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ORIGINAL RESEARCH

Impact of Vermicompost Formulations on Black Carrot Yield, Quality, and Soil Fertility

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ABSTRACT: Excessive use of chemical fertilizers and declining soil fertility pose significant challenges to sustainable agriculture, often leading to degraded soil health and reduced crop quality. This experiment aimed to evaluate alternative fertilization strategies to optimize black carrot yield and quality while improving soil fertility. Organic residues, including paddy straw and deciduous tree leaves, were combined with cow dung and biogas slurry in a 1:1 ratio to prepare vermicompost treatments, which were tested along with integrated nutrient management and chemical fertilizer treatments. Over two years, the data revealed that integrated nutrient management, involving 50% recommended dose of chemical fertilizers and 50% deciduous tree leaves vermicompost, resulted in the highest yield and yield attributes of black carrot, while the control treatment produced the lowest productivity. The integrated nutrient management also showed greater improvements in soil properties, including pH, electrical conductivity (EC), organic carbon (OC), cation exchange capacity (CEC), nitrogen (N), phosphorus (P), potassium (K), and micronutrients, especially in the later years of the study. This is likely due to the initially low organic carbon and nutrient content of the experimental soil, with organic amendments typically taking three to four years to elicit a positive response. Overall, the study demonstrates that integrated nutrient management is more effective in enhancing both carrot yield and soil fertility, providing a sustainable approach to improving crop production and long-term soil health.

KEYWORDS: Carrot, yield, quality, soil fertility, vermicompost, integrated nutrient management.

1. Introduction

Carrot (*Daucus carota* L.), belonging to the family *Umbelliferae*, is one of the most important vegetable crops grown globally (Kielkowska et al., 2023). Its high yield per unit area makes it economically significant (Mou et al., 2023). Although a biennial plant, carrots are cultivated as an annual crop, known for their moderate climate and soil requirements (Godwin et al., 2024). Carrots are consumed in various forms, including salads and cooked dishes, and are widely cultivated across India for both forage and human consumption. Rich in bioactive compounds such as carotenoids, flavonoids, citric acid, and dietary fiber, carrots also possess health-promoting properties, including antioxidant and anticancer effects (Ahmad et al., 2019). While orange varieties are more common, black carrot consumption is steadily increasing due to its high phenolic content, flavonoids, vitamins (A, B, C, E), calcium, iron, zinc, selenium, and fiber-rich calcium pectate.

Carrots are heavy feeders, making proper nutrient management essential for optimal growth and yield. In India, intensive agriculture over the past three decades has depleted soil nutrients, degraded soil structure, and reduced microbial populations, which has negatively affected vegetable quality (Agarwal, 2003). Additionally, small-scale farmers often find it challenging to afford chemical fertilizers due to their high cost. Organic manures, such as farmyard manure and vermicompost, provide an eco-friendly, cost-effective alternative that enhances crop productivity (Iqbal et al., 2019). These organic amendments not only supply essential nutrients but also improve soil organic matter, soil structure, and microbial diversity, supporting sustainable vegetable production (Rastogi et al., 2023).

However, the slow nutrient release from organic manures can limit immediate crop responses, particularly in the early stages of soil restoration (Chatoo et al., 2003). This challenge highlights the importance of integrated nutrient management, which combines the quick nutrient availability of chemical fertilizers with the sustained benefits of organic amendments. Such an approach optimizes yield and crop quality while maintaining long-term soil health. Organic manure, with its balanced supply of macro- and micronutrients, improves soil microbial activity, enhances soil physical and chemical properties, and promotes a gradual release of nitrogen, leading to higher nutrient use efficiency (NUE) and better crop quality. Despite these advantages, organic fertilizers alone often lack the nutrient density and quick-release capability needed to meet crop requirements under intensive farming conditions. Thus, combining organic and inorganic fertilizers has proven to be a more effective strategy for sustaining soil fertility and enhancing crop productivity than relying solely on either type (Yatoo et al., 2020).

In addition to organic and chemical fertilizers, biofertilizers have emerged as a promising component of nutrient management (Kumar et al., 2022). These eco-friendly, low-cost inputs can enhance plant nutrition when used alongside organic and inorganic fertilizers in an integrated nutrient management system. Therefore, the current experiment was conducted to evaluate the effects of vermicompost formulations, derived from paddy straw and deciduous tree leaves combined with cow dung and biogas slurry, on black carrot yield and quality. Additionally, the study aimed to compare the performance of integrated nutrient management, which combines organic and inorganic fertilizers, with conventional chemical fertilization in black carrot production. It also sought to assess the impact of different nutrient management strategies on soil fertility parameters, such as organic carbon content, nutrient availability, and soil microbial activity. Furthermore, the experiment aimed to identify the optimal nutrient management strategy that not only ensures high yield and quality of black carrot but also improves soil health, particularly in low fertility soils. This research provides valuable insights into the effectiveness of integrated nutrient management strategies, offering a balanced approach to enhancing crop yield and quality while promoting soil fertility and sustainable agricultural practices.

2. 2. Materials and methods

2.1 Experimental location

The experimental trial was conducted at the Integrated Farming System Farm, Punjab Agricultural University, Ludhiana, during the Rabi seasons of 2022-23 and 2023-24, starting in November. The farm is located at 30°54´N latitude and 75°48´E longitude, at an altitude of 247 meters above sea level. The mean relative humidity during the cropping season ranged from 63% to 81%, and the total rainfall received during this period was 32.1 mm.

2.2 Experimental Design and treatments details

The experiment was arranged in a randomized block design with twelve treatments and three replications. The treatments included: T0 (Control), T1 (Recommended dose of fertilizers), T2 (Recommended dose of fertilizers + Liquid Biofertilizer (*Burkholderia seminalis*), T3 (Recommended dose of fertilizers + Farm Yard Manure), T4 (Recommended dose of fertilizers + Liquid (Biofertilizer (*Burkholderia seminalis* + FYM), T5 (50% Recommended dose of fertilizers + 50% Deciduous tree leaves (*Ficus benghalensis*)), T6 (50% Recommended dose of fertilizers + 50% Deciduous tree leaves vermicompost using biogas slurry), T7 (50% Recommended dose of fertilizers + 50% Paddy straw vermicompost), T8 (50% Recommended dose of fertilizers + 50% Cow dung vermicompost), T9 (Natural farming), T10 (100% N through deciduous tree leaves vermicompost), T11 (100% N through paddy straw vermicompost), and T12 (100% N through cow dung vermicompost). A total of 39 plots, each measuring 4.0 m × 3.0 m, were prepared according to layout specifications.

Table 1. Soil properties before sowing of black carrot.

Characters	Experimental field	
	Surface	Sub-Surface
pH	7.15	7.22
Electrical Conductivity (dS m^{-1})	0.19	0.16
Organic carbon (%)	0.31	0.29
Available N (Kg ha^{-1})	121.8	95.6
Available P (Kg ha^{-1})	18.42	13.99
Available K (Kg ha^{-1})	132.6	117.2
Available Zn	2.08	1.01
Available Fe (mg kg^{-1})	7.40	5.52
Available Mn (mg kg^{-1})	5.25	4.86
Available Cu (mg kg^{-1})	0.37	0.21

Note: N - Nitrogen, P - Phosphorus, K - Potassium, Fe - Iron, Mn - Manganese, Cu - Copper

The seeds of the black carrot variety 'Punjab Black Beauty' were sown with a spacing of 45 cm × 7.5 cm. For the natural farming treatment, ghanjeevamrit (350 kg ha $^{-1}$), jeevamrit (350 ml ha $^{-1}$), and beejamrit (350 kg ha $^{-1}$) were applied. The recommended doses of nitrogen, phosphorus, and potassium (90:60:60 kg ha $^{-1}$) were supplied using urea, diammonium phosphate, and muriate of potash, respectively, based on the treatment. Organic manures, such as well-decomposed farmyard manure (FYM) and vermicompost, were incorporated into the respective plots before sowing, based on nitrogen content. Liquid biofertilizer (300 ml ha $^{-1}$) was used to treat the seeds before sowing. The crop was harvested 90 days after sowing for data collection, once the foliage turned pale yellow (Bose et al., 1990). Ten plants were randomly selected from each plot for individual plant data, and the entire plot was harvested to collect plot-level data.

