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Research Article

Effects of *Eisenia fetida* coelomic fluid and vermicompost on broccoli (*Brassica oleracea* var. *italica*) yield

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Abstract: Broccoli (*Brassica oleracea* L. var. *italica*) is an excellent source of health-promoting nutrients. This study aimed to investigate the effects of applications of earthworm (*Eisenia fetida*) coelomic fluid and vermicompost on the growth and yield of broccoli over a four-month cultivation period. Significant differences were observed among the treatments for all growth parameters. The highest plant length was recorded under coelomic fluid treatment (88 cm) and the lowest in the control (66 cm). The combined vermicompost and coelomic fluid application resulted in the greatest leaf length (20 cm), while the control had the lowest. Leaf width was highest with coelomic fluid (16.4 cm) and lowest in the control and vermicompost treatments (13 cm). Mineral analysis revealed significant treatment effects. The highest concentrations of Al (79.32 µg g^{-1}), Fe (86.33 µg g^{-1}), Mg (1872.76 µg g^{-1}), K (209.15 µg g^{-1}), and Na (633.30 µg g^{-1}) were observed in the control treatment. Vermicompost application reduced Al and Fe concentrations by 76% and 55%, respectively. The combined vermicompost and coelomic fluid treatment increased Cu levels nearly fourfold and Zn levels by 71% compared to the control. Coelomic fluid treatment resulted in the lowest Mg and K levels, with reductions of 53% and 48%, respectively, while organic (Coelomic fluid and vermicompost) treatments also reduced Na accumulation. Phosphorus, cadmium, and lead were below the limit of detection in all treatments. This study demonstrates that coelomic fluid and vermicompost are environmentally friendly resources that enhance broccoli growth and yield in sustainable agriculture.

INTRODUCTION

Broccoli (*Brassica oleracea* L. var. *italica*) is a winter vegetable with high nutritional value and economic importance, whose production and consumption have increased globally in recent years. China, India, the United States, Spain, and Mexico are the major producers (Güneş& Erçetin, 2022), while production in Türkiye reached 106,972 tons in 2021 (TÜİK, 2022). The growing demand for broccoli is largely driven by its classification as a functional food due to its high content of vitamins, minerals, and bioactive compounds (Adiloglu *et al*., 2018). Broccoli is particularly rich in glucosinolates, phenolic compounds, flavonoids, vitamins, and plant growth regulators, which contribute to its antioxidant, antimicrobial, and anticarcinogenic properties (Martínez-Villaluenga *et al*., 2008; Ünsal & Hayoğlu, 2018; Yemiş *et al*., 2007). Among these, phenolic compounds play a central role in both plant defense and human health.

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These secondary metabolites, characterized by hydroxylated aromatic rings, regulate plant–environment interactions and contribute to pigmentation, growth, and resistance against biotic and abiotic stresses (Brouillard, 2006; Nichenametla, 2006; Rahimi & Rahmanpour, 2020). Phenolic acids and flavonoids also improve the nutritional quality, sensory attributes, and antioxidant capacity of foods (Heim, 2002; Middleton, 2000; Ren, 2003; Rice-Evans, 2001). However, intensive broccoli cultivation commonly relies on chemical fertilizers and pesticides, which, although effective in enhancing short-term yield, pose risks to soil health, environmental sustainability, and food safety. Consequently, interest has increased in alternative fertilization strategies that enhance productivity while reducing ecological and health impacts. Vermicompost, produced through the biological activity of earthworms and associated microorganisms, has emerged as a promising organic amendment that improves soil structure, nutrient availability, and microbial activity (Rakkini *et al.,* 2017). Its application has been shown to significantly enhance broccoli growth and yield compared with chemical fertilization (Nadana *et al*., 2025). Earthworms (Lumbricidae), key components of soil fauna, regulate organic matter decomposition, nutrient cycling, and soil physical properties (Bhadauria & Saxena, 2010; Lavelle, 1995). Beyond their role in vermicomposting, earthworms secrete biologically active coelomic fluid containing enzymes, microorganisms, plant nutrients, and hormone-like compounds that stimulate plant growth and enhance resistance to pathogens (Chelkha *et al*., 2025; Nadana *et al.,* 2020; Yakkou *et al.,* 2022). These secretions, when incorporated into vermicompost or applied in liquid form, have been shown to promote plant development and strengthen plant defense systems (Jandaik et al., 2015; Sultana *et al.*, 2015).

