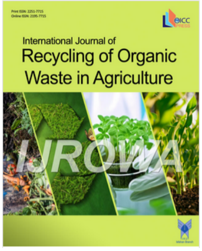

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Development of enriched compost formulations and evaluation of their effects on growth, yield, and quality of palak (*Beta vulgaris* var. *bengalensis* L.)

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Original Research

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Abstract:

Purpose: The enriched compost has good potential as an alternative source of nutrients. In particular, less work has been done on enriched compost for green leafy crops.
Method: The current study intended to determine how enriched compost affected the horticultural characteristics of Palak. Three repetitions of a randomized complete block design (RCBD) were used to test ten combinations, i.e. T_1-Recommended dosage of fertilizers (RDFs) + Farmyard manure (FYM) (85:30:0 N: P: K kg/ha + 20 t/ha); T_2-50% RDFs + FYM 10 t/ha; T_3-FYM 20 t/ha; T_4-mineral (Rock Phosphate) enriched compost (MEC_1) 5 ha^{-1}; T_5-microbial enriched compost (MEC_2) 5 t/ha; T_6-vermicompost (VC) 5 t/ha; T_7-50% MEC_1 + MEC_2 + 50%; T_8-MEC_1 + MEC_2 (75% + 25%); T_9-MEC_1 + MEC_2 (25% + 75%); T_{10}-absolute control (no application) for two consecutive years.
Results: The results for growth and yield parameters revealed that the application of MEC_1 + MEC_2 (50% + 50%) during cultivation were found statistically at par with treatment combination T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (10 t/ha) and led to remarkable rise in height of plants, numbers of leaves, length of petiole, leaf area, petiole diameter, giving rise to the maximum Yield in contrast to other modules (105.71 q/ha). Regarding characteristics of quality, ascorbic acid (88.54 mg), total phenols (22.52 mg), minerals content, and antioxidant activity (4.46%) were recorded higher in the same treatment T_7 due to organically nutrition availability.
Conclusion: It can be concluded that the application of enriched compost (MEC_1 + MEC_2) results in a decreased use of chemical fertilizers, leading to increased growth and Yield and enhancing the quality of leafy vegetables for human consumption.

Keywords: Rock phosphate; Biofertilizer; Compost; Palak; Sustainable agriculture; Production

1. Introduction

Spinach beet (*Beta vulgaris* var. *bengalensis*; 2n = 2x = 18) belongs to the Beta genus and the Chenopodiaceae family of plants. It is frequently referred to as "Palak" in Hindi and "Indian spinach" in English (Ganvit et al., 2023). It is native to the Indo-Chinese area. This variety of leaves is called var. bengalensis because it is believed to have originated in Bengal. It is also known as Desi palak and beet leaf. It is closely related to sugar beet, swiss chard, and beetroot. It is frequently grown for its delicate, succulent leaves. Organic farming is still relatively new in India. Organic farming in India covers 2,78 million acres, accounting for 2% of the country's 140,1 million hectares area. Madhya Pradesh, Rajasthan, and Maharashtra are the top three member states, covering 27% of India's land. The top 10 countries cover 80% of the total organic farming land. In 2021, China was the largest spinach producer in the Asia-Pacific region, producing more than 29.8 million metric tonnes of spinach. In comparison, Brunei produced about 500 tonnes of spinach in 2021 (Anonymous, 2021).

Organic fertilizers such as farmyard manure, animal wastes, compost, and vermicompost enhance crop yield and soil fertility. However, poor nutritional content, bulkiness, handling challenges, and labour-intensive application restrict producers from extensively using these conventional organic manures (Lida et al., 2024). Composting from these biodegradable wastes is currently not a financially viable option. If traditional composting technology is enhanced in nutrient content, it may be able to halt nutrient depletion trends to a greater extent. The toxic effect of chemical fertilizers is higher in vegetables, especially leafy vegetables. It's very harmful to human beings, so today, we need to enrich the traditional organic manures and compost to reduce the use of chemical fertilizers and promote organic production, leading to a reduction in the application quantity of traditional manures, as enriched composts are easy in handling and have higher nutrient content of organic manures (Sharma et al., 2022; Thakur et al., 2023).

Using mineral additives like rock phosphate and pyrites were discovered to be helpful during composting. Thus, a nitrogen-enriched phosphor-compost technology has been developed based on phosphate-solubilizing microorganisms, notably *Aspergillus awamori*. *Pseudomonas straita* and *Bacillus megaterium*, as well as phosphate rock, pyrite, and bio-solids, are used to boost the manurial benefit of FYM and compost (Opala, 2023). The preparation and use of enhanced organic manure should be encouraged among a more significant number of vegetable producers for both organic and traditional crop development. The various enrichment methods and their use encouraged the farming community to enrich accessible organic manures, reducing soil pollution and environmental degradation caused by fossil fuels. Using more enriched organic manures regularly reduced the amount of organic manure required and increased the efficiency of the applied manures (Sindhu et al., 2020).

Using compost, in particular rich compost, equalizes the seasonal changes in the availability of soil temperature, air, water, and nutrients and, therefore, the production of crops. Composting is a practical plant nutrition management approach for a sustainable agricultural system (Meena et al., 2021). According to different studies at local and national levels, it is identified that low nutritional content, bulkiness, handling challenges, and labour-intensive application prohibit producers from making more use of these conventional organic manures, or they are facing problems in moving towards organic farming, so today we need to enrich the traditional organic manures and compost for reducing the use of chemical fertilizers and facilitate the application quantity of compost and limited work has been done on enriched compost, especially in leafy vegetables so we need to focus on it. The current study was carried out to investigate the impact of enriched compost, inorganic fertilizers, ordinary manures, and vermicompost on the growth, productivity, and quality of palak for two consecutive cropping seasons.

