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Effects of Liquid Vermicompost and Cinnamon Application on Morpho-Agronomic Traits, Biomass Accumulation, and Macro Nutrient Content in Radish (*Raphanus sativus* L.)

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ABSTRACT

This study was conducted in the unheated glass greenhouses of Van Yuzuncu Yil University to evaluate the effects of liquid vermicompost (LWF) and cinnamon applications on the yield and associated parameters of radish (Raphanus sativus L.). The experiment was designed in a randomized block design with three replications and included six treatment groups: control (K), 1% LWF (LWF1), 2% LWF (LWF2), 3 g cinnamon (CIN3), and their combinations (LWF1+CIN3 and LWF2+CIN3). Plant height, stem diameter, root length, leaf number, radish size, and biomass values were measured and statistically analyzed. According to the results, the LWF2 treatment significantly increased plant height (20.27 cm) and total fresh weight (59.87 g) compared to the control. Cinnamon alone yielded the highest stem diameter (6.07 mm) and radish diameter (17.83 mm). Furthermore, it achieved the highest dry matter accumulation (15.10 g), representing a 5.4% increase relative to the control. Although the combined applications of LWF and cinnamon, particularly LWF2+CIN3, led to notable reductions in plant height (15,2%), fresh weight (37,3%), and dry weight (27.4%), this treatment also maximized the uptake of potassium, magnesium, iron, and calcium, while reducing sodium accumulation by approximately 21.3% compared to the control. Correlation analysis revealed strong positive relationships between plant height and fresh weight (r = 0.93), and between stem diameter and radish diameter (r = 0.90). The findings indicate that LWF alone promotes plant growth, whereas its combination with cinnamon may exert antagonistic interactions that suppress yield. These results suggest that organic inputs influence not only yield-related traits but also nutrient uptake dynamics, highlighting the need for further research into dosage and combination optimization.

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Introduction

Radish (*Raphanus sativus* L.), a member of the Brassicaceae family, is a nutrient-rich crop typically cultivated as a winter vegetable. Due to its high content of dietary fiber, vitamins (C, B6, folate and etc.), and essential minerals (potassium, calcium, magnesium and etc.), it holds a significant place in human nutrition. With antioxidant properties and digestive benefits, radish is also considered a functional food. Moreover, it is utilized in agricultural systems as a soil-enhancing crop (Smith et al., 2023).

Globally, radish production is predominantly concentrated in Asia, with China and India being the leading producers. According to FAO (2024) data, the annual global production of radish is approximately 20 million tons. In contrast, production in Türkiye is relatively limited, with around 50,000 tons reported annually by the Ministry of Agriculture and Forestry (2024). However, the cultivation of radish during the cold season presents certain challenges. Low temperatures can lead to a decline in microbial activity in the soil, reduced root development, and overall yield loss. While conventional fertilization practices and chemical inputs offer partial solutions to these issues, the growing emphasis on sustainable and ecological farming practices has increased the demand for organic alternatives (Jones & Patel, 2022). In this context, applications of liquid vermicompost and cinnamon are believed to have beneficial effects on radish cultivation. Liquid vermicompost enhances soil microbial activity due to its content of beneficial microorganisms, plant growth hormones (such as auxins and cytokinins), and essential nutrients, thereby supporting both soil fertility and root development in plants (Arancon et al., 2006). Cinnamon powder (*Cinnamomum zeylanicum*) is notable not only for

its antifungal properties but also for its ability to promote plant growth. In a study conducted by Kowalska et al. (2019), the application of cinnamon water filtrates resulted in significant increases in growth parameters such as leaf number, branch number, and fresh weight of tomato plants under both greenhouse and field conditions. These findings suggest that cinnamon functions not only as a pathogen suppressor but also as a potential plant growth stimulator (biostimulant). This study aims to evaluate the effects of liquid vermicompost (at 1% and 2% concentrations) and cinnamon (at 3 g dose), applied individually and in combination, on the morphological and agronomic growth parameters of radish (*Raphanus sativus* L.). In particular, it seeks to determine whether these natural inputs produce statistically significant differences in growth and yield compared to the control group, and whether their combined application results in a synergistic effect on plant development.