Despite growing evidence of the agronomic benefits of vermicompost, limited information is available regarding the combined effects of liquid vermicompost and earthworm coelomic fluid on the nutritional and bioactive composition of broccoli. Therefore, investigating their influence on broccoli growth, yield, and phytochemical attributes is essential for developing sustainable and health-oriented production systems. Such approaches are expected to improve product quality and market value while contributing to safer and more environmentally friendly broccoli cultivation.

MATERIAL and METHODS

Plant Material and Growth Conditions

The Monet broccoli (*Brassica oleracea* var. *italica)* variety was used as the plant material in the experiment. The vegetative organs of broccoli were grown from seeds in the Plant Physiology Laboratory of the Department of Biology, Faculty of Science, Pamukkale University. Broccoli seeds were germinated under controlled laboratory conditions at 25 ± 1 °C. During the germination period, seeds were irrigated regularly every two days. When the seedlings reached an appropriate growth stage, they were transplanted into plastic pots, with two seedlings per pot. The plants were maintained under controlled environmental conditions throughout the experimental period.

Preparation of Liquid Vermicompost

Liquid vermicompost used in the broccoli experiment was produced from solid vermicast obtained from *Eisenia fetida*. Ten subsamples (50 g each) were suspended in distilled water, homogenized (TOPS SR30, Turkey), and incubated for 24 h at room temperature (Adhikary, 2012). The suspension was filtered and processed using a mechanical stirrer and heating plate (Heidolph AZR 2021 and MR3001, Germany). After heating and stirring for 10 min, 14 g Solveson was added to reduce pH, followed by 8 g KOH, 5 g seaweed extract (Atocrop), and 6 g amino acids (NH_2–R–COOH) for pH stabilization. Sodium benzoate (0.26 g) was added as a preservative. The mixture was stirred for 50 min and pasteurized at 57.2 °C, then cooled to 36 °C in a cold-water bath (Manyuchi *et al*., 2013). The final pH was adjusted to 7.14, and the solid content of the liquid vermicompost was 19.48 g.

Extraction of Coelomic Fluid

For the extraction of coelomic fluid, California red worms (*Eisenia fetida*) were individually collected from the soil and washed with distilled water to remove adhering debris. The cleaned worms were placed in a beaker, and 500 mL of distilled water was added. An electrical current of 15 V was applied to the worms to induce stress, thereby stimulating the secretion of coelomic fluid (Kobayashi *et al*., 2004; Nadana *et al*., 2020). The released coelomic fluid was collected and used for subsequent experimental analyses.

Experimental Design and Treatments

Broccoli seedlings transplanted into the pots. Vermicompost and coelomic fluid were applied separately and together. Applications were performed as foliar treatments using a plastic spray device to facilitate ionic absorption (Kamçı & Bicer, 2022). Each treatment group has five pots with two seedlings per pot. The experimental design consisted of four groups: control, vermicompost, coelomic fluid, and combined (vermicompost + coelomic fluid), resulting in a total 10 plants per group (Figure 1). Treatment solutions were prepared by adding 15 mL of vermicompost and/or coelomic fluid to 1.5 L of distilled water**.** Broccoli seedlings, at the age of four weeks, were individually transplanted into plastic pots. Initial treatments were applied to the root zone during planting, followed by subsequent applications delivered as foliar sprays. Vermicompost and coelomic fluid applications were repeated at defined intervals to ensure sustained effects on plant growth. The treatments were reapplied 20 days after the initial application. Morphological parameters such as stem, leaf, and curd development were recorded throughout the active growth period (April–July). In addition, phenolic compounds, secondary metabolites, and plant hormones were analyzed. Plant tissues were also evaluated for macronutrient contents (N, P, K, Ca, Mg) and micronutrient contents (B, Cu, Fe, Mn, Zn), basic components (water, protein, fat, and carbohydrates), total vitamins, and total mineral contents (Na, K, Ca, Mg, Cl, P, S, Fe, Zn, Mn, and Cu).

