RESEARCH PAPER

Influence of Enriched Vermicompost on Growth, Yield, Quality and Nutrient Dynamics of *Abelmoschus esculentus* (L.) Moench

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ABSTRACT

Sustainable nutrient management plays a vital role in improving crop productivity while maintaining soil health. Enriched vermicompost, which integrates organic and inorganic nutrient sources, has emerged as an effective approach to enhance nutrient availability and use efficiency in vegetable crops. A controlled pot culture experiment was conducted to evaluate the impact of enriched vermicompost on the growth, yield, quality, and nutrient dynamics of bhendi (*Abelmoschus esculentus* (L.) Moench). The experiment was laid out in a Completely Randomized Design with eleven treatments and three replications. Vermicompost was enriched using organic inputs such as Azolla (nitrogen source), bone meal and rock phosphate (phosphorus sources), and banana pseudostem (potassium source), along with inorganic fertilizers including ammonium sulphate, single super phosphate, and muriate of potash. These were applied at graded levels equivalent to 1.25, 2.5, and 3.75 t ha^{-1}. The results revealed that enriched vermicompost treatments significantly enhanced plant growth, yield attributes, and nutrient uptake compared to control and vermicompost alone. Among the treatments, vermicompost enriched with banana pseudostem and muriate of potash at 3.75 t ha^{-1} recorded the highest plant height (108.3 cm), dry matter production (38.4 g plant^{-1}), fruit yield (295 g plant^{-1}), and number of fruits (21 plant^{-1}). This treatment also improved fruit quality and extended shelf life up to 8 days. Furthermore, nitrogen, phosphorus, and potassium content and uptake were markedly higher under enriched treatments. The findings demonstrate that integrated enrichment of vermicompost enhances nutrient use efficiency, improves soil fertility, and promotes sustainable production of bhendi.

Keywords: Enriched vermicompost, Abelmoschus esculentus, Integrated nutrient management, Azolla, Banana pseudostem.

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INTRODUCTION

Vegetable production systems are increasingly facing challenges such as declining soil fertility, nutrient imbalance, and environmental degradation due to the excessive and continuous use of chemical fertilizers (Xu et al., 2025). Among vegetable crops, *Abelmoschus esculentus* (L.) Moench (bhendi) is an important crop cultivated widely in tropical and subtropical regions for its high nutritional and economic value. It is a rich source of vitamins, minerals, and dietary fiber, making it an essential component of human diets (Gaur et al., 2025; Ali et al., 2022). However, sustaining its productivity under intensive cultivation requires efficient nutrient management strategies that not only improve yield but also maintain soil health. Continuous reliance on synthetic fertilizers has been reported to adversely affect soil structure, microbial activity, and long-term fertility, thereby necessitating alternative sustainable approaches (Edwards et al., 2011).

In recent years, organic amendments such as vermicompost have gained considerable attention as eco-friendly and sustainable nutrient sources. Vermicompost is a stabilized organic product obtained through the biological activity of earthworms and microorganisms, which convert organic wastes into nutrient-rich humus (Rehman et al., 2023; Abad and

Shafiqi, 2024). It is known to contain essential macro- and micronutrients, plant growth regulators, enzymes, and beneficial microbial populations that enhance plant growth and soil fertility (Atiyeh et al., 2002). Application of vermicompost has been shown to improve soil structure, increase water holding capacity, and enhance nutrient availability, thereby leading to better crop performance. In vegetable crops like bhendi, vermicompost application has resulted in significant improvements in plant height, biomass accumulation, and fruit yield (Arancon et al., 2004). Despite its numerous advantages, the relatively lower nutrient concentration of vermicompost compared to chemical fertilizers limits its ability to meet the high nutrient demands of intensive cropping systems (Toor et al., 2024; Basak, 2023). To address this limitation, recent research has focused on the development of enriched vermicompost by incorporating nutrient-rich organic and inorganic materials. Enrichment enhances the nutrient density of vermicompost and improves its agronomic efficiency (Sande et al., 2024; Kumar et al., 2025; Kumaresan et al., 2024a). Studies have shown that the addition of nutrient sources such as bone meal, crop residues, and mineral fertilizers to vermicompost significantly increases its nitrogen, phosphorus, and potassium content, thereby improving crop productivity (Singh et al., 2021).

