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Impact of different biofertilizers on growth and yield of chilli crop in northern plains of Jammu India

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Abstract

Low productivity in chilli (*Capsicum annuum*) cultivation is often attributed to nutrient-depleted soils and excessive dependence on chemical fertilizers, which pose environmental and sustainability concerns. To explore sustainable alternatives, a field experiment was conducted in Rahya, Samba, Jammu & Kashmir, to evaluate the effect of selected biofertilizer combinations on the growth and yield of chilli plants. The experimental design comprised four treatment groups, each consisting of 10 chilli plants. The control group was treated solely with vermicompost, while the three experimental groups received distinct combinations of biofertilizers: (i) vermicompost + Duckweed (*Lemna minor*), (ii) vermicompost + Coontail (*Ceratophyllum demersum*), and (iii) vermicompost + Duckweed + Coontail. Morphological parameters including plant height, leaf length, leaf breadth, number of leaves, and fruit size were systematically recorded and analyzed. Among the treatments, the combination of vermicompost, Duckweed, and Coontail yielded the most significant improvements in plant growth and productivity. This group exhibited a mean plant height of 33.20 ± 3.35 cm, leaf length of 13.32 ± 0.67 cm, leaf breadth of 6.73 ± 0.50 cm, and a leaf count of 46.00 ± 3.04 , along with marked enhancement in fruit size and quality. In contrast, the control group displayed the lowest values across all observed parameters. This study clearly demonstrates the potential of biofertilizers—especially the synergistic combination of vermicompost, Duckweed, and Coontail—in significantly enhancing chilli plant growth and fruit production. These findings support the adoption of such organic treatments as viable, sustainable alternatives to conventional fertilizers, offering valuable benefits for both farmers and the environment.

Keywords Biofertilizer, Organic, Vermicompost, Duckweed, Coontail

1 Introduction

The application rate of organic fertilizers poses a challenging decision for farmers, especially small-scale rural farmers. Farmers aim to boost crop yields while seeking cost-effective and environment friendly fertilizer options [21]. Organic farming, an agricultural method that has gained prominence in recent years, promotes production



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practices that support the environment [9, 18]. Organic production adheres to specific standards tailored for food production, striving to create socially and ecologically sustainable agro ecosystems [26]. Essentially, organic farming involves cultivating plants without synthetic fertilizers and pesticides, relying on techniques like crop rotation, green manure, legumes, crop residues, animal manure, off-farm organic waste, and biological pest control to maintain soil health, supply plant nutrients, and manage pests, diseases, and weeds [11, 16, 17]. In organic gardening, a holistic approach begins with soil improvement through the addition of locally available organic materials [31]. Organic manures, such as farmyard manure, crop residues, waste, biogas slurry, oilcakes, earthworms, and compost, play a significant role in enhancing soil fertility [31]. Compost, typically created from biodegradable materials like paper, leaves, fruit peels, left-over food, and fruit juices, enriches the soil, making it suitable for planting [6]. *Lemna minor* L., commonly known as lesser duckweeds, often forms dense mats in nutrient-rich freshwater and brackish water environments [29]. These aquatic plants, belonging to the subfamily Lemnoideae or duckweeds, purify contaminated water using only sunlight and provide a concentrated source of protein and nutrients that can be harvested for food production. Freshly harvested duckweed contains up to 43% protein by dry weight and can serve as a complete fish feed without additional processing. Duckweed can potentially become a valuable source of plant protein, reducing the need for extensive arable land for food crops [10]. Composting and vermicomposting are two methods for producing high-quality organic fertilizers from organic residues [27].

Vermicompost is the waste produced by earthworms, which enhances soil health and nutrient content. Vermiculture involves the conversion of various biodegradable wastes, including farm, kitchen, market, agro-based industry, and livestock waste, into nutrient-rich vermicompost as earthworms process them [2]. Vermicompost's impact on the growth of various crops, including cereals, legumes, vegetables, ornamental plants, and flowers, has been studied in greenhouses and, to some extent, in field crops [8]. Vermicompost not only provides nutrients and organic matter but also boosts the size, diversity, and activity of the soil's microbial population [20]. *Ceratophyllum demersum*, also known as coontail or hornwort, is a fully submerged plant commonly found in ponds, lakes, ditches, and nutrient-rich streams [1]. It forms thick mats just below the water surface and is known to accumulate heavy metals like Cd, Cu, Cr, Pb, and Hg [25]. Coontail serves as a cost-effective, safe, readily available, and environmentally friendly carbohydrate source for fish like Nile tilapia in biofloc systems [15]. These plants lack roots and absorb nutrients directly from the water column without the complexity of differential nutrient uptake between shoots and roots [13]. Considering coontail's attributes, such as its carbohydrate content, nutrient value, and antioxidative properties, it is being explored as a bio-fertilizer for chilli growth in the context of Jammu and Kashmir, a region heavily dependent on agriculture for revenue and employment [28]. This study aims to investigate the impact of different biofertilizer combinations on chilli (*Capsicum annuum*) production in Jammu, India.