2.3 Sampling and measurements

Soil samples were collected from all replicates both before the experiment and after the harvest of black carrots from each treatment. These samples were air-dried and ground to pass through a 2 mm sieve. Soil pH and electrical conductivity (EC) were determined in a 1:2 soil-to-water suspension. Organic carbon was analyzed using the Walkley and Black method (1934), and cation exchange capacity (CEC) was measured following Jackson's method (1987). Available nitrogen was assessed using the Subbiah and Asija method (1965), available phosphorus by Olsen's method (1954), and available potassium according to Merwin and Peech (1951). Micronutrients, including DTPA-extractable zinc (Zn), iron (Fe), copper (Cu), and manganese (Mn), were determined using the Lindsay and Norvell method (1978). Additionally, the heavy metal content of the soil was measured. After the harvest, total nitrogen, phosphorus, and potassium uptake in plant samples were analyzed using Jackson’s methods (1987).

The total phenolic content of the juice sample was determined using the Folin-Ciocalteu method (Malick and Singh, 1980). The total flavonoid content was measured via the colorimetric assay technique (Chang et al., 2002), while beta carotenoids were analyzed using the Dimethyl Sulfoxide (DMSO) method (Kozuki et al., 1999). Total sugars in the juice sample were assessed by the phenol-sulfuric acid colorimetric method (Dubois et al., 1956), and reducing sugars were quantified using the Miller method. Anthocyanin content in the juice sample was analyzed following the procedure outlined by Cheng et al. (1991).

2.4 Statistical Analysis

Statistical analysis of the different parameters were analysed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez 1984) for randomized block design using CPCS-1 software developed by the Department of Mathematics and Statistics, PAU, Ludhiana (Cheema and Singh 1991). Figures were created by Grapad GraphPad Prism (version 5.0; GraphPad Software Inc., La Jolla, CA)

3. Results

3.1 Yield attributing characteristics of black carrot

3.1.1. Plant height and number of branches

The study investigated the effects of different fertilization treatments on plant height over two consecutive years, 2022-23 and 2023-24. The treatments varied from traditional control to combinations of chemical and organic vermicompost using biogas slurry (T6) produced substantial heights, with a mean of 36.6 cm. Treatments with 50% RDF combined with 50% paddy straw vermicompost (T7) and cow dung vermicompost (T8) resulted in mean heights of 24.9 cm and 24.7 cm, respectively, showing moderate improvements. Natural farming practices (T9) resulted in a mean plant height of 22.4 cm, which was higher than the control but lower than most treatments. When 100% nitrogen was supplied through deciduous tree leaves vermicompost (T10), paddy straw vermicompost (T11), and cow dung vermicompost (T12), plant heights were fairly consistent, with mean values of 23.8 cm, 23.6 cm, and 22.6 cm, respectively.

Table 2. Effect of inorganic fertilizers and vermicompost application on plant height and number of branches of black carrot.

Treatments	Plant height (cm)			Number of branches		
	2022-23	2023-24	Mean	2022-23	2023-24	Mean
T0	20.3±1.7	21.6±3.5	20.9±3.7	8±2.0	8±2.0	8±2.0
T1	24.0±2.7	25.9±3.5	24.9±2.1	10±3.0	9±2.0	9.5±2.5
T2	23.6±3.1	25.0±3.5	24.3±3.1	8±3.0	9±2.0	8.5±2.5
T3	29.6±4.3	32.0±3.3	30.8±3.8	10±3.0	11±3.0	10.5±1.5
T4	25.6±2.5	27.1±1.9	26.3±1.6	10±1.0	11±3.0	10.5±1.5
T5	36.0±3.1**	45.9±3.0**	40.9±2.8*	13±3.0	13± 3.0	13±3.0*
T6	31.3±3.1	41.9±2.2	36.6±3.6	11±3.0	10±1.0	10.5±1.5
T7	24.6±3.0	25.3±2.6	24.9±4.5	10±2.0	10±1.0	10±1.5
T8	24.3±2.9	25.2±3.7	24.7±2.2	9±2.0	11±3.0	10±1.5
T9	22.0±3.6	22.9±3.9	22.4±3.3	8±2.0	9±2.0	8.5±2.5
T10	23.3±2.9	24.4±3.0	23.8±2.6	10±3.0	9±2.0	9.5±2.5
T11	23.3±3.5	24.0±3.2	23.6±5.3	9±3.0	10±3.0	9.5±1.5
T12	22.3±2.6	23.0±3.1	22.6±3.6	9±1.0	11±3.0	10±3.5
LSD (p=0.05)	5.0	6.6	6.5	Ns	Ns	2.3

Note: T1: Recommended dose of fertilizers (RDF), T2: RDF + Liquid Biofertilizer (Burkholderia seminalis), T3: RDF + FYM, T4: RDF + Liquid Biofertilizer + FYM, T5: 50% RDF + 50% Deciduous Tree Leaves Vermicompost, T6: 50% RDF + Deciduous Tree Leaves Vermicompost (Biogas Slurry), T7: 50% RDF + Paddy Straw Vermicompost, T8: 50% RDF + Cow Dung Vermicompost, T9: Natural Farming, T10: 100% N from Deciduous Tree Leaves Vermicompost, T11: 100% N from Paddy Straw Vermicompost, T12: 100% N from Cow Dung Vermicompost. LSD (p=0.05): Least Significant Difference. NS: non-significant; * and ** indicate significant differences at P<0.05 and P<0.01, respectively.

Table 3. Effect of inorganic fertilizers and vermicompost application on carrot root length and root diameter.

Treatments	Root Length (cm)			Root diameter (cm)		
	2022-23	2023-24	Mean	2022-23	2023-24	Mean
T0	13.7±2.5	14.9±2.4	14.3±2.1	1.95±0.2	2.12±0.1	2.03±0.8
T1	16.9±3.0	18.3±3.4	17.6±2.8	2.26±0.2	2.46±0.6	2.36±0.6
T2	16.7±2.1	18.0±2.7	17.3±2.4	2.19±0.1	2.31±0.5	2.25±0.3
T3	17.7±2.9	19.2±3.0	18.4±3.4	2.48±0.1	2.63±0.8	2.55±0.5
T4	17.4±2.4	18.6±3.6	18.0±3.0	2.45±0.2	2.62±0.8	2.53±0.6
T5	18.3±3.4	20.8±2.9	19.5±2.7	2.58±0.1*	2.66±0.5*	2.62±0.4*
T6	18.1±2.9	20.5±2.4	19.3±2.5	2.52±0.3	2.64±0.4	2.58±0.5
T7	17.2±1.9	18.7±3.8	17.9±3.1	2.43±0.1	2.53±0.6	2.48±0.6
T8	17.1±2.0	18.5±3.6	17.8±3.0	2.37±0.2	2.50±0.4	2.43±0.5
T9	14.7±2.6	15.7±2.4	15.2±2.1	2.00±0.9	2.18±0.1	2.09±0.7
T10	15.9±2.6	16.4±1.8	16.1±1.4	2.13±0.1	2.26±0.2	2.19±0.5
T11	15.5±2.8	16.4±1.8	15.9±2.6	2.12±0.1	2.25±0.3	2.18±0.2
T12	15.4±2.5	15.9±2.6	15.6±2.5	2.10±0.3	2.21±0.2	2.15±0.6
LSD (p=0.05)	Ns	Ns	Ns	0.3	0.2	0.1

Note: For treatment details, please check table 2, LSD (p=0.05): Least Significant Difference at 5%. LSD (p=0.05): Least Significant Difference. NS: non-significant; * and ** indicate significant differences at P<0.05 and P<0.01, respectively.

Overall, the study demonstrates that the application of RDF combined with various organic fertilizers significantly enhances plant height, with deciduous tree leaves vermicompost treatments (T5 and T6) showing the most pronounced effect (Table 1). The LSD (Least Significant Difference) values indicated that differences in plant height were statistically significant for most treatments, underscoring the efficacy of integrated nutrient management in improving plant growth. However, Number of branches were found non-significant among all the treatments in respective of two years. Although, the mean number of branches were slightly higher in all treatments as compared to control treatment (Table 1).

3.1.2. Root length and root diameter

The study investigated the effects of different fertilization treatments on root length over two consecutive years, 2022-23 and 2023-24. The effect of inorganic fertilizers and different overoptimistic treatments on root length was recorded non-significant. The slightly increase in a mean root length was observed in (T5) 50% RDF combined with 50% Deciduous tree leaves vermicompost and (T6) 50% RDF + 50% Deciduous tree leaves vermicompost using biogas slurry (19.5 and 19.3 cm, respectively).

However, (T3) showed the mean root length was 18.4cm and in (T4) showed the 18.0cm of mean root length. The minimum root length was observed in control treatment. So, results had shown that chemical fertilizers within organic manure increase root length but not showed any significant difference compared to control treatment (Table 2).

