



Plant Archives

Journal homepage: <http://www.plantarchives.org>DOI Url : <https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.2.028>

ENHANCING KHASI MANDARIN PRODUCTIVITY AND FRUIT QUALITY THROUGH VERMICOMPOST AND BIOINOCULANT BASED ORGANIC NUTRIENT MANAGEMENT UNDER RAINFED CONDITIONS OF NORTH EAST INDIA

Nilim Kalita*, Bijit Kumar Saud, Monuj Gogoi, Jahnabi Hazarika, Priyanka Borbaruah and Raaj Kumar Kakoti

¹ AAU-Citrus and Plantation Crops Research Station, Assam Agricultural University, Tinsukia, Pin-786125, Assam, India

*Corresponding author E-mail: nilim.kalita@aau.ac.in

(Date of Receiving-14-05-2026; Date of Revision-19-07-2026; Date of Acceptance-03-08-2026)

ABSTRACT

A field experiment was conducted in a Khasi mandarin orchard under rainfed conditions to evaluate the effect of integrated organic nutrient management practices on fruit yield and quality. The experiment was laid out in a Randomized Block Design with five treatments and four replications. The treatments comprised different combinations of vermicompost, *Trichoderma harzianum*, *Pseudomonas fluorescens*, *Azotobacter chroococcum* and Azadirachtin. The application of 75% vermicompost on nitrogen equivalent basis of the recommended dose of fertilizer (RDF) along with *Trichoderma harzianum*, Azadirachtin and *Pseudomonas fluorescens* recorded the highest number of fruits per tree (483.0), average fruit weight (120.25 g), fruit yield per tree (58.13 kg) and yield per hectare (23.25 t ha⁻¹), which were significantly superior to the control. The same treatment also produced fruits with the highest juice content (48.7%), total soluble solids (9.7 °Brix) and ascorbic acid content (46.1 mg 100 ml⁻¹ juice). Fruit acidity was not significantly affected by the treatments, although comparatively lower acidity (0.38%) was recorded under the integrated organic treatment. The results demonstrated that integrated application of vermicompost, beneficial microorganisms and botanical pesticides substantially improved both productivity and fruit quality of Khasi mandarin. The study indicates that the combined use of 75% vermicompost with *Trichoderma harzianum*, Azadirachtin and *Pseudomonas fluorescens* can serve as an effective organic management strategy for sustainable Khasi mandarin production.

Key words: Khasi mandarin, organic nutrient management, vermicompost, *Trichoderma harzianum*, *Pseudomonas fluorescens*, fruit yield, fruit quality.

Introduction

Khasi mandarin is one of the most important citrus fruits cultivated in the North Eastern region of India owing to its superior fruit quality, pleasant flavor, high juice content and significant economic value (Deka, 2018). The northeastern region of India is considered as one of the natural home or primary gene center (Ghosh, 2007) and reservoir of various citrus species including mandarin orange (Hazarika 2012). Assam and Meghalaya occupy the maximum area under the production of Khasi mandarin (Singh, 2016). It covers nearly 38.2% of the total citrus area and contributes about 43.6% of the total

citrus fruits produced in India. Citrus cultivation plays a vital role in improving the livelihood and nutritional security of farmers in the region. However, the productivity and fruit quality of mandarin orchards have shown a declining trend in recent years due to continuous dependence on chemical fertilizers, deterioration of soil health, nutrient imbalance and increased incidence of pests and diseases. Excessive use of synthetic agrochemicals has also raised concerns regarding environmental pollution, residue accumulation, and sustainability of production systems.

Organic fruit production has emerged as an environmentally sound and economically viable approach

for sustainable horticulture. The growing consumer preference for safe, nutritious and residue-free fruits has increased the demand for organically produced citrus fruits in both domestic and export markets. Among the organic inputs, vermicompost has gained considerable importance because of its balanced nutrient composition, presence of growth-promoting substances and ability to improve soil structure and water holding capacity. Bio-agents like *Trichoderma harzianum* and *Pseudomonas fluorescens* are known for their antagonistic activity against soil-borne pathogens and their role in inducing systemic resistance in plants. Likewise, *Azotobacter chroococcum* enhances nitrogen availability through biological nitrogen fixation, while azadirachtin-based formulations provide eco-friendly management of insect pests without leaving harmful residues.

Integrated use of organic nutrient sources and beneficial microbial inoculants has demonstrated considerable potential in enhancing vegetative growth, fruit yield, quality attributes, and soil health in several fruit crops. However, information on the combined effects of integrated organic nutrient management practices on the productivity and fruit quality of Khasi mandarin under the rainfed conditions of North East India remains limited. Therefore, the present investigation was undertaken to evaluate the influence of different organic nutrient management practices involving vermicompost, biofertilizers, biocontrol agents and botanical pesticides on the yield and quality of Khasi mandarin. The study was designed to assess the long-term effects of these integrated organic inputs on orchard productivity and fruit quality under rainfed conditions. The findings are expected to contribute to the development of sustainable, environmentally friendly, and economically viable nutrient management strategies for Khasi mandarin cultivation under the prevailing agro-climatic conditions of the region.

Materials and Method

The present investigation was initiated in October 2012 in a Khasi mandarin orchard planted at a spacing of 5 m × 5 m under rainfed conditions at the experimental farm of AAU–Citrus and Plantation Crops Research Station, Tinsukia, Assam. The experiment comprised five treatments laid out in a Randomized Block Design (RBD) with four replications. Each treatment consisted of four plants, and observations were recorded from all tagged experimental trees. The recommended dose of fertilizers (RDF) for Khasi mandarin was 600:300:600 g N:P: K was applied along with 25 kg farmyard manure (FYM) plant per year.