Mineral Content Analysis

Mineral element concentrations in broccoli tissues were determined using an ICP-OES system (Perkin Elmer Optima 8000). Plant samples were pre-digested with nitric acid and hydrogen peroxide (7:1, v/v), followed by microwave-assisted wet digestion using a HNO_3–H_2O_2 mixture (2:3, v/v) in a Speedwave MWS-2 system (Berghof Products + Instruments, Germany). The microwave program was carried out in three steps. 145 °C at 75% power for 5 min, 180 °C at 90% power for 10 min, and 100 °C at 40% power for 10 min. After the procedures, mineral elements were quantified by ICP-OES (Perkin-Elmer Optima 2100 DV, USA) according to Wang *et al*. (2022). Nitrate (NO_3^-) content was determined using a nitrate test kit and reflectometer following AOAC (Association of Official Analytical Chemists, 2005).



Figure 1. Potted broccoli plants (*Brassica oleracea* var. italica) under different treatments: a. control group, b. seedlings treated with coelomic fluid, c. seedlings treated with vermicompost, d. seedlings treated with a combination of vermicompost and coelomic fluid.

Statistical Analysis

Statistical significance was accepted at $p \leq 0.05$. All statistical analyses were performed using SPSS software (IBM SPSS Statistics 29). Data were expressed as mean ± standard deviation

(*Mean* ± *SD*). Comparisons between two independent groups were conducted using the independent samples *t*-test, while comparisons among more than two groups were performed using one-way analysis of variance (ANOVA). Pairwise comparisons were applied to determine differences among groups, and Bonferroni correction was used to adjust for multiple testing. In addition, variability among groups was evaluated by calculating the coefficient of variation (CV = 100 × standard deviation/mean).

RESULTS

Throughout the conducted experiment, significant differences were observed among the treatments in plant growth parameters. Leaf length, leaf width, and stem length increased consistently over time in all groups; however, treated plants exhibited significantly higher values than the control group at all measurement stages. At the first measurement, leaf length increased by 52% in the vermicompost treatment (9.1 cm) and by 87% in the coelomic fluid treatment (11.2 cm) compared to the control (6.0 cm). The combined application resulted in the highest initial leaf length (12.0 cm), representing a 100% increase over the control. Similarly, stem length increased from 16.6 cm in the control to 21.0 cm (+26%), 25.6 cm (+54%), and 27.4 cm (+65%) in the vermicompost, coelomic fluid, and combined treatments, respectively. In the second measurement, stem length reached 40.0 cm in the coelomic fluid treatment and 41.1 cm in the combined treatment, corresponding to increases of 43% and 47%, respectively, compared to the control (28.0 cm). Leaf width showed a similar trend, increasing from 5.8 cm in the control group to 9.0 cm (55% increase) with coelomic liquid application and to 11.6 cm (100% increase) with combined application. At the third measurement, stem length was 43.8 cm in the control group, 49.0 cm (+12%) in the coelomic fluid treatment, and 51.0 cm (+16%) in the combined treatment. Leaf length increased by 23% in both the coelomic fluid and combined treatments compared with the control group. The highest stem length was recorded in the coelomic fluid treatment (88.0 cm) at the final measurement, which corresponds to a 33% increase over the control (66.0 cm), followed by the combined treatment (86.0 cm; +30%) and vermicompost treatment (79.0 cm; +20%). Final leaf length reached 20.0 cm in the combined treatment and 18.1 cm in the coelomic fluid treatment, corresponding to increases of 25% and 13%, respectively, compared to the control (16.0 cm) (Figure 2 and Table 1). These findings demonstrate that the applications significantly enhanced leaf and stem growth relative to the control. The greatest and most consistent increases were observed in the coelomic fluid and combined applications.