2. Materials and methods

Experiment location

In the Lovely Professional University, Phagwara, Punjab, the investigation was carried out in the vegetable farm, Domain of horticulture, School of Agriculture for two consecutive cropping seasons of 2020 – 2021 and 2021 – 2022, which is located at 31ºN (latitude) and 75°E (longitude) at the altitude of 234 m above mean sea level. Phagwara (Jalandhar) has a humid subtropical climate with hot summers and winds from April to July, followed by a hot, humid rainy season and cold winters associated with January.

Treatment details

The experiment was established in a randomized complete block design with three replications containing each of the following ten assimilated treatment (T) combinations: T_1-recommended dose of fertilizers (RDFs) + farmyard manure (FYM) (85:30:0 N: P: K kg/ha + 20 t/ha); T_2-RDFs + FYM (50% + 10 t/ha); T_3-FYM (20 t/ha); T_4-mineral (rock phosphate) enriched compost (MEC_1) (5 t/ha); T_5-microbial enriched compost (MEC_2) (5 t/ha); T_6-vermicompost (VC) (5 t/ha); T_7-MEC_1 + MEC_2 (50% + 50%); T_8-MEC_1 v MEC_2 (75% + 25%); T_9-MEC_1 + MEC_2 (25% + 75%); T_{10}-absolute control (no application) for two years straight. The NPK was given according to the standard protocol, which contained urea (46% nitrogen) and single super phosphate (16% phosphorus). As a basal dosage, the entire quantity of P and K and half the amount of N were administered before seed sowing. After 30 days of sowing, the remaining half dosage of N was used as a top dressing. All enriched compost and manures were physically added to the different plots based on their treatment combination during the soil preparation step.

Planting material

The variety used for this experiment is Harit Shobha, procured from an agriculture farm store, school of agriculture, and Lovely Professional University. UPL Advanta Ltd produced this variety. It is an open-pollinated, multi-cut variety with more giant leaves at the plant's base and smaller leaves further up the flowering stem. Direct seed sowing in lines has been done, and the plant population maintained at 25 cm × 10 cm spacing.

Preparation of enriched compost

We used a variety of organic substrates on and off the farm, including mature composts, residual straws, grass clippings, crushed wood pallets, crushed hardwood materials, weed residues, crop residues, fruits/vegetable peels, livestock wastes, and so on. Minerals such as rock phosphate are commonly utilized as mineral additions in compost enrichment. Mineral additions were employed for compost enrichment due to their low cost and high availability, ability to absorb heavy metals, and reduction in greenhouse gas emissions from composting, among other advantages. Composting material was inoculated with various microorganisms, i.e., N, P, K biofertilizers, biopesticide *Trichoderma*, and *Pseudomonas*, to enrich the compost. The trench or pit was filled in stages (5 – 6 layers). Biodegradable organic material, such as agricultural leftovers, farm waste, animal feed waste, and tree leaves, was deposited on the trench bottom (about 20 cm thick layers). The layer of rock phosphate, at the rate of 120 kg/tonne, was spread evenly on biodegradable organic material/waste, and cattle dung, at the rate of 10 kg/tonne, was turned into a slurry by adding water, and this was sprinkled over the rock phosphate layer. Layering was then performed until all compostable materials were incorporated. Aeration to the pit was provided by periodic rotation (at a monthly interval). The compost-making process takes 90 – 100 days for field application. After compost harvesting, the final product was inoculated at the rate of 100 gm with nitrogen-fixing microorganisms, phosphate and potassium solubilizing microbes, and biopesticide *Pseudomonas* spp. and also *Trichoderma* spp. was used as a bio-inoculant during compost enrichment.

Characterization of enriched compost for its chemical properties

Upon the completion of the composting process, samples were collected for the assessment of both chemical and physical properties. Each sample was meticulously prepared by combining five sub-samples from random points within the pile. These samples were then securely placed in polyethene bags and transported to the laboratory for comprehensive analysis. The composting procedure spanned approximately three months, and three sets of compost replicates were subject to analysis. The collected compost samples were subjected to a series of preparatory steps, which included drying, grinding, and sieving through a 20-mesh sieve size. The initial step involved oven-drying the samples at a temperature of 70 °C. To determine the pH level of the samples, a glass electrode pH meter was employed, and the results were reported as soil pH measured in a water solution with a sample-to-water ratio of 1:5. In addition, the electrical conductivity (EC) of the obtained soil samples was measured electrometrically by utilizing a conductivity meter calibrated with a 0.01 M KCl solution, at a sample-to-water ratio of 1:5.

The total nitrogen content was calculated using the Kjeldahl technique, where the samples underwent digestion with concentrated H_2SO_4 and a catalyst mixture. The nitrogen content in the digested samples was assessed through distillation using 40% NaOH and titration of the resulting distillate with 0.01% HCl. A spectrophotometer was used to determine total phosphorus levels employing the vanadomolybdo phosphoric acid yellow colour method. Readings were taken at a wavelength of 440 nm. Total potassium was analyzed through percent emission and measured using an Eel flame photometer. Micronutrients were quantified via atomic absorption spectrophotometer analysis. The determination of organic matter content was carried out through the loss on ignition method, where a five-gram sample was placed in pre-weighed porcelain crucibles and subjected to a five-hour exposure into a muffle furnace at 550 °C. After cooling, the crucibles were weighed to ascertain the loss of ignition.

