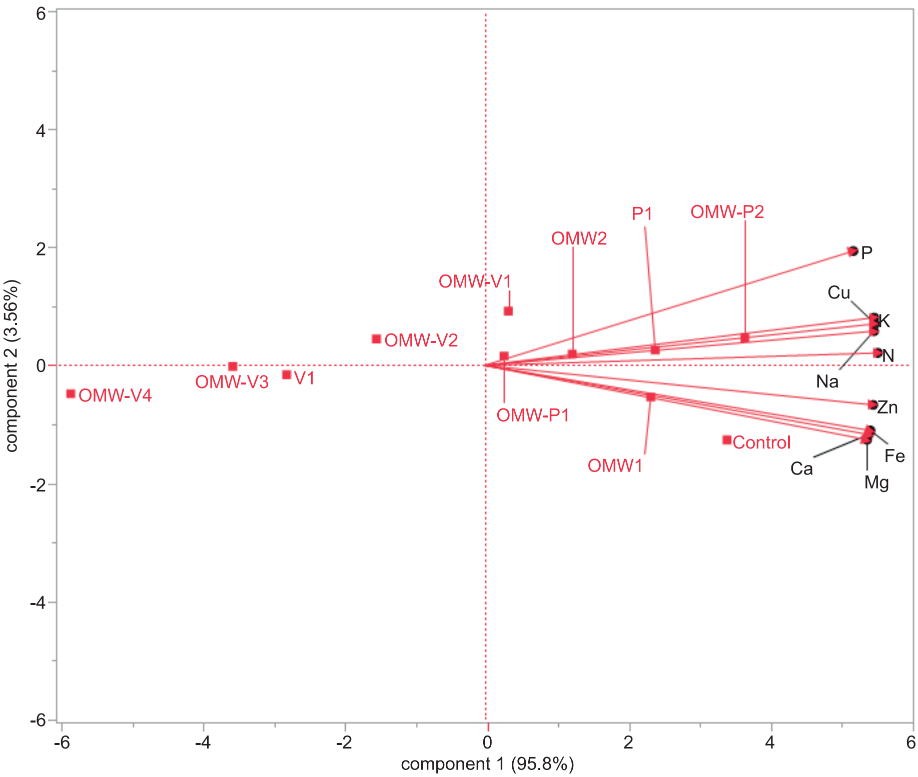

Fig. 1. Relationships among the treatments and the mineral content in yjr Uzunbacak local spring onion variety obtained from the PCA biplot analysis

biplot method. The first two components PC1 (95.8%) and PC2 (3.56%) accounted for 99.36% of the total variation (Figure 1). Minerals which have narrow angles are positively correlated with each other. In the biplot graph, it can be seen that the variation among minerals increases as the vector of each mineral moves away from the origin, while the variation among minerals decreases as the vectors move closer to the origin. Considering the distance of the vectors from the origin, it can be concluded that the variation in the mineral content is similar. A two-way hierarchical cluster analysis (HCA) revealed that OMW treatments were divided into different groups in terms of their effects on the mineral content of Uzunbacak local spring onion variety (Figure 2). The dendogram presented two major clusters depending on the mineral content, and within each cluster there were differences and similarities. Cluster I comprised four treatments; OMW-V2, OMW-V3, V1 and OMW-V4, and was divided into two subgroups. The other cluster (cluster II) consisted of seven treatments and was divided into subgroups. A high degree of similarity based on the mineral content was observed between treatments OMW1 and P1, OMW-V1 and OMW-P1, OMW-V3 and V1.