Materials and Methods

This study was conducted to determine the effects of liquid worm fertilizer and cinnamon applications on yield and yield parameters in the cultivation of radish (*Raphanus sativus* L.). The experiment was arranged in a randomized complete block design (RCBD) with three replications. A total of 1,080 seeds were used, with 60 seeds sown in each replication. In the experiment, Cherry Belle variety radish (*Raphanus sativus* L.) seeds supplied by Bursa Tohum Company were used.

The experimental groups were established according to the randomized block design as follows:

- C (Control) : No treatment was applied.
- LWF1 : 1% liquid worm fertilizer application.
- LWF2 : 2% liquid worm fertilizer application.
- CIN3 : 3 grams of cinnamon applied to the growing medium.
- LWF1+CIN3: Combination of 1% liquid worm fertilizer and 3 grams of cinnamon.
- LWF2+CIN3: Combination of 2% liquid worm fertilizer and 3 grams of cinnamon.

The experiment was conducted in custom-made growing containers measuring 40 × 50 × 15 cm (width × length × height). The growing medium was prepared by homogeneously mixing 5 parts garden soil with 1-part well-decomposed farmyard manure. In each container, 3 grams of cinnamon powder were applied to the surface of the medium; the medium was then mixed using a small hand rake, and the surface was leveled to prepare it for sowing. Following seed sowing, liquid vermicompost was applied once at concentrations of 1% and 2% via irrigation water. During the growing period, no additional cultural practices were performed other than regular irrigation.

During the growing period, the maximum and minimum temperatures in the greenhouse were recorded as 32.8 °C and -7.5 °C, respectively. The maximum relative humidity was 84%, while the minimum was 10%. Throughout the cultivation period, irrigation and maintenance practices were carried out regularly. At the end of the experiment, the harvested plants were analyzed in the laboratory of our university, and the data obtained were recorded.

Measurement of Plant Growth Parameters

At the end of an approximately 90-day growth period, plants were harvested and all measurements were conducted. The parameters evaluated for the treatment groups are listed below:

- *Plant height (cm):* The length from the base of the stem (root collar) to the tip of the highest leaf was measured in centimeters.
- *Stem diameter (mm):* The diameter at the junction of the leaves and radish taproot was measured in millimeters using a digital caliper.
- *Root length (cm):* The root lengths of the plants removed from the growing medium were measured in centimeters using a ruler.
- *Number of leaves:* The number of leaves on each harvested plant was counted and recorded.
- *Radish diameter (mm):* The diameter of the radish radish was measured in millimeters using a digital caliper and recorded.
- *Radish height (mm):* The height of the radish radish was measured with a digital caliper in millimeters and recorded.
- *Total fresh weight (g):* The fresh weight of harvested plants was measured in grams using a precision scale.
- *Total dry weight (g):* After drying, the plants were weighed in grams using a precision scale and the values were recorded.
- *Determination of nutrient elements (Na, K, Ca, Mg, Fe):* Plant samples were collected from the shoot and leaf parts and dried at 65 °C until a constant weight was achieved. The dried samples were ground into a fine powder, and 2 g of powdered leaf material from each sample was transferred into porcelain crucibles. For preliminary combustion, a small amount of ethyl alcohol was added to the samples and ignited with a lighter to partially remove organic matter. Subsequently, the samples were placed in a muffle furnace at 500 °C for approximately 8 hours to complete the dry ashing process. The resulting ash was filtered through blue-banded filter paper and washed with distilled water. The filtrate was then diluted to a fixed volume with distilled water to prepare the final solution for analysis. Elemental analyses were performed using a flame atomic absorption spectrophotometer (Flame AAS) (İbrikçi et al., 1994).

Statistical Analysis

The data obtained were subjected to analysis of variance (ANOVA) using the STATGRAPHICS 15.1 software package. To determine the differences between the groups, a one-way analysis of variance (One-Way ANOVA) was performed. Statistical significance was evaluated using Duncan's multiple range test at a 5% significance level ($p < 0.05$). Additionally, Pearson correlation analysis was performed to examine the relationships among the investigated morpho-agronomic parameters.