Morphological yield traits

Data on several observations, including growth and yield characteristics and quality attributes, were recorded from two cropping seasons of Palak during both years. During the crop growth period, morphological parameters of palak were taken at 25, 40, and 55 DAS. The plants were chosen randomly from each experimental plot, and their average values were determined for statistical analysis. The exclusion of plants from the outside rows was performed to reduce the possible impact of the border effect.

Using a meter scale, the plant's height was measured from the ground to the top of the giant leaf. No. of leaves was counted per plant, and the mean was calculated. The mean length of petiole was worked out from the observations of ten leaves selected from the observational plants of each treatment. It was recorded only at the time of leaf cutting. Ten leaves were chosen randomly from each treatment, and the average leaf area per plant was measured using an electronic area meter. The petiole's girth was measured with vernier callipers' help, and means were calculated. At each cutting, the leaf yield per plant was taken in grams (with petiole). Leaf yield per net plot was measured at each cutting, and the total was treated as leaf yield per plot. Leaf yield in q/ha was calculated based on total leaf yield per net plot.

Quality parameters

Moisture % was estimated by obtaining 100 g samples of Palak leaves selected from each treatment and recording fresh and oven-dry weights at 80 °C for 48 hours. It was then calculated by using the formula accordingly.

After harvesting the leaves, the fresh weight of five observational plants was measured and dried in an oven. The average dry weight was worked out after that. To calculate the total quantity of carotenoids, roughly 15 g of samples and 3 g of celite 454 (Tedia, Ohio, USA) were weighed in a mortar using a digital balance (Bel Engineering, model MA0434/05). To extract carotenoids, add 25 mL of acetone until a paste forms. Transfer the paste to a sintered funnel (5 µm) attached to a 250 mL Buchner flask and vacuum filter. This method was done three times or until the material was colourless. The extract was transferred to a 500 mL separatory funnel with 40 mL of petroleum ether. To avoid emulsion formation, the acetone was gradually eliminated by slowly adding ultrapure water (Milli-Q -Millipore). The aqueous phase was discarded. This method was done four times until no more solvents remained. The extract was then funnelled into a 50 mL volumetric flask containing 15 g of anhydrous sodium sulphate. The volume comprised petroleum ether, and the samples were read at 450 nm. The formula for calculating the total carotenoid content was as follows:

$$\text{Total carotenoids}(\text{mg}/100\text{g}) = \frac{\text{Absorbance} \times \text{Volume (mL)} \times 10000}{\text{Absorbance coefficient (2592)} \times \text{sample weight (g)}}$$

The ascorbic acid content of Palak was determined using the 2,6-dichlorophenol indophenols visual titration technique. (AOAC, 2016).

The total quantity of phenols in the sample was evaluated using the Folin-Ciocalteu reagent and gallic acid as a standard. One gram of material was ground with 10 mL of 80 percent ethanol in a pestle and mortar, then centrifuged for 20 minutes at 1000 rpm and filtered. The filtrate was evaporated in the oven until dry, and the dried extract was dissolved in 5 mL distilled water. 0.2 – 2.0 mL aliquots were placed in various test tubes, and the volume was increased to 3 mL with distilled water. Then 0.5 mL of Folin-Ciocalteu reagent was added. After 3 minutes, 2 mL of Na_2CO_3 (20%) was added to the test tube. Test tubes were immersed in a boiling water bath for one minute before being allowed to cool. The absorbance was measured at 650 nm. The concentration was determined using the usual technique and the standard curve. The standard curve was created using the same approach with various amounts of gallic acid. The final values were given as mg/g or percent.

DPPH (2, 2-diphenyl-1-picrylhydrazyl) was utilized as a free radical source to decrease itself and provide a percentage inhibition reading. 3.9 mL of 6×10^{-5} mol/L DPPH prepared in methanol was added to a test tube containing 0.1 mL of sample extract. After 30 minutes in the dark, the absorbance was measured at 515 nm (Brand-Williams et al., 1995). The methanol solution was used as a blank. The equation for calculating antioxidant activity was as follows:

$$\text{Antioxidant activity } (\%) = \frac{Ab_{(B)} - Ab_{(S)}}{Ab_{(B)}} \times 100$$

While,
$Ab_{(B)}$ = Absorbance of the blank
$Ab_{(S)}$ = Absorbance of the sample

Mineral estimation (mg/100g)

Total Fe, Mn, and Cu in the plant were determined using DTPA extractable by AAS (Lindsay and Novell, 1978). Hennerberg, Stohmann, and Rauterberg Method: During the acid and subsequent alkali treatments, oxidative hydrolytic destruction of the native cellulose and significant degradation of lignin occur. The residue from the final filtration is weighed, burned, cooled, and weighed again. The weight loss determines the crude fibre content.

Statistical analysis

The recorded data were analyzed per standard statistical procedure at a level of 5% significance for both the cropping season of 2021 – 22 and 2022 – 23 via the software OPSTAT. The three replications for the field experiment using RBD (randomized block design) were laid out to verify the influence of different variables.

