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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Evaluation of Spent Coffee Grounds as an Ecological Fertilizer for Enhancing Soil Fertility and Radish Nutrition (*Raphanus sativus* L.)

Kahve Telvesinin Toprak Verimliliği ve Turp (*Raphanus sativus* L.) Beslenmesini Artırmada Ekolojik Bir Gübre Olarak Değerlendirilmesi

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Abstract

Globally, rising coffee consumption has led to an increase in coffee grounds waste. This study evaluated the feasibility of using spent coffee grounds (SCG) as an alternative fertilizer in agriculture from an environmental perspective. To this end, various application rates of coffee grounds (0, 7.5, 15, and 30 t ha^{-1}) were tested to determine their effects on the yield and nutrient content of red radish, as well as on selected physical and chemical soil properties. Coffee grounds applications significantly increased the organic matter content and the amounts of N, P, K, Mg, and Zn in loamy sand soil following radish cultivation. Compared with the control, 30 t ha^{-1} of SCG raised soil organic matter by 50% and enhanced P, Mg, and Mn contents by 27.5%, 14.6%, and 55.5%, respectively. SCG treatments significantly improved the P, Mg, Zn, and Mn contents in radish leaves and tubers, as well as K and vitamin C levels in the tubers. Notably, the 30 t ha^{-1} dose increased tuber Mg and Mn contents by 32% and 55%, respectively, while the 15 t ha^{-1} dose increased vitamin C content by 35%. However, these applications did not affect radish tuber yield, dry matter content, leaf N, Fe, and Cu levels, or tuber N, Ca, and Fe concentrations. Consequently, the application of spent coffee grounds enriched the mineral profile of radish, an important nutritional source, thereby enhancing its overall nutritional value. The findings indicate that spent coffee grounds applications to soil can improve the mineral content of both plants and soil while also enhancing soil properties, suggesting significant potential as an alternative fertilizer. Additionally, repurposing large quantities of coffee grounds in agriculture contributes to sustainable soil fertility and offers environmental benefits.

Keywords: Spend coffee grounds (SCG), Soil fertility, Radish, Nutrients, Vitamin C

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Öz

Küresel olarak kahve tüketimdeki artışlar beraberinde kahve telvesi atıklarının da artışına neden olmaktadır. Bu çalışmada çevresel bir yaklaşımla kahve telvesinin, alternatif bir gübre olarak tarımda kullanılabilirliği araştırılmıştır. Bu amaçla 0, 7.5, 15, 30 t ha^{-1} olmak üzere farklı oranlarda uygulanan kahve telvesinin kırmızı turpun verim, besin element içeriği ve toprakların bazı fiziksel ve kimyasal özelliklerine etkileri değerlendirilmiştir. Kahve telvesi uygulamaları, turp vejetasyonu sonrası, tınlı kum tekstüre sahip topraktaki organik madde içeriğini ve bitki besin maddelerinden N, P, K, Mg, Zn miktarlarını önemli olarak artırmıştır. Kontrol ile karşılaştırıldığında 30 t ha^{-1} kahve telvesi uygulamaları toprak organik madde içeriğini %50, P, Mg ve Mn içeriklerini sırasıyla %27.5, %14.6, %55.5 oranlarında zenginleştirmiştir. Kahve telvesi uygulamaları turp yaprak ve yumrularının P, Mg, Zn ve Mn içeriklerini önemli olarak iyileştirmiştir. Ayrıca yumruda K ve C vitamini düzeyleri de artmıştır. Özellikle, 30 t ha^{-1} kahve telvesi dozunun yumru Mg ve Mn içeriğini sırasıyla %32, %55 oranında artırırken, 15 t ha^{-1} dozunu ise vitamin C içeriğini %35 oranında arttırması dikkat çekici olmuştur. Turp yumru verimi, kuru madde değerleri, yapraklarının N, Fe, Cu yumruların ise N, Ca ve Fe miktarları kahve telvesi uygulamalarından etkilenmemiştir. Bu bağlamda, SCG uygulamaları, sağlıklı bir yaşam için önemli bir besin kaynağı olan turpun mineral içeriğini zenginleştirerek besin değerini artırmıştır. Araştırma sonuçları toprağa kahve telvesi uygulamalarının, bitkinin ve toprağın mineral içeriğini zenginleştirebildiğini ve toprak özelliklerini iyileştirebildiğini dolayısıyla gübre alternatifi olarak önemli bir potansiyel olduğunu ortaya koymaktadır. Ayrıca önemli miktarlara ulaşan kahve telvesi atıklarının tarımda yeniden kullanımı, sürdürülebilir toprak verimliliğine katkı sağlarken aynı zamanda çevresel açıdan da önem taşımaktadır.