According to Table 1, plant growth parameters (leaf length, leaf width, and stem length) increased progressively over time in all groups, with the highest values consistently observed in the vermicompost + coelomic fluid group, while the control group exhibited the lowest measurements throughout the study period. The relatively similar standard deviation values across groups and time points may be attributed to the controlled experimental conditions and the homogeneous nature of the measurements. Mineral analysis (Table 2 and Figure 3) indicated that the applied treatments significantly affected elemental accumulation in broccoli tissues. Copper concentration varied markedly between applications. The combined treatment of worm castings and coelomic fluid resulted in the highest Cu content (1.93 µg g^{-1}), which was significantly higher than all other treatments. The control group exhibited the lowest Cu concentration (0.49 µg g^{-1}), whereas the individual applications of vermicompost and coelomic fluid resulted in intermediate Cu levels. Zinc accumulation also showed significant differences among the treatments. The highest Zn concentration was recorded in the combined treatment (14.05 µg g^{-1}). Then, the control group showed (8.20 µg g^{-1}), whereas the lowest Zn concentration was observed in the coelomic fluid treatment (5.63 µg g^{-1}). The enhanced accumulation of micronutrients observed under the combined application of vermicompost and coelomic fluid suggests a synergistic effect of these amendments on nutrient availability and uptake in broccoli. In particular, the markedly higher concentrations of Cu and Zn compared with the control indicate that this treatment may improve micronutrient bioavailability through

improved soil biological activity, chelation processes, and root–microbe interactions. Vermicompost is known to increase micronutrient solubility and retention, while coelomic fluid may further stimulate nutrient mobilization and plant uptake. The approximately twice as much increase in Cu and Zn concentrations highlights the potential of this integrated approach to enhance the nutritional quality of broccoli, which is of agronomic and nutritional significance.

Significant differences in mineral element concentrations were observed among treatments ($p < 0.05$). Although the macro- and micro-element compositions vary among different parts of the broccoli plant, the florets, stalks, and leaves share several similarities in their mineral profiles, even though they are clearly different from the sprouts (Majkowska-Gadomska *et al*., 2024).

Aluminum content showed significant differences between treatments ($p < 0.05$). The highest Al concentration was observed in the control group (79.32 μg g^{-1}), while significantly lower values were recorded in all other treatments. The lowest Al level was recorded in the vermicompost application (18.78 μg g^{-1}), followed by the coelomic fluid application (25.03 μg g^{-1}). The combined application showed a slightly higher Al concentration (28.16 μg g^{-1}) compared to the individual applications, but it remained significantly lower than the control group. Copper concentration varied markedly between applications. Iron concentration was higher in the control group (86.33 μg g^{-1}) compared to all others. Among the treatment groups, the combined application resulted in higher Fe content (56.04 μg g^{-1}) compared to individual applications, while the lowest Fe concentration was detected in coelomic fluid treatment (37.29 μg g^{-1}). Magnesium content showed significant variations between treatments. The control group showed the highest Mg concentration (1872.76 μg g^{-1}). Among the treated plants, the combined application resulted in higher Mg content (1160.48 μg g^{-1}) compared to single applications. The lowest Mg level was observed in the coelomic fluid treatment (617.9 μg g^{-1}). Potassium concentration was highest in the control (209.15 μg g^{-1}) and combined treatments (185.48 μg g^{-1}); there is no significant difference between them. Lower K concentrations were observed in the individual applications, and the lowest value was recorded in the coelomic fluid treatment (108.84 μg g^{-1}). Sodium accumulation showed high differences among the treatments. The highest Na concentration was measured in the control group (633.30 μg g^{-1}), whereas the lowest Na level was observed in the worm castings treatment (129.24 μg g^{-1}). The combined treatment exhibited an intermediate Na concentration compared to the control and single applications. (290.12 μg g^{-1}). Phosphorus, cadmium, and lead concentrations were below the limit of detection (<LOD) in all treatments. These results indicate that the treatments do not cause heavy metal contamination risk.