3. Result and discussion

Characterization of enriched compost for its chemical properties

The enriched compost used in the experiment, *viz*. Mineral (Rock phosphate) enriched compost (E_1), Microbial (N, P, K biofertilizer and biopesticides) enriched compost (E_2), and mineral + microbial enriched compost (E_3) were analyzed after enrichment for their chemical properties. The pH after enrichment of E_1 (mineral compost), E_2 (microbial compost), and E_3 (Mineral + microbial compost) were recorded as 7.90, 7.80, and 7.40. respectively (Table 1). The pH of enriched compost ranges between 7.40 – 7.90, which is slightly neutral, so it is most suitable for plant growth. The pH of E_3 compost was slightly decreased due to forming organic acids and phenolic compounds during incubation. However, pH was stabilized after some time due to the buffering nature of humic substances. The total soluble salt content after compost enrichment of E_1 (mineral compost), E_2 (microbial compost), and E_3 (Mineral + microbial compost) were 3.4, 3.1 and 2.1 dS/m, respectively. The increase in electrical conductivity is due to increased concentration of salts due to decomposition of organic matter. These findings align with those reported by Surekha et al. (2016). The organic carbon content after enrichment of E_1 (mineral compost), E_2 (microbial compost), and E_3 (Mineral + microbial compost) were 12.5, 13.1, and 13.5 percent, respectively. Organic carbon content is higher due to better decomposition of different organic sources used in compost enrichment.

The nitrogen (N) after enrichment of E_1 (mineral compost), E_2 (microbial compost), and E_3 (Mineral + microbial compost) were 1.25, 1.12, and 1.37 percent, respectively (Table 2). The improved nitrogen content could be due to the decomposition of complex N-compounds affected by the degradation of labile organic carbon compounds, which reduce the weight of composting mass and increase microbial activity. The phosphorus (P) content after enrichment of E_1 (mineral compost), E_2 (microbial compost), and E_3 (Mineral + microbial compost) were 1.35, 0.50, and 1.75 percent, respectively. The increase in phosphorus content in all enriched composts might be due to enrichment with a microbial consortium that resulted in the efficient mineralization of rock phosphate, which enhanced the phosphorus content in E_3 (Mineral + microbial) compost. The

Table 1. pH, EC (dS/m), and organic carbon content (%) in different enriched compost.

Observations	EC_1	EC_2	EC_3
pH	7.90 ± 0.10	7.80 ± 0.10	7.40 ± 0.12
EC (dS/m)	3.40 ± 0.21	3.10 ± 0.06	2.10 ± 0.06
Organic carbon (%)	12.50 ± 0.88	13.10 ± 1.05	13.50 ± 0.93

*The results are represented as the mean ± SD of three replicates.
Enriched compost: EC_1– Mineral (Rock Phosphate) enriched compost; EC_2– Microbial (N, P, K biofertilizer + biopesticide-*Trichoderma*, *Pseudomonas*) enriched compost; EC_3– Mineral + Microbial enriched compost.

Table 2. N (%), P (%), K (%), Ca (ppm), Mg (ppm) and S (ppm) content in different enriched compost.

Macronutrient	Enriched compost		
	EC_1	**EC_2**	**EC_3**
N (%)	1.25 ± 0.03	1.12 ± 0.04	1.37 ± 0.02
P (%)	1.35 ± 0.05	0.50 ± 0.07	1.75 ± 0.04
K (%)	0.86 ± 0.05	0.73 ± 0.12	1.14 ± 0.05
Ca (ppm)	73370.00 ± 12.60	42250.00 ± 12.60	54760.00 ± 5.78
Mg (ppm)	6177.00 ± 13.01	7012.00 ± 166.54	8124.00 ± 7.45
S (ppm)	3683.00 ± 14.85	3453.00 ± 39.05	4672.00 ± 12.68

*The results are represented as the mean ± SD of three replicates.
Enriched compost: EC_1– Mineral (Rock Phosphate) enriched compost; EC_2– Microbial (N, P, K biofertilizer + biopesticide-*Trichoderma*, *Pseudomonas*) enriched compost; EC_3– Mineral + Microbial enriched compost.

potassium (K) content after enrichment of E_1 (mineral compost), E_2 (microbial compost), and E_3 (Mineral + microbial compost) were 0.86%, 0.76% and 1.14%, respectively. A higher amount of K in E_3 compost might be due to quick microbial activity leading to a decrease in the volume of the material. These outcomes align with findings from Kumar et al. (2018). The calcium (Ca) and magnesium (Mg) content after enrichment of E_1 (mineral compost), E_2 (microbial compost), and E_3 (Mineral + microbial compost) were 7.33, 4.22 and 5.4 percent and 0.61, 0.70, and 0.81 percent, respectively. The increase in Ca and Mg is due to the enrichment of compost with rock phosphate because its content has a higher amount of Ca and Mg. The sulphur (S) content after enrichment of E_1 (mineral compost), E_2 (microbial compost) and E_3 (mineral + microbial compost) were 0.36, 0.34 and 0.46%, respectively (Table 3). After enrichment, sulphur content did not improve. The micronutrient content after enrichment of E_1 (mineral compost), E_2 (microbial compost), and E_3 (Mineral + microbial compost) were available in higher amounts, and it might be due to the organic chelation of micronutrients. These findings corroborate the results reported by Mwangi et al. (2020).

Effect of enriched compost on the growth parameter of palak

The data about plant height of palak presented in Table 4, the plant height (22.36, 32.58 and 28.39 cm) at 25, 40 and 55 DAS was found maximum in treatment T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (20 t/ha) which was at par withT7 (50% Mineral enriched compost + 50% microbial enriched compost) in terms of plant height. During pooled data analysis, the least plant height (9.95, 18.80, and 13.95 cm) was reported in absolute control (T_{10}). A similar discovery was reported by Rady et al. (2016), Jagadeesha et al. (2019), and Jamoh (2021) in French bean, finger millet-cowpea, and palak crops, respectively. It is well known that Mineral + microbial enriched compost enhances soil's physical and biological properties and performs in a way equivalent to RDF treatment, including delivering nearly all needed plant nutrients for plant growth and development. Thus, adequate nourishment in a suitable environment may have aided in the formation of new tissues and the growth of new shoots.