Among organic enrichment materials, Azolla has attracted attention due to its high nitrogen content and its symbiotic association with nitrogen-fixing cyanobacteria. Incorporation of Azolla into soil or compost systems has been reported to improve nitrogen availability and reduce the need for synthetic nitrogen fertilizers (Wagner, 1997; Kumaresan et al., 2024b). Similarly, bone meal is a rich source of phosphorus and calcium, which are essential for root development and reproductive growth. It releases nutrients slowly, ensuring sustained availability throughout the crop growth period. Banana pseudostem, an abundant agricultural by-product in tropical regions, is a valuable source of potassium and organic carbon, and its utilization in compost enrichment contributes to both nutrient recycling and waste management (Suge et al., 2011).

In addition to organic sources, the integration of inorganic fertilizers such as ammonium sulphate, single super phosphate (SSP), and muriate of potash (MOP) into vermicompost enrichment strategies offers a balanced and efficient nutrient supply system (Sande et al., 2024; Kumar et al., 2026). These inorganic fertilizers provide readily available nutrients that complement the slow-release nature of organic amendments. Integrated nutrient management approaches combining organic and inorganic sources have been reported to improve nutrient use efficiency, enhance crop productivity, and sustain soil health over time (Mishra et al., 2019). Such integration ensures both immediate and prolonged nutrient availability, reduces nutrient losses, and promotes efficient nutrient cycling within the soil-plant system. Recent studies on vegetable crops have emphasized the benefits of combining vermicompost with biofertilizers and reduced levels of chemical fertilizers (Toor et al., 2024). These integrated approaches have resulted in improved growth parameters, higher yields, and enhanced quality attributes compared to the sole application of either organic or inorganic inputs (Ravimycin et al., 2020). Furthermore, vermicompost-based nutrient management systems have been shown to increase microbial biomass, enhance enzymatic activity, and improve soil physicochemical properties, thereby contributing to sustainable agricultural production (Domínguez et al., 2014). Although significant progress has been made in understanding vermicompost and its enrichment, there remains a need to develop customized nutrient-enriched vermicompost formulations tailored to specific crop requirements (Yatoo et al., 2022). In particular, the combined use of nitrogen-rich Azolla, phosphorus-rich bone meal and rock phosphate, and potassium-rich banana pseudostem along with inorganic fertilizers represents an innovative and holistic approach to nutrient management (Behera et al., 2024; Kumar et al., 2025; Sangeetha and Baskar, 2023). Such integrated enrichment strategies have not been extensively studied in bhendi cultivation. Therefore, the present study was undertaken to develop and evaluate novel enriched vermicompost formulations using a combination of organic (Azolla, bone meal, banana pseudostem) and inorganic (ammonium sulphate, SSP, MOP) nutrient sources. The objective was to assess their influence on growth, yield, quality, and nutrient uptake of bhendi, while also examining their potential to improve soil fertility and promote sustainable agricultural practices. This approach is expected to enhance nutrient use efficiency, reduce dependence on chemical fertilizers, and support environmentally sustainable vegetable production systems.

MATERIALS AND METHODS

Experimental Site and Climatic Conditions

The experiment was conducted at the School of Agriculture, Vels Institute of Science, Technology and Advanced Studies (VISTAS), Pallavaram, Chennai, Tamil Nadu, India (12.9675° N latitude and 80.1498° E longitude). The study was performed under controlled pot culture conditions to evaluate the influence of enriched vermicompost formulations on the growth, yield, and nutrient dynamics of *Abelmoschus esculentus* (L.) Moench. The experimental site falls under a tropical climatic zone characterized by warm temperatures, moderate humidity, and adequate sunlight, which are conducive for vegetable cultivation. The controlled conditions ensured minimal environmental variability and improved precision in treatment evaluation.

Preparation and Enrichment of Vermicompost

Vermicompost was prepared using locally available biodegradable organic residues following standard vermicomposting procedures. Raw materials such as crop residues, farmyard manure, and other organic wastes were initially subjected to partial decomposition to reduce heat generation and create a favorable environment for earthworm activity. The pre-decomposed materials were then processed using both bed and pit methods under shaded conditions to maintain optimal temperature and moisture. The earthworm species Eudrilus eugeniae was utilized due to its high efficiency in organic matter degradation and rapid multiplication rate. Moisture content of the substrate was maintained at 60–70% through regular watering, and adequate aeration was ensured by periodic turning. The composting process was completed within 45–60 days, resulting in a stabilized, dark-colored, finely granulated vermicompost rich in plant nutrients.