2 Materials and methods

2.1 Experimental site

In the agricultural expanse of Village Rahya, nestled in the District of Samba, Jammu and Kashmir, a pioneering experiment unfolded. This study, carried out from March to June

2023, sought to unravel the impact of organic compost on the yield of chilli (*Capsicum annum*) in the Northern plains of Jammu.

2.2 Organic biofertilizers preparation

2.2.1 Preparation of vermicompost

To produce nutrient-rich vermicompost, a plastic tank was chosen to accommodate the raw materials. Cow dung collected from the farmyard, finely chopped dried leaves, kitchen waste, and other biodegradable materials were gathered and left to decompose in the sun for 8 to 10 days (Fig. 1). The composting process began by placing a 2–3 inch layer of wet soil and sand at the bottom of the tank. After a few days, fine beds were prepared by combining partially decomposed cow dung, dried leaves, kitchen waste, and other biodegradable materials.

The mixture was consistently moistened through regular water sprinkling. *Eisenia fetida* earthworms were introduced into the waste mixture, and another layer of soil was added (Fig. 2). Water was sprinkled regularly to maintain optimal moisture levels. During hot and sunny days, the tank was covered with gunny bags to protect it from excessive heat. Periodic checks were conducted to regulate the moisture content and temperature, preventing the compost from overheating.

In the T_1 plot, the pits were filled with a blend of Vermicompost and Duckweed. Meanwhile, the T_2 plot received a filling of Vermicompost and Coontail, and the T_3 plot had a mixture of Vermicompost, Coontail, and Duckweed integrated into the soil. The control plot, on the other hand, had its pits filled exclusively with Vermicompost, seamlessly blended with the soil.



Fig. 1 Food waste, cow dung and soil



Fig. 2 Earthworms (*Eiseniafetida*)

2.3 Collection of aquatic plants for making organic fertilizers

Two distinct plant species, Common Duckweed (*Lemnoideae*) and Coontail (*Ceratophyllum demersum*), were collected manually from the local pond in polythene bags (Fig. 3). In further process, the plants were spread on separate sheets. The wet vegetation underwent manual squeezing and was then passed through a large sieve to eliminate excess water thoroughly. Subsequently, the moisture-deprived samples were left in the sun for a span of 9 to 10 days, ensuring complete drying (Fig. 4). After the drying period of 10 to 11 days, the desiccated plants were manually rubbed and sieved (Figs. 5 and 6), followed by crushing with a Pestle and Mortar to alleviate the hardness of the stems. The resulting crushed material was then ground into a powder using a conventional grinder. The obtained powders, approximately 500 gm each for Duckweed and Coontail, were carefully stored in airtight bags for future use.

2.4 Field preparation

The selected field measured and designated as “Experimental Field”. The field was meticulously prepared, with thorough digging aided by a spade and meticulous removal of weeds (Fig. 7). It was then divided into four distinct plots: Treatment Plots (T_1 , T_2 , T_3) and a Control Plot (C). A total of 40 pits were carefully crafted using a spade, with 30 pits allocated to the treatment plots and an additional 10 pits designated for the control plot.

2.5 Soil analysis

Soil samples with different combination of fertilizers were taken to the University Laboratory for analysis. Soil samples were analyzed for pH, electrical conductivity, moisture content, water holding capacity and soil organic matter [30]. Total nitrogen was



Fig. 3 Collection of aquatic plants



Fig. 4 Sun drying of duckweed and coontail



Fig. 5 Crushing of desiccated plants



Fig. 6 Sieving of crushed material

calculated by using Kjeldhal method, phosphorus and potassium levels by using PUSA Soil Test and Fertilizer Recommendation Meter.

2.6 Collection of soil and treatment with prepared biofertilizers

Soil was collected from the agricultural land. Collected soil was treated with certain combinations of organic fertilizers. These combinations are–

Treatment one (T_1) = Soil + Duckweed + Vermicompost.

Treatment two (T_2) = Soil + Coontail + Vermicompost.

Treatment three (T_3) = Soil + Duckweed + Coontail + Vermicompost.



Fig. 7 Field preparation



Fig. 8 and 9 Sowing of seeds in the seed germination tray

Control (C) = Soil + Vermicompost.