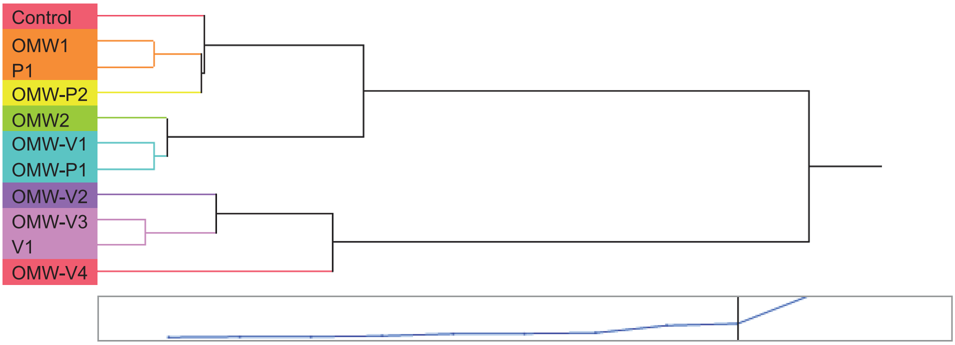

Fig. 2. The dendogram obtained from the cluster analysis the mineral content of the Uzunbacak local spring onion variety

Effect of olive mill wastewater on the mineral content of the Kirmizibacak local garlic variety

The effect of OMW treatments on the mineral content of the Kilis Kirmizibacak logal garlic variety is shown in Table 4. The highest nitrogen value (3.77%) was obtained from OMW-V1, while the highest phosphorus (0.57 mg kg^{-1}), potassium (4.41 mg kg^{-1}), sodium (169.82 mg kg^{-1}), magnesium (0.24 mg kg^{-1}), calcium (0.26 mg kg^{-1}), zinc (21.87 mg kg^{-1}), iron (41.23 mg kg^{-1}) and copper (3.25 mg kg^{-1}) values were obtained from V1 (2 tons da^{-1} V) treatment. Compared with the control, OMW-V1 treatment increased N content by 15.19%, and V1 treatment increased P, K, Na, Mg, Ca, Zn, Fe and Cu contents by 11.76%, 31.64%, 12.19%, 14.28%, 30.00%, 10835%, 13.27% and 12.07%, respectively. According to the results of the research, vermicompost

Table 4

Effect of OMW treatments on the mineral content of Kirmizibacak local garlic variety

Treat-ments	N (%)	P (mg kg^{-1})	K (mg kg^{-1})	Na (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})	Zn (mg kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})
Control	3.29*c**	0.51*b*	3.35*c*	151.36*b*	0.21*d*	0.20*b*	0.20*e*	36.40*b*	2.90*b*
OMW1	2.91*e*	0.46*f*	3.06*f*	135.98*d*	0.23*b*	0.15*h*	0.16*e*	32.64*e*	2.52*f*
OMW2	3.11*d*	0.48*d*	3.12*e*	140.11*c*	0.14*i*	0.19*c*	0.20*e*	33.68*c*	2.68*d*
OMW-V1	3.79*a*	0.46*f*	3.01*g*	136.58*d*	0.20*e*	0.18*e*	0.19*e*	33.22*cd*	2.59*e*
OMW-V2	3.27*c*	0.50*c*	3.16*e*	139.42*c*	0.22*c*	0.19*d*	0.19*e*	33.59*c*	2.57*e*
OMW-V3	2.29*h*	0.47*e*	3.07*f*	133.40*ef*	0.16*h*	0.17*f*	0.18*e*	32.37*f*	2.70*d*
OMW-V4	3.57*b*	0.48*d*	3.28*d*	136.21*d*	0.21*d*	0.18*e*	0.19*e*	33.03*e*	2.78*c*
V1	3.77*a*	0.57*a*	4.41*a*	169.82*a*	0.24*a*	0.26*a*	21.87*a*	41.23*a*	3.25*a*
OMW-P1	2.89*e*	0.41*h*	2.96*h*	126.15*g*	0.17*g*	0.16*g*	16.08*c*	30.96*g*	2.42*h*
OMW-P2	2.67*g*	0.37*i*	2.14*i*	117.39*h*	0.13*j*	0.14*i*	15.26*d*	28.04*h*	2.25*i*
P1	2.74*f*	0.42*g*	3.41*b*	134.33*de*	0.18*f*	0.19*c*	16.88*b*	32.22*f*	2.45*g*
LSD%5	0.053	0.0056	0.053	1.666	0.0023	0.0023	0.151	0.404	0.0318

* P<0.05, values shown with different letters are different from each other

added to OMW and pomace treatments had a positive effect on the nutrient content of Kirmizibacak local garlic variety. Similarly, Boutasknit et al. (2020) reported that N and P values in garlic were positively affected by pomace treatments. Kenea and Gedamu (2019) reported that vermicompost treatments had a positive effect on nitrogen (0.56%), phosphorus (25.82 ppm) and potassium (23.69%) in garlic.