Table 1. Leaf and stem length values of broccoli under vermicompost, coelomic fluid, and vermicompost + coelomic fluid treatments.

Time	April			May			June			July		
Applications	Leaf Length	Leaf Width	Stem Length	Leaf Length	Leaf Width	Stem Length	Leaf Length	Leaf Width	Stem Length	Leaf Length	Leaf Width	Stem Length
Control Group	6.00 ± 0.18	5.00 ± 0.18	16.60 ± 0.18	9.00 ± 0.18	5.80 ± 0.18	28.00 ± 0.18	14.70 ± 0.18	8.70 ± 0.18	43.80 ± 0.18	16.00 ± 0.18	13.00 ± 0.18	66.00 ± 0.18
Vermicompost	9.11 ± 0.19	7.20 ± 0.18	21.00 ± 0.18	10.00 ± 0.18	7.90 ± 0.18	32.00 ± 0.18	15.00 ± 0.18	13.00 ± 0.18	45.80 ± 0.18	19.00 ± 0.18	13.00 ± 0.18	79.00 ± 0.18
Coelomic Fluid	11.20 ± 0.18	8.70 ± 0.18	21.00 ± 0.18	13.40 ± 0.18	9.00 ± 0.18	40.00 ± 0.18	17.80 ± 0.18	11.40 ± 0.18	49.00 ± 0.18	18.10 ± 0.18	16.40 ± 0.18	88.00 ± 0.18
Vermicompost + Coelomic Fluid	12.00 ± 0.18	10.50 ± 0.18	27.40 ± 0.18	13.90 ± 0.18	11.60 ± 0.18	41.10 ± 0.18	18.10 ± 0.18	12.60 ± 0.18	51.00 ± 0.18	20.00 ± 0.18	14.00 ± 0.18	86.00 ± 0.18

Data are presented in centimeters as mean ± standard deviation (Mean ± SD).