Various combinations of organic fertilizers were applied to soil filled in germination trays. Chilli (*Capsicum annum*) seeds were acquired from the local market in Vijaypur, Samba. Two germination trays, each containing 25 cells, were utilized for the experiment (Figs. 8 and 9). The treatments were designated as follows: Treatment one (T_1) was applied to 10 cells, Treatment two (T_2) to another 10 cells, Treatment three (T_3) to a further 10 cells and the remaining 10 cells served as the Control (C) (Figs. 10 and 11).

The chilli seeds were sown in the trays for germination, and the trays were positioned in a shaded area. Regular watering was carried out. The timing of seed germination in the experimental plots was meticulously observed to assess the impact of fertilizers on the germination process.



Fig. 10 and 11 Seed germination trays with their respective combinations of treatments



Fig. 12 and 13 Chilli saplings plantation

2.7 Chilli plantation

Mature chilli saplings (5–9 cm in height) were carefully taken from the seed germination trays and subsequently transplanted into the designated experimental field. Within this field, 30 chilli saplings were strategically placed in treatment plots, while an additional 10 saplings were allocated to the control plot (Figs. 12 and 13).

2.8 Weeding, irrigation & use of biofertilizer

A systematic irrigation schedule was implemented, taking into consideration soil moisture levels and prevailing weather conditions throughout the entire experimental process. Weeding management was efficiently executed whenever necessary in the chilli field. Periodic removal of weeds from all groups was conducted as needed. After 20 days of chilli plantation, equal quantities of fertilizers were administered to both the treatment plots and the control plot to promote optimal plant growth (Figs. 14 and 15).

2.9 Growth parameters observed

A systematic irrigation schedule was implemented, taking into consideration soil moisture levels and prevailing weather conditions throughout the entire experimental process. Weed control was systematically carried out across all treatment and control groups as required. Periodic observations of plants from each group were conducted to assess morphological characteristics in accordance with the experimental protocol. After 20 days of chilli plantation, equal quantities of fertilizers were administered to both the treatment plots and the control plot to promote optimal plant growth.



Fig. 14 and 15 Administration of biofertilizer



Fig. 16 and 17 Plant Growth Observation

- (i) **Plant height (PH):** The height of the chilli plants was determined by measuring the distance from the base to the tip above the ground, utilizing a meter scale (Figs. 16 and 17).
- (ii) **Leaf length (LL):** The length of a chosen leaf from each plant was directly measured using a meter scale.
- (iii) **Leaf breadth (LB):** The width or breadth of a selected leaf from each plant was measured employing a meter scale.
- (iv) **Number of leaves (LN):** The total count of green leaves on each plant was manually tallied and recorded.

2.10 Statistical analysis

The gathered and documented data underwent statistical analysis using One-way ANOVA, followed by Duncan's multiple range tests for post hoc comparisons, along with descriptive analysis. Results with a significance level of $P \leq 0.001$ were deemed statistically significant.

3 Results and discussion

3.1 Changes of different physico-chemical parameters of soil from control and treatment plot

The following factors, including pH, electrical conductivity, soil moisture, water holding capacity, soil organic matter, nitrogen, potassium, and phosphorus, were examined