Results and Discussion

Morphological Characteristics and Growth Parameters

In this study, the effects of different treatments on plant growth parameters were investigated. The data obtained revealed that the applications caused significant variations in plant height, stem diameter, root length, and number of leaves (Table 1). The differences between the treatment groups were found to be statistically significant for all parameters ($p < 0.05$).

Evaluation of Plant Height

In this study, the effects of different treatments on the plant height of radish (*Raphanus sativus* L.) were found to be statistically significant ($p = 0.0000$). The highest plant height was obtained from the 2% liquid vermicompost treatment (LWF2), with an average height of 20.27 ± 0.51 cm, which showed a significant increase compared to the control group (18.83 ± 0.40 cm). This result indicates that liquid vermicompost promotes plant growth, likely due to its rich organic matter content and microbial diversity.

Vermicompost contains readily available macro- and micronutrients as well as plant growth-promoting phytohormones (e.g., auxins, cytokinins, gibberellins), which can enhance root development and nutrient uptake capacity, thereby supporting vegetative growth (Arancon et al., 2004; Aira et al., 2010). The increased plant height observed with the LWF2 treatment can be attributed to these physiological and biochemical benefits.

Similarly, Shukla et al. (2021) reported a significant increase in plant height with liquid vermicompost application in sugarcane, as compared to the control. In addition, Edwards et al. (2007) stated that organic vermicompost improves soil structure and enhances water retention, which supports plant growth even under stress conditions.

On the other hand, combined treatments such as LWF1+CIN3 and LWF2+ CIN3 resulted in lower plant height than the LWF2 treatment alone. This suggests that the phenolic compounds present in cinnamon may exert growth-inhibitory effects when applied at higher concentrations. This phenomenon may be explained by the allelopathic effects of phenolic substances (Zeng, 2014). Specifically, cinnamic acid and its derivatives found in cinnamon (*Cinnamomum* spp.) extracts have been reported to inhibit cell division and elongation in certain plant species (Kostka-Rick & Manning, 1993).

In conclusion, the application of liquid vermicompost at a 2% concentration appears to be effective in promoting plant height in radish cultivation. However, when combined with cinnamon, this positive effect may be attenuated due to potential allelopathic interactions.

Changes in Stem Diameter

According to the treatments applied, stem diameter values in radish plants differed significantly at a highly significant statistical level ($p = 0.0001$). The highest stem diameter was obtained from the cinnamon (T3) treatment, with a value of 6.07 ± 0.33 mm. This value was found to be statistically higher than those of the LWF1, LWF 2, LWF1+T3, and LWF 2+T3 treatments. Although the cinnamon treatment resulted in an approximately 7% increase compared to the control group, the difference was within the same level of statistical significance.

Additionally, the antimicrobial and antioxidant properties of cinnamon may positively influence nutrient uptake by modulating soil microflora, thereby indirectly contributing to increased stem thickness (Zhang et al., 2016).

On the other hand, the combined treatment of LWF2 and CIN3 resulted in the lowest stem diameter (4.52 ± 0.16 mm). This suggests a potential negative synergistic effect when high concentrations of liquid vermicompost and cinnamon are applied together. One possible explanation could be that the simultaneous presence of high levels of organic matter and phenolic compounds creates excessive osmotic stress or allelopathic interference. This may lead to hormonal imbalances, disruptions in water relations, or suppression of cell division in plants (Rice, 2012).

Moreover, vermicompost treatments such as LWF1 and LWF2 generally resulted in stem diameters similar to or slightly lower than the control group.

These findings indicate that while vermicompost supports overall vegetative growth, it may not significantly contribute to stem thickening when applied alone. Arancon et al. (2004) reported that vermicompost primarily promotes root and leaf development, and its effects on stem tissues can vary depending on environmental conditions and dosage.

In conclusion, cinnamon application alone exerts a positive effect on stem diameter, whereas this effect may diminish or reverse in certain combined treatments. These results underscore the importance of carefully planning doses and treatment combinations in agricultural practices.

