Research Article

The Role of Organic Fertilizer in Vegetative Growth Indicators and Some Bioactive Compounds of Two Hybrids of Broccoli

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Abstract | This study aims to assess the influence of organic fertilizer on the growth parameters of two types of hybrids and certain bioactive compounds. The experimental design was split plot as randomized complete block design (RCBD), where three replications were taken. The results indicated that the Purple Magic F1 hybrid outperformed in the number of leaves, leaf area, ascorbic acid concentration, and sulforaphane content, with values of (25.60 leaf. plant^{-1}, 303.7 dm^2. plant^{-1}, 132.20 mg. 100g^{-1} fresh weight, 364.14 mg. kg^{-1}) respectively. On the other hand, Besty F1 recorded higher values in dry matter percentage in the vegetative mass, total chlorophyll content, and glutathione content with (17.18 g.plant^{-1}, 173.07 mg. 100g^{-1} fresh weight, 64.20 mg. kg^{-1}) respectively. Vermicompost organic fertilizer surpassed spent mushroom compost (SMC) in plant height, stem diameter, number of leaves, leaf area, and dry matter percentage of the vegetative mass with values of (69.89 cm, 28.70 mm, 30.31 leaf. plant^{-1}, 376.8 dm^2. plant^{-1}, 17.93 g. plant^{-1}) respectively. Vermicompost recorded higher mean values of Total Soluble Solids %TSS, ascorbic acid, glutathione, and sulforaphane with (7.42%, 138.56 mg.100g^{-1} fresh weight, 69.52 mg.kg^{-1}, 386.21 mg .kg^{-1}) respectively. However, SMC recorded a significant increase in total chlorophyll content (185.06 mg.100g^{-1} fresh weight). The interaction between Purple Magic F1 and vermicompost achieved the highest mean values for plant height, stem diameter, number of leaves, leaf area, dry matter percentage, %TSS, ascorbic acid, and sulforaphane with values of (71.84 cm, 28.82 mm, 32.98 leaf. Plant^{-1} and 503.6 dm^2. plant^{-1}, 18.12 g. plant^{-1}, 7.42% and 146.76 mg.100g^{-1} fresh weight, 397.94 mg. kg^{-1}) respectively, while Besty F1 combined with SMC showed the highest chlorophyll content (193.67mg.100g^{-1} fresh weight) and Besty F1 with vermicompost had the highest glutathione content (73.93 mg. kg^{-1}).

Received | June 13, 2025; **Accepted** | October 01, 2025; **Published** | June 30, 2026
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Citation | Howeidi, M.A.R., A.I. Manea and M.J.H. AL-Shareefi. 2026. The role of organic fertilizer in vegetative growth indicators and some bioactive compounds of two hybrids of broccoli. *Pakistan Journal of Agricultural Research,* 39(2): 39-47.
DOI | https://dx.doi.org/10.17582/journal.pjar/2026/39.2.39.47
Keywords | Broccoli, Organic fertilization, Food production, Active compounds

Introduction

Broccoli *(Brassica oleracea* L. *var. italica Plenck)* is a plant within the family Brassicaceae. It is a result of an evolution of wild cabbage species which grow along the northern shores of the Mediterranean, at the frontiers of Greece to the British Isles in Western Europe (Pyasi and Deshlehra, 2022). Broccoli is an edible vegetable, which belongs to the cabbage family, since it preys on the floral head of

the plant (Marino *et al*., 2016). Broccoli is cultivated across the world but China tops on the list of the largest producers followed by India and the United States then Mexico then Spain and Italy and then Bangladesh and then Poland and then Algeria and finally France according to the 2023 FAO statistics. In Iraq, the planted acreage amounted to 804 hectares and production was 12,400 tons giving an average yield of 9.7 tons. ha^{-1}. The area under cultivation was 1,400,000 hectares globally with 26,000,000 tons of production with an average of 19 tons/ hectare (FAO, 2023). Cruciferous vegetables are healthy Phyto transcriptional compounds (Khalil *et al*., 2022).