Anahtar kelimeler: Kahve telvesi, Toprak verimliliği, Turp, Besin elementleri, C vitamini

1. Introduction

Coffee is one of the most widely consumed beverages globally, with millions of people drinking it every day. This high demand for coffee leads to a significant amount of waste generated in the form of spent coffee grounds (SCG), which is the residual waste produced after brewing coffee. In recent years, there has been an increasing interest in using SCG as a fertilizer in agriculture, as it has the potential to provide a cost-effective and environmentally friendly solution for improving soil fertility. According to the International Coffee Organization (ICO) statistics global coffee consumption in 2024 is stated as 10.8 million tons (International Coffee Organization, 2024). SCG can cause serious the environment problems due to storage requirements. They contain high levels of nitrogen, phosphorus, and potassium, as well as other nutrients such as calcium, magnesium, and iron. Additionally, they have a relatively high organic matter content, which can improve soil structure and fertility. The high levels of nitrogen in SCG make it an attractive option as a fertilizer, as nitrogen is an essential nutrient for plant growth and development. They also contain many harmful components as caffeine, tannin, and polyphenol contaminants (Cruz et al., 2012). Furthermore Mussatto et al. (2011) reported SCG contains compounds of carbohydrates (82%) and proteins (13%) with high contents of N (1.2%–2.3%), K (0.35%) and P (0.02%–0.5%). In addition, SCG contain more N and K than common organic materials such as cow manure (Kasongo et al., 2011).

However, the composition of SCG can vary greatly depending on the origin and processing method of the coffee beans, as well as the brewing method used. This variability in composition can lead to potential imbalances in nutrients, which can impact plant growth and soil fertility. Moreover, the high levels of caffeine and other alkaloids present in SCG can have toxic effects on plants.

On the other hand, the organic matter in SCG can improve soil structure, increase water-holding capacity, and enhance soil fertility. Thus, SCG have also been used as organic amendments for soils (Cruz et al., 2012 and 2015; Yamane et al., 2014; Cervera-Mata et al., 2019 and 2022; Hirooka et al., 2022). Hirooka et al. (2022) also reported that top dressing with SCG after crop germination is an efficient method for sustainable agricultural production. It can substantially reduce weed biomass if a sufficient quantity of SCG is used, and enrich the soil C and N in the long. Cruz et al. (2015) stated the positive impact of SCG as a soil amendment in lettuce physical and nutritional features. On the other hand Turek et al. (2019), emphasized that at high concentrations of SCG, plant growth was inhibited.

Considering this information, the use of SCG as a fertilizer has the potential to reduce waste and pollution, as well as provide a cost-effective solution for farmers.

The aim of this study was to investigate the effect of SCG applied to soils at different rates on radish yield and nutrient content in Loamy-Sand soil.

2. Materials and Methods

The study was conducted with radish plants (*Raphanus sativus* L.) in the experimental fields of the Odemis Vocational School at Ege University, Izmir (38°16' N; 27°59' E; 123 m above sea level). The spent coffee grounds (SCG) used in the study were collected from Starbucks outlets in Izmir. Additionally, Turkish coffee wastes (TSCG), which have a distinct brewing style, were also utilized to provide a broader perspective. At the beginning of the study, physical and chemical analyses were conducted on soil samples taken from the trial area and the SCG samples to be used in the research.