Table 4 presents data regarding the number of leaves in palak. The number of leaves (9.06, 13.01, and 8.65) at 25, 40, and 55 DAS was found maximum in treatment T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (20 t/ha), which was at par with T_7 (50% Mineral enriched compost + 50% microbial enriched compost) in terms of several leaves. During pooled data analysis, the lowest number of leaves (4.2, 5.87, and 5.42) was reported in absolute control (T_{10}). This may be brought about by the microbial consortium found in organic fertilizers, and a favourable environment is created for root respiration, nutrient absorption, and upper part growth when organic manure improves soil formation, air circulation, water retention capacity, and nutrient flow all contribute to a greatly enhanced character. Similar outcomes were published by Anwar et al. (2017) and Jagadeesha et al. (2019), and Jamoh (2021) in spinach, finger millet-cowpea, and palak crops, respectively.

The data about length of petiole in palak presented in Table 4, length of petiole (15.95, 22.36 and 15.98 cm) at 25, 40 and 55 DAS was found maximum in treatment T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (20 t/ha) which

Table 3. Fe, Cu, Mn, Zn, Mo, B (ppm) content in different enriched compost.

	Enriched compost					
	Fe	Cu	Mn	Zn	Mo	B
EC_1	15400.00±88.30	76.84±2.12	352.20±4.98	383.00±6.02	41.66±1.97	127.70±1.37
EC_2	10570.00±63.01	130.50±3.01	470.90±7.60	779.00±8.10	36.12±2.84	131.30±2.69
EC_3	18100.00±57.80	222.00±4.34	446.90±6.18	317.20±4.40	42.15±1.50	101.10±1.58

*The results are represented as the mean ± SD of three replicates.
Enriched compost: EC_1– Mineral (Rock Phosphate) enriched compost; EC_2– Microbial (N, P, K biofertilizer + biopesticide-*Trichoderma*, *Pseudomonas*) enriched compost; EC_3– Mineral + Microbial enriched compost.

Table 4. Impact of enriched compost on growth attributes in Palak.

Treatments	Plant height			Number of leaves			Length of petiole (cm)			Average leaf area per plant (cm^2) at 40 DAS		
	25 DAS	40 DAS	55 DAS	25 DAS	40 DAS	55 DAS	25 DAS	40 DAS	55 DAS	25 DAS	40 DAS	55 DAS
T_1	22.36^{a}	32.58^{a}	28.39^{a}	9.06^{a}	13.01^{a}	8.65^{a}	15.95^{a}	22.36^{a}	15.98^{a}	51.76^{a}	63.27^{a}	108.53^{a}
T_2	21.58^{b}	30.39^{bc}	27.64^{a}	8.47^{b}	12.02^{b}	7.91^{b}	14.71^{b}	20.9^{b}	14.77^{b}	49.25^{b}	60.24^{b}	99.38^{b}
T_3	15.63^{g}	24.82^{f}	19.41^{e}	5.17^{g}	7.84^{f}	7.17^{d}	10.8^{f}	16.44^{e}	12.08^{d}	37.8^{e}	40.92^{e}	70.3^{f}
T_4	19.75^{c}	30.22^{c}	25.01^{b}	6.63^{d}	9.48^{cd}	7.88^{b}	13.36^{c}	19.13^{c}	14.12^{c}	48.21^{bc}	55.3^{c}	88.44^{c}
T_5	17.8^{e}	28.19^{d}	21.35^{d}	6.16^{e}	8.81^{e}	7.46^{cd}	11.94^{e}	17.2^{e}	12.54^{d}	45.64^{d}	51.21^{d}	80.9^{e}
T_6	19.19^{cd}	29.32^{cd}	22.22^{cd}	7.14^{c}	9.42^{cd}	7.69^{bc}	12.96^{cd}	18.67^{cd}	13.86^{c}	46.75^{cd}	54.21^{c}	83.97^{de}
T_7	21.8^{ab}	31.51^{ab}	27.79^{a}	8.83^{a}	12.69^{a}	8.3^{a}	15.49^{a}	21.6^{ab}	15.47^{a}	49.97^{ab}	61.05^{ab}	106.52^{a}
T_8	18.8^{d}	29.46^{c}	23.36^{c}	6.55^{d}	9.59^{c}	7.64^{bc}	13.1^{c}	18.2^{d}	13.65^{c}	48.31^{bc}	53.6^{cd}	86.89^{cd}
T_9	16.32^{f}	26.48^{e}	21.66^{d}	5.59^{f}	9.11^{de}	7.24^{d}	12.49^{d}	15.59^{f}	12.61^{d}	45.28^{d}	51.64^{d}	80.35^{e}
T_{10}	9.95^{h}	18.89^{g}	13.95^{f}	4.2^{h}	5.87^{g}	5.42^{e}	9.95^{g}	12.66^{g}	10.52^{e}	29.55^{f}	32.76^{f}	53.54^{g}
Mean	**18.32**	**28.19**	**23.08**	**6.78**	**9.78**	**7.54**	**13.08**	**18.27**	**13.56**	**45.25**	**52.42**	**85.88**
CD	**0.85**	**1.55**	**1.14**	**0.36**	**0.50**	**0.45**	**0.66**	**1.03**	**0.77**	**2.94**	**3.13**	**5.08**
CV %	**2.10**	**2.48**	**6.30**	**2.42**	**2.30**	**2.24**	**2.28**	**2.54**	**1.90**	**2.93**	**2.69**	**4.28**

*Different letters showing the significant differences among the different treatment combinations.

was at par with T_7 (50% Mineral enriched compost + 50% microbial enriched compost) in connection with length of petiole. During pooled data analysis, the minimum petiole size (9.95, 12.66, and 10.52 cm) was reported in absolute control (T_{10}). The excellent effect of enriched compost on these parameters might be attributed to its participation in providing more plant nutrients and enhancing the availability of native soil nutrients due to enhanced microbial activity, which gives positive results equal to RDF treatment. Similar results were reported by Meena et al. (2017) in green gram crops.