Table 1. Data table on plant height, stem diameter, root length, and leaf count

Treatments	*Plant height (cm)*	*Stem diameter (mm)*	*Root length (cm)*	*Number of leaves (no.)*
Control	18.83 ± 0.40 b	5.67 ± 0.18 ab	5.35 ± 0.20 a	7.17 ± 0.24 ab
LWF1	16.72 ± 0.34 c	5.23 ± 0.21 b	4.63 ± 0.20 bc	6.73 ± 0.22 b
LWF2	20.27 ± 0.51 a	5.42 ± 0.22 b	5.35 ± 0.19 a	6.87 ± 0.23 b
CIN3	18.40 ± 0.35 b	6.07 ± 0.33 a	4.57 ± 0.19 bc	7.60 ± 0.22 a
LWF1+CIN3	17.13 ± 0.49 c	5.41 ± 0.18 b	4.28 ± 0.23 c	7.67 ± 0.24 a
LWF2+CIN3	15.97 ± 0.47 c	4.52 ± 0.16 c	5.02 ± 0.42 ab	6.70 ± 0.19 b
Main	17.89 ± 0.20	5.39 ± 0.10	4.87 ± 0.11	7.12 ± 0.10
p-value	0.0000***	0.0001***	0.0116*	0.0043**

The letters within the columns indicate statistically significant differences according to Duncan's multiple range test at the $p < 0.05$ significance level.; $p < 0.001$ (Highly significant) ***, $p < 0.01$ (Very significant) **, $p < 0.05$ (Significant) *

Table 2. Data table on radish diameter, radish height, total fresh weight, and total dry weight

Treatments	*Radish diameter (mm)*	*Radish height (mm)*	*Total fresh weight (g)*	*Total dry weight (g)*
Control	17.25 ± 0.46 ab	27.69 ± 0.74 a	54.70 ± 3.46 ab	14,33 ± 1,08 ab
LWF1	16.03 ± 0.44 b	25.38 ± 0.90 b	46.63 ± 1.51 b	12,30 ± 0,72 cd
LWF2	16.35 ± 0.52 ab	24.57 ± 0.75 b	59.87 ± 5.21 a	14,23 ± 1,33 ab
CIN3	17.83 ± 0.69 a	24.89 ± 0.72 b	54.97 ± 3.99 ab	15,10 ± 1,31 a
LWF1+CIN3	14.24 ± 0.57 c	23.63 ± 0.90 b	47.93 ± 3.36 b	12,80 ± 1,15 bc
LWF2+CIN3	12.20 ± 0.49 d	23.70 ± 0.90 b	34.30 ± 2.72 c	10,40 ± 0,69 d
Main	15.65 ± 0.26	24.98 ± 0.35 b	49.73 ± 2.34	13,19 ± 1,85
p-value	0.0000***	0.0073**	0.0040**	0,0020

The letters within the columns indicate statistically significant differences according to Duncan's multiple range test at the $p < 0.05$ significance level.; $p < 0.001$ (Highly significant) ***, $p < 0.01$ (Very significant) **, $p < 0.05$ (Significant) *

Evaluation of Root Length

A statistically significant difference was observed among the treatments in terms of root length ($p = 0.0116$). The highest mean root length (5.35 ± 0.20 cm) was obtained equally in both the control and LWF2 (2% liquid vermicompost) groups. In contrast, the shortest route length was recorded in the LWF1+CIN3 treatment (4.28 ± 0.23 cm).

Root development plays a critical role in enabling the plant to absorb water and essential nutrients from the soil. Vermicompost applications are generally known to positively influence root morphology due to the presence of humic and fulvic acids, which stimulate root cell division (Edwards et al., 2007; Canellas et al., 2002). However, the fact that LWF2 yielded a value equivalent to the control in this study suggests that it did not produce a pronounced increase in root growth. This may be attributed to a plateau effect observed with humic substances, where their impact on root development becomes less pronounced at certain concentrations or in specific plant species (Trevisan et al., 2010).