The essential biological substances (Valverde *et al*., 2015) are mainly glucosinolates, isothiocyanates, phenolic compounds, ascorbic acid, tocopherols, carotenoids, and minerals, calcium, magnesium, sulfur, and selenium, which are abundant in broccoli. These phytochemical compounds are strongly influenced by genetic regulation and environmental factors in their synthesis in vegetables (Nunez Gomez *et al*., 2020). The edible floral heads of broccoli are rich in compounds including indole-3-carbinol, sulforaphane, flavonoids, and vitamins A, B, and C, and contain high fiber and low-fat content, making it the ideal food to include in the diet in case of weight loss (Le *et al*., 2020). Essential nutrients must be available in adequate and balanced amounts for plants to produce their best yields, particularly broccoli, which possesses unique health benefits. To compensate for nutrient deficiencies in the soil, large amounts of chemical fertilizers are currently used. However, continuous use of chemical fertilizers poses health and environmental risks, including nitrate leaching that can contaminate surface and groundwater (Eswaran and Mariselvi, 2016). To prevent the use of harmful chemicals, especially pesticides and industrial fertilizers, researchers have focused on reducing pollutant accumulation in agricultural ecosystems through organic farming (Ignacimuthu and Vendan, 2007).

Waling and Chani (2022) explained the *Brasica Oleracea Var. Italica* to manage integrated nutrients. A field experiment was carried out on a experimental farm of the University of Nagalland. The results showed that the application of different levels of fertilizers and organic waste, both separately or combined, led to a noticeable increase in growth, yield and broccoli quality compared to the control unit. Record the full dose application of RDF (which indicates the recommended amount of nutrients such as nitrogen, phosphorous and potassium to achieve the optimal growth of the plant) the highest height of the plant (50.3 cm), the number of leaves (18.2), the leg diameter (20.7 mm), the Ascorbic acid content (60.9 mg per 100 grams), and the percentage of soluble solids. (T.S.S) (9.97%). The treatment of poultry dung also showed 2.5 tons/hectare + half the RDF dose is statistically similar results to the previous treatment in terms of the height of the plant (47.5 cm), the number of leaves (16.5), the leg diameter (19.5 mm), the ascorbic acid content (60.7 mg per 100 grams), and the T.S.S (9.57%).

Tsagi and Kozugo (2023) have found the effects of the use of vermicompost (worm fertilizer) and green manure on the production qualities and quality of broccoli. The results showed that the treatment of vermicompost at a rate of 30 kg/ha recorded the highest pink head weight (1567.77 g) and the highest content of vitamin C and total phenolic compounds (92.31 mg/100 g; 1308.87 mg 100 GAE $ml–^{1}$), compared to the minimum mean obtained from the application of green manure at 1.6 kg/ha for these traits.

Another organic fertilizer is spent mushroom compost (SMC), aby-product of mushroom production. It is generally composed of wheat straw, horse manure, and other components, enriched together. It contains high levels of organic matter, salts, enzymes, and nutrients, making it a low-cost and high-quality organic amendment for improving soil health and crop performance, while reducing reliance on chemical fertilizers (Singh *et al*., 2020). Ahmed *et al*. (2023) in their study on the effect of mushroom residues and sulfur on the growth of broccoli recipes in gypsum soils showed that there are significant differences in the diameter of the flower head, where the highest value (27.67 cm) of the diameter of the flower head, the length of the leaf (35.67 cm), the highest weight of the flower head (1338.3 grams), and the number of leaves per plant (19.67 leaves/plant), in addition to the highest total yield (148,702 kg/ha) when applying the treatment (15% mushroom fertilizer + 3000 kg/ ha sulfur).

Ismail and Sarhan (2024) have identified such an effect of foliar spraying using humic acid, algae extract and organic fertilizers on growth and production of

broccoli (Brassica oleracea) of the (Agassirz) variety. Optimum values were obtained as a result of the triple interaction of humic acid (4 ml L^{-1}), algae extract (4 ml L^{-1}), algae extract (4 ml L^{-1}), and organic manure (animal manure) at a concentration of (10 tons per hectare). It was compared to the control treatment and the other doses and was characterized by a large effect on vegetative characteristics, such as height of plant (40.25 cm), and the number of leaves per plant (24.81 leaves $plant^{-1}$) and the number of heads per plant (10.93). Although interaction of humic acid with algae extracts at (2 ml L^{-1}) with the applied organic fertilizer at (10 tons $dunam^{-1}$) resulted in a significant increase in fresh weight of vegetative growth (2.68 kg). This study was undertaken to determine effects of organic fertilizer on growth and Indicators and Some Bioactive Compounds of Two Hybrids of Broccoli.