In the samples pH (Jackson, 1967), total soluble salt (Anonymous, 1957), $CaCO_3$ (Kacar, 1995), organic matter content (Reuterberg and Kremkurs, 1951) were determined. Total N was analyzed according to Bremner (1965), available K, Ca and Na was determined after extraction with 1 N NH_4OAc using a flame photometer (Kacar, 1995) and available P was measured by a colorimeter (Olsen et al., 1954). Available Fe, Cu, Zn and Mn were extracted with 0.05 M DTPA+TEA and measured by Atomic Absorption Spectrophotometer (Lindsay and Norvell, 1978). Following dry-ashing, sample B contents were determined spectrophotometrically with the use of azomethine-H method (Wolf, 1971).

Table 1 shows the physical and chemical properties and mineral content of SCG used in the experiment. The SCG exhibited a high abundance of organic matter with a C:N ratio of 26%, acidic properties, and a substantial supply of essential macronutrients and micronutrients required by plants. Particularly noteworthy were the significantly high levels of N, P, K, Ca, and Mg.

Table 1. Physicochemical properties of SCG and TSCG used in the experiment

Parameter	SCG	TSCG
pH	4.65	4.66
Organic Matter (%)	98	96
C (%)	56.84	55.68
C/N	26.56	26.64
N (%)	2.14	2.09
P (ppm)	1110	1036
K (ppm)	4432	4301
Ca (ppm)	1427	1374
Mg (ppm)	1739	1675
Na (ppm)	401	388
Fe (ppm)	8.17	32.99
Cu (ppm)	19.33	18.19
Zn (ppm)	16.59	15.99
Mn (ppm)	32.53	31.44
B (ppm)	25.58	22.82
Al (ppm)	1.31	1.65
Cd (ppm)	0.19	0.18
Cr (ppm)	0.08	0.06
Ni (ppm)	0.35	0.45
Pb (ppm)	2.18	2.16

Table 2 represents the physical and chemical properties of the experimental soil. This soil was slightly acidic, had no salinity problem, was low in $CaCO_3$ and organic matter (Emerson, 1991; Charman and Roper, 2007), and had Loamy-Sand texture. The total N, Mn, contents of the soil were low, while available K, Ca, Mg and Zn were at medium level, according to Anonymous (1990) and P, Fe levels were high according to Chapman and Pratt (1961) and Anonymous, (1990). The contents of Cu were found sufficient (Anonymous, 1990).

The field experiment was designed as a randomized complete block, consisting of three replications. Additionally, mineral fertilizer and control plots were also arranged in order to compare the effects of SCG. Spent espresso coffee grounds, used as a potential plant nutrient and soil conditioner, were applied at increasing doses of 0, 7.5, 15 and 30 t ha^{-1}, and spent Turkish coffee grounds at 7.5 t ha^{-1}. SCG were incorporated into the soil two months prior to sowing at a depth of 15-20 cm. The amount of SCG at the lowest rate corresponded to an application of 170 kg N ha^{-1}, in accordance with the European Union Nitrates Directive (Wiering et al., 2020). Mineral fertilizers were applied only mineral fertilizer plos at recommended doses of 120 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1}. All P fertilizer and 60% of N and K fertilizers were applied uniformly as basal fertilizers at the time of sowing, and the remaining N and K fertilizers were applied during tuber formation. The sources of the N, P, and K fertilizers were $(NH_4)_2SO_4$, TSP and K_2SO_4 respectively. Radish seeds were sown in each plot in with a spacing of 10 cm between rows and 5-7 cm within the rows. Six treatments, including the control, were conducted in three replications across 18 plots, each measuring 0.5 m^2. At the end of the vegetation, the radish tubers and leaves were harvested and samples were taken for measurement and analysis.

In order to determine the nutritional status of the plants, leaf and tuber samples were taken and dried at 65°C. In leaf and tuber samples the total N was analysed according to the modified Kjeldahl method (Bremner, 1965), and P was determined using a colorimeter after wet digestion with mixed acid (1 part $HClO_4$ + 4 parts HNO_3) (Lott et al., 1956). Potassium and Ca were determined using a flame photometer, and Mg, Fe, Cu, Mn and Zn were determined using an Atomic Absorption Spectrophotometer (AAS) (Kacar and Inal, 2008). The content of Vitamin C was determined through titration with Dichlorphenol-Indophenol indicator using extracts obtained from radish tubers (Tee et al., 1988). The dry matter content in radish tubers was measured by drying in an oven at 105°C (Kacar and Inal, 2008). At the end of the radish harvest, soil samples were collected from all plots at a depth of 0-20 cm and changes in macro- micro nutrients were determined.