The reductions observed in LWF1+CIN3 and CIN3 treatments may be due to the inhibitory effects of phenolic compounds in cinnamon at high concentrations, which have the potential to suppress root cell proliferation (Inderjit & Duke, 2003). Derivatives of cinnamic acid found in cinnamon are known to inhibit meristematic activity at the root apex in some cases, thereby limiting root elongation.

Evaluation of Leaf Number

A statistically significant difference was observed among the treatments in terms of leaf number ($p = 0.0043$). The highest average number of leaves was recorded in the LWF1+CIN3 combined treatment, with 7.67 ± 0.24 leaves. This was followed by the CIN3 treatment (7.60 ± 0.22 leaves) and the control group (7.17 ± 0.24 leaves). The lowest number of leaves was observed in the LWF2+CIN3 treatment (6.70 ± 0.19 leaves).

Leaf development is one of the key morphological traits determining the photosynthetic capacity of plants. Cinnamon application, either alone or in combination with LWF1, was found to increase the number of leaves. This increase suggests that cinnamon may play a stimulatory role in leaf development by activating antioxidant defense mechanisms (Zhang et al., 2016). Additionally, cinnamon extracts have been reported to suppress certain pathogenic soil microorganisms, thereby promoting healthier plant development (Gull et al., 2012).

On the other hand, the lower leaf number observed in the LWF2+CIN3 treatment supports the idea that a high dose of organic matter combined with phenolic compounds may induce allelopathic stress in plants, adversely affecting leaf development (Rice, 2012).

Physiological Interpretation of the Findings

The increase in leaf number alongside a reduction in plant height observed in the LWF1+CIN3 treatment can be interpreted through the lens of the "resource allocation" strategy, wherein plants prioritize directing limited resources to vital photosynthetic organs. This strategy is particularly relevant under environmental stress conditions, where plants redistribute their energy and carbon resources between growth and survival. Indeed, Poorter et al. (2012) noted that plants allocate biomass differently among leaves, stems, and roots depending on environmental factors, and that such adjustments represent adaptive responses aimed at optimizing photosynthetic efficiency. In this context, the increase in leaf number can be regarded as a physiological adaptation to enhance photosynthetic potential. On the other hand, although the LWF2 treatment alone showed a positive impact on plant development, a decline in performance was observed when combined with cinnamon. This may be due to a possible dosage incompatibility or suboptimal timing of application. Such findings highlight the possibility of antagonistic rather than synergistic interactions between different biostimulants, emphasizing the importance of carefully optimizing application parameters when using such combinations.

Radish Yield and Biomass Evaluation

The findings related to radish diameter, radish height, total fresh weight, and total dry weight are presented in Table 2. The data indicate that the treatments caused significant differences in these parameters (Table 2). Furthermore, the differences among the treatment groups were found to be statistically significant for all parameters ($p < 0.05$).

Effects on Radish Diameter and Radish Height

The highest radish diameter was recorded in the 3 g cinnamon treatment with a value of 17.83 ± 0.69 mm. Although this represented a 3.36% increase compared to the control group, the difference was not statistically significant and remained within the same level of significance. This result may be attributed to the antifungal properties of cinnamon, which likely reduced pathogen pressure and promoted radish development (Khan et al., 2020).

However, the combination treatments of LWF1+CIN3 (14.24 ± 0.57 mm) and LWF2+CIN3 (12.20 ± 0.49 mm) resulted in a marked reduction in radish diameter, suggesting a possible antagonistic interaction between cinnamon and liquid worm fertilizer applications. Similarly, previous studies have reported that certain organic compounds may suppress microbial activity, thereby hindering root or radish development (Rouphael et al., 2018).

Regarding radish height, the control group (27.69 ± 0.74 mm) exhibited the highest performance among all treatments. The reductions in radish height by 8–15% observed in the LWF1, LWF2, and cinnamon treatments suggest that these applications might have negatively affected the plant's vertical growth potential. This may be associated with a stress-induced resource reallocation strategy, in which plants prioritize survival mechanisms over vertical or axial growth under challenging conditions (Poorter et al., 2012).