(Table 1). The highest soil pH in the treatment group was recorded for T₁ (9.01 ± 0.02), followed by T₃ (8.50 ± 0.09) and T₂ (8.43 ± 0.03), all of which were significantly lower than the control group's pH (8.12 ± 0.03). This reduction in pH may be attributed to the nitrification process and cation leaching. These findings align with Ahmed et al. [4], who stated that the addition of organic manure can influence soil pH depending on environmental conditions. They further noted that soil with a slightly acidic to neutral pH is generally optimal for nutrient availability, plant growth, and microbial activity [22]. In comparison to $22.98 \pm 0.5\%$ in the control plot, the soil moisture level in the treated plot T₁, T₂ and T₃ was $25.27 \pm 0.25\%$, $24.77 \pm 0.23\%$ and $25.99 \pm 0.29\%$ respectively. The electrical conductivity of the soil in the treated plots was significantly lower than that of the control plot ($p < 0.01$). The recorded conductivity values were 16.21 ± 0.22 $\mu\text{S}/\text{cm}$ for T₁, 17.33 ± 0.21 $\mu\text{S}/\text{cm}$ for T₂, and 17.99 ± 0.30 $\mu\text{S}/\text{cm}$ for T₃, compared to 19.42 ± 0.32 $\mu\text{S}/\text{cm}$ in the control. This reduction suggests that the application of organic manure influences soil conductivity, likely due to its lower concentration of readily soluble salts, as reported by Zhang et al. [23, 33]. The water retention capacity of the soil was significantly higher ($p < 0.01$) in the treated plots compared to the control. The recorded values were $18.53 \pm 0.31\%$ for T₁, $20.54 \pm 0.09\%$ for T₂, and $21.70 \pm 0.07\%$ for T₃, whereas the control plot exhibited a lower retention capacity of $15.82 \pm 0.11\%$. Soil water retention plays a crucial role in crop productivity and is influenced by soil texture and organic matter content. The application of compost enhances the soil's water-holding capacity, thereby reducing rapid mineral leaching, as reported by Haverkamp et al. [7, 14, 32]. The soil organic matter content was significantly higher in the treated plots compared to the control. The recorded values were $90.17 \pm 0.26\%$ for T₁, $91.92 \pm 0.45\%$ for T₂, and $94.23 \pm 0.39\%$ for T₃, whereas the control plot had a considerably lower organic matter content of $22.61 \pm 0.32\%$. This increase in organic matter in the treatment plots is likely due to the incorporation of compost, which enhanced carbon availability and contributed to improved plant morphology, as reported by Adugna [3, 5]. The nutrient composition of the soil was significantly higher in the treated plots compared to the control. The nitrogen content was recorded as 310.09 ± 0.04 kg/ha in T₁, 315.11 ± 0.30 kg/ha in T₂, and 324.88 ± 0.56 kg/ha in T₃. Similarly, phosphorus levels were 34.05 ± 1.22 kg/ha in T₁, 35.04 ± 0.33 kg/ha in T₂, and 38.02 ± 0.05 kg/ha in T₃. Potassium concentrations were 290.60 ± 3.92 kg/ha in T₁, 280.24 ± 0.54 kg/ha in T₂, and 300.66 ± 0.88 kg/ha in T₃. These values indicated a significant improvement in soil fertility in the treated plots compared to the control [12, 32].

Table 1 Physico-chemical parameters of soil from control and treatment plot

Groups				
Parameters	T ₁	T ₂	T ₃	Control
pH	9.01 ± 0.02^a	8.43 ± 0.03^b	8.50 ± 0.09^b	8.02 ± 0.03^c
Soil moisture(%)	25.27 ± 0.25^a	24.77 ± 0.23^a	25.99 ± 0.29^b	22.98 ± 0.51^c
Electrical conductivity($\mu\text{S}/\text{cm}$)	16.21 ± 0.22^a	17.33 ± 0.21^b	17.99 ± 0.30^b	19.42 ± 0.32^c
Water holding capacity(%)	18.53 ± 0.31^a	20.54 ± 0.09^b	21.70 ± 0.07^c	15.82 ± 0.11^d
Soil organic matter (%)	90.17 ± 0.26^a	91.92 ± 0.45^b	94.23 ± 0.39^c	22.61 ± 0.32^d
Total nitrogen(kg/ha)	310.09 ± 0.04^a	315.11 ± 0.3^b	324.88 ± 0.56^c	290.05 ± 0.25^d
Phosphorus(kg/ha)	34.05 ± 1.22^a	35.04 ± 0.33^a	38.02 ± 0.05^b	30.26 ± 0.15^c
Potassium(kg/ha)	290.60 ± 3.92^a	280.24 ± 0.54^b	300.66 ± 0.88^c	190.05 ± 3.02^d

Values expressed as Mean $\pm$ Standard Error

Mean $\pm$ Standard Error with different superscript in the same column are significantly different from their respective value

3.2 Changes in morphological parameters of chilli (*Capsicum annuum*)

Morphological parameters, including plant height, leaf length, leaf breadth, and the number of leaves, were systematically recorded on a weekly basis for chilli plants. The data were analysed using Sigma Stat 3.5, and the mean values were calculated for each parameter (Table 2). Subsequently, statistical tests were conducted to analyse the significance of the obtained mean values. The results, as illustrated in the accompanying table and graphs, clearly indicate significant changes in all morphological parameters across the four groups. Notably, plants subjected to treatment in plots two (T_2) and three (T_3) exhibited a substantial increase in every aspect of morphological development. This notable enhancement is attributed primarily to the application of nutrients derived from coontail and duckweed. This observation underscores the efficacy of the applied treatments, suggesting a positive influence on the overall growth and development of chilli plants. The data presented herein provide valuable insights into the impact of specific nutrient applications on morphological parameters and contribute to our understanding of optimal plant cultivation practices.