The first two components PC1 (63.6%) and PC2 (26%) accounted for 89.6% of the total variation (Figure 3). Minerals which have narrow angles

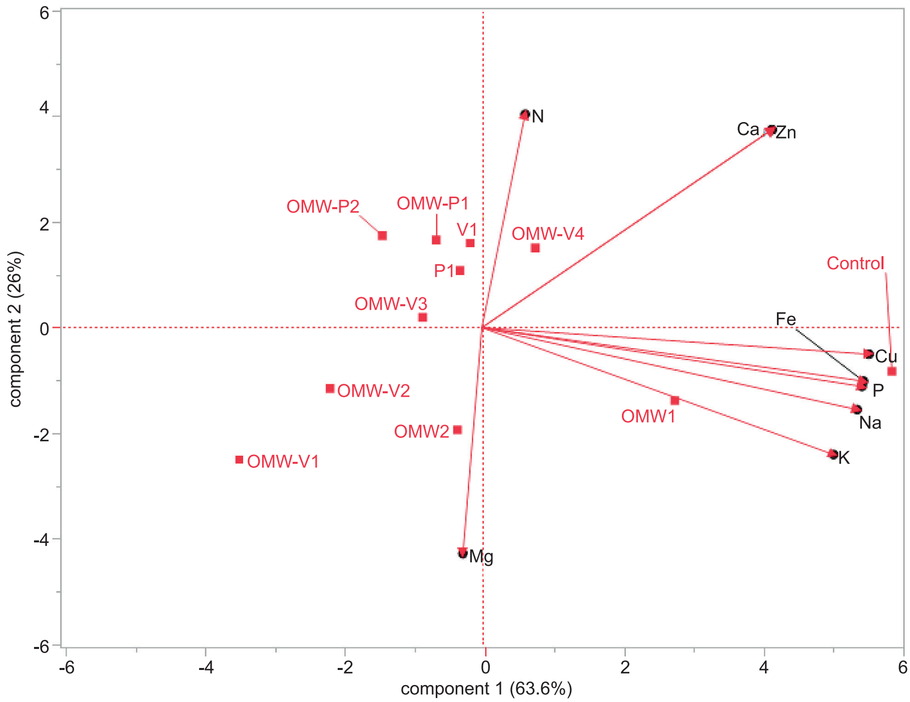

Fig. 3. Relationships among OMW treatments and the mineral content in the Kirmizibacak local garlic variety obtained from the PCA biplot analysis

are positively correlated with each other, while minerals with wide angles are negatively correlated with each other. Cu, P, Fe, Na and K were positively related to each other. In the biplot graph, the vectors of Ca, Zn, Cu, Na, P, K, Mg minerals move away from the origin, hence the variation between these minerals increases; on the contrary, the variation decreases for the N mineral. The dendogram presented two major clusters, and in each cluster there were differences and similarities among the treatments based on the mineral content (Figure 4). Cluster I divided into 2 groups. The first group was divided into two different subgroups, while the second group was divided into 4 different subgroups. A high degree of similarity based on the mineral content was observed between treatments OMW-V1 and OMW-V2, V1 and OMW-P1, OMW-P2 and P1.