Materials and Methods

The experiment was carried out in the training and demonstration farm of the Al-Mahnawiyah region of the Al-Musayyib district, 40 km north of the center of Babylon governorate (32.7 north and 44.5 east) in the 2024-2025 agricultural season. The objective of the experiment was to observe the enhancement of the growth of two broccoli hybrids when they were fertilized using organic fertilizer and to examine their contents of certain active compounds. To examine some of the physical and chemical features of soil, soil samples were collected in the field at different areas before planting with a range of depths of 0-30 cm. The samples were then air-dried, ground and sieved through a 2 mm mesh sieve, and examined at the Central Soil Laboratory of the Department of Agriculture in Babylon to identify some of the chemical and physical characteristics of the soil. Table 1 indicates some of the physical and chemical characteristics of the soil before the planting.

The experiment soil was prepared by cultivation, in a meticulous and routine fashion, by enlarging the soil as used by planting out the planted plants and shrubs followed by ploughing, leveling and aeration of soil. The plot had been broken down into six plots with each plot being distributed in form of duplicates, 1 meter each. Plots were separated in six pilot units of 3 meters long and 1 meter wide each, which is 3 square meters per pilot unit. There was 1 meter separation between pieces and 0.75-meter separation between the pilot units to eliminate interference between transactions with additional buffer separation at the start and end of each section. The plants were watered with drip irrigation system.

Table 1: *Physical and chemical properties of the field soil before planting*

Property	Unit	Value	Property	Unit	Value
Soil PH	–	7.14	Available Potassium	mg/kg	31.7
Electrical conductivity	ds/m	3.0	Bulk density	g/cm^3	1.12
Organic matter	%	11.5	Sand	g/kg	176
Available Nitrogen	mg/kg	12.3	Silt	g/kg	484
Available phosphorus	mg/kg	9.52	Clay	g/kg	340
Soil texture	–	Loamy clay silt			

This experiment was planned in the form of the experimental working design (2x3) in the total random system of squares with division of coefficients and repeated three times. The first major factor is hybrids (A1, A2), and the second one is the type of compost. The experimental units were 6 units per iteration, which increased the experimental units in the field to 18.

Hybrid seeds of broccoli Besty F1 (produced by the Swiss company Syngenta) and Purple Magic F1 (produced by the German company Bobby-Seeds were received). On 27/8/2024, the nurseries of the project area in Musayyib district, Babylon Governorate, the seeds were planted in polystyrene trays on peat material so that a single seed germinated in each of the eyes in an area shaded by green saran netting to minimize sunlight, which would otherwise cause drying of the seed. Once the seedlings reach a stage at which they have four or five true leaves they will be moved to the field on 3/10/2024 to start the planting season. Planting was done in the hills where 12 seedlings were spaced on both sides of the row in alternate places (one row) with 50 cm between rows and 50 cm between plants. The service, irrigation, and pest control activities were conducted based on the recommendations (Al-Sabayla and Tarawneh, 2007). Irrigation was applied by drip system twice a week in the initial period of planting, and it was later changed according to the real requirements of the plants and weather. The experiment was a two-factor experiment:

The first factor is two hybrids of the broccoli plant

The green variety F1 Besty Broccoli: produced by the Swiss company Syngenta, with a germination rate of 97% and purity of 99.9%. The maturity period is 85-90 days with a curd weight of 350 grams.

The purple variety Purple Magic F1: produced by the German company Bobby-Seeds, with a germination rate of 98% and purity of 100%, maturation period of 70-85 days, and a curd weight of 400 grams.

The second factor is organic fertilization.

It includes two types: vermicompost and mushroom waste compost, as follows:

Control treatment

Organic fertilizer, mushroom waste (SMC), produced by the Future University Laboratories / locally manufactured, was added to the soil under the plant at a rate of 3 kg per experimental unit, with its specifications detailed in Table 2.

Organic vermicompost from livestock and poultry farms in Al-Kut / locally produced, with the soil application under the plant at a rate of 3 kg per experimental unit, and its specifications are detailed in Table 2.