3.2.1 Plant height

The acquired data unveiled a positive correlation between the temporal progression and the elevation in the height of *Capsicum annuum* (chilli) plants. Height measurements of the treatment groups and the control group were systematically recorded on a weekly basis. On the 64th day, the observed heights were as follows: 33.20 ± 3.35 cm (PHT₁), 31.28 ± 3.43 cm (PHT₂), 28.80 ± 3.44 cm (PHT₃), and 23.90 ± 1.75 cm (PHC) for the treatment groups and control group, respectively (Fig. 18). Statistical analysis revealed a significant disparity, with the plant height of chilli plants in the treatment groups surpassing that of the control group ($P < 0.001$). These results are in agreement with the findings of Kumari et al. [18], who reported enhanced vegetative growth in okra when organic manure prepared from kitchen waste was applied. This supports the conclusion that organic inputs can significantly promote plant growth across different vegetable crops.

3.2.2 Leaf length

Chilli plants across all four groups, encompassing both treatment and control cohorts, exhibited a progressive increase in leaf length over the experimental duration. On the 64th day, the measured leaf lengths for *Capsicum annuum* plants were as follows: 13.54 ± 1.03 cm (LLT₁), 13.32 ± 0.67 cm (LLT₂), 11.10 ± 0.94 cm (LLT₃), and 11.14 ± 0.65 cm (LLC) for the treatment groups and control group, respectively (Fig. 19). Notably, statistical analysis indicated a significant divergence, with the treatment groups displaying markedly longer leaves compared to the control group ($P < 0.001$). These findings are consistent with those of Kumari et al. [16], who reported enhanced leaf growth in cabbage, cauliflower, and radish when compost derived from food waste was applied under sub-tropical conditions. Their study highlights the effectiveness of organic amendments in improving vegetative parameters, thereby supporting the observed results in the current chilli study.

Table 2 Changes in the morphological parameters in chilli

	Day 1	Day 8	Day 15	Day 22	Day 29	Day 36	Day 43	Day 50	Day 57	Day 64
PHT ₁	7.95 [±] 0.40	12.03 [±] 0.86	16.50 [±] 1.83	16.82 [±] 1.29	20.13 [±] 1.86	23.11 [±] 2.42	25.73 [±] 2.40	29.97 [±] 2.48	33.03 [±] 3.41	33.20 [±] 3.35
PHT ₂	8.30 ^{**} ±0.60	15.66 ^{**} ±1.08	15.52 ^{**} ±1.33	18.11 [±] 1.45	21.18 [±] 1.65	20.44 [±] 2.81	25.79 [±] 2.55	26.19 [±] 3.44	29.35 [±] 3.29	31.28 [±] 3.43
PHT ₃	6.48 [±] 0.30	8.68 [±] 0.51	12.27 [±] 0.94	14.40 [±] 0.93	17.33 [±] 1.20	19.28 [±] 1.21	21.61 [±] 1.85	18.98 [±] 2.27	37.30 [±] 4.33	28.80 [±] 3.44
PHC	4.91 [±] 0.38	8.83 [±] 0.80	11.55 [±] 1.23	13.60 [±] 1.44	16.30 [±] 1.83	18.22 [±] 1.99	19.06 [±] 2.28	19.98 [±] 2.39	23.16 [±] 1.77	23.90 [±] 1.75
LLT ₁	4.07 ^{**} ±0.24	5.93 ^{**} ±0.37	6.28 [±] 0.39	7.38 [±] 0.62	7.95 [±] 0.67	9.37 [±] 0.51	10.94 [±] 0.47	12.58 [±] 0.79	12.70 [±] 0.84	13.54 [±] 1.03
LLT ₂	4.04 [±] 0.40	4.92 [±] 0.39	5.76 [±] 0.49	6.86 [±] 0.62	8.82 ^{**} ±0.69	8.84 [±] 0.81	10.79 [±] 0.40	12.82 ^{**} ±0.51	12.88 [±] 0.98	13.32 [±] 0.67
LLT ₃	2.82 [±] 0.14	3.89 [±] 0.48	5.63 [±] 0.50	6.42 [±] 0.52	6.57 [±] 0.58	7.68 [±] 0.59	10.01 [±] 0.53	10.35 [±] 0.86	10.71 [±] 1.01	11.10 [±] 0.94
LLC	2.82 [±] 0.36	4.53 [±] 0.51	5.42 [±] 0.48	5.69 [±] 0.42	6.54 [±] 0.59	7.34 [±] 0.66	8.89 [±] 0.94	10.12 [±] 0.93	10.96 [±] 0.66	11.14 [±] 0.65
LBT ₁	2.02 [±] 0.14	3.07 ^{**} ±0.20	3.15 [±] 0.18	3.63 [±] 0.32	4.10 [±] 0.37	4.87 [±] 0.27	5.50 [±] 0.27	6.49 [±] 0.40	6.39 [±] 0.38	6.73 [±] 0.50
LBT ₂	2.05 ^{**} ±0.22	2.51 [±] 0.25	2.89 [±] 0.26	3.32 [±] 0.26	4.32 [±] 0.28	4.35 [±] 0.35	5.31 [±] 0.20	6.39 [±] 0.28	6.53 ^{**} ±0.31	6.58 [±] 0.31
LBT ₃	1.44 [±] 0.07	2.00 [±] 0.30	2.72 [±] 0.25	3.43 [±] 0.38	3.59 [±] 0.46	4.34 [±] 0.43	5.04 [±] 0.37	5.29 [±] 0.50	5.34 [±] 0.47	5.51 [±] 0.45
LBC	1.41 [±] 0.19	2.19 [±] 0.24	2.69 [±] 0.24	2.80 [±] 0.23	3.40 [±] 0.34	3.91 [±] 0.36	4.45 [±] 0.47	5.44 [±] 0.50	5.46 [±] 0.35	5.58 [±] 0.33
LNT ₁	6.67 ^{**} ±0.41	9.90 ^{**} ±1.05	12.80 ^{**} ±1.48	15.90 [±] 1.59	21.40 ^{**} ±1.17	27.30 ^{**} ±1.70	28.40 ^{**} ±1.61	29.95 [±] 4.93	40.60 [±] 2.68	46.00 ^{**} ±3.04
LNT ₂	5.90 [±] 0.38	8.00 [±] 0.97	10.50 [±] 0.92	13.70 [±] 1.35	20.40 [±] 1.61	23.50 [±] 1.82	23.50 [±] 1.11	39.30 [±] 2.51	42.70 [±] 2.78	44.50 [±] 2.75
LNT ₃	5.10 [±] 0.43	7.30 [±] 0.87	9.30 [±] 1.00	12.60 [±] 0.92	17.30 [±] 0.84	18.50 [±] 1.72	22.50 [±] 1.61	32.70 [±] 4.78	37.30 [±] 4.33	41.80 [±] 4.13
LNC	4.50 [±] 0.31	5.90 [±] 0.53	7.10 [±] 0.50	11.50 [±] 1.03	12.80 [±] 0.94	20.20 [±] 1.58	17.90 [±] 2.15	28.60 [±] 3.25	31.50 [±] 3.06	33.50 [±] 2.70