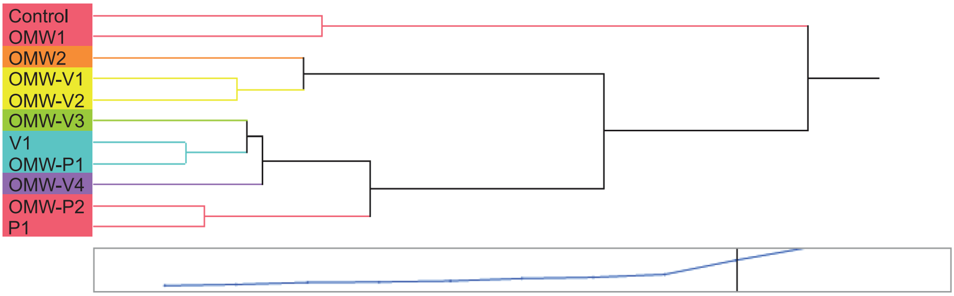

Fig. 4. The dendogram obtained from the cluster analysis of the mineral content of the Kirmizibacak local garlic variety

Effect of olive mill wastewater on the mineral content of *Spinacia oleracea* L. cv. 'Matador'

The effect of OMW treatments on the mineral content of cv. Matador spinach is summarized in Table 5. In the study, the highest nitrogen value (2.72%) was obtained from OMW2 (10 tons da^{-1} OMW) treatment; the highest phosphorus (245.51 mg kg^{-1}), sodium (39.69 mg kg^{-1}), zinc (2.64 mg kg^{-1}), iron (51.52 mg kg^{-1}) concentrations were obtained from P1 (1 ton/da pomace) treatment; the highest potassium (1592.22 mg kg^{-1}) and copper (1.98 mg kg^{-1}) values were obtained from OMW-P2 (10 tons da^{-1} OMW +1 ton da^{-1} P) treatment; the highest magnesium (190.84 g 100 g^{-1}) and calcium (359.50 mg kg^{-1}) amounts were obtained from V1 (2 tons da^{-1} V) treatment. Compared with the control, OMW2 treatment increased N by 3.03%, P1 treatment increased P and Na by 22.54% and 29.285%, respectively; OMW-P2 treatment increased K and Cu by 1.30% and 46.67%, respectively; OMW-V1 and P1 treat-

Table 5

Effect of olive mill wastewater on the mineral content of cv. Matador spinach

Treat-ments	N (%)	P (mg kg^{-1})	K (mg kg^{-1})	Na (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})	Zn (mg kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})
Control	2.64*ab**	200.35*d-f*	1571.82*bc*	30.70*f*	190.84*a*	359.50*a*	1.58*d*	31.73*h*	1.35*fg*
OMW1	2.67*a*	196.15*f*	1559.83*c-e*	31.05*f*	183.83*b*	349.88*b*	1.68*d*	35.30*g*	1.32*gh*
OMW2	2.72*a*	201.72*de*	1569.96*b-d*	32.69*e*	183.95*b*	347.66*b*	1.92*c*	41.42*ef*	1.39*ef*
OMW-V1	2.51*c*	202.09*d*	1574.45*ab*	34.62*d*	184.50*b*	346.04*bc*	2.08*c*	51.52*a*	1.55*c*
OMW-V2	2.43*d*	203.76*d*	1582.84*a*	36.77*c*	178.61*c*	333.81*d*	2.01*c*	45.46*b*	1.47*cd*
OMW-V3	2.33*e*	204.95*d*	1585.41*a*	37.70*b*	170.31*d*	323.67*e*	1.67*d*	43.19*c*	1.44*c-e*
OMW-V4	2.10*f*	206.79*d*	1582.07*a*	38.94*a*	164.89*e*	314.40*f*	1.51*d*	41.60*de*	1.49*c*
V1	2.02*g*	219.86*c*	1584.49*a*	38.53*ab*	190.84*a*	359.50*a*	1.58*d*	31.73*h*	1.66*b*
OMW-P1	1.87*h*	222.70*c*	1585.60*a*	39.40*a*	183.83*b*	349.88*b*	2.02*c*	35.30*g*	1.72*b*
OMW-P2	1.91*h*	231.51*b*	1592.22*a*	39.37*a*	183.95*b*	347.66*b*	2.29*b*	41.42*ef*	1.98*a*
P1	1.75*i*	245.51*a*	1589.21*a*	39.69*a*	184.50*b*	346.04*bc*	2.64*a*	51.52*a*	1.95*a*
LSD%5	0.075	4.855	12.268	0.871	4.234	5.341	0,067	0,484	0.053