The data about the average leaf area per plant of palak presented in Table 4, the maximum average leaf area per plant (51.76, 63.27 and 108.53 cm^2) at 25, 40 and 55 DAS was found in treatment T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (20 t/ha) which was at par with T_7 (50% Mineral enriched compost + 50% microbial enriched compost) in terms of average leaf area per plant. During pooled data analysis, the lowest average leaf area per plant (29.55, 32.67, and 53.54 cm) was reported in absolute control (T_{10}). Enriched compost also serves as a source of energy for soil microflora, resulting in the transformation of inorganic nutrients contained in soil into accessible forms or provided as fertilizers that are readily utilized by developing plants, so similar results were obtained by Rady et al. (2016) in french bean.

The data about the diameter of the middle of the petiole in palak is presented in Table 5. The maximum diameter of the middle of the petiole (0.66 cm) at 25 DAS was recorded in treatment T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (20 t/ha), which was at par with T_7 (50% Mineral enriched compost + 50% microbial enriched compost) and T_2. Whereas, at 40 and 55 DAS, the maximum diameter of the middle of the petiole (0.86 and 0.89 cm), which was at par with T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (20 t/ha) which was at par with T_7 (50% Mineral enriched compost + 50% microbial enriched compost). The lowest diameter of the middle of the petiole (0.21, 0.36, and 0.47 cm) was reported in absolute control (T_{10}) during pooled data analysis. The diameter of the petiole recorded maximum in the treatments mentioned above might be due to better plant height, maximum count for leaves, petiole length, and more leaf area, so there is an overall improvement in vegetative growth of the plant in the case of inorganic and organic treatments. Similar outcomes were disclosed by Pangaribuan et al. (2017) in gherkin and sweet corn crops, respectively.

Plant leaf yield

The data about average leaf yield per plant in palak presented in Table 5 revealed that the maximum average leaf yield per plant (30.38 gm) was found to be maximum in treatment T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (20 t/ha) which was at par with T_7 (50% Mineral enriched compost + 50% microbial enriched compost) and followed by T_2 RDF 50% + FYM (10 t/ha) in terms of average Yield per plant. The lowest average leaf yield per plant (14.24 gm) was reported in absolute control (T_{10}) in the pooled data analysis.

The data of average leaf yield per plot (kg) in palak presented in Table 5 revealed that the maximum average leaf yield per plot (12.99 kg) was found to be maximum in treatment T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (20 t/ha) which was at par with T_7 (50% Mineral enriched compost + 50% microbial enriched compost) and followed by T_2 RDF 50% + FYM (10 t/ha) in terms of average leaf yield per plot. During pooled data analysis, the lowest average leaf yield per plot (5.98 kg) was reported in absolute control (T_{10}).

The data about leaf yield q/hain palak presented in Table 5

Table 5. Impact of enriched compost on yield attributes in Palak.

Treatments	Diameter of the middle of the petiole (cm)			Avg. yield per plant (gm)	Avg. yield per plot (kg)	Avg. Yield (q/ha)
	25 DAS	40 DAS	55 DAS			
T_1	0.66^a	0.86^a	0.89^a	30.38^a	12.99^a	108.7^a
T_2	0.61^a	0.79^b	0.83^b	27.93^b	11.73^b	98.69^b
T_3	0.32^e	0.48^f	0.65^d	18.43^g	7.74^f	65.8^g
T_4	0.52^b	0.73^c	0.83^b	26.64^c	11.19^c	95.1^c
T_5	0.39^{cd}	0.64^d	0.74^c	22.06^f	9.27^e	78.76^f
T_6	0.44^c	0.67^d	0.81^b	24.27^d	10.19^d	86.65^d
T_7	0.62^a	0.82^{ab}	0.86^{ab}	29.58^a	12.63^a	105.71^a
T_8	0.4^{cd}	0.62^{de}	0.74^c	23.14^e	9.72^e	82.62^e
T_9	0.35^{de}	0.58^e	0.65^d	22.05^f	9.26^e	78.71^f
T_{10}	0.21^f	0.36^g	0.47^e	14.24^h	5.98^g	50.84^h
Mean	**0.45**	**0.65**	**0.75**	**23.87**	**10.07**	**85.16**
CD	**0.02**	**0.03**	**0.01**	**1.24**	**0.58**	**4.17**
CV %	**0.01**	**0.01**	**0.00**	**2.35**	**2.62**	**2.21**

*Different letters showing the significant differences among the different treatment combinations.

revealed that the maximum leaf yield q/ha (108.70 q) was found maximum in treatment T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (20 t/ha) which was at par with T_7 (50% Mineral enriched compost + 50% microbial enriched compost) and followed by T_2 RDF 50% + FYM (10 t/ha) in terms of leaf yield q/ha. The lowest leaf yield q/ha (50.84 q) was reported in absolute control (T_{10}) in pooled data analysis. The increase in yield comparison to RDF treatment caused by the addition of enriched compost could be attributed to an overall improvement in soil physico-chemical properties, such as a decrease in pH, improved electrical conductivity (EC), and an increase in all nutrients. These advantageous results promoted improved availability of plant nutrients and their consistent delivery throughout growth for optimal development. Similar results related to overall Yield have been seen by Rady et al. (2016), Meena et al. (2017), Pascual et al. (2017), Jagadeesha et al. (2019), and Jamoh (2021) in French bean, green gram, melons, finger millet-cowpea, and palak crops, respectively.