PHT: Plant height treatment; PHC: Plant height control; LLT: Leaf length treatment; LLC: Leaf length control; LBT: Leaf breadth treatment LBC: Leaf breadth control; LNT: No. of leaves treatment; LNC: No. of leaves control

*Values expressed as mean ± S.E

**Significantly different from their respective values

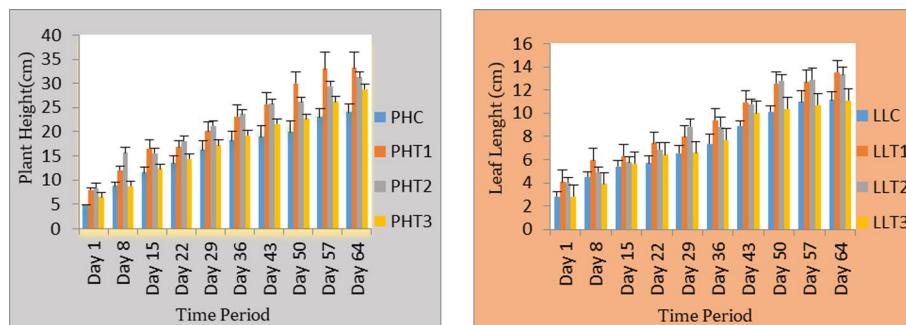


Fig. 18 and 19 Graphical representation of changes in plant height and leaf length of chilli

3.2.3 Leaf breadth

The data revealed a consistent increase in leaf breadth of chilli plants within the treatment group over the duration of the study. On the 64th day, the leaf breadth of *Capsicum annuum* plants in the treatment groups and the control group measured 6.73 ± 0.50 cm (LBT_1), 6.58 ± 0.31 cm (LBT_2), 5.51 ± 0.45 cm (LBT_3), and 5.58 ± 0.33 cm (LBC), respectively (Fig. 20). Analysis of this information indicated that, while the treatment group's leaves were broader than those of the control group, this difference did not reach statistical significance.