Six plants were randomly taken from each experimental unit with the aim of making vegetative measurements and analyzing broccoli's content of active compounds. The experimental results were analyzed using the method of analysis of variance and the test of the minimum significant difference (L.S.D.) between the coefficients at a probability level of 0.05 (Al-Sahawi and Wahab, 1990). GenStat software was used for statistical analysis. The qualities measured were as follows:

- Plant height (cm)
- Stem diameter (mm)
- Number of leaves (leaf. plant^{-1})
- Leaf area (dm^2. plant $^{-1}$)
- The percentage of dry matter in the vegetative mass (g. plant-1)
- Estimation of total chlorophyll in leaves (mg/100g fresh weight)
- The percentage of total soluble solids (%) in the curd
- Concentration of ascorbic acid (Vitamin C) in the curd (mg. 100g-1 fresh weight)
- Estimation of glutathione (mg. kg-1) in the curd
- Estimation of sulforaphane (mg. kg-1) in the curd

Table 2: *Physical and chemical properties of vermicompost and SMC*

Property	Unit	SMC Value	Vermicompost value
Electrical Conductivity	ds/m	1.5	3.4
PH	–	6.6	6.5
Total Nitrogen	%	1.12	3.50
Phosphorus	%	0.29	1.80
Potassium	%	1.04	1.70
Total carbon	%	14.29	35.43
C/N ratio	–	12.79	10.18

* The analysis was conducted in the laboratories of the Babil Agriculture Directorate.

Results

Vegetative growth traits

Results in Table 3 show significant differences between broccoli hybrids in vegetative growth traits, except for plant height and stem diameter, which did not differ significantly. Purple Magic F1 recorded higher values for the number of leaves and leaf area (25.60 leaf. plant^{-1} and 303.7 dm^2. plant^{-1}) respectively. while Besty F1 showed higher dry matter percentage in the vegetative mass (17.18g. plant^{-1}).

Regarding organic fertilization, organic fertilizer (vermicompost) greatly outperformed the organic fertilizer (SMC) in the height of the plant, the diameter of the leg, the number of leaves, the area of the leaves, and the percentage of the dry material, where the following values were recorded: (69.89 cm, 28.70 mm, 30.31 sheets plant^{-1}, 376.8 d vicinity/plant, and 17.93 grams plant^{-1}) respectively. However, the bilateral reactions between the type of hybrid and organic fertilization showed moral differences in the characteristics of vegetative growth through the interaction between the Purple Magic F1 and the Vermicompost, which recorded the highest average in the height of the plant, the diameter of the stem, the number of leaves, the area of the leaves, and the percentage of the dry material in the vegetative part, with the following values: (71.84 cm, 28.82 mm, 32.98 leaf. plant^{-1}, 503.6 dm^2. plant^{-1} and 18.12 g. plant^{-1}) respectively.

Bioactive compounds

Results in Table 4 indicate significant differences

between hybrids for some bioactive compounds, except %TSS, which showed no significant differences. Purple Magic F1 had higher ascorbic acid and sulforaphane contents (132.20 mg. $100g^{-1}$ FW and 364.14 mg .kg^{-1}), while Besty F1 had higher total chlorophyll and glutathione contents (173.07 mg. $100g^{-1}$ FW and 64.20 mg. kg^{-1}) .

Vermicompost significantly outperformed SMC in %TSS, ascorbic acid, glutathione, and sulforaphane (7.42%, 138.56 mg .$100g^{-1}$ FW, 69.52 mg. kg^{-1}, and 386.21 mg. kg^{-1} respectively). SMC, however, recorded a higher total chlorophyll content (185.06 mg $100g^{-1}$ FW). We find that the dual interactions of hybrid treatment and organic fertilization showed significant differences in the active compounds

Table 3: *The effect of organic fertilizer on two hybrids of broccoli in vegetative growth traits and their interaction.*

Hybrid	Plant height (cm)	Stem diameter (mm)	Number of leaves (leaf. plant^{-1})	Leaf area (dm^2. plant^{-1})	Dry matter % (g. plant^{-1})
Besty F1	66.93	27.54	23.31	192.8	17.18
Purple Magic F1	68.87	27.60	25.60	303.7	16.13
L.S.D.0.05	NS	NS	1.12	45.75	0.24
Organic fertilization					
Control	65.13	25.61	16.52	97.0	14.51
Mushroom waste (SMC)	68.68	28.40	26.54	270.9	17.53
Vermicompost	69.89	28.70	30.31	376.8	17.93
L.S.D.0.05	1.67	0.21	1.11	44.79	0.20
Organic fertilization X hybrids					
A1B0	64.42	25.66	17.03	101.2	16.28
A1B1	68.43	28.38	25.28	227.0	17.52
A1B2	67.93	28.57	27.63	250.1	17.75
A2B0	65.83	25.56	16.01	92.7	12.73
A2B1	68.93	28.42	27.80	314.9	17.55
A2B2	71.84	28.82	32.98	503.6	18.12
L.S.D.0.05	3.59	0.40	1.39	56.25	0.27