The analysis of the variance was performed using the SAS statistical program, and the significant differencesbetween treatments were compared using least squared means (JMP®, Version 16.).

Table 2. Physical and chemical properties of experimental soil

Characteristic	Value
pH	6.56
Salt (µS/cm)	138.8
$CaCO_3$ (%)	1.10
Organic Matter (%)	0.77
Sand (%)	81.12
Clay (%)	5.28
Silt (%)	13.60
Texture	Loamy-Sand
Total N (%)	0.05
Available P (mg kg^{-1})	22.2
Available K (mg kg^{-1}))	154
Available Ca (mg kg^{-1})	1352
Available Mg (mg kg^{-1})	205
Na (mg kg^{-1})	467.90
Available Fe (mg kg^{-1})	6.83
Available Cu (mg kg^{-1})	0.65
Available Zn (mg kg^{-1})	1.17
Available Mn (mg kg^{-1})	6.19

3. Results and Discussion

Changes in some chemical properties and mineral content of soils after radish harvest with applied SCG are shown in *Table 3* and *4*. Examination of *Table 3* and *4* reveals that SCG applications have statistically significantly increased the amounts of organic matter, N, P, K, Mg, Zn, and Mn in the soil, while decreasing the pH and $CaCO_3$ values. However, the effects of these applications on the EC, Ca, and Na amounts were found to be insignificant.

Soil pH, one of the most important properties affecting the availability of plant nutrients, decreased from 6.85 in the control to 6.50 with the highest dose of 30 t ha^{-1} SCG application, indicating a reduction of 5.1%. This decrease in pH values can be associated with the acidic character of SCG. Additionally, organic acids found in SCG, such as chlorogenic acid and citric acid, can also be the reason behind the decrease in soil pH values (Khan et al., 2023). Similarly, various studies have also reported a decrease in soil pH values after SCG applications (Hardgrove and Livesley, 2016; Cervera-Mata et al., 2017, 2019 and 2023; Khan et al., 2023). Conversely, Kasango et al. (2011), reported an increase in soil pH from 5.21 to 6.24 with the application of 20 t ha^{-1} SCG; Chrysargyris et al. (2021) recorded a 5% increase in the pH value of the growing medium, peat, from 4.68 to 5.96 with the addition of SCG. SCG applications have significantly reduced the $CaCO_3$ content of the soil. These findings are consistent with those reported by Cervera-Mata et al. (2017).

The study found no statistically significant difference in the effect on soil pH between mineral fertilizer applications and the application of 30 t ha^{-1} of SCG. However, the SCG, which are rich in organic matter, significantly enhanced the organic matter content of the trial site soils, originally low in organic matter ($P<0.05$). Notably, the application of 30 tons per hectare of SCG resulted in a 50% increase in organic matter compared to the control, which was considered significant. Similarly, Cervera-Mata et al. (2017) reported that SCG applications increased the soil organic carbon content. Şenay and Tepecik (2024) stated that biochar applications enhanced the soil organic matter content; they reported that the organic matter content, measured as 1.28% in the control group, increased to 2.81% with the application of 80 t ha^{-1} of biochar.

Table 3. Effect of SCG on chemical properties of loamy-sand soil after harvest

Treatments ($t\ ha^{-1}$)	pH	EC ($mS\ cm^{-1}$)	$CaCO_3$ (%)	Organic Matter (%)
Control	6.85 a	169	1.12 a	0.86 c
Mineral Fertilizer	6.40 b	139	0.62 b	0.93 bc
SCG 7.5	6.83 a	137	0.79 b	1.09 ab
SCG 15	6.73 a	137	0.82 ab	1.02 bc
SCG 30	6.50 b	134	0.88 ab	1.29a
TSCG 7.5	6.74 a	132	0.82 ab	1.05 bc
LSD	0.19**	ns	0.31*	0.23*