The root diameter was significantly influenced by different organic manures and chemical fertilizers. The average two-year data showed that maximum root diameter was shown in 50% RDF + 50% Deciduous tree leaves vermicompost (2.62 cm) and in (T6) 50% RDF + 50% RDF + 50% Deciduous tree leaves vermicompost using biogas slurry (2.58 cm) (Table 2). Treatments with RDF combined with farm yard manure(T3) and farm yard manure within liquid biofertilizer (T4) resulted in mean diameter of 2.55 cm and 2.53 cm, respectively, showing moderate improvements. Natural farming practices (T9) resulted in a mean root diameter of 2.09 cm, which was higher than the control but lower than most treatments. When 100% nitrogen was supplied through deciduous tree leaves vermicompost (T10), paddy straw vermicompost (T11), and cow dung vermicompost (T12), root diameter were fairly consistent, with mean values of 2.19 cm, 2.18 cm, and 2.15 cm, respectively. Overall, the study demonstrates that the application of RDF combined with various organic fertilizers significantly enhances root diameter, with deciduous tree leaves vermicompost treatments (T5 and T6) showing the most pronounced effect.

3.1.3. Root weight, Days to maturity and Root yield

The root weight has a direct impact on root yield production. During the first and second year, the maximum root weight and root yield was observed in 50% RDF + 50% Deciduous tree leaves vermicompost (128.0 g and 490.3 q ha^{-1}) and 50% RDF + 50% Deciduous tree leaves vermicompost using biogas slurry (128.0 g and 479.q ha^{-1}) (Table 3). Treatments with RDF combined with farm yard manure (T3) and farm yard manure within liquid biofertilizer (T4) resulted in mean root weight and root yield of (125.0 g and 475.9 q ha^{-1}) and (125.7 g and 470.6 q ha^{-1}), respectively, showing moderate improvements. Natural farming practices (T9) resulted in a mean root weight and root yield was (108.1 g and 230.3 q ha^{-1}), which was higher than the control but lower than most treatments. When 100% nitrogen was supplied through deciduous tree leaves vermicompost (T10), paddy straw vermicompost (T11), and cow dung vermicompost (T12), root weight and root yield were fairly consistent, with mean values of (112.4 g and 376.0 q ha^{-1}), (111.7 g and 360.1 q ha^{-1}), and (110.3 g and 351.2 q ha^{-1}), respectively. The study shows that combining RDF with different organic fertilizers significantly increases root diameter, with the most pronounced effects observed in treatments using vermicompost made from deciduous tree leaves (T5 and T6). The significantly early maturity was observed in 50% RDF + 50% Deciduous tree leaves vermicompost in the average of first and second year of experiment (79.6 days) (Table 3). The mean late maturity was observed in natural farming and control treatment (115.0 and 117.5 days) respectively.

3.2 Soil attributing characteristics after harvesting of black carrot

3.2.1. Soil pH and EC of soil

Soil pH is the most important factor, which affect nutrient availability in soil. In the present study, the intital soil was 6.9. In this two year experiment, the pH started to increased and goes from acidic to alkaline nature after the application of organic manures and fertilizers. The maximum increase in pH was observed within the application of T11 (100% N through paddy straw vermicompost (7.34) (Table 4). Treatments 50% RDF + 50% Deciduous tree leaves vermicompost using biogas slurry and RDF + Liquid Biofertilizer (*Burkholderia seminalis*) + FYM had shown similar results. The minimum pH was observed in T9 (Natural farming) and T10 (100% N through deciduous tree leaves vermicompost) (7.18), respectively. However, soil pH has shown non-significant result among all the treatments in respective of two years.

Table 4. Effect of inorganic fertilizers and vermicompost application on soil pH and electrical conductivity at different years after harvesting of black carrot

Treatments	Soil pH (1:2)			Soil EC (dS m^{-1})		
	2022-23	2023-24	Mean	2022-23	2023-24	Mean
T0	7.22±0.07	7.34±0.08	7.28±0.06	0.65±0.03	0.69±0.04	0.67±0.03
T1	7.24±0.03	7.37±0.09	7.30±0.08	1.21±0.03	1.26±0.03	1.23±0.04
T2	7.16±0.03	7.29±0.07	7.22±0.04	0.88±0.03	0.97±0.05	0.92±0.04
T3	7.15±0.03	7.25±0.04	7.20±0.08	1.04±0.03	1.09±0.06	1.06±0.03
T4	7.25±0.03	7.39±0.06	7.30±0.06	1.28±0.03*	1.34±0.03*	1.31±0.03*
T5	7.25±0.04	7.41±0.07*	7.33±0.04	0.71±0.04	0.89±0.04	0.80±0.03
T6	7.25±0.03	7.39±0.08	7.32±0.05*	0.96±0.03	1.06±0.03	1.01±0.04
T7	7.21±0.03	7.32±0.06	7.26±0.07	1.16±0.04	1.22±0.04	1.19±0.03
T8	7.18±0.03	7.26±0.04	7.22±0.05	0.67±0.04	0.72±0.04	0.69±0.03
T9	7.21±0.02	7.16±0.02	7.18±0.04	0.67±0.03	0.71±0.03	0.69±0.04
T10	7.15±0.04	7.22±0.06	7.18±0.06	1.00±0.09	1.05±0.03	1.02±0.03
T11	7.28±0.05	7.41±0.06*	7.34±0.07	1.11±0.03	1.15±0.04	1.13±0.03
T12	7.27±0.05	7.39±0.07	7.33±0.05	0.69±0.03	0.78±0.04	0.73±0.04
LSD (p=0.05)	Ns	0.03	0.03	0.07	0.06	0.07

Note: For treatment details, please check table 2, EC, electrical conductivity, LSD (p=0.05): Least Significant Difference. NS: non-significant; * and ** indicate significant differences at P<0.05 and P<0.01, respectively.

EC of soil is the measurement of amount of salts in the soil (salinity). It is a good predictor of loss and availability of nutrients, soil texture and accessible water capacity. Compared to the initial soil sample, the slight increase was recorded as presented in table 4. On an average, the higher soil EC was recorded with RDF + Liquid biofertilizer (*Burkholderia1 seminalis*) + FYM (1.31) (Table 4). Natural farming practices (T9) resulted in a mean soil EC was 0.69 dS m^{-1}, which was higher than the control but lower than most treatments. When 100% nitrogen was supplied through deciduous tree leaves vermicompost (T10), paddy straw vermicompost (T11), and cow dung vermicompost (T12), EC were fairly consistent, with mean values of 1.02 dS m^{-1}, 1.13 dS m^{-1}, and 0.73 dS m^{-1}, respectively. So, the results has shown that soil EC was increased after the application of combined fertilizers.

3.2.2. Soil OC and CEC of soil

With the increase in soil organic carbon levels, it leads to improved soil health and hence crop yield. The average of two years data represented a comparatively slight increase in the soil organic carbon content with different treatments (Table 5).

Table 5. Effect of inorganic fertilizers and vermicompost application on soil organic carbon and cation exchange capacity of black carrot

Treatments	OC (g kg^{-1})			CEC (me/100g soil)		
	2022-23	2023-24	Mean	2022-23	2023-24	Mean
T0	3.10±0.3	3.14±0.4	3.12±0.6	3.56±0.3	3.59±0.5	3.57±0.3
T1	3.59±0.5	3.64±0.6	3.61±0.4	9.34±0.3	9.42±0.6	9.38±0.4
T2	3.50±0.4	3.55±0.5	3.52±0.4	10.74±0.4	10.81±0.3	10.77±0.3
T3	4.90±0.4*	4.98±0.7*	4.94±0.5*	12.73±0.4**	12.80±0.3*	12.76±0.5*
T4	4.80±0.5	4.85±0.5	4.82±0.3	11.69±0.3	11.78±0.4	11.73±0.4
T5	4.30±0.3	4.35±0.4	4.32±0.4	9.35±0.4	9.42±0.4	9.38±0.3
T6	4.40±0.5	4.46±0.6	4.43±0.5	10.33±0.5	10.43±0.3	10.38±0.3
T7	4.20±0.4	4.23±0.5	4.21±0.4	11.58±0.3	11.66±0.3	11.62±0.3
T8	4.10±0.3	4.12±0.3	4.11±0.6	11.49±0.4	11.54±0.5	11.51±0.4
T9	3.40±0.2	3.44±0.4	3.42±0.5	4.00±0.4	4.12±0.3	4.06±0.4
T10	4.00±0.4	4.08±0.3	4.04±0.4	11.24±0.4	11.34±0.3	11.29±0.3
T11	3.80±0.3	3.84±0.5	3.82±0.3	11.25±0.3	11.32±0.4	11.28±0.4
T12	3.80±0.4	3.82±0.3	3.81±0.3	10.50±0.4	10.68±0.3	10.59±0.3
LSD (p=0.05)	0.50	0.14	0.11	0.10	0.11	0.10

Note: For treatment details, please check table 2, EC: lectrical conductivity, LSD (p=0.05): Least Significant Difference. NS: non-significant; * and ** indicate significant differences at P<0.05 and P<0.01, respectively.