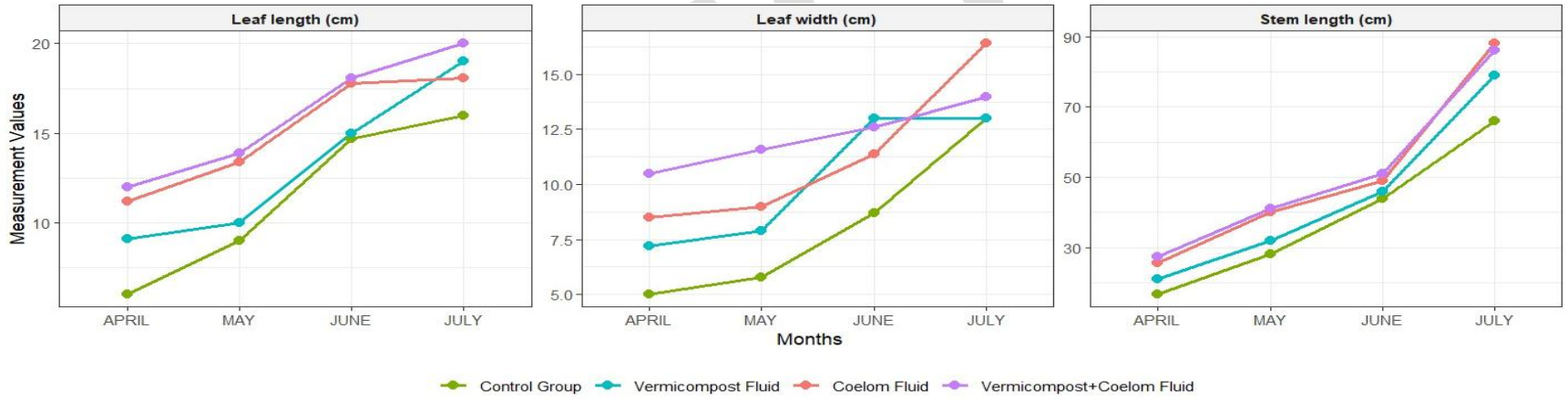


Figure 2. Stem and Leaf Length with leaf Width values of broccoli under the coelomic fluid, vermicompost and coelomic fluid + vermicompost treatments.

Table 2. Mineral content analysis values.

Application	Al (µg/g)	Cu (µg/g)	Zn (µg/g)	Fe (µg/g)	Mg (µg/g)	K (µg/g)	Na (µg/g)	P (µg/g)	Cd (µg/g)	Pb (µg/g)
Control group	79.32±0.92^{a*}	0.49±0.10^{c*}	8.20±0.19^{b*}	86.33±2.04^{a*}	1872.76±7.75^{a*}	209.15±7.25^{a*}	633.30±6.20^{a*}	<LOD	<LOD	<LOD
Vermicompost	18.78±0.17^{d}	0.71±0.03^{b}	7.5±0.15^{c}	39.23±0.37^{c}	617.9±7.71^{c}	145.71±12.04^{b}	129.24±8.57^{d}	<LOD	<LOD	<LOD
Coelomic fluid	25.03±1.83^{c}	0.68±0.07^{b}	5.63±0.16^{d}	37.29±1.17^{c}	878.17±6.50^{c}	108.84±12.75^{c}	417.61±3.42^{b}	<LOD	<LOD	<LOD
Vermicompost +Coelomic fluid	28.16±0.26^{b}	1.93±0.09^{a}	14.05±0.05^{a}	56.04±0.32^{b}	1160.48±31.05^{b}	185.48 ±11.90^{a}	290.12±8.45^{c}	<LOD	<LOD	<LOD
Coefficient of Variation (CV)	2.74	8.12	1.66	2.19	1.48	6.90	1.90	_	_	_

*Values indicated by the same letter are not statistically different from each other ($p \leq 0.05$). Data are presented as mean ± standard deviation (SD).