Total Fresh Weight

The highest total fresh weight was obtained in the LWF 2 treatment with a value of 59.87 ± 5.21 g. Although this corresponded to a 7.6% increase compared to the control group (54.70 ± 3.46 g), the difference was not statistically significant and remained within the same level of significance. This result supports the hypothesis that LWF2 enhances plant metabolism and improves photosynthetic efficiency (Calvo et al., 2014). However, the dramatic decline in fresh weight observed in the LWF2+CIN3 combination (34.30 ± 2.72 g) indicates that the addition of cinnamon completely counteracted the positive effects of LWF2. This may be explained by the possibility that phenolic compounds in cinnamon (e.g., cinnamic acid) inhibited the activity of beneficial microorganisms present in the LWF2 formulation (Nazzaro et al., 2017). The approximately 42% reduction in fresh weight under the LWF2+CIN3 treatment suggests the occurrence of severe water stress or potential cell membrane damage in the plants exposed to this combination.

Total Dry Weight

In the study, when the effects of different treatments on total dry weight (g) were examined, the control group recorded a dry weight of 14.33 ± 1.08 g, while the other treatments showed varying degrees of deviation from this value. Although no significant difference was observed between LWF1 (12.30 ± 0.72 g) and LWF2 (14.23 ± 1.33 g), the LWF1 treatment resulted in a statistically significant reduction in dry matter content compared to the control. The LWF2 group, on the other hand, showed a dry weight value similar to the control, suggesting that different doses of worm fertilizer may exert differential effects on dry matter accumulation. The cinnamon treatment (3 g) yielded the highest dry weight (15.10 ± 1.31 g), indicating that cinnamon may contribute to dry matter accumulation by reducing water loss or by stimulating growth-promoting mechanisms. Previous studies have suggested that cinnamon exhibits growth-promoting properties in plants and may accelerate metabolism through its bioactive compounds (Örnek, 2021).

The LWF1+CIN3 combination produced a dry weight of 12.80 ± 1.15 g, which was close to that of the LWF1 treatment alone. However, the LWF2+CIN3 combination caused a significant reduction in total dry weight, decreasing it to 10.40 ± 0.69 g. This decline suggests that the combination of cinnamon and worm fertilizer may, under certain circumstances, result in antagonistic interactions or induce stress responses depending on the dose. The p-value of 0.002 indicates that the differences among treatments were statistically highly significant ($p < 0.01$), highlighting the significant impact of different applications on total dry matter accumulation. In particular, the cinnamon treatment yielded notably positive results.

The findings suggest that while worm fertilizer applications may sometimes reduce dry matter content, cinnamon treatments can have beneficial effects on dry matter accumulation. Nevertheless, combinations of cinnamon and worm fertilizer may lead to unexpected interactions, indicating the need for more detailed physiological investigations.

Physiological Interpretation of the Findings

Although the LWF2 treatment exhibited a positive effect on total fresh weight, the observed reduction in radish height may indicate a physiological reallocation of resources within the plant. This can be explained by the redirection of photosynthetic assimilates from vertical growth toward lateral organs, particularly increasing radish diameter. Indeed, Liu et al. (2016) reported that plants can modify their carbon allocation strategies in response to environmental or treatment-induced stress factors, prioritizing the development of roots and storage organs. On the other hand, the yield reductions observed in the treatments combining cinnamon and LWF may be attributed to factors such as application timing, interactions between components, or dosage incompatibility. Zhao et al. (2021) emphasized that plant extracts can significantly influence soil microbial populations and pH, potentially leading to negative outcomes such as microbial antagonism or inhibition within the soil biota. In this context, it is plausible that phenolic compounds present in cinnamon interacted with the microbial content of LWF, suppressing the activity of beneficial microorganisms.

Correlation Matrix Analysis and Interpretation

To evaluate the relationships between plant growth parameters, radish characteristics, and biomass, Pearson correlation analysis was conducted (Figure 1). The resulting correlation coefficients revealed both strong positive/negative associations and notable biological dynamics among the measured parameters.

Strong Positive Correlations

Plant height and total fresh weight ($r = 0.93$): The very high positive correlation ($r > 0.90$) between plant height and biomass indicates that increases in plant height are directly related to photosynthetic capacity and dry matter accumulation.