* *P*<0.05, values shown with different letters are different from each other

ments increased Zn and Fe by 30.82% and 62.37, respectively. The lowest nitrogen value value was obtained in P1 (1 ton da^{-1} P) treatment; lowest phosphorus and potassium values were obtained from the OMW1 (5 tons da^{-1} OMW) treatment; the lowest sodium value was determined from untreated control plants. Lowest magnesium, calcium, and zinc values were obtained from OMW-V4 (10 tons da^{-1} OMW + 2 tons da^{-1} V) treatment; the lowest copper value was determined from the OMW2 (10 tons da^{-1} OMW) treatment. In contrast to onion and garlic, the effect of OMW treatments on the mineral content of spinach was found to be more positive. Belaqziz et al. (2016) stated that OMW had a significant effect on the total salt and organic matter content of the soil, and reported that the salt and organic matter content

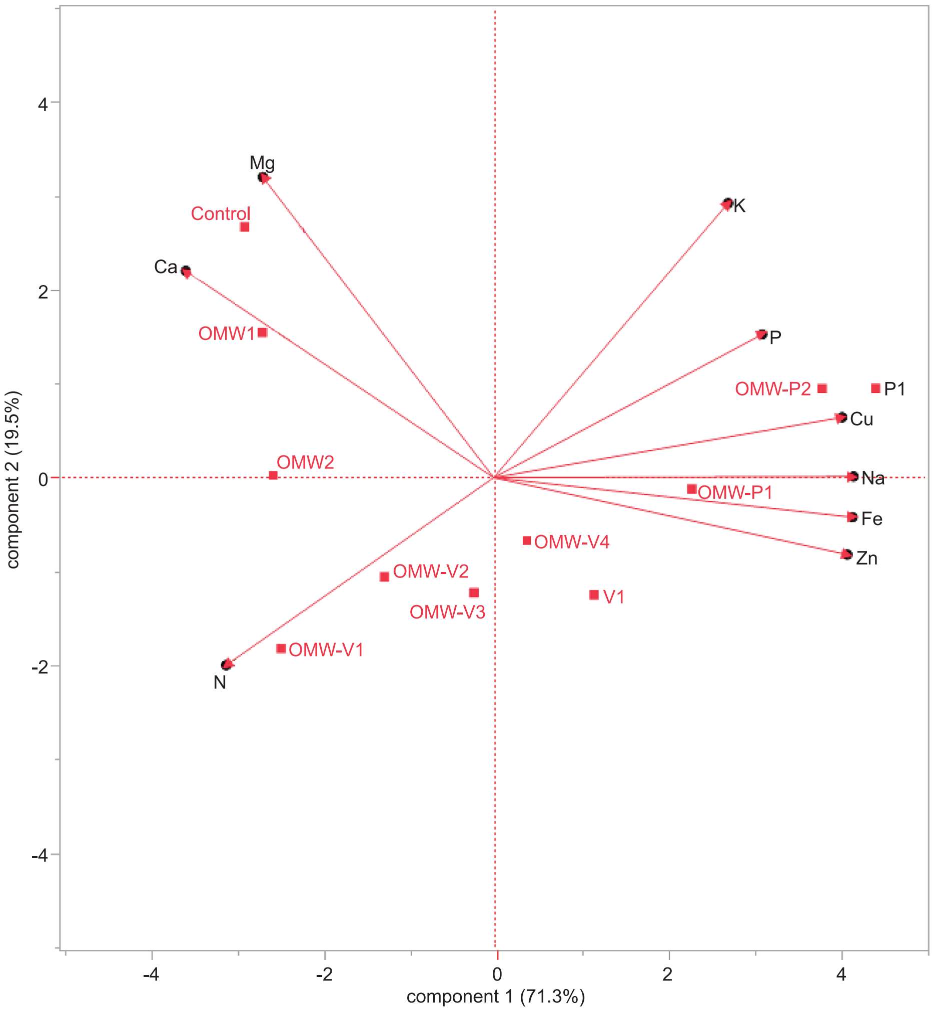

Fig. 5. Relationships among the treatments and the mineral content in cv. Matador spinach obtained from the PCA biplot analysis

of the soil increased with increasing doses of OMW, but did not cause a significant change in pH level. Montemurro et al. (2015) noted that olive pomace composts could have practical importance for farmers. Similarly, Asfi et al. (2012) reported that OMW treatments increased the potassium content in spinach (29400 ± 65 μg g^{-1}), while Fe, Ca and Mg levels decreased compared to the control.