3.2.4 Number of leaves

Leaves count among four groups varied significantly as indicated by the collected data (Table 2). All experimental groups exhibited an increase in leaf count, and upon computing the mean leaf count for each group, it became evident that plants within the treatment groups displayed a greater leaf count compared to those in the control group. On the 64th day, the observed leaf numbers for *Capsicum annuum* plants were 46.00 ± 3.04 (LNT_1), 44.50 ± 2.75 (LNT_2), 41.80 ± 4.13 (LNT_3), and 33.50 ± 2.70 (LNC) for the treatment groups and control group, respectively (Fig. 21). The results revealed a statistically significant difference in leaf count between the treatment and control groups, with the treatment groups showing a notably higher number of leaves ($P < 0.001$). These findings are consistent with those reported by Kumari et al. [16, 18]. In their respective studies, organic compost derived from food and kitchen waste significantly enhanced vegetative growth parameters, including leaf production, in cabbage, cauliflower, radish, and okra. The improved nutrient availability and soil health associated with organic amendments

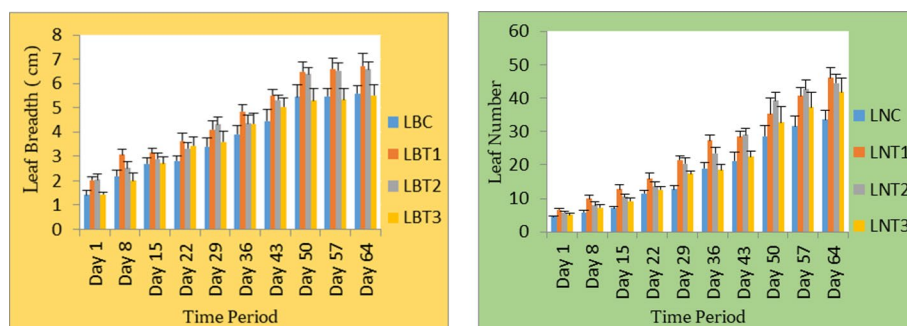


Fig. 20 and 21 Graphical representations of changes in leaf breadth and number of leaves of chilli

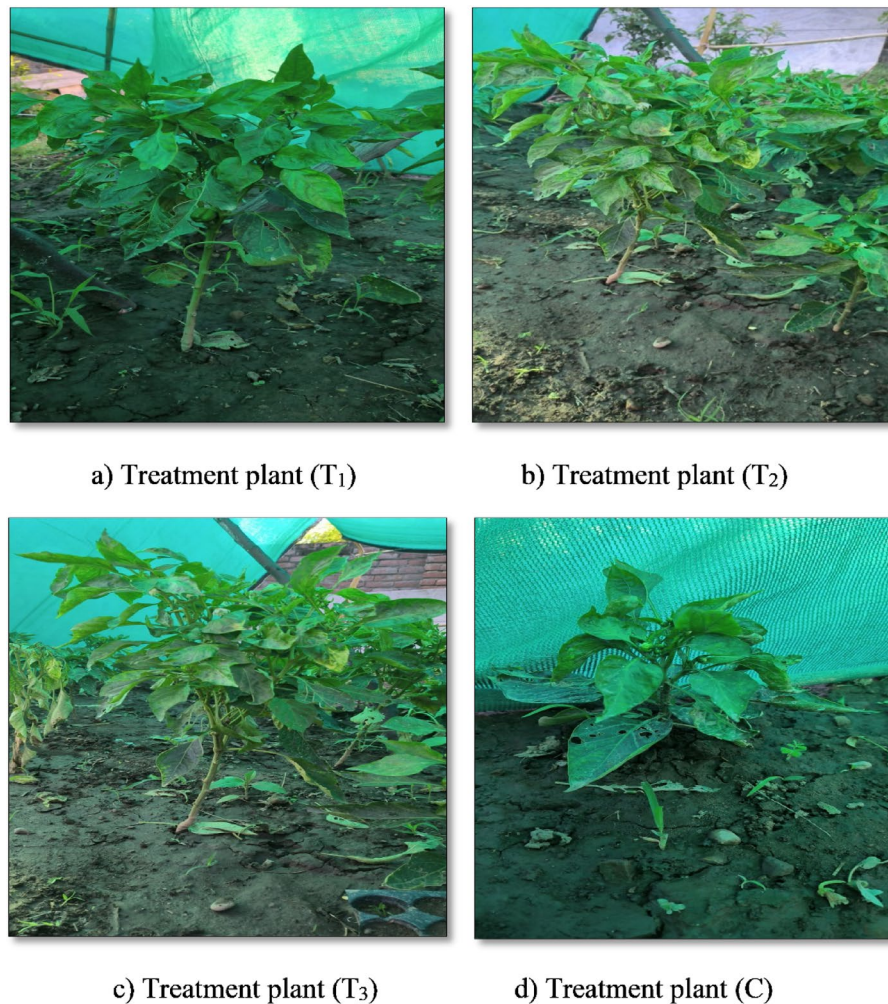


Fig. 22 a–d Morphological difference between the treatment (T₁, T₂, T₃) and Control (C) plants

likely contributed to the increased leaf number observed in the present chilli crop study, reinforcing the effectiveness of organic inputs across various vegetable crops.