This finding is consistent with the idea that taller plants exhibit greater light interception efficiency (Poorter et al., 2012).

Stem diameter and radish diameter ($r = 0.90$): The strong correlation between stem thickness and radish size can be explained by the vascular tissue's capacity for nutrient transport. Thicker stems may facilitate the delivery of greater amounts of carbohydrates and water to the radish, thereby supporting its development (Liu et al., 2016).

Treatments	Plant Height	Stem Diameter	Root Length	Number of Leaves	Radish Diameter	Radish Height	Total Fresh Weight
Plant Height	1						
Stem Diameter	0.62	1					
Root Length	0.54	-0.14	1				
Number of Leaves	0.16	0.70	-0.56	1			
Radish Diameter	0.70	0.90	0.15	0.33	1		
Radish Height	0.39	0.44	0.50	-0.05	0.66	1	
Total Fresh Weight	0.93	0.83	0.26	0.36	0.86	0.44	1

Figure 1. Correlation matrix table

Table 3. Macro nutrient (Na, K, Ca, Mg, and Fe) contents of plants under different treatments.

Treatments	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)
Control	45.66±2.40 ab	167.03±11.37 ab	41.83±1.94	26.29±0.79	1.39±0.21
LWF1	52.61±6.37 a	175.59±12.82 ab	44.01±3.28	27.47±1.40	2.05±0.32
LWF2	36.76±1.76 b	125.64± 4.08 c	37.97±2.43	26.42±0.66	1.43±0.16
CIN3	41.04±2.69 b	178.26±10.12 ab	37.16±1.62	25.20±0.96	1.53±0.27
LWF1+CIN3	35.85±1.02 b	153.17± 8.20 bc	35.58±2.33	26.50±2.50	1.63±0.09
LWF2+CIN3	35.95±5.08 b	199.50±17.66 a	42.01±2.46	30.35±3.44	3.47±1.19
Total	41.31±1.96 b	166.53± 6.82	39.76±1.10	27.04±0,77	1.92±0.25
p-value	0.0439*	0.0123*	0.1677	0.5357	0.1116

The letters within the columns indicate statistically significant differences according to Duncan's multiple range test at the $p < 0.05$ significance level.; $p < 0.001$ (Highly significant) ***, $p < 0.01$ (Very significant) **, $p < 0.05$ (Significant) *

Plant height and radish diameter (r = 0.70): The moderately strong correlation between plant height and radish diameter suggests that the plant is capable of simultaneously investing in both vegetative and storage organs. This phenomenon is likely observed in cases where genetic or environmental factors optimize resource allocation (Zhang et al., 2018).

Negative Correlations

Number of leaves and root length (r = -0.56): The inverse relationship between leaf number and root length reflects the plant's resource allocation strategies. Prioritization of photosynthetic organs such as leaves may restrict energy allocation to the root system, altering the source-sink balance (Smith et al., 2018).

Root length and stem diameter (r = -0.14): The weak negative correlation may be associated with the notion that in plants with deeper root systems, stem thickening becomes a secondary priority.

Functional Relationships Between Parameters

Stem diameter and number of leaves (r = 0.70): An increase in stem thickness provides mechanical and physiological advantages that support leaf formation.

Thicker stems can structurally support more leaves and facilitate nutrient transport via vascular tissues (Niklas, 1994).

Radish height and root length (r = 0.50): The moderate positive correlation between vertical radish growth and root development indicates a tendency toward coordinated growth of below-ground organs. This may be explained by root–radish signaling mechanisms (Roumeliotis et al., 2012).

Effects on Macro-Nutrient Content

Macro-nutrients are essential mineral elements that play critical roles in plant metabolic processes and have a direct impact on growth and development. In this study, the effects of liquid worm fertilizer and cinnamon applications on the macro-nutrient contents (Na, K, Ca, Mg, and Fe) of *Raphanus sativus* L. were evaluated. The results are presented in Table 3.