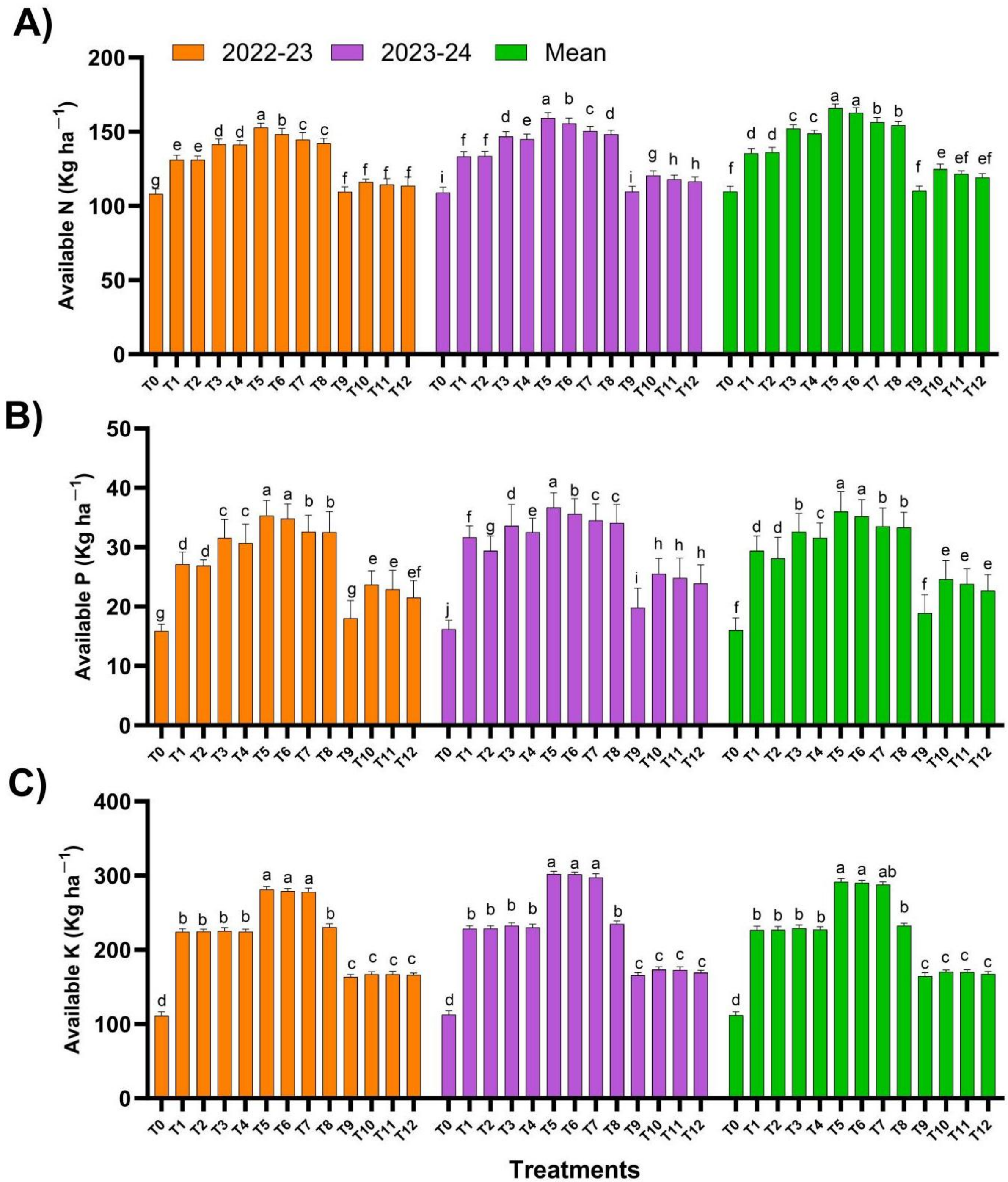

Figure 1. Effect of inorganic fertilizers and vermicompost application on soil (A) available N, (B) available P, and (C) available K after harvesting of black carrot. Note: N - Nitrogen, P - Phosphorus, K - Potassium. Different letters indicate significant differences at $p < 0.05$ using the LSD test. For treatment details, please refer to Table 2.

The soil supplied with RDF within farm yard manure (4.94 g kg^{-1}) and RDF + Liquid Biofertilizer (*Burkholderia seminalis*) along with farm yard manure (4.82 g kg^{-1}) showed significant increase in comparison to control treatment. Alone application of chemical fertilizers in (T2) has shown the mean organic carbon (3.61 g kg^{-1}). When 100% nitrogen was supplied through deciduous tree leaves vermicompost (T10), paddy straw vermicompost (T11), and cow dung vermicompost (T12), organic carbon were fairly consistent, with mean values of 4.04 g kg^{-1}, 3.82 g kg^{-1}, and 3.81 g kg^{-1}, respectively. So, the results has shown that organic carbon of soil increased within the combined application of manure and fertilizers as compared to alone application of fertilizers. Soils have negative charges which attract cations (potassium, sodium, calcium, magnesium, ammonium, etc.). Exchangeable cations can be leached or uptake by crops. Cation exchange capacity (CEC) is affected by soil pH, clay content and organic materials as shown in table 5. The maximum cation exchange capacity (12.76 me/100g soil) was observed in treatment (RDF along with farm yard manure) on an average of two years. The lowest CEC of soil was observed in T9 (Natural farming) and T0 (Control) (4.06 and 3.57 me/100g soil). Increased in cation exchange capacity might be due to an application of organic inputs increased the organic carbon stock in soil which, ultimately resulted in higher cation exchange capacity (CEC).

3.2.3. Available N, P and K of soil

Higher availability of nitrogen was observed in case of treatments that received combined application of organic manures and inorganic fertilizers (50% RDF + 50% Deciduous tree leaves vermicompost) on an average of two years (159.3) (Table 6). By decreasing the fixation of water soluble P and promoting mineralization, the concurrent use of inorganic and organic sources, such as (50% RDF + 50% Deciduous tree leaves vermicompost) (36.0) on the basis of two year data. Similarly, the maximum potassium content was observed within the application of (50% RDF + 50% Deciduous tree leaves) (291.6). Treatments with RDF combined with farm yard manure (T3) and farm yard manure within liquid biofertilizer (T4) resulted in mean available nitrogen, phosphorus and potassium, respectively, showing moderate improvements. Natural farming practices (T9) resulted in a mean available nitrogen, phosphorus and potassium of (109.8, 18.9 and 164.5 kg ha^{-1}), which was higher than the control but lower than most treatments. When 100% nitrogen was supplied through deciduous tree leaves vermicompost (T10), paddy straw vermicompost (T11), and cow dung vermicompost (T12), available nitrogen, phosphorus and potassium were fairly consistent, with mean values of (120.4, 24.6 and 170.1 kg h^{-1}, 117.9, 23.8 and 169.9 kg ha^{-1}), and (116.4, 22.7 and 167.6 kg ha^{-1}), respectively. Overall, the study demonstrates that the application of RDF combined with various organic fertilizers significantly enhances available nitrogen, phosphorus and potassium, with deciduous tree leaves vermicompost treatments (T5) showing the most pronounced effect.

3.2.4. Soil micronutrients

Micronutrients are the elements required by the plants in very small amounts.

Considerable differences were noted in the micronutrient content of soil (Table 7). The present study conducted has shown the increased available micronutrient content with different treatments in comparison to control treatment. The higher soil available Fe content was recorded with 50% RDF along with 50% Deciduous tree leaves vermicompost (28.55) on an average of two year of data and higher Zn, content was also observed in 50% RDF along with 50% Deciduous tree leaves vermicompost (9.18) on the basis of two year data.

The higher soil available Cu content was recorded with 50% RDF along with 50% Deciduous tree leaves vermicompost (3.35) on an average of two year of data and higher Mn, content was also observed in 50% RDF along with 50% Deciduous tree leaves vermicompost (11.79 mg kg^{-1}) on the basis of two year data (Table 8). The lowest content of Cu and Mn was observed in natural farming and control treatment (1.13, 7.00 and 1.08, 5.92 mg kg^{-1}). Treatment (RDF) has shown mean value of Cu and Mn content was (2.42 and 9.81 mg kg^{-1}). When 100% nitrogen was supplied through deciduous tree leaves vermicompost (T10), paddy straw vermicompost (T11), and cow dung vermicompost (T12), iron and zinc content were fairly consistent, with mean values of (1.68, 8.24 mg kg^{-1}) , (1.30, 7.20 mg kg^{-1}), and (1.25, 7.07 mg kg^{-1}), respectively.