Quality parameters

The data on moisture content is presented in Table 6. It is vividly seen in pooled data analysis that treatments performed randomly regarding moisture content. The moisture content (90.06%) was found to be maximum in treatment T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (20 t/ha), which was at par with T_7 (50% Mineral enriched compost + 50% microbial enriched compost), T_2, T_4, T_6, and T_8 in terms of moisture content in palak. The lowest moisture content (76.63%) was reported in absolute control (T_{10}) in pooled data analysis.
The data presented to dry matter represented in Table 6 revealed that, in pooled data analysis, T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (20 t/ha) recorded maximum dry matter (16.65%) in the palak leaves which was at par with T_7 (50% Mineral enriched compost + 50% microbial enriched compost) treatment. During the pooled data analysis, Palak's lowest dry matter (7.75%) was found in absolute control (T_{10}). Better nitrogen availability and uptake may have contributed to increased plant metabolism, a balanced C/N ratio, and improved dry matter. The outcome mentioned above is consistent with the findings of Jabeen et al. (2018) on palak crops.
The pooled data presented to ascorbic acid represented in Table 6 indicate the highest ascorbic acid content (88.54 Mg) was found in treatment T_7 (50% Mineral enriched compost + 50% microbial enriched compost) which was significantly superior overall treatments and followed by T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (20 t/ha) as regards ascorbic acid in palak. At the same time, the lowest ascorbic acid of palak (50.91 mg) was found in absolute control (T_{10}) during the pooled data analysis. Similar findings were reported by Gogoi and Phookan (2017); Kulal and Pillewad (2023) in knol and chickpea crops. The pooled data presented to total carotenoids represented in Table 6 also indicates the highest total carotenoids (3.46 mg) were found in T_7 (50% Mineral enriched compost + 50% microbial enriched compost), which was at par with treatment T_6 (vermicompost 5 t/ha). During pooled analysis, treatment T_{10} (absolute control) had minimum total carotenoids (2.4 mg) in Palak leaves. It is frequently stated that the amount of applied nitrogen and the vitamin C content are negatively correlated (Tan et al., 2000). This could be because plants receiving organic treatments have smaller leaves and, in

Table 6. Impact of enriched compost on quality attributes in Palak.

Treatments	Moisture content (%)	Dry matter content (%)	Ascorbic Acid (mg/100g)	Total carotenoids (mg/100g)	Phenols (mg/100g)	Mineral estimation (mg/100g)			Crude Fibre content (%)	Antioxidant activity (DPPH%)
						Fe	Zn	Cu		
T_1	90.06^a	16.65^a	80.84^c	26.85^a	17.6^e	10.22^d	7.86^{bc}	3.08^e	11.3^a	2.57^{cd}
T_2	89.04^a	15.1^b	75.96^f	26.05^a	18.19^{de}	9.59^e	7.32^{de}	2.99^e	9.5^b	2.62^{cd}
T_3	80.82^b	10.21^g	69.5^g	15.65^e	16.34^f	8.29^f	7.17^e	2.31^f	8.06^{cd}	3.26^{bcd}
T_4	86.89^a	13.69^{cd}	79.97^{cd}	18.98^d	19.22^{cd}	15.08^b	8.03^b	4.05^{bc}	8.02^{cd}	3.49^{abcd}
T_5	82.58^b	12.42^f	76.93^{ef}	16.48^e	19.89^{bc}	13.29^c	7.94^{bc}	3.56^d	8.19^{bcd}	3.31^{bcd}
T_6	87.35^a	13.24^{de}	77.56^e	18.25^d	22.07^a	14.58^b	7.91^{bc}	3.46^d	8.42^{bcd}	3.34^{bcd}
T_7	89.64^a	16.09^a	88.54^a	26.25^a	22.52^a	16.67^a	8.56^a	4.6^a	7.27^d	4.46^a
T_8	87.05^a	14.2^c	82.86^b	21.25^b	20.55^b	14.48^b	8.04^b	4.24^b	8.01^{cd}	3.58^{abc}
T_9	83.36^b	12.66^{ef}	78.94^d	19.95^c	18.24^{de}	13.58^c	7.62^{cd}	3.92^c	8.18^{bcd}	3.92^{ab}
T_{10}	76.63^c	7.75^h	50.91^h	10.41^f	14.79^g	3.71^g	4.69^f	1.54^g	8.71^{bc}	2.4^d
Mean	**85.34**	**13.20**	**76.20**	**20.01**	**18.94**	**11.95**	**7.51**	**3.37**	**8.57**	**3.29**
CD	**3.86**	**0.89**	**1.70**	**1.09**	**1.40**	**0.76**	**0.44**	**0.26**	**1.56**	**1.30**
CV %	**2.03**	**3.06**	**1.01**	**2.46**	**3.33**	**2.87**	**2.66**	**3.63**	**8.21**	**17.90**

*Different letters showing the significant differences among the different treatment combinations.

comparison to plants receiving inorganic treatments, lower vegetative growth. As a result, all the leaves receive adequate light and function as a source of carbohydrates. Since carbohydrates constitute the building block of ascorbic acid biosynthesis, an excess of carbohydrates is thus accessible for their conversion to ascorbic acid synthesis, similar results reported by Kumar et al. (2016) in cabbage.