3.2.5 Number of flower bud and fruit per plant

The number of flower buds and fruits per plant was determined through direct observation. Plants from each treatment group were regularly monitored, and the flower buds and fruits were manually counted at the appropriate growth stages. Treatment Group Three (T₃) exhibited a significantly higher number of flower buds, indicating enhanced reproductive potential. Similarly, T₃ showed an increased number of fruits per plant, which may be attributed to the overall plant vigor and the higher leaf count observed in this group. A positive correlation was also noted between nitrogen application and the number of fruits per plant, suggesting that increased nitrogen availability positively influenced fruit production. Additionally, fruits from Treatment Group One (T₃), which received vermicompost and duckweed and coontail were larger in size compared to fruits from other treatments. This finding highlights the potential role of these organic amendments in improving fruit size and quality (Figs. 23, 24).



Fig. 23 (a-d) Fruit size of treatment and control groups



a) Fruit of treatment plant (T_1)

b) Fruit of treatment plant (T_2)



c) Fruit of treatment plant (T_3)

d) Fruit of control plant (C)

Fig. 24 (a-d) Comparison between the fruits of treatment (T_1, T_2, T_3) and (C) control plant.

All measured growth parameters in the treatment groups showed a statistically significant improvement compared to the control group. This enhancement can be linked to the synergistic effect of using *Lemna minor* (Duckweed), *Ceratophyllum demersum* (Coontail), and vermicompost as organic amendments. The nutrient-rich profile of

Lemna minor, particularly its high nitrogen content, is known to stimulate vegetative growth and improve overall plant vigor [24]. Beyond nitrogen, it also contains essential micronutrients such as iron, zinc, and vitamin A, along with complete proteins, which collectively support healthy plant development [19]. Vermicompost contributes significantly to soil fertility by supplying readily available forms of nitrogen (1.5–2.2%), phosphorus (1.8–2.2%), and potassium (1.0–1.5%)—macronutrients vital for plant growth and yield [2].

Moreover, *Ceratophyllum demersum* has traditionally been explored for its use in aquaculture systems, but its role in agriculture remains underexplored. This study offers new insights by demonstrating its effectiveness as a sustainable biofertilizer in enhancing the growth and productivity of chilli plants. Its accessibility, eco-friendly nature, and carbohydrate content make it a valuable input in low-cost farming systems [15]. The combined application of these organic resources not only improved growth parameters such as plant height, leaf number, and fruit yield but also suggests potential for broader use in vegetable cultivation. The positive outcomes observed affirm the utility of integrating aquatic biomass and vermicompost to promote sustainable, organic agriculture.

4 Conclusion

The findings of the present study demonstrate that the combined application of vermicompost, Duckweed (*Lemna minor*), and Coontail (*Ceratophyllum demersum*) significantly enhances the growth, yield, and quality attributes of chilli (*Capsicum annuum*) plants. Among the different treatments, the group receiving vermicompost supplemented with both aquatic biofertilizers recorded the highest mean values for plant height, leaf length, leaf breadth, and number of leaves, along with notable improvements in fruit size and quality. In contrast, the control group, treated with vermicompost alone, exhibited the lowest performance across all evaluated parameters. These results highlight the potential of integrating biofertilizers as a sustainable and eco-friendly alternative to chemical fertilizers. The synergistic effect of vermicompost, Duckweed, and Coontail not only enhances nutrient availability and uptake but also promotes superior plant growth and fruit development.

Although the study demonstrates the positive impact of biofertilizer combinations on chilli growth and yield, certain limitations exist. The experiment was conducted at a single site in the northern plain region of Jammu, which may not fully represent the diverse agro-climatic conditions across other chilli-growing regions. The sample size per treatment group was limited to 10 plants, which may restrict the statistical strength of the conclusions. Additionally, the study duration was confined to a single growing season, which does not allow evaluation of the long-term sustainability or cumulative effects of repeated biofertilizer applications. Expanding the research to include multiple locations, larger sample sizes, and multi-season trials would help in validating the effectiveness and consistency of these biofertilizer treatments under varied field conditions.

Author contributions

1-Madhu Rani: Conducted the investigation and drafted the manuscript 2-Indu Kumari: Analyzed and interpreted the data; prepared graphs 3-Neha Salaria: Edited and finalized the manuscript.

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Competing interests

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