* Significantly different at the P < 0.05 level; ** Significantly different at the P < 0.01 level; ns: no significant difference

Table 4. Effect of SCG on mineral content of loamy-sand soil after harvest

Treatments ($t\ ha^{-1}$)	N (%)	P ($mg\ kg^{-1}$)	K ($mg\ kg^{-1}$)	Ca ($mg\ kg^{-1}$)	Mg ($mg\ kg^{-1}$)	Cu ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)
Control	0.0737 ab	22.27 d	181 c	1246	198 b	0.53 b	0.57 bc	6.90 b
Mineral Fertilizer	0.0789 a	34.80 a	200 abc	1096	200 b	0.93 a	0.54 bc	10.19 a
SCG 7.5	0.0821 a	25.53 c	267 a	1276	207 ab	0.54 b	0.88 a	6.68 b
SCG 15	0.0808 a	27.87 c	251 ab	1093	223 ab	0.50 b	0.96 a	6.72 b
SCG 30	0.0765 a	28.40 bc	232 abc	1144	227 a	0.53 b	0.66 b	10.73 a
TSCG 7.5	0.0667 b	31.13 b	214 bc	1259	206 ab	0.60 b	0.46 c	7.15 b
LSD	0.00872*	3.07**	5.17*	ns	26.87*	0.143**	0.13**	2.09**

* Significantly different at the P<0.05 level; ** Significantly different at the P<0.01 level; ns: no significant difference

In the research, the Total N content of the soil was significantly increased by SCG applications, but no significant difference was found between the doses. This situation could be attributed to the activation of soil microorganisms by SCG, which has a high organic matter content, and to some extent, immobilization (Cervera-Mata et al., 2022). Indeed, no statistically significant changes were observed in the nitrogen content of radish leaves and tubers with increasing SCG applications in the study. Similarly, Tarakcioglu et al. (2019) suggested in their study that the lesser effect of biochar on soil nitrogen content might be related to the insufficient duration of decomposition. In the study,with the highest application rate of 30 t ha^{-1} SCG, the soil's available P, Mg, and Mn contents reached the highest levels after the harvest. Compared to the control, the soil P content increased by 27.5%, Mg content by 14.6%, and Mn content by 55.5% with the 30 t ha^{-1} SCG application. However, the increase in the soil phosphorus content was 40% with the application of 7.5 t ha^{-1} Turkish Spent Coffee Ground (TSCG), which is obtained by a different brewing method. SCG applications have significantly improved the soil's K content. Compared to the control, 47.5% increase was observed with the 7.5 t ha^{-1} SCG application, reaching the highest value of 267 mg kg^{-1}. The increases in these elements' amounts in the soils can be considered a reflection of SCG's high content of N, P, K, Mg, and Mn (*Table 2*). Similarly, Kasango et al. (2011), and Cervera-Mata et al. (2017) have reported that SCG improves the amounts of total N, available P, K, Ca, Mg in the soils; Cruz et al. (2014) and Chrysargyris et al. (2021) have additionally stated significant improvements in the availability of Fe, Cu, Zn. Cervera-Mata et al. (2023), in their study in Mediterranean soils of Spain, indicated that while SCG applications increased the N, K content in the soils, they did not affect the P content.

Post-harvest, the lowest soil pH values were observed in the plots with the 30 t ha^{-1} SCG application, which had a similar effect as the plots treated with mineral fertilizer, and the highest amounts of available Mn were also determined. In this case, it can be considered that the decrease in soil pH values due to the highest rate of SCG applications has increased the release and availability of Mn. Kasongo et al. (2011) also reported that SCG applications raised the soil pH and immobilized Mn.

The available Fe and Cu content in soils was found to be higher in plots treated with chemical fertilizers (P<0.01). Available Fe content showed a slight increase with SCG applications when compared to the control, but the difference between doses was not found to be statistically significant. These findings are in accordance with the results of Cervera-Mata et al. (2017). The available Zn amounts in soils have significantly increased with 7.5 and 15 t ha^{-1} SCG applications compared to the control (P<0.01). The increases in available Zn content were inversely proportional to the pH reductions (*Table 3* and *4*). Acidic nature of SCG applied to soil increased the biological availability of zinc (Cervera-Mata et al., 2017). However, the available Zn levels were determined to be the lowest in TSCG application obtained with a different brewing method.