The prepared vermicompost was subsequently enriched with selected organic and inorganic nutrient sources to improve its agronomic efficiency. Organic enrichment materials included Azolla as a biological nitrogen source, bone meal as a slow-release phosphorus source, banana straw as a potassium-rich organic residue, and rock phosphate. In addition, inorganic fertilizers such as ammonium sulphate (NH_4SO_4), single super phosphate (SSP), and muriate of potash (MOP) were incorporated to provide readily available nutrients. The enrichment process involved thorough mixing of vermicompost with the respective additives in predetermined proportions, followed by incubation under moist and aerated conditions for 10–15 days. This incubation period facilitated nutrient stabilization, enhanced microbial activity, and improved mineralization, resulting in nutrient-enriched vermicompost formulations suitable for efficient crop production.

Experimental Design and Treatments

A pot culture experiment was laid out in a Completely Randomized Design (CRD) with three replications. Red soil, representative of the local agricultural soil, was used as the growth medium. The experiment comprised eleven treatments involving vermicompost and enriched vermicompost applied at graded levels.

The treatments included control (no amendment), vermicompost alone, and vermicompost enriched with different nutrient sources such as Azolla combined with ammonium sulphate, bone meal combined with rock phosphate, and banana straw combined with muriate of potash, each applied at three levels (1.25, 2.5, and 3.75 t ha^{-1} equivalent). The treatments were randomly assigned to pots to minimize experimental bias and ensure statistical validity.

Pot Preparation, Crop Management, and Analytical Methods

Uniform grow bag were filled with well-sieved red soil, and the required quantities of vermicompost or enriched vermicompost were incorporated as per treatment specifications. The amendments were thoroughly mixed with the soil before sowing. Healthy seeds of *Abelmoschus esculentus* were sown directly in the pots, and after germination, thinning was performed to retain one vigorous plant per pot to ensure uniform plant population.

Observations were recorded at three important growth stages, namely vegetative, flowering, and harvest stages. Data collection included growth parameters, yield attributes, and quality characteristics. Plant height was measured from the base to the apex and expressed in centimeters. Dry matter production was determined by oven-drying plant samples at a constant temperature until a stable weight was obtained. Yield attributes such as number of fruits per plant, fruit length, and individual fruit weight were recorded during harvest. Total yield per plant was calculated and expressed in grams. Shelf life of harvested fruits was assessed under ambient conditions by recording the number of days until visible deterioration occurred.

Plant samples collected at different growth stages were analyzed for nutrient content. Total nitrogen was estimated using the Kjeldahl digestion method, phosphorus content by the vanadomolybdate yellow color method, and potassium content using a flame photometer. Nutrient uptake was computed by multiplying nutrient concentration with dry matter yield and expressed as kg ha^{-1}.

The vermicompost and enriched formulations were analyzed for their physicochemical properties. Soil reaction (pH) and electrical conductivity (EC) were measured using standard digital instruments. Organic carbon content was determined by the Walkley and Black method. Bulk density and particle density were measured following standard procedures, while total nitrogen, phosphorus, and potassium contents were estimated using established analytical techniques to evaluate the nutrient status of the compost.

RESULTS AND DISCUSSION

Physico-Chemical Properties of Vermicompost

The physicochemical properties of enriched vermicompost indicated its suitability as a soil amendment for sustainable crop production. The pH of the compost ranged from 6.8 to 7.4, which is considered optimal for most crops. Electrical conductivity (EC) values were within acceptable limits, indicating the absence of salinity hazards.

The organic carbon content ranged from 12 to 18%, reflecting the high organic matter content of the compost. Adequate levels of total nitrogen, phosphorus, and potassium were observed, indicating the effectiveness of the enrichment process. The improved nutrient composition of vermicompost can be attributed to the addition of organic and inorganic nutrient sources during enrichment (Kumar et al., 2025; Sande et al., 2024; Behera et al., 2023)

The balanced nutrient composition, along with favorable physical properties, enhances soil fertility and supports sustainable crop production. Vermicompost also improves soil structure, increases water holding capacity, and promotes microbial activity, thereby contributing to long-term soil health (Rehman et al., 2023; Sande et al., 2024; Mohite et al., 2024).