Table 4: *The effect of organic fertilizer on two hybrids of broccoli in some effective compounds and their interaction*

Hybrid	TSS (%)	Ascorbic acid (mg/100g FW)	Total chlorophyll (mg/100g FW)	Glutathione (mg/kg)	Sulforaphane (mg/kg)
Besty F1	6.71	119.17	173.07	64.20	338.46
Purple Magic F1	6.55	132.20	157.33	57.37	364.14
L.S.D.0.05	NS	1.87	5.79	0.441	1.578
Organic fertilization					
Control	5.47	110.00	129.94	50.87	308.68
Mushroom waste (SMC)	7.01	128.50	185.06	61.96	358.99
Vermicompost	7.42	138.56	180.61	69.52	386.21
L.S.D.0.05	0.12	0.56	0.67	0.416	1.195
Organic fertilization X hybrids					
A1B0	5.70	105.26	136.11	53.01	295.52
A1B1	7.03	121.89	193.67	65.65	345.37
A1B2	7.40	130.36	189.44	73.93	374.48
A2B0	5.25	114.74	123.78	48.73	321.84
A2B1	7.00	135.11	176.44	58.28	372.62
A2B2	7.42	146.76	171.78	65.11	397.94
L.S.D.0.05	1.55	1.42	5.27	0.526	1.596

thru the interaction between the Purple Magic F1 hybrid and vermicompost, which recorded the highest average in the percentage of total soluble solids (TSS) and the concentration of ascorbic acid and sulforaphane with values of (7.42% and 146.76 mg.100g^{-1} fresh weight, 397.94 mg. kg^{-1}) respectively. While the interaction between the hybrid Besty F1 and the SMC mushroom waste fertilizer excelled in the total chlorophyll content of the leaves with a value of (193.67 mg.100g $^{-1}$ fresh weight), the Besty F1 hybrid with vermicompost fertilizer showed a significant superiority in the average glutathione compound with a value of (73.93 mg. kg^{-1}).

Discussion

The two hybrids were not significantly different in certain vegetative growth indicators like plant height and stem diameter, owing to the composition of the camels and their adaptation to the conditions of the area in which it was being cultivated. Nevertheless, Purple Magic F1 hybrid had a better average leaf count and leaf area than the Besty F1 hybrid. The Besty F1 hybrid on the other hand did better in the average dry matter ratio in the vegetative mass. The genetic differences between the two hybrids are explained by the fact that the two genetic constructions are different and the genes are expressed differently in response to the conditions that surround them, resulting in differences in growth rates (Manea, 2017).

The Purple Magic F1 hybrid excelled in the concentration of ascorbic acid and sulforaphane, while the Besty F1 hybrid excelled in the total chlorophyll and glutathione content of the leaves, which may be due to differences in the genetic makeup of the two hybrids. These differences physiologically affect the representation of many of the feedstocks that are formed through their biological processes, which in turn affects their morphological formation, and this ultimately reflects on their productivity and response to environmental factors (Omar and Abdullah, 2014). These findings are in line with the findings of Al-Husseini (2019).

The addition of organic vermicompost fertilizer had a significant impact on all vegetative traits (plant height, stem diameter, number of leaves, leaf area, and percentage of dry matter in vegetative mass). This is due to the important role of vermicompost fertilizer in improving the vegetative growth of the plant, as it contributes to increasing the activity of the root system, which positively affects the availability of nutrients by increasing the activity of microorganisms in the soil that play an effective role in the decomposition of organic matter and the release of nutrients, leading to increased productivity. This is consistent with the results of the study of Jain *et al.* (2023).