The nutrient element contents of radish leaves are presented in *Table 5*. When compared with the macro element sufficiency threshold percentages for fully developed radish leaves given by Bergmann (1993) which are N: 3-4%, P: 0.3-0.6%, K: 2.8-4.5%, Ca: 0.7-2.0%, Mg: 0.25-0.6%, and for the microelements Cu: 6-12, Zn: 20-80, Mn: 40-100 mg kg^{-1}, it was noted that the trial plant leaves had adequate levels of N, P, Mg, Zn, Mn, slightly high levels of Ca, and that K and Cu values were slightly low in some plots. In the trial, available K values in leaves were found to be adequate in the plots treated with 15 t ha^{-1} SCG and mineral fertilizer, while the control and other dosages of SCG application were found to be marginally low.

Table 5. Effect of SCG applications on the nutrient element content of radish leaves

Treatments (t ha^{-1})	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})
Control	3.4	0.378 b	2.72 b	2.45 a	0.305 ab	840	6.28	30.87 c	44.81 b
Mineral Fertilizer	3.5	0.427 a	3.42 a	1.96 ab	0.287 b	887	5.71	38.57 ab	65.25 a
SCG 7.5	3.5	0.396 ab	2.80 b	2.14 ab	0.332 a	958	5.50	32.51 bc	46.79 b
SCG 15	3.3	0.396 ab	2.95 ab	2.21 ab	0.318 ab	716	5.86	34.72 abc	50.78 ab
SCG 30	3.5	0.396 ab	2.72 b	2.18 ab	0.334 a	801	6.23	39.81 a	50.20 ab
TSCG 7.5	3.2	0.394 ab	2.66 b	1.76 b	0.323 ab	956	5.87	30.29 c	44.48 b
LSD	ns	0.044*	0.57*	0.62*	0.043*	ns	ns	6.62*	15.98*

* Significantly different at the P < 0.05 level; ** Significantly different at the P < 0.01 level; ns: no significant difference

As seen in *Table 5,* SCG applications significantly increased leaf P, K, Mg, Zn, Mn content while reducing the levels of Ca (p<0.05); however, there were no significant effects on the content of N, Fe, and Cu. The increase in leaf K content was significant only at the 15 t ha^{-1} SCG application (8.4% increase compared to the control), while the effects of other SCG doses were the same as the control. The leaf Mg content reached the highest values with 9.5% increase at 15 t ha^{-1} and an 9% increase at 7.5 t ha^{-1} SCG applications.

The highest leaf Zn content was determined with the 30 t ha^{-1} SCG, recording 29% increase compared to the control. Cervera-Mata et al. (2017 and 2020), have mentioned that some polyphenols and other chelating compounds in Fresh SCG applied to the soil could mobilize Fe, Zn in the plant, thereby increasing their uptake and consequently the Fe, Zn concentrations in lettuce plants. Our research found that leaf contents of Mg and Zn were higher with SCG applications than with mineral fertilizer applications. Manganese levels were also significantly higher with 15 and 30 t ha^{-1} SCG applications compared to the control. Consistent with our results, Cervera-Mata et al. (2019) have stated that SCG applications increased P, Mg, Zn, Mn in lettuce; Chrysargyris et al. (2021) indicated an increase in N, P, K, Cu values in cauliflower, broccoli, and cabbage. In a different study, Cervera-Mata et al. (2017) have noted that compared to the control, available potassium in lettuce increased by 45% and phosphorus by 9% with SCG applications. Jeon et al. (2024) reported in their studies on lettuce leaves that increasing SCG applications raised the contents of Na, Mg, P, K, Fe, while a reverse trend was observed in Ca, Zn, Mn contents. Contrary to lettuce, they noted that Japanese Hogfennel leaf mineral content was positively affected, especially marking a 288% increase in Fe content at the SCG dose compared to the control. Our research determined that the leaf Ca contents significantly decreased with SCG applications (P<0.05). Similarly, Çalişkan et al. (2020) recorded that as SCG applications increased, the concentrations of N, P, K in all components of pine seedlings rose, whereas the calcium values decreased. Differently, Cervera-Mata et al. (2019) reported that SCG applications increased the calcium content in lettuce. Cruz et al. (2014) determined that Fresh SCG applications at increasing doses from 2.5% to 20% reduced the content of macro and microelements in lettuce leaves, excluding potassium. It was noted that these reductions in the plant's mineral content were particularly high for Mg and P, up to 60%, and for Ca 40%, while an increase of up to 10% was determined for K content. Remarkably, researchers have also reported an increase in the amounts of these elements in the soil after harvest. In our research, leaf contents of P, K, Mn were determined to be higher with mineral fertilizer applications compared to SCG (*Table 5*).