The data presented to phenols revealed that the highest phenols (22.52 mg) were found in treatment T_7 (50% mineral-enriched compost + 50% microbial-enriched compost), which was at par with T_6 (vermicompost 5 t/ha) concerning phenols (Table 6). In contrast, during pooled data analysis, T_{10} (absolute control) had minimum phenols (14.79 mg) in palak leaves. Nitrogen administration in ammonium and nitrogen caused a considerable drop in leaf-blade phenol content, so organically grown palak had a higher amount of total phenols. Similar outcomes were published by Vethamoni and Thampi (2018) and Jagadeesha et al. (2019) in crops palak and cowpea. In spinach beet, according to Kumar et al. (2016), using biofertilizers and organic fertilizers improves the production of phenolic chemicals. Thus, data suggests that, as noted by Scheible et al. (2004), reduced soil nitrogen content stimulates the manufacture of total phenol content.

The data presented to Fe mineral estimation recorded the highest Fe mineral (16.67 mg) in the treatment T_7 (50% Mineral-enriched compost + 50% microbial-enriched compost). They were significantly superior overall treatments, followed by T_4 (mineral enriched compost 5 t/ha), T_8 and T_6 regarding Fe mineral estimation in palak. Meanwhile, during pooled data analysis, T_{10} (absolute control) recorded a minimum Fe mineral (3.71 mg) in the Palak leaves. The data presented to Zn mineral estimation revealed that the highest Zn Mineral (7.86 mg) was found in the treatment T_7 (50% Mineral enriched compost + 50% microbial enriched compost, which was significantly superior overall treatments and followed by T_4 (mineral enriched compost 5 t/ha), T_8, and T_6 as to Zn mineral estimation in palak. At the same time, T_{10} (absolute control) had a minimum Zn Mineral (24.69 mg) in the Palak leaves during the pooled data analysis. The highest Cu Mineral (4.6 mg) was found in the treatment T_7 (50% Mineral enriched compost + 50% microbial-enriched compost), which was significantly superior to overall treatments and followed by T_4 (mineral-enriched compost 5 t/ha), and T_8 as to Cu mineral estimation in palak. At the same time, T_{10} (absolute control) had a minimum Cu Mineral (1.54 mg) in the Palak leaves during the pooled data analysis. It has been observed that compounds like lactate and citrate react with the minerals in the soil to increase their availability to plant roots. Likewise, there is a rise in the mineral content of vegetables because of using organic manures rather than conventional ones, as earlier reported by Dongyan et al. (2020) in ragi crops.

The crude fibre content of leaves (11.30%) was found to be maximum under treatment T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (10 t/ha) which was significantly superior overall treatments and followed by T_2 in terms of crude fibre content in palak. Meanwhile, during pooled data analysis, T_{10} (absolute control) had minimum oil fibre content (8.71%) in the Palak leaves. The plants that receive the least amount of organic manure have compacted soil (greater bulk density), which reduces their responsiveness to overall growth but increases the amount of fibre in the soil. However, because of the impact of organic acids released

by the microorganisms, treatment T_7, which received the most significant amount of organic manure and consortia, tended to yield sensitive palak leaves with the least fibre, as reported by Evers (1989).
The data presented to antioxidant activity (%), the highest antioxidant activity (4.46%) was found in treatment T_7 (50% mineral-enriched compost + 50% microbial-enriched compost), which was at par with treatment T_8 (75% Mineral enriched compost + 25% Microbial enriched compost) and T_9 (25% Mineral enriched compost + 75% Microbial enriched compost) in terms of antioxidant activity. Meanwhile, during pooled data analysis, T_{10} (absolute control) had minimum antioxidant activity (2.40 mg) in the palak leaves. There has previously been evidence of a favourable link between phenols and antioxidants in leaves and petioles, with phenols being the primary source of antioxidant capacity. As observed by Gouda et al. (2023); Vethamoni and Thampi (2018) in crops palak and rice.

4. Conclusion

Based on the findings of the present investigation, the performance of T_7 (50% mineral-enriched compost + 50% microbial-enriched compost) was statistically similar to T_1 RDF 100% (85:30:0 N: P: K kg/ha) + FYM (20 t/ha) in terms of plant height, number of leaves, length of petiole, the diameter of middle of the petiole at 25 DAS, 40 DAS and 55 DAS, yield per plant, yield per plot in kg and Yield per hectare at harvesting as well as in case of quality parameters. As per the obtained results, it could be concluded that T_7 (50% mineral-enriched compost + 50% microbial-enriched compost) can be used as a good substitute for chemical fertilizers, enhancing the quality of agricultural output and soil health. However, it is worth noting that the availability of rock phosphate and effective microorganisms, locally accessible and cost-effective sources of nutrients, particularly phosphorus fertilizers, should be subject to further testing and exploration. These resources can potentially play a vital role in sustainable agriculture and soil health, warranting further investigation. It is also environmentally beneficial because of the recycling of organic waste and the potential decrease of nitrogen losses to the environment. Thus, the study has broad use in the global climate and the fertilizer business.

Authors contributions
All authors contributed equally to performing experiments, analyzing data, and writing the paper.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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