Table 6. Effect of inorganic fertilizers and vermicompost application on soil attributing characteristics

Treatments	Available Fe (mg kg^{-1})			Available Zn (mg kg^{-1})		
	2022-23	2023-24	Mean	2022-23	2023-24	Mean
T0	15.08±2.0	15.62±2.4	15.35±2.1	1.30±0.5	1.89±0.4	1.59±0.4
T1	21.63±3.1	24.96±3.4	23.29±3.6	8.12±0.5	9.01±0.4	8.56±0.5
T2	20.74±3.6	22.24±3.1	21.49±3.2	6.89±0.3	7.11±0.3	7.00±0.4
T3	23.90±3.1	27.20±4.2	25.55±4.5	8.21±0.4	8.44±0.2	8.32±0.3
T4	21.80±3.5	25.05±3.6	23.42±3.7	8.15±0.6	8.36±0.6	8.25±0.4
T5	25.62±2.7	31.49±2.9	28.55±3.5	9.02±0.5	9.34±0.6	9.18±0.3
T6	25.30±2.8	30.24±2.1	27.77±2.5	8.41±0.4	8.97±0.4	8.69±0.2
T7	20.28±3.0	22.15±3.4	21.21±2.7	6.16±0.3	6.84±0.5	6.50±0.4
T8	19.28±4.0	21.59±3.2	20.43±2.9	5.88±0.4	6.04±0.2	5.96±0.3
T9	15.55±2.6	18.14±2.4	16.84±3.2	4.15±0.5	4.21±0.4	4.18±0.4
T10	17.98±2.6	20.47±2.9	19.22±3.1	5.87±0.7	6.14±0.3	6.00±0.5
T11	17.90±2.1	19.54±3.1	18.72±2.4	5.60±0.5	5.97±0.3	5.78±0.4
T12	15.88±2.7	19.14±2.9	17.51±2.2	4.17±0.2	4.42±0.4	4.29±0.6
LSD (p=0.05)	0.11	0.50	0.10	0.12	0.10	0.10

Note: For treatment details, please refer to Table 2. Fe: iron, Zn: zinc, LSD (P=0.05): Least Significant Difference. NS: non-significant; * and ** indicate significant differences at $P<0.05$ and $P<0.01$, respectively.

Table 7. Effect of inorganic fertilizers and vermicompost application on soil attributing characteristics after harvesting of black carrot

Treatments	Available Cu (mg kg^{-1})			Available Mn (mg kg^{-1})		
	2022-23	2023-24	Mean	2022-23	2023-24	Mean
T0	1.07±0.05	1.09±0.04	1.08±0.03	5.88±0.09	5.97±0.08	5.92±0.09
T1	2.40±0.04	2.44±0.05	2.42±0.03	9.40±0.09	10.22±0.09	9.81±0.09
T2	2.10±0.05	2.15±0.05	2.12±0.03	8.37±0.08	8.56±0.08	8.46±0.08
T3	2.94±0.05	2.97±0.05	2.95±0.05	10.42±0.09	10.58±0.09	10.50±0.05
T4	2.75±0.04	2.79±0.06	2.77±0.04	10.41±0.06	10.51±0.08	10.46±0.06
T5	3.32±0.06	3.38±0.08	3.35±0.03	11.70±0.05	11.89±0.05	11.79±0.08
T6	3.24±0.08	3.28±0.06	3.26±0.04	11.54±0.06	11.65±0.06	11.59±0.09
T7	1.98±0.04	2.03±0.05	2.00±0.04	9.35±0.08	9.42±0.06	9.38±0.09
T8	1.95±0.05	2.00±0.04	1.97±0.05	9.24±0.06	9.28±0.07	9.26±0.08
T9	1.11±0.08	1.16±0.04	1.13±0.08	6.97±0.09	7.03±0.08	7.00±0.05
T10	1.65±0.06	1.71±0.06	1.68±0.04	8.21±0.08	8.27±0.06	8.24±0.06
T11	1.29±0.04	1.32±0.05	1.30±0.06	7.17±0.04	7.23±0.08	7.20±0.04
T12	1.22±0.04	1.28±0.04	1.25±0.05	7.04±0.06	7.10±0.06	7.07±0.05
LSD (p=0.05)	0.14	0.10	0.19±	0.11	0.11	0.10

"Note: For treatment details, please refer to Table 2. Cu: copper, Mn: manganese, LSD (P=0.05): Least Significant Difference. NS: non-significant; * and ** indicate significant differences at $P<0.05$ and $P<0.01$, respectively.

Application of organic fertilizers along with inorganic fertilizers increased the micronutrients content in soil by reducing precipitation, oxidation and leaching.

3.2.5. Total nitrogen, phosphorus and potassium content in black carrot

The chemical analysis of roots revealed that maximum total nitrogen, phosphorus and potassium were observed in the application of (50% RDF + 50% Deciduous tree leaves vermicompost) (1.57, 1.10 and 2.83%). The nutrient content of soil might have enhanced due to breakdown of organic sources of manures which become readily accessible to plants and increase the concentration of NPK in plants (Table 9). The lowest content of total N, P and K was observed in natural farming and control treatment (0.82, 0.40, 1.42 and 0.78, 0.30, 1.07%). Treatment (RDF) has shown mean value of total N, P and K content was (1.18, 0.60 and 2.66 %). When 100% nitrogen was supplied through deciduous tree leaves vermicompost (T10), paddy straw vermicompost (T11), and cow dung vermicompost (T12), total N, P and K content were fairly consistent, with mean values of (1.01, 0.50 and 1.91 %), (0.89, 0.50 and 1.83 %), and (0.89, 0.50 and 1.58 %), respectively. The results has shown that the combination of organic manure especially deciduous tree leaves vermicompost and chemical fertilizers increased the N, P and K content in black carrot.

3.3 .Quality attributes of black carrot

3.4.1 Total phenols, flavonoids and beta carotenoids of black carrot

Phenolic content is one of the most important biochemical attribute of black carrot which occurs as secondary metabolites in all plant species. The phenolics are divided into several main groups one of which include the anthocyanins. The value of these compounds relies on the conditions under which the plants are grown.

In the present investigation a consistently higher levels of total phenols (12.9 mg/g) was observed in treatment T5 (50% RDF + 50% Deciduous tree leaves vermicompost) (Table 10). This was attributed to a slow, gradual and balanced release of plant-available nutrients.

Flavonoids are important bioactive compounds known for their wide range of biochemical and pharmacological effects including anti- oxidation, anti-inflammation, anti-atherosclerotic effects, inhibition of platelet aggregation, antitumor effect, antimicrobial activities and anti-allergic effects. Data (Table 4.29) revealed that the higher levels of total flavonoids (5.0 mg/g) observed in treatment (50% RDF + 50% Deciduous tree leaves vermicompost) (Table 10). This was due to the slow release of nutrients and better utilization of roots.

Carotenoids are the major lipophilic antioxidants present in carrot performing many health promoting functions in human body. Among four major carotenoids, beta-carotene is the predominant carotenoid in carrot. Beta-carotene in carrot constitutes nearly 44-79% of total carrot carotenoids and is nutritionally important because of its provitamin A activity.

A consistently higher level of beta-carotenoids (0.874 mg/100ml) was observed in treatment (50% RDF + 50% Deciduous tree leaves vermicompost) (Table 10).

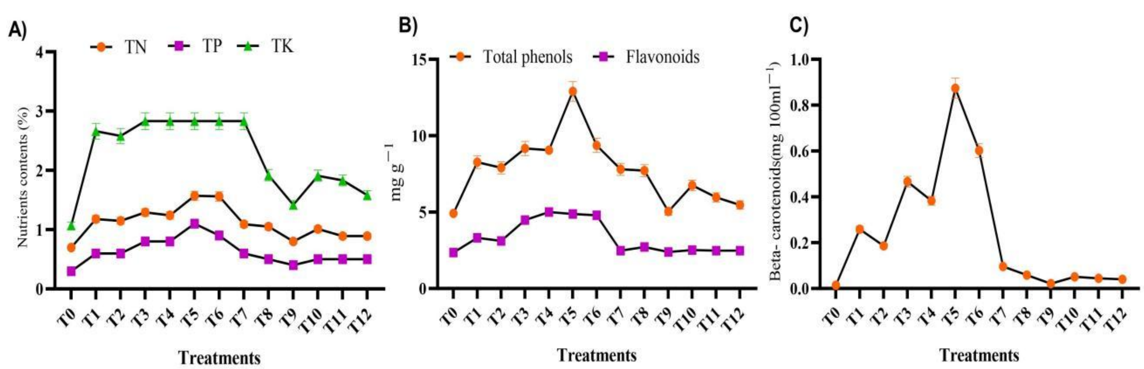

Figure 2. Effect of different fertilization on (A) nutrient contents, (B) total phenols and flavonoids, and (C) beta carotenoids of Black Carrot. Note: T0 (Control) is the baseline treatment with no additional fertilizers. TN - Total Nitrogen, TP - Total Phosphorus, TK - Total Potassium. For treatment details, please refer to Table 2.