The effect of SCG applications on the nutrient element content of radish tubers is depicted in *Table 6*. It has been determined that SCG applications significantly increased the tuber content of P, K, Mg, Cu, Zn, and Mn. The highest content of Mg ($P<0.05$) and Mn ($P<0.01$) in radish tubers was observed with the highest dose of 30 t ha^{-1} SCG. Compared to the control, the increases in Mg and Mn content were 32% and 55%, respectively, which were significantly higher than the increases after mineral fertilizer applications. The highest Cu content in the tubers was determined with the 7.5 t ha^{-1} TSCG application ($P<0.05$), which recorded a 45% increase compared to the control. No significant difference was found in the P, K, Zn contents of the tubers among SCG application doses. While the N, Ca, Fe contents in the tubers increased with SCG applications, these increases were not statistically significant. The fact that both leaf and tuber N content were unaffected by SCG applications, which are high in organic matter and N content, may be due to soil microorganisms using mineral nitrogen for their development and thereby immobilizing it (Cervera-Mata et al., 2019). Tuber values of P, K, Zn, Mn significantly increased with SCG applications compared to the control but were lower than those with mineral fertilizer applications (*Table 6*).

Table 6. Effect of SCG applications on the nutrient element content of radish tubers

Treatments (t ha^{-1})	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})
Control	1.4	0.337 b	2.81 b	0.3	0.169 b	293	8.16 ab	18.72 b	13.04 c
Mineral Fertilizer	1.9	0.453 a	4.00 a	0.4	0.214 ab	380	6.29 ab	27.68 a	22.54 a
SCG 7.5	2.0	0.377 ab	3.26 ab	0.3	0.181 ab	314	2.98 b	19.73 ab	14.50 c
SCG 15	1.6	0.375 ab	3.29 ab	0.3	0.195 ab	346	6.82 ab	22.62 ab	15.43 bc
SCG 30	1.7	0.398 ab	3.54 ab	0.3	0.223 a	337	3.64 ab	24.48 ab	20.27 ab
TSCG 7.5	1.5	0.357 b	3.20 ab	0.4	0.215 ab	298	11.83 a	24.22 ab	14.24 c
LSD	ns	0.082*	0.91*	ns	0.049*	ns	8.46*	8.87*	5.07**

* Significantly different at the $P<0.05$ level; ** Significantly different at the $P<0.01$ level; ns: no significant difference

In accordance with the enrichment of soil P, K, and Mg contents through SCG applications, an increase in these elements has also been observed in radish leaves and tubers (*Tables 4, 5* and *6*). Our findings, when compared to the study by Akay (2019), which investigated the effects of vermicompost doses on radish nutrition, indicate that radish leaves and tubers treated with SCG have noticeably higher concentrations of K and Fe, which are particularly important for nutritional value, than those treated with vermicompost. However, it has been observed that the P, Cu, Mn, Zn concentrations in leaves, and Mn, Zn levels in tubers were lower in SCG-treated plants.

Our research has determined that the concentrations of N, P, Ca, Mg, Fe, Zn, Mn were higher in the leaves than in the tubers, yet the K content was found to be higher in the tubers compared to the leaves. Similarly, Goyeneche et al. (2015) reported that the mineral content of radish leaves was higher than that of the tuber; the leaves contained five times more Ca compared to the tuber.