Growth Parameters

Application of enriched vermicompost significantly influenced the growth performance of *Abelmoschus esculentus* across all developmental stages. Plant height increased progressively with the level and type of enrichment, indicating the positive role of integrated nutrient supply. Among the treatments, T_{11} (vermicompost enriched with banana straw + MOP @ 3.75 t ha^{-1}) recorded the maximum plant height at harvest (108.3 cm), followed by T_8 (104.2 cm). The enhancement in plant height can be attributed to the synergistic effect of organic and inorganic nutrient sources, particularly potassium, which plays a crucial role in cell elongation, enzyme activation, and photosynthetic efficiency (Wang et al., 2023; Zörb et al., 2024; Sande et al., 2024). The presence of readily available nutrients from inorganic sources, combined with the slow-release nature of organic amendments, ensured a continuous nutrient supply throughout the crop growth period (Sande et al., 2024; Kumar et al., 2025; Rehman et al., 2023). This balanced nutrient availability likely promoted vigorous vegetative growth and improved physiological processes. Similar findings have been reported by Singh et al. (2021), who observed enhanced plant height in vegetable crops with integrated nutrient management practices involving vermicompost and mineral fertilizers.

Dry matter production also followed a similar trend, with T_{11} recording the highest biomass accumulation (38.4 g plant^{-1}). Increased dry matter production reflects improved photosynthetic efficiency and assimilate accumulation, which can be linked to enhanced nutrient uptake and improved soil microbial activity (Zhang et al., 2023; Sande et al., 2024; Mohite et al., 2024). Vermicompost is known to stimulate microbial populations and enzymatic activity, thereby improving nutrient mineralization and availability (Domínguez et al., 2014; Kumaresan et al., 2023). The integration of Azolla, bone meal, and banana straw further contributed to improved nutrient dynamics, resulting in higher biomass production.

Yield Attributes

Yield attributes such as number of fruits per plant, fruit length, and fruit weight were significantly influenced by enriched vermicompost treatments. The number of fruits per plant increased with higher levels of enrichment, with T_{11} recording the maximum (21 fruits per plant), compared to only 8 fruits in the control. This substantial increase can be attributed to improved nutrient availability and enhanced reproductive efficiency (Kumar et al., 2025; Sande et al., 2024; Behera et al., 2023).

Fruit length (14.5 cm) and fruit weight (19.8 g) were also highest in T_{11}, indicating better fruit development under enriched nutrient conditions. The improved fruit characteristics may be due to enhanced assimilate partitioning and efficient translocation of photosynthates from source to sink. Potassium plays a vital role in carbohydrate metabolism and translocation, which directly influences fruit size and weight (Wang et al., 2023; Zörb et al., 2024; Hafsi et al., 2023). The combined use of organic and inorganic nutrient sources ensured both immediate and sustained nutrient availability, thereby supporting continuous flowering and fruiting. Similar results have been reported by Ravimycin et al. (2020), who observed improved yield attributes in okra with integrated nutrient management practices. The presence of micronutrients and growth-promoting substances in vermicompost may also have contributed to improved fruit development (Rehman et al., 2023; Mohite et al., 2024; Sande et al., 2024).

Yield Performance

Fruit yield per plant was significantly affected by the application of enriched vermicompost. The highest yield (295 g plant^{-1}) was recorded in T_{11}, followed by T_8 (262 g plant^{-1}), while the control recorded only 82 g plant^{-1}. The substantial increase in yield under enriched treatments highlights the effectiveness of integrated nutrient management strategies in enhancing crop productivity (Kumar et al., 2025; Behera et al., 2023).

The yield improvement can be attributed to multiple factors, including balanced nutrient supply, improved soil physical properties, and enhanced microbial activity. Vermicompost improves soil structure, aeration, and water holding capacity, which create a favorable environment for root growth and nutrient uptake (Rehman et al., 2023; Sande et al., 2024). The addition of inorganic fertilizers ensures the immediate availability of essential nutrients, thereby supporting rapid crop growth.