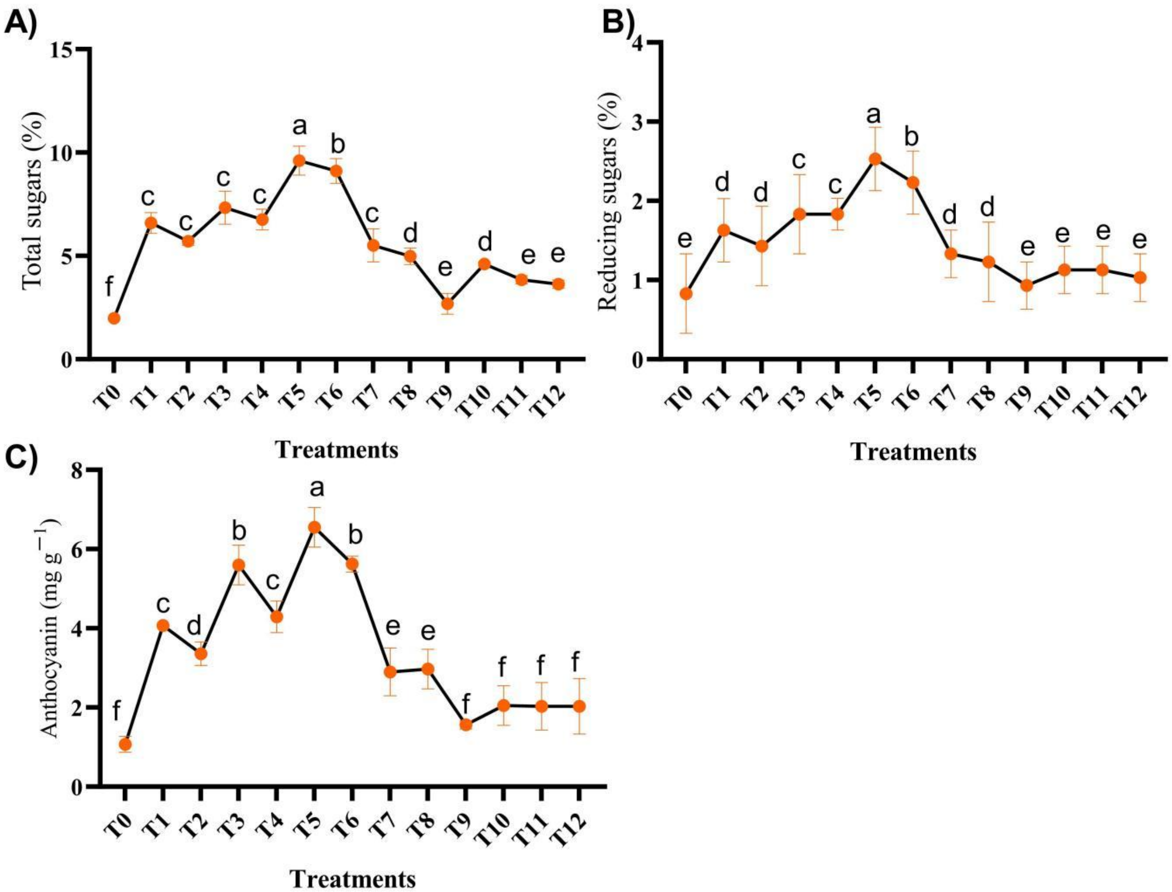

Figure 3. Effect of different fertilization on (A) total sugar content, (B) reducing sugar (%), and (C) anthocyanin content of black carrot. . Different letters indicate significant differences at $p < 0.05$ using the LSD test. For treatment details, please refer to Table 2.

This may be due to the action of specific soil nutrients that might be made more readily available for plant absorption as a result of mineral fertilizer for the synthesis of beta-carotene in carrot.

3.4.2 Impact of different fertilizations on total sugars, reducing sugars and anthocyanin of black carrot

In the present study, it was observed that vermicompost application along with inorganic fertilizers enhanced the activity of microbes which play an important role in mobilization of nutrients and uptake by plants and resulting in better results. The results pertaining to table showed a significant increase in total sugars (9.61%) with the application of 50% RDF along with 50% deciduous tree leaves vermicompost (Table 11). The lowest total sugars present in natural farming and control treatment (2.68 and 1.98 %), respectively. Treatment RDF along with farm yard manure has shown slightly increase in total sugar content (6.60%). Application of alone application of vermicompost in T10, T11 and T12 has shown total sugars (4.61, 3.84 and 3.63 %). Results had shown that application of organic manure along with inorganic fertilizers increased the sugar content as compared to alone application.

The results pertaining to table showed a significant increase in reducing sugars (2.53%) with the application of 50% RDF along with 50% deciduous tree leaves vermicompost (Table 11). The lowest reducing sugars present in natural farming and control treatment (0.93 and 0.83 %), respectively. Treatment RDF along with farm yard manure has shown slightly increase in reducing sugar content (1.83 %). Application of alone application of vermicompost in T10, T11 and T12 has shown total sugars (1.13, 1.13 and 1.03 %). Results had shown that application of organic manure along with inorganic fertilizers increased the sugar content as compared to alone application.

Anthocyanin is increasing as a potential nutraceutical in health promotion and protection from cancer and cardiovascular diseases by reducing inflammation, lipid oxidation causing induction of anti-inflammatory and vaso protective effects. In the present study, the maximum anthocyanin content (6.55 mg g^{-1}) was observed in treatment (50% RDF along with 50% deciduous tree leaves vermicompost) (Table 11). This might be due to combined application of organic manure along with chemical fertilizers increase in phenolic content has resulted in increase in anthocyanin content.

4. Discussion

4.1 Yield and yield components

The increase in plant height due to the application of vermicompost alongside inorganic fertilizers can be attributed to the rich content of macro- and micronutrients, vitamins, growth hormones, and beneficial microflora in vermicompost. Specific metabolites produced by earthworms may also contribute to plant growth stimulation, enhancing the effects of the nutrients and secretions found in vermicompost (Rekha et al., 2018). Birhanu (2015) demonstrated the impact of combining organic phosphorus and inorganic nitrogen fertilizers on carrot yield, achieving the highest plant height (44.27 cm), root weight (105.47 g), root volume (96.67 cm^3), and root yield (11.33 t/ha) with a 50% organic + 50% inorganic fertilizer application. However, in our study, no significant differences were observed across treatments involving vermicompost. Singh et al. (2020) also noted that the combined application of organic manure and inorganic fertilizers positively influenced the growth and development of carrot branches.

In treatments where 50% deciduous tree leaves vermicompost was combined with 50% recommended fertilizers (RDF), root length improved. This could be due to the higher phosphorus content in the deciduous tree leaves vermicompost, which enhanced root growth when paired with inorganic fertilizer. Phosphorus is known to stimulate root development, nutrient absorption, and translocation, as well as to participate in enzyme functions and energy-rich ATP synthesis, leading to improved root growth (Kumar et al., 2014). Singh et al. (2023) also found that the combination of NPK and organic manures significantly influenced carrot root length.

Carrot root weight was significantly increased by the combined application of organic vermicompost and NPK fertilizers. This rise in root weight is likely related to improved solubilization of plant nutrients, leading to enhanced nutrient uptake. The results suggest that the correct balance of mineral fertilizers and organic manures can greatly enhance root weight (Singh et al., 2023). The maximum root diameter was recorded in treatment T5 (50% deciduous tree leaves vermicompost + 50% RDF), likely due to increased cell division and rapid cell multiplication. Biswas et al. (2020) similarly found that a 50% NPK + 50% vermicompost treatment resulted in the highest values for plant height, leaf count, root diameter, length, and fresh root weight. Singh et al. (2023) further revealed that the combined use of inorganic fertilizers and organic manures significantly improved root diameter.

The increased root weight observed in treatment T5 (50% RDF + 50% deciduous tree leaves vermicompost) can be attributed to the slow release of nutrients from vermicompost, which, in combination with chemical fertilizers, enhanced nutrient utilization throughout the carrot's growth period. This effect may be linked to improved nutrient solubilization, increasing the intake of both macro- and micronutrients. The use of a combination of mineral and organic fertilizers offers the benefit of enhanced fertilizer efficiency, reduced nutrient loss, and improved fresh root weight (Singh et al., 2023).