Vermicompost also helps to increase nutrient supply in the soil because the organic matter and useful microorganisms that are present in vermicompost assist in releasing nutrients and making them more readily available to plants. This makes sure that the crops receive the nutrients they require, which helps in the development of healthier and livelier plants (Mupambwa and Mnkeni, 2018). Organic matter added to the soil also contributes to the improvement of the soil structure in binding the light soil particle like sandy soils and light clay soils and also breaking the heavy soil particle like clay soils (AL-Shahat, 2007). This could be so since organic fertilizers have major and minor nutrients and organic compounds required to support plant growth and development leading to greater vegetative growth in the form of plant height, leaf area, plant leaves and plant dry weight. This can also be attributed to the fact that organic fertilizers do have nitrogen which promotes the production of auxin (IAA) because nitrogen is a component element in the formation of the amino acid, tryptophan, which is the fundamental substance in the formation of indole acetic acid and the role of auxin in the promotion of cell division and extension is a known fact (Abdul, 1987). The above findings are consistent with (Saeed et al., 2018) and (Al-Tamimi, 2022) in their studies with broccoli plants.

Significant differences were observed in some of the active compounds, with vermicompost outperforming mushroom waste fertilizer (SMC) in terms of total suspended solids (TSS) and concentration of ascorbic acid, clotiacin, and sulforaphane. In contrast, mushroom waste fertilizer (SMC) was significantly superior in terms of total chlorophyll content in the leaves. The superiority of vermicompost is attributed to its high content of highly degradable and peat-like substances, which are porous, breathable, drainage, water retention, and highly absorbed and retain nutrients. It contains easily absorbable nutrients such as nitrates, exchangeable phosphorus, potassium, calcium, and soluble magnesium (Nair *et al.*, 2006). This may be due to the ability of organic fertilizers

to improve the chemical and physical properties of the soil, which indirectly affects plant growth and the absorption of nutrients such as nitrogen, potassium, phosphorus, calcium, and magnesium. In addition to their humic acid content, which helps form complexes for dissolved ions and makes them available to plants. These ions also facilitate the movement of these ions with water, as they prepare organic matter and facilitate the absorption of nutrients by increasing cation exchange surfaces and improving soil permeability. Organic acids also increase water retention (Murphy, 2015). The increase in the content of some active compounds (clothianidin, sulforaphane, and ascorbic acid) is also largely consistent with the findings of Naguib *et al.* (2012) that showed that organic fertilization led to an increase in the content of total phenols, flavonoids, and glucosinolates in broccoli tablets, increasing their nutritional value. Shahin and Al-Nakhlawi (2008) have also pointed out that the increase in active compounds in response to organic fertilization is due to increased photosynthesis and carbohydrate synthesis, which ultimately leads to the storage of secondary compounds.

The increase in chlorophyll content in plant leaves as a result of fertilization with mushroom waste is due to the fact that these fertilizers increase the rates of nitrogen released from the soil, which in turn increases the accumulation of nitrogen in the plant, which is involved in the formation of chlorophylls as well as in the formation of amino acids that are involved in the formation of green pigments (Pang and Letey, 2000). Or because these fertilizers contain auxins and cytokinins that promote physiological activities and increase total chlorophyll. These results are consistent with those of (Mohammed, 2009 and Ali *et al.*, 2012).

Conclusions

The Purple Magic F1 hybrid outperformed in most vegetative growth traits and bioactive compounds. Vermicompost application resulted in the highest means for both vegetative traits and bioactive compounds compared to SMC. The interaction between Purple Magic F1 and vermicompost significantly enhanced most of the studied traits.

Acknowledgements

We express our sincere thanks and appreciation to the Faculty of Agriculture at Al-Qasim Green University and to all those who contributed to the completion of this research. noting that the research did not receive any financial support and was done through the personal efforts of the researchers.

Novelty Statement

Use of synthetic fertilizers can cause long-term problems for the environment. Developing a suitable strategy for agricultural application of alternative types of fertilizer is important. Commercial organic fertilizers were utilized to investigate effects on growth indicators and some bioactive compounds of two hybrids of Broccoli (*Brassica oleracea L. var. italica Plenck)*

Author's Contribution

Marwa Abdel Rasoul Howeidi: The idea of research, field implementation, sample collection, laboratory analysis, and writing the results.
Ali Ibadi Manea: Supervision and overall management of research, experimental design, and statistical data analysis.
Mohammed J. H. AL-Shareefi: Field research, data collection, and source review.

Generative AI and AI-assisted technology statement

The authors declare that no artificial intelligence techniques were used in the preparation, analysis, or editing of this manuscript. The research design, data collection, and analysis were performed solely by the authors.

Conflicts of interest

The authors declare that they do not encounter any conflicts of interest.

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