Furthermore, the enrichment of vermicompost with specific nutrient sources such as Azolla (nitrogen), bone meal and rock phosphate (phosphorus), and banana straw with MOP (potassium) provided a targeted nutrient supply tailored to crop requirements. This approach enhances nutrient use efficiency and reduces nutrient losses (Behera et al., 2024; Kumar et al., 2025; Sande et al., 2024). Similar findings were reported by Mishra et al. (2019), who demonstrated that integrated nutrient management practices significantly increased crop yield and nutrient use efficiency compared to sole application of chemical fertilizers.

Shelf Life

Shelf life of bhendi fruits was significantly improved with enriched vermicompost treatments. The maximum shelf life (8 days) was recorded in T_{11}, while the control exhibited only 3 days of shelf life. The improvement in shelf life can be attributed to better nutrient balance, particularly potassium, which enhances cell wall strength, regulates water balance, and reduces physiological deterioration (Lester et al., 2010; Wang et al., 2013).

Potassium is known to regulate water balance, enzyme activation, and structural integrity of plant tissues, thereby improving post-harvest quality and storage life. The presence of organic matter and micronutrients in vermicompost may also contribute to improved fruit quality and reduced post-harvest losses. These findings are in agreement with previous studies that reported enhanced shelf life and quality of vegetables under integrated nutrient management systems (Arancon et al., 2004).

Nutrient Content and Uptake

Nutrient content (%) and uptake (kg ha^{-1}) were significantly influenced by enriched vermicompost treatments. The highest nitrogen (2.40%), phosphorus (0.50%), and potassium (2.60%) contents were recorded in T_{11}. Similarly, nutrient uptake was maximum in T_{11}, with nitrogen uptake of 60 kg ha^{-1}, phosphorus uptake of 22 kg ha^{-1}, and potassium uptake of 65 kg ha^{-1}.

The increased nutrient content and uptake can be attributed to improved nutrient availability and enhanced root absorption capacity. Vermicompost is known to improve soil microbial activity, which plays a crucial role in nutrient mineralization and availability (Rehman et al., 2023; Mohite et al., 2024). The integration of organic and inorganic nutrient sources ensures a continuous supply of nutrients, thereby enhancing nutrient uptake efficiency. The presence of Azolla contributed to increased nitrogen availability through biological nitrogen fixation, while bone meal and rock phosphate improved phosphorus availability. Banana straw and MOP provided a rich source of potassium, which is essential for various physiological processes (Behera et al., 2024; Sangeetha and Kumar et al., 2025).

CONCLUSION

The study demonstrates that enriched vermicompost is an effective and eco-friendly nutrient management strategy for improving growth, yield, quality, and nutrient uptake of Abelmoschus esculentus. Integration of organic inputs with inorganic fertilizers enhanced nutrient availability and use efficiency compared to sole applications. The treatment involving vermicompost enriched with banana pseudostem and MOP at 3.75 t ha^{-1} proved superior in terms of crop performance and fruit quality. Improved nutrient uptake and soil biological activity indicate better nutrient cycling and soil health. Hence, enriched vermicompost can be recommended as a sustainable alternative for enhancing productivity and maintaining long-term soil fertility.

Table 1. Physico-chemical characterization of enriched vermicompost.

Parameter	Value
pH	6.8 - 7.4
EC (dS m^{-1})	1.2 - 1.8
Organic Carbon (%)	12 – 18
Bulk Density (g cm^{-3})	0.8 - 1.1
Particle Density (g cm^{-3})	2.2 - 2.5

Total N (%)	1.5 - 2.5
Total P (%)	0.4 - 0.8
Total K (%)	1.2 - 2.8

Table 2. Effect of enriched vermicompost on nutrient content (%) and uptake (kg ha-1) of bhendi (*Abelmoschus esculentus* L.)

Treatment	N (%)	P (%)	K (%)	N (kg ha-1)	P (kg ha-1)	K (kg ha-1)
T_1 Control	1.2	0.25	1.1	25	8	22
T_2 VC alone	1.6	0.32	1.4	38	12	34
T_3 Azolla+N (1.25 t)	1.8	0.35	1.5	42	14	38
T_4 Azolla+N (2.5 t)	2	0.38	1.7	48	16	45
T_5 Azolla+N (3.75 t)	2.2	0.4	1.8	54	18	49
T_6 Bone+RP (1.25 t)	1.9	0.42	1.6	45	17	42
T_7 Bone+RP (2.5 t)	2.1	0.45	1.8	50	19	47
T_8 Bone+RP (3.75 t)	2.3	0.48	2	56	21	52
T_9 Banana+MOP (1.25 t)	1.8	0.34	2.1	43	13	55
T_{10} Banana+MOP (2.5 t)	2	0.36	2.3	48	15	60
T_{11} Banana+MOP (3.75 t)	2.4	0.5	2.6	60	22	65
Mean	1.9	0.4	1.8	46.3	15.9	46.3
SEm (±)	0.05	0.02	0.06	1.65	0.72	1.85
CD (0.05)	0.14	0.06	0.18	4.8	2.1	5.4