Applications of SCG to the soil have significantly increased the vitamin C values of radish tubers ($P<0.05$) (*Table 7*). The highest vitamin C values were determined with the 15 t ha^{-1} SCG application (22.01mg/100g), which recorded a 35% increase compared to the control (16.28 mg/100g) (*Table 7*). Similarly, Cruz et al. (2012 and 2015) have reported that SCG applications supported the production of vitamin C in lettuce plants. The vitamin C values in radish tubers obtained with our SCG applications were found to be considerably higher than the 16.59 mg 100 g^{-1} value determined by Goyeneche et al., 2015 for lettuce. This reveals that SCG applications enrich the vitamin C content of radish roots, which is also important for human health. Turhan and Özmen (2021) reported that organic fertilizers, compared to control and chemical fertilizer treatments, resulted in the highest vitamin C content in industrial tomatoes.

In our study, a decrease in radish tuber yield was observed with SCG applications compared to the control and mineral fertilizer applications (*Table 7*). However, this decrease was not found to be statistically significant. The inhibitory effect of SCG applications on plant growth has been observed by different researchers (Yamane et al., 2014; Hardgrove and Livesley, 2016; Cervera-Mata et al., 2017 and 2019). The growth-inhibitory effect of SCG on plants may be due to phytotoxins originating from fresh organic matter or nitrogen immobilization (Hardgrove and Livesley, 2016; Cervera-Mata et al., 2022). Additionally, caffeine, tannins and polyphenols present in SCG may negatively affect plant growth. Conversely, Cruz et al. (2012), reported that fresh SCG applied at concentrations of 2.5–10% increased lettuce biomass, whereas higher concentrations inhibited growth.

In our study, changes in the dry matter content with SCG application were not found to be statistically significant as shown in *Table 7*.

Table 7. Effect of SCG applications on Tuber yield, dry matter and vitamin C content of radish tubers

Treatments (t ha^{-1})	**Tuber yield (g (m^2)$^{-1}$)**	**DM (%)**	**C Vit (mg 100 g^{-1})**
Control	1023	12.2	16.28 c
Mineral Fertilizer	1203	12.9	19.34 b
SCG 7.5	990	13.1	19.79 ab
SCG 15	853	12.9	22.01 a
SCG 30	750	12.7	19.06 b
TSCG 7.5	983	12.4	19.16 b
LSD	ns	ns	2.53*

* Significantly different at the P<0.05 level; ns: no significant difference

4. Conclusions

The use of Spent Coffee Grounds (SCG), rich in organic matter and minerals, as a soil conditioner has been shown to enhance the nutritional value of red radish by enriching its mineral content. SCG applications significantly increased the concentrations of P, K, Mg, Zn, and Mn in radish leaves and tubers. Moreover, the application of SCG improved the C vitamin content of radishes, which is crucial for healthy nutrition. However, while SCG use as a soil conditioner did not significantly affect radish tuber yield, it caused a slight reduction, possibly due to the bioactive residues such as caffeine inducing stress in the plant. Further research is required to gain a clearer understanding of this phenomenon.

At the end of the vegetation period, SCG applications significantly enriched the soil's organic matter content and concentrations of N, P, K, Mg, and Zn. Particularly, the application of 30 t ha^{-1} SCG resulted in the highest levels of organic matter, K, Mg, and Mn in the soil.

These findings suggest that SCG is a highly effective organic soil conditioner and a valuable nutrient source for plants. Given the significant quantities of SCG generated as waste, its reuse in agriculture contributes to sustainable soil fertility and carries important environmental implications. This practice not only supports ecological and sustainable agriculture but also reduces the need for chemical fertilizers, offering economic benefits. SCG holds significant potential for the production of nutritionally rich agricultural products.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflict of interest

The authors declare that they have no conflicts of interest.

Author contributions

Concept: Ceylan, Ş.; Data Collection or Processing: Ceylan, Ş., Yoldaş, F. Mordoğan, N., Bayız, O; Statistical Analyses: Mordoğan, N., Bayız, O.; Literature Search: Ceylan, Ş.; Writing, Review and Editing: Ceylan, Ş.; Authors read and approved the final manuscript.

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