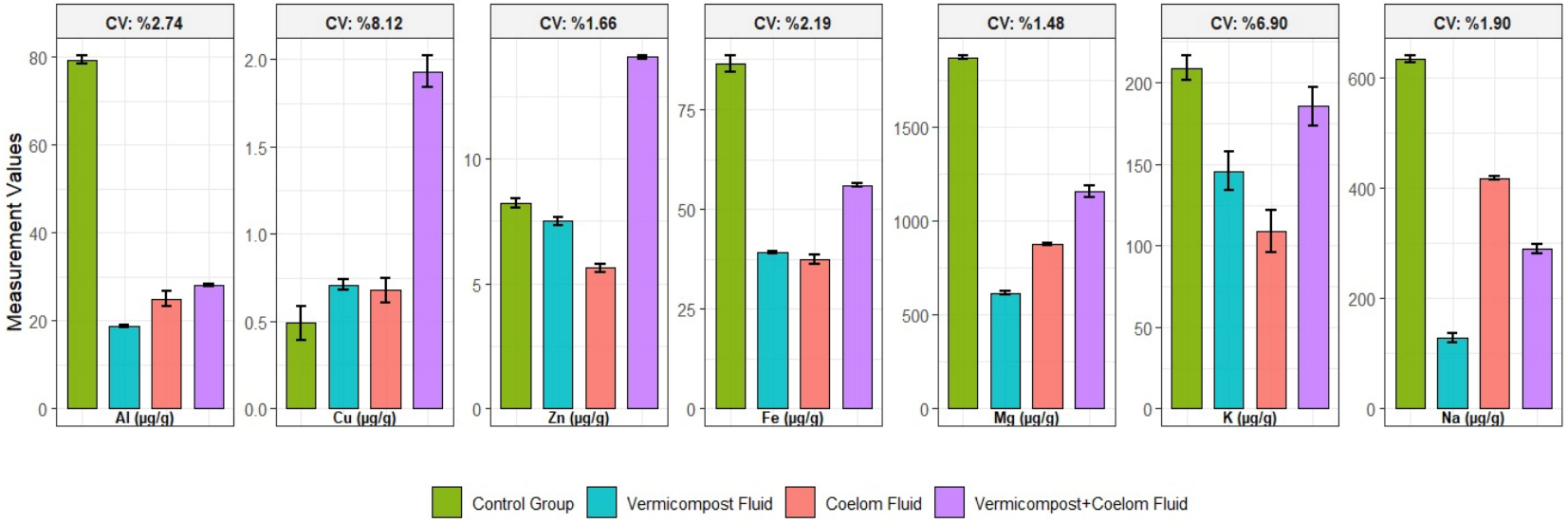


Figure 3. Mineral content analysis values.

DISCUSSION

The vegetative growth of broccoli (*Brassica oleracea* var. *italica*) plants is an important indicator of yield and quality. In this study, the application of vermicompost (VC) and coelomic fluid (CF) significantly improved morphological parameters such as leaf length, leaf width, and stem length compared to the control group. Stem length is a critical parameter in broccoli, as it determines the plant's structural capacity to support heavy floral heads.

Coelomic Fluid (CF) treatment provided the longest stem length (88 cm) by July; this corresponds to a 33.3% increase compared to the control group (66 cm). Previous studies on Brassicaceae species have shown that worm-derived liquid biostimulants contain phytohormones, such as auxins and gibberellins, which promote cell elongation (Kaur *et al.*, 2023). In the present study, stem length was greater in plants treated with coelomic fluid (CF) compared to those receiving vermicompost (VC) alone, reaching 79 cm. This response is likely attributable to the bioactive compounds present in the coelomic fluid. Leaf length and width are critical determinants of photosynthetic surface area in broccoli plants. Accordingly, the CF application resulted in the greatest leaf width (16.4 cm) up to July, whereas the combined application of vermicompost and coelomic fluid produced the maximum leaf length (20 cm). Previous research has shown that vermicompost enhances the uptake of nitrogen (N) and magnesium (Mg), which are essential for chlorophyll synthesis and leaf expansion (Rehman *et al*., 2023). The greater leaf width observed in the CF group is consistent with reports that amino acid-rich biostimulants increase metabolic efficiency and support leaf lamina expansion by reducing the energy requirement for native protein synthesis (Sun *et al*., 2024).

A considerable trend was observed in the early growth stage in April. The earthworm vermicompost+coelomic fluid treatment showed the highest values in all parameters (stem length was 27.4 cm compared to 16.6 cm in the control group). This model indicates a synergistic initial effect. Vermicompost enhances soil physical structure and microbial activity, while coelomic fluid provides an immediate biochemical stimulus (Hussain & Abbasi, 2018). By July, the CF treatment exhibited the greatest stem length. This indicates that the bioactive compounds in coelomic fluid may play a more effective role during the vegetative stage of broccoli growth. Throughout the study, the control group consistently demonstrated low performance. This indicated that natural soil nutrient levels were insufficient to support the high metabolic needs of the broccoli plant. These findings support the hypothesis that worm-derived amendments, particularly coelomic fluid, function as effective growth regulators. They enhance the expression of broccoli's genetic growth potential (Amit *et al.*, 2024).