Fig 1. Influence of enriched vermicompost on plant height (cm) of bhendi (*Abelmoschus esculentus* L.) at different growth stages

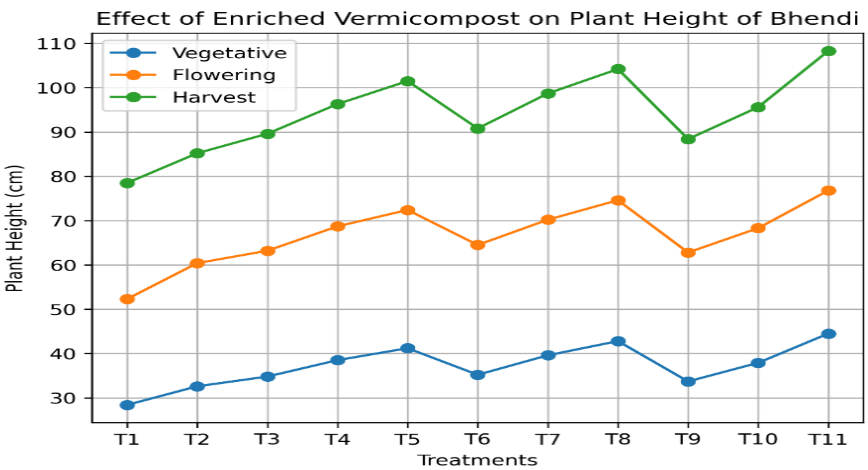


Fig 2. Effect of enriched vermicompost on dry matter production (g plant^{-1}) of bhendi (*Abelmoschus esculentus* L.)

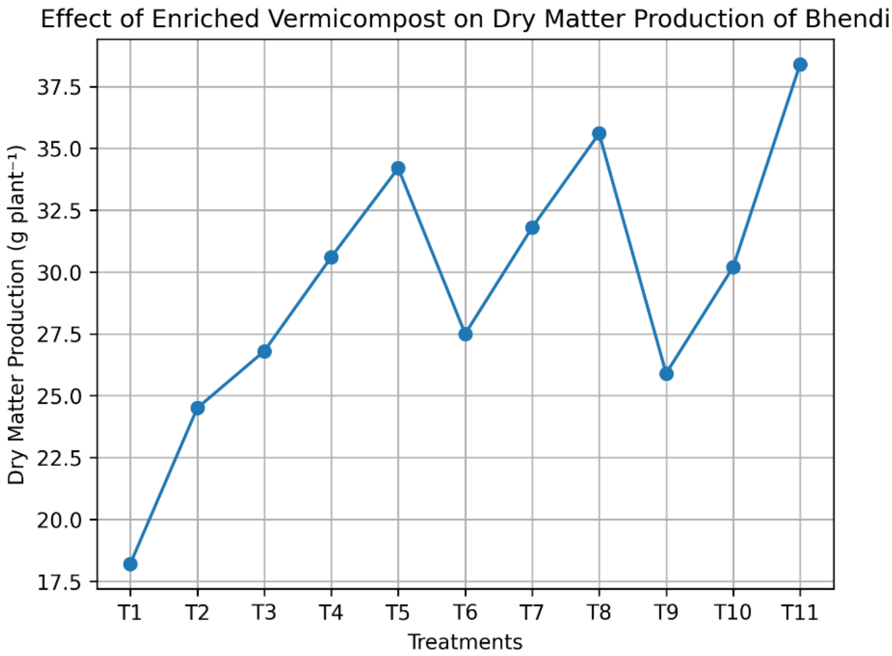


Fig 3. Effect of enriched vermicompost on number of fruits per plant and fruit length (cm) of bhendi (*Abelmoschus esculentus* L.)