Treatment T6 (50% RDF + 50% deciduous tree leaves vermicompost) resulted in significantly earlier maturity (81 days). Singh et al. (2020) found that applying 60:80:75 kg NPK/ha delayed maturity to 84.08 days for the first root harvest, while treatments involving FYM (10 t/ha), 50% NPK, and biofertilizer (2 kg/ha) led to noticeably earlier maturity (82.33 days).

The maximum increase in root yield was observed in treatments combining deciduous tree leaves vermicompost with inorganic fertilizers in a 50:50 ratio. Kiran et al. (2022) found that combining organic and inorganic treatments resulted in significantly higher yields, with increases ranging from 170-200% and 198-269% compared to control treatments across two years.

4.2 Soil properties

No significant differences were observed in soil pH among the different treatments, with pH values remaining within the neutral range. This aligns with findings from Chimdessa and Sori (2020), who also reported no significant changes in soil pH when using vermicompost, chemical fertilizers, or integrated nutrient management. Similarly, Nasrin et al. (2019) found that applying vermicompost and compost at rates of 4, 8, and 12 tons per hectare kept soil pH neutral. Chahal et al. (2019) also noted no substantial differences in soil electrical conductivity (EC) among treatments, though EC slightly increased due to the accumulation of salts in the soil.

The application of farmyard manure (FYM) and vermicompost significantly increased soil organic carbon content, which can be attributed to the direct incorporation of these organic materials into the soil. Their subsequent decomposition contributed to enhanced organic carbon levels. Ilker et al. (2016) also found that adding organic matter, such as vermicompost and FYM, significantly improved soil organic matter content, especially in alkaline soils with high lime content.

The highest cation exchange capacity (CEC) of 12.7 me/100g soil was recorded in treatment T3 (RDF + FYM). This increase is likely due to the organic inputs, which boost soil organic carbon levels, ultimately improving CEC. Tana and Woldesenbet (2017) similarly demonstrated that using inorganic fertilizer in combination with organic manure enhances soil CEC.

Treatments that received both organic manures and inorganic fertilizers, such as T5 (50% RDF + 50% Deciduous tree leaves vermicompost), showed higher availability of nitrogen, phosphorus, and potassium. This could be partly due to the release of native soil nitrogen and nutrient mineralization from the organic inputs (Singh, 2018). Organic acids produced during the decomposition of manures likely played a role in mobilizing non-exchangeable forms of potassium, making them more available (Chander et al., 2010).

The highest increase in total micronutrient content (Fe, Zn, Cu, Mn) was observed in treatment T5. This increase is attributed to the production of organic and inorganic acids during the decomposition of organic fertilizers, which helped reduce soil pH and chelate ions, thereby increasing the availability of these elements in the rhizosphere. Chahal et al. (2019) noted that the combined use of organic and inorganic fertilizers reduces nutrient losses through precipitation, oxidation, and leaching, which in turn enhances soil micronutrient content. Kumar et al. (2023) reported that applying recommended nitrogen doses (RDN) through vermicompost, coupled with seed treatment using biofertilizers (Azotobacter + PSB), significantly improved nitrogen content and uptake by roots and leaves. Treatment T_4, in particular, showed significantly higher phosphorus and potassium uptake by roots.

4.3. Qualitative attributes of black carrot

In this study, treatment T6 (50% RDF + 50% Deciduous tree leaves vermicompost) consistently demonstrated superior quality attributes in black carrot. The highest total phenolic content (12.9 mg/g) was observed in this treatment, likely due to the gradual and balanced release of plant-available nutrients, as reported by Asami et al. (2003). Nisar et al. (2020) similarly found that nutrient combinations including vermicompost and farmyard manure (FYM) led to elevated phenolic levels.

The total flavonoid content (5.0 mg/g) was also highest in T6, which can be attributed to the slow nutrient release and improved root nutrient uptake, as supported by Nisar et al. (2020). In terms of beta-carotenoid content, T6 showed a significant increase. This may be due to the enhanced availability of specific soil nutrients that promote the synthesis of beta-carotene in carrots, as highlighted by Zakir et al. (2012). Yadav et al. (2022) similarly reported increased β-carotene levels in roots with the application of RDF and organic manure.

The total sugar content (9.61%) was notably higher in T6, which could be explained by the enhanced microbial activity resulting from vermicompost application, leading to improved nutrient mobilization and plant uptake, as noted by Nisar et al. (2020). A similar trend was observed for reducing sugars (2.53%), with better nutrient availability contributing to improved quality, consistent with findings from Indumathi (2000) and Peyast et al. (2008).

Lastly, the anthocyanin content (6.55 mg/g) was highest in T6, likely due to the synergistic effect of organic manure and chemical fertilizers, which increased phenolic content and, consequently, anthocyanin levels. This observation aligns with Nasir et al. (2020), who emphasized the role of anthocyanins as key determinants of black carrot color.

5. Conclusion

Among the various types of vermicompost, vermicompost derived from deciduous tree leaves demonstrated superior results. Applying a half dose of nitrogen from deciduous tree leaves vermicompost in combination with a half dose from conventional fertilizers improved soil properties compared to plots receiving only chemical fertilizers, without significantly reducing carrot yield. This combination enhanced nutrient solubility, making nutrients more readily available to plants. Furthermore, the use of deciduous tree leaves vermicompost, alongside recommended fertilizers, improved the quality traits of black carrots.

Author Contribution:

Gursimran Kaur: Fieldwork, collection of soil and root samples, Analysis of samples, data analysis, and preparation of manuscript, Neeraj Rani: Planning and execution, Overall supervision of experiment, data analysis and preparation of manuscript, Manisha Thakur: Planning of treatments

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REFERENCES

Acharya, C. I., & Mandal, K. G. Integrated plant nutrient supply in vegetable crops. In: Compendium Recent Advances in Vegetable Production Technology. Proceedings of Winter School. Indian Institute of Vegetable Research, Varanasi, U. P. India, (2002), pp. 79–104.

Ahmad, T., Cawood, M., Iqbal, Q., Arino, A., Batool, A., Tariq, R. M. S., Azam, M., & Akhtar, S. Phytochemicals in Daucus carota and Their Health Benefits—Review Article. Foods, (2019), 8(424), https://doi.org/10.3390/foods8090424.

Asami, D. K., Hang, Y. J., Barnett, D. M., & Mitchell, A. E. Comparison of the total phenolic and ascorbic content of freeze-dried and air-dried marionberry, strawberry and corn grown using conventional, organic and sustainable agricultural practices. Journal of Agriculture Food Chemistry, (2003), 51, 1237–1241.

Bhatt, R., Naresh, R. K., Tiwari, H., Singh, P. K., Das, D., Kumar, M., Banik, R., & Tomar, G. Farm-yard manure as a resource for integrated nutrient management. The Pharma Innovation Journal, (2023), 12, 672–681.

Birhanu, M. Effects of combined application of organic-P and inorganic N fertilizers on yield of carrot (Daucus carota L.) Agriculture Research Technology, (2015), 2, 2472–2500.

Biswas, P., Mahato, B., Mahato, D. C., Rahman, F. H., & Ghosh, C. Effect of vermicompost and biochar on growth and yield of carrot in red lateritic soils of Purulia District of West Bengal. International Journal of Plant Soil Science, (2020), 32, 15–20.

Chahal, H. S., Singh, S., Dhillon, I. S., & Kaur, S. Effect of integrated nitrogen management on macronutrient availability under cauliflower (Brassica oleracea var. botrytis L.). International Journal of Current Microbiology Applied Science, (2019), 8, 1623–1633.

Chander, G., Verma, T. S., & Sharma, S. Nutrient content of cauliflower (Brassica oleracea var. botrytis L.) as influenced by boron and farm yard manure in north-west Himalayan alfisols. Journal of Indian Society of Soil Science, (2010), 58, 248–251.

Chang, C. C., Yang, M. H., Wen, H. M., & Chern, J. C. Estimation of total flavonoid content in propolis by two complementary colorimetric methods. Journal of Food Drug Analysis, (2002), 10, 178–182.

Chattoo, A., Ahmad, N., Narayan, S., & Faheema, S. Influence of organic manures on cabbage cv. Golden Acre. In: Souvenir National Seminar on Organic Products and Their Future Prospects. S. K. University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar (J&K), (2003), pp. 94.

Cheema, H. S., & Singh, B. Software Statistical Package CPCS-1. Department of Statistics, Punjab Agricultural University, Ludhiana, India, (1991).

Chimdessa, D., & Sori, G. Integrated effects of vermicompost and NPS fertilizer rates on soil chemical properties and maize production in Bedele District, Western Oromia. Plant, (2020), 8, 115–121.