Sodium (Na) Content

Statistically significant differences were observed among the treatments in terms of sodium (Na) content ($p < 0.05$). The highest Na level was recorded in the group treated with 1% liquid worm fertilizer (LWF1), reaching 52.61 mg/L. This suggests that low-dose worm fertilizer may enhance sodium uptake. In contrast, the lowest Na levels were observed in the LWF1+CIN3 (35.85 mg/L) and LWF2+CIN3 (35.95 mg/L) treatments, implying that the combination of high-dose worm fertilizer with cinnamon may have a suppressive effect on sodium accumulation. It has been reported that organic amendments can improve soil cation exchange capacity, thereby limiting Na accumulation (Singh et al., 2011).

Potassium (K) Content

Potassium plays essential roles in intracellular osmotic regulation, enzyme activation, and photosynthesis. In the study, significant differences were found among the treatments in terms of potassium content ($p < 0.05$). The highest potassium value was detected in the LWF2+CIN3 group, with 199.50 mg/L. This suggests that the combination of high-dose worm fertilizer and cinnamon has a synergistic effect in promoting K uptake. This result is supported by the fact that worm fertilizer is rich in potassium, and cinnamon may stimulate microbial activity, thereby increasing nutrient availability (Edwards et al., 2006; Srivastava et al., 2020).

Calcium (Ca) and Magnesium (Mg) Content

No statistically significant differences were detected among the treatments for calcium and magnesium contents (p

= 0.1677 and p = 0.5357, respectively). However, slight increases in both Ca and Mg levels were observed in the LWF1 group compared to the control. This increase may be attributed to the potential of worm fertilizer to improve soil structure and enhance cation exchange capacity (Lazcano & Domínguez, 2011). Cinnamon application alone did not exhibit a notable effect on these elements.

Iron (Fe) Content

Although no statistically significant differences were found among the treatments regarding iron content (p = 0.1116), a noteworthy increase was observed in the LWF2+CIN3 group, reaching 3.47 mg/L. This finding suggests that cinnamon may stimulate microbial activity and thereby enhance iron availability. As a vital micronutrient for plants, Fe plays a crucial role in chlorophyll synthesis, and its deficiency directly impairs photosynthesis. In this context, it can be inferred that the treatments may have positive effects on iron bioavailability (Srivastava et al., 2020).

Conclusion and Recommendations

This study investigated the effects of liquid worm fertilizer and cinnamon applications on the cultivation of radish (*Raphanus sativus* L.), aiming to assess the contribution of organic inputs to yield and plant growth parameters within the framework of sustainable agricultural practices. The findings revealed that different treatments had significant effects on plant growth, root and radish characteristics, as well as total biomass.

In terms of macro-nutrient content, the results demonstrated that mobile macro-elements such as potassium and sodium were significantly affected by the treatments. The combination of 2% liquid worm fertilizer and 3 g cinnamon increased the levels of potassium, magnesium, iron, and calcium to the highest values while also limiting sodium accumulation. These findings suggest that the combined use of organic fertilizers and bioactive compounds can have beneficial effects on plant nutrition. The results highlight the importance of incorporating organic and natural inputs in nutrient management strategies for sustainable agriculture.

Based on these findings, the 2% liquid worm fertilizer treatment can be considered the most effective organic fertilization method for radish cultivation. While cinnamon alone improved specific growth parameters, its combination with worm fertilizer may lead to adverse effects. Therefore, further studies should focus on the appropriate dosage and timing of cinnamon application.

In conclusion, liquid vermicompost application showed positive effects on certain morpho-agronomic traits of radish. Although the high-dose treatment (LWF2) resulted in increases in some developmental parameters, these improvements were not statistically superior to the control group. Therefore, while liquid vermicompost has potential as a biostimulant in radish cultivation, it is recommended that higher doses and different application intervals be tested to better understand its efficacy. Moreover, further research is needed to clarify the interactions of natural biostimulants such as cinnamon. Future studies should focus on evaluating the long-term effects of these organic inputs under different agricultural ecosystems in order to determine optimal doses and application methods. In this way, more efficient and environmentally friendly production systems can be developed, contributing to both productivity and ecological sustainability.

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