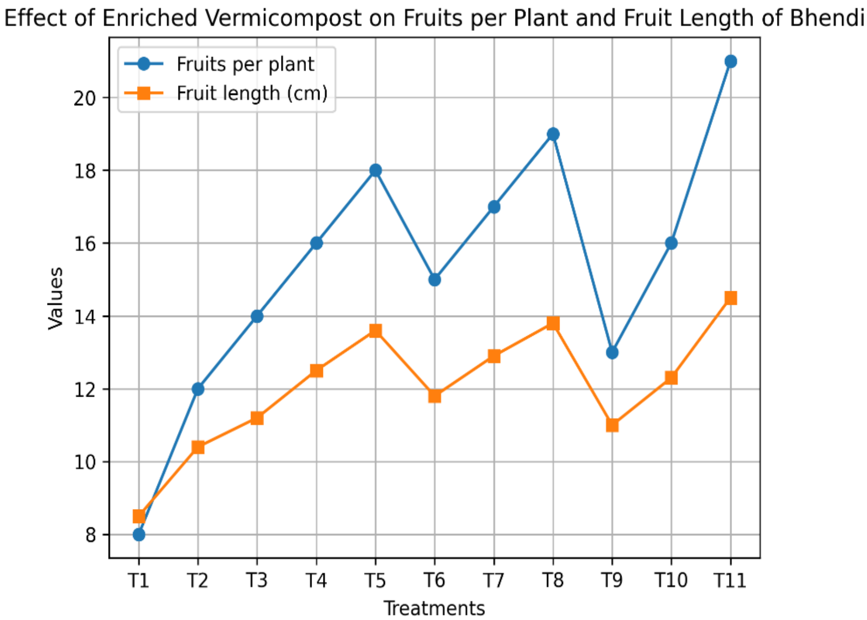
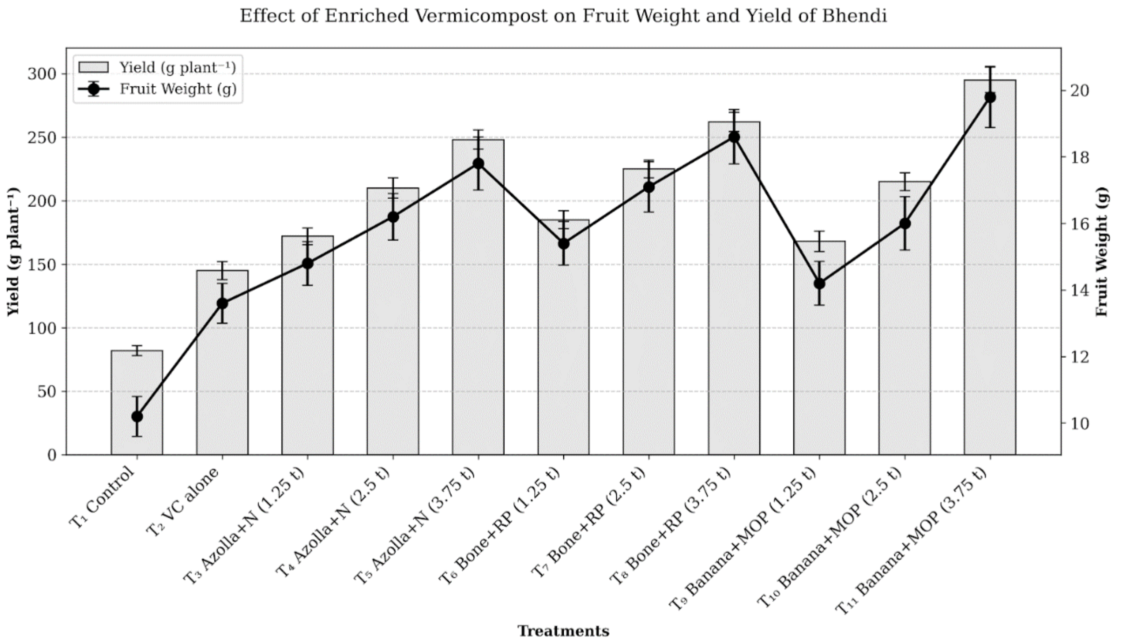


Fig 4. Effect of enriched vermicompost on fruit weight (g) and tield (g plant-1) of bhendi (*Abelmoschus esculentus* L.)



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