In this study, organic fertilizers significantly altered the mineral accumulation in broccoli plants. All applications reduced aluminum (Al) levels compared to the control group. This reduction indicates a detoxification effect associated with vermicompost and coelomic fluid. The increase in Cu and Zn concentrations, under the combined application of vermicompost and coelomic fluid, can enhance the availability and uptake of essential micronutrients. Humic substances and beneficial microorganisms improve soil structure and nutrient solubility (Arancon *et al*., 2004). Higher micronutrient levels under the combined treatment may support metabolic processes and photosynthetic capacity, leading to improved plant development. The patterns observed for Mg, K, and Fe are similar to findings showing that organic fertilizers change nutrient availability by improving soil properties and the root environment. Although the control group exhibited the highest concentrations of these elements, the treated plants demonstrated a more balanced nutrient profile. This observation is supported by reports showing that vermicompost both increases soil organic matter and improves the availability of exchangeable nutrients, thus promoting nutrient uptake without excessive accumulation that could restrict plant growth (Trang & Chuong, 2025).

Cd and Pb concentrations were below the detection limit in all treatments. This result shows that vermicompost and coelomic fluid do not increase the risk of heavy metal contamination. Previous studies also report that vermicompost can reduce the bioavailability of toxic metals

such as Cd and Pb. This effect occurs through interactions with organic matter and the transformation of these elements into forms that are less readily available to plants (Alam *et al*., 2024). Vermicompost improves nutrient uptake through several mechanisms. It increases soil organic carbon and supports microbial populations involved in nutrient cycling. It also provides humic substances that chelate micronutrients and improve their availability for root absorption (Alam *et al.*, 2024; Blouin, 2013).

Coelomic fluid contains biologically active compounds that may stimulate root activity and microbial interactions in the rhizosphere. From an agronomic and sustainability perspective, these findings indicate that vermicompost and coelomic fluid can serve as an eco-friendly fertilization strategy (Gülser *et al*., 2019). Altogether, these results suggest that the synergistic effect of the combined treatment is driven by improved soil nutrient status and increased nutrient uptake efficiency, highlighting its potential to reduce the use of chemical fertilizers.

CONCLUSION

This study demonstrated that the application of *Eisenia fetida* coelomic fluid and vermicompost significantly enhanced the vegetative growth and mineral composition of broccoli (*Brassica oleracea* var. *italica*) compared to the untreated control. Among the individual treatments, coelomic fluid proved most effective in promoting stem elongation and leaf expansion, likely due to its content of bioactive compounds such as phytohormones and amino acids. The combined application of vermicompost and coelomic fluid produced the greatest leaf length and markedly increased the concentrations of essential micronutrients, particularly Cu and Zn, suggesting a synergistic effect on nutrient availability and uptake. Organic treatments also reduced the accumulation of potentially harmful elements such as Al, Fe, and Na, while Cd and Pb remained below the detection limit in all groups, confirming the safety of these amendments. These findings highlight that vermicompost and coelomic fluid represent environmentally friendly and effective biostimulants with strong potential to replace or reduce chemical fertilizers in sustainable broccoli production. Future studies should investigate their effects under field conditions and assess the influence on phytochemical and bioactive compound profiles to further evaluate their agronomic and nutritional benefits.

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Declaration of Conflicting Interests and Ethics

The authors declare no conflict of interest. This research study complies with research and publishing ethics. The scientific and legal responsibility for manuscripts published in IJSM belongs to the authors.

Data Availability Statement

No datasets were generated or analysed during the current study.

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Authorship Contribution Statement

U.U.: Carrying out the research process, obtaining the necessary resources, transforming the data into visual representations, utilizing software tools, and conducting analytical assessments of the results. **K.K:** Determining the research methods and design, scientifically overseeing all stages of the study, and validating the reliability of the results. **Y.K.:** Actively conducting the research process, scientifically supervising all stages of the work, and preparing the first (original) draft of the article.

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