The first two components PC1 (71.3%) and PC2 (19.5%) accounted for 90.8% of the total variation (Figure 5). Cu, Na, Fe and Zn were positively related, while Mg, Ca, and N were negatively related, and phosphorus showed the least variation among minerals. A two-way hierarchical cluster analysis (HCA) revealed that OMW treatments were also separated from each other according to the mineral content of cv. Matador (Figure 6).

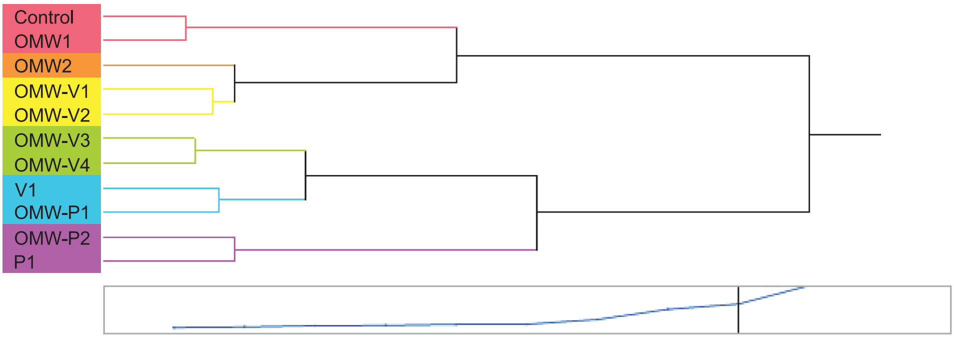

Fig. 6. The dendogram obtained from the cluster analysis of the mineral content of cv. Matador spinach

The dendogram presented two major clusters, and in each cluster there were differences and similarities among the treatments. Cluster I divided into two subgroups. The first group was divided into two different subgroups, while the second group was divided into there different subgroups. Cluster II divided two subgroups. The first group was divided into two different subgroups, while the second group was divided into four different subgroups. A high degree of similarity based the on mineral content was observed between treatments Control and OMW1, OMW-V3 and OMW-V2, OMW-V3 and OMW-V4, V1 and OMW-P1.

CONCLUSIONS

The positive effect of vermicomposting on the mineral content was noticeable in all species. In the study, it was concluded that vermicompost and pomace added to OMW reduced its negative effects on plants. For example, in onion, the highest copper value (1.54 mg kg^{-1}) was obtained from OMW-V2 (5 tons da^{-1} OMW+2 tons da^{-1} vermicompost) treatment, and the highest sodium value (280.06 mg kg^{-1}) was obtained from OMW-V1 (5 tons da^{-1} OMW+1 ton da^{-1} V) treatments. In cv. 'Matador', the highest nitrogen value (2.72%) was obtained from OMW2 (10 tons da^{-1} OMW) treatment; the highest phosphorus (245.51 mg kg^{-1}), sodium (39.69 mg kg^{-1}), iron (51.52 mg kg^{-1}) were obtained from P1 (1 ton da^{-1} P) treatment; the highest potassium (1592.22 mg kg^{-1}) and copper value (1.98 mg kg^{-1}) were obtained from OMW-P2 (10 tons da^{-1} OMW +1 ton da^{-1} P) treatment. The research findings are valuable in revealing the possibilities of economic utilization of olive mill wastewater.

Author contributions

İ.G. – Conceptualization, supervision, methodology, visualization, writing; O.A. – investigation, methodology, visualization; F.Y.K. – writing, view, editing. All authors helped with the interpretation of the results and provided critical feedback overall manuscript. All authors have read and agreed to the published version of the manuscript.

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