Demir, Z. Effects of vermicompost on soil physicochemical properties and lettuce (Lactuca sativa Var. Crispa) yield in greenhouse under different soil water regimes. Commun Soil Science Plant Analysis, (2019), 50, 2151–2168.

Dhakal, Y., Meena, R. S., & Kumar, S. Effect of INM on nodulation, yield, quality and available nutrient status in soil after harvest of greengram. Agricultural Research Communication Centre, (2015), 1–5.

Dubois, M., Gilles, K. A., Hamilton, J. D., Rebers, P. A., & Smith, F. Colorimetric method for determination of sugars and related substances. Analytical Chemistry, (1956), 28, 350–368.

Glick, B. R. Plant growth – Promoting Bacteria: Mechanisms and Applications. Scientifica, (2012), 963401.

Godwin, A., Pieralli, S., Bobcheva, S. S., Ward, A., & McGill, S. Comparing vegetative growth patterns of cultivated (Daucus carota L. subsp. sativus) and wild carrots (Daucus carota L. subsp. carota) to eliminate genetic contamination from weed to crop. Journal of Agriculture and Food Research, (2024), 16, 101213.

Gomez, K. A., & Gomez, A. A. Statistical Procedures for Agricultural Research. 2nd Ed. John Wiley and Sons, New York, (1984).

Hassan, I. K., Bakhsh, K., Salik, M., Khalil, M. H., & Ahmad, N. Determination of factors contributing towards the yield of carrot in Faisalabad (Pakistan). International Journal of Agriculture Biology, (2005), 7, 323–324.

Ilker, U. Z., Sonmez, S., Tavali, I. E., Citak, S., Uras, D. S., & Citak, S. Effect of vermicompost on chemical and biological properties of an alkaline soil with high lime content during celery (Apium graveolens L. var. dulce Mill.) production. Not Bot Horti Agrobo, (2016), 44, 280–290.

Indumathi, S. Integrated nutrient management in radish (Raphanus sativus L.). M. Sc. thesis submitted to Acharya N. G. Ranga Agricultural University, Hyderabad, (2000).

Iqbal, A., He, L., Khan, A., Wei, S., Akhtar, K., Ali, I., Ullah, S., Munsif, F., Zhao, Q., & Jiang, L. Organic manure coupled with inorganic fertilizer: An approach for the sustainable production of rice by improving soil properties and nitrogen use efficiency. Agronomy, (2019), 9, 651. https://doi.org/10.3390/agronomy9100651.

Jackson, M. L. Soil Chemical Analysis. Prentice-Hall, New Jersey, (1967), pp. 134–165, 429–451.

Kielkowska, A., & Kiszczak, W. History and current status of haploidization in carrot (Daucus carota L.). Agronomy, (2023), 13(676), https://doi.org/10.3390/agronomy13030676.

Kiran, M., Jilani, M. S., Waseem, K., Haq, F., Khan, M. S., Nadim, M. A., Rahman, K., & Hussain, K. Growth and yield enhancement of carrot through integration of NPK and organic manures. Journal of Horticulture Science, (2022), 17, 341–346.

Kozuki, Y., Miura, Y., & Yagasaki, K. Inhibitory effects of carotenoids on the invasion of rat ascites hepatoma cells in culture. Cancer Letters, (1999), 151, 111–115.

Kumar, P., Meghwal, P. R., & Painuli, D. K. Effect of organic and inorganic nutrient sources on soil health and quality of carrot. Indian Journal of Horticulture, (2014), 71, 222–226.

Kumar, S., Diksha., Sindhu, S. S., & Kumar, R. Biofertilizers: An ecofriendly technology for nutrient recycling and environmental sustainability. Current Research in Microbial Sciences, (2022), 3, 100094.

Kumar, S., Panghal, V. P. S. N., & Kumar, S. Effect of organic manures and natural farming on soil properties and nutrient uptake by carrot. International Journal of Plant Soil Science, (2023), 35, 1172–1177.

Lindsey, W. L., & Norvell, W. A. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Science Society Amorial Journal, (1978), 42, 421–428.

Malik, C. P., & Singh, M. B. Plant Enzymology and Histoenzymology. Kalyani Publishers, New Delhi, India, (1980).

Mou, F. I., Hossain, M. M., Haque, T., & Yasmin, A. Impact of tillage depth and planting spacing on growth and root yield of carrot (Daucus carota L.). Journal of Tropical Crop Science, 2023, 10(3): 186–195. https://doi.org/10.29244/jtcs.10.03.186-195

Muktamar, Z., Adiprasetyo, T., Yulia, S., Sari, L., Fahrurrozi, F., & Setyowati, N. Residual effect of vermicompost on sweet corn growth and selected chemical properties of soils from different organic farming practices. International Journal of Agriculture Technology (2018), 14, 1471-1482.

Nasrin, A., Khanom, S., & Hossain, S. A.. Effects of vermicompost and compost on soil properties and growth and yield of Kalmi (Ipomoea aquatica Forsk.) in mixed soil. Dhaka University Journal of Biology Science, (2019), 28, 121–129.

Nisar, F., Mufti, S., Afroza, B., Mushtaq, F., Bhat, R., Andrabi, N., Majid, I., & Din, S. Effect of integrated nutrient management on quality attributes of black carrot (Daucus carota subsp. sativus var. atrorubens Alef.). International Journal of Chemistry Studies, (2020), 8, 3991-3994.

Olsen, B. C., Cole, C. V., Watenabe, F. S., & Dean, L. A. Estimation of available phosphorus by extraction with sodium carbonate. USDA Circ, (1954): 939, 1019.

Peyast, G., Olfati, J. A., Madeni, S., Forghani, A., & Samizadeh, H. Vermicompost as a soil supplement to improve growth and yield of parsley. International Journal of Vegetable Science, (2008), 14, 82-92.

Rastogi, M., Verma, S., Kumar, S., Bharti, S., Kumar, G., Azam, K., & Singh, V. Soil health and sustainability in the age of organic amendments: A review. International Journal of Environment and Climate Change, (2023), 13(10), 2088-2102.

Rekha, G. S., Kaleena, P. K., Elumalai, D., Srikumaran, M. P., & Maheswari, V. N.. Effects of vermicompost and plant growth enhancers on the exo-morphological features of Capsicum annum (Linn.) Hepper. International Journal of Recyclable Organic Waste Agriculture (2018), 7, 83–88.

Singh, B. Are nitrogen fertilizers deleterious to soil health? Agronomy, (2018), 8, 48-57.

Singh, S., Mishra, A., & Greene, A. Assessment of growth, yield and quality of carrot (Daucus carota L.) var. Pusa Kesar under integrated nutrient management. International Journal of Current Microbiology and Applied Science (2020), 9, 1086-1093.

Singh, S., Jogdand, S. V., Naik, R. K., Victor, V. M., Pradhan, M. K., & Sonboir, H. L. To study the physical and engineering properties of vermicompost. The Pharma Innovation Journal (2023)., 12, 236-241.

Subbiah, B. V., & Asija, G. L. A rapid procedure for the estimation of available nitrogen in soils. Current Science (1965), 25, 259-260.

Sylvestre, H., Constance, M., Esdras, N., & Athanase, N. Effect of poultry manure and NPK (17-17-17) on growth and yield of carrot in Rulindo District, Rwanda. International Journal of Novel Resource Life Science (2015), 2, 42-48.

Tana, T., & Woldesenbet, M. Effect of combined application of organic and mineral nitrogen and phosphorus fertilizer on soil physico-chemical properties and grain yield of food barley (Hordeum vulgare L.) in Kaffa Zone, Southwestern Ethiopia. Momona Ethiopian Journal of Science (2017)., 9, 242-261.

Vilela, N. J. Cenoura: um alimento nobre na mesa popular. Horticultra Brasileira, (2004) 22, p.

Walkley, A., & Black, C. A. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science (1934)., 37, 2-8.

Yadav, A., Jakhar, R. K., Kumari, N., Yadav, G. N., Sharma, R. K., Yadav, S. L., Meena, H. K., & Khandelwal, A. K. Response of organic manures and fertilizers on yield and quality of carrot under sandy soil condition. The Pharma Innovation Journal, (2022),11, 1822-1827.

Yatoo, A. M., Rasool, S., Ali, S., Majid, S., Muneeb, U., Rehman, A., Eachkoti, N. R., Shabhat Rasool, Rashid, S. M., & Farooq, S. (2020). Vermicomposting: An eco-friendly approach for recycling/management of organic wastes. Bioremediation and Biotechnology, (2020). ISBN: 978-3-030-35690-3.

Zakir, H. M., Sultana, M. N., & Saha, K. C. Influence of commercially available organic vs inorganic fertilizers on growth, yield and quality of carrot. Journal of Environmental Science and Natural Resources (2012), 5, 39-45.

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