The treatment details were as follows:

- T₁: Control
- T₂: 100% vermicompost on nitrogen equivalent basis of RDF
- T₃: 75% vermicompost on nitrogen equivalent basis of RDF + *Trichoderma harzianum* (30–40 ml plant⁻¹) + azadirachtin 1% (3–4 ml litre⁻¹ as foliar spray)
- T₄: 75% vermicompost on nitrogen equivalent basis of RDF + *Trichoderma harzianum* (30–40 ml plant⁻¹) + azadirachtin 1% (3–4 ml litre⁻¹ as foliar spray) + *Pseudomonas fluorescens* (30–40 ml plant⁻¹)
- T₅: 50% vermicompost on nitrogen equivalent basis of RDF + *Trichoderma harzianum* (30–40 ml plant⁻¹) + azadirachtin 1% (3–4 ml litre⁻¹ as foliar spray) + *Pseudomonas fluorescens* (30–40 ml plant⁻¹) + *Azotobacter chroococcum* (30–40 ml plant⁻¹)

Vermicompost was applied on nitrogen equivalent basis of the recommended fertilizer dose. Bio-agents and biofertilizers were applied in the root zone around the tree basin, whereas *Azadirachtin* was sprayed uniformly on the canopy at the recommended concentration.

Observations on fruit yield and quality attributes were recorded at harvest over five consecutive years (2019–2023) following standard experimental protocols and recommended analytical procedures. The yield attributes included number of fruits per tree, average fruit weight (g), yield per tree (kg), and estimated yield per hectare (t ha⁻¹). Fruit quality parameters such as total soluble solids (TSS), titratable acidity, TSS:Acid ratio, juice content, vitamin C, and shelf life were analyzed using standard laboratory procedures wherever applicable.

The five years' experimental data were subjected to pooled analysis and analysis of variance (ANOVA) appropriate for Randomized Block Design as described by standard statistical procedures. The significance of treatment differences was tested at the 5% probability level.

Results and Discussion

Fruit yield and yield attributing characters

Organic nutrient management practices significantly influenced yield and yield-attributing characters of Khasi mandarin. The integrated application of vermicompost, bio-agents and biofertilizers markedly improved number of fruits per tree, average fruit weight and overall fruit yield compared to the control (Table 1). Among the treatments, application of 75% vermicompost on nitrogen

Table 1: Effect of organic nutrient management practices on yield and yield attributes of khasi mandarin (pooled data for 2019–2023).

Treatments	No. of fruits per tree	Average fruit weight (g)	Yield (kg tree ⁻¹)	Yield (t ha ⁻¹)
Control	311.8	98.67	30.77	12.31
100% Vermicompost (on N equivalent basis of RDF)	366.2	110.5	40.46	16.18
75% Vermicompost (on N equivalent basis of RDF) + <i>Trichoderma harzianum</i> (30-40 ml/plant) + Azadirachtin (1% at 3-4 ml/litre as spray)	347.4	114.55	39.83	15.93
75% Vermicompost (on N equivalent basis of RDF) + <i>Trichoderma harzianum</i> (30-40 ml/plant) + Azadirachtin (1% at 3-4 ml/litre as spray) + <i>Pseudomonas fluorescens</i> (30-40 ml/plant)	483.0	120.25	58.13	23.25
50 % Vermicompost (on N equivalent basis of RDF) + <i>Trichoderma harzianum</i> (30-40 ml/plant) + Azadirachtin (1% at 3-4 ml/litre as spray) + <i>Pseudomonas fluorescens</i> + <i>Azotobacter chroococcum</i> (30-40 ml/plant)	319.6	101.67	32.52	13.01
CD	14.75	2.41	1.81	0.72
SE(m)	4.878	0.798	0.600	0.240
C.V.	2.983	1.634	3.325	3.320

equivalent basis of RDF along with *Trichoderma harzianum*, azadirachtin and *Pseudomonas fluorescens* recorded the highest number of fruits per tree (483.0), which was significantly superior to all other treatments. The control recorded the lowest number of fruits per tree (311.8). Similarly, the highest average fruit weight (120.25 g) was also recorded under the treatment comprising 75% vermicompost along with *Trichoderma harzianum*, azadirachtin and *Pseudomonas fluorescens*, which was significantly higher than all other treatments. The highest fruit yield per tree (58.13 kg/tree) and yield per hectare (23.25 t/ha) were obtained under the combined application of 75% vermicompost, *Trichoderma harzianum*, azadirachtin and *Pseudomonas fluorescens*. This treatment produced nearly double the yield compared to the control (30.77 kg/tree and 12.31 t/ha).

The substantial increase in fruit number, fruit weight and yield under integrated organic management might be attributed to improved nutrient availability, enhanced microbial activity, enhanced root growth and efficient translocation of assimilates towards developing fruits resulting in higher fruit retention and reduced fruit drop. Further, the integrated approach possibly ensured continuous nutrient availability and improved physiological efficiency, ultimately resulting in higher productivity (Paramanik 2024; Sharma *et al.*, 2025; Singh *et al.*, 2025).

Application of 100% vermicompost alone also significantly improved yield attributes over the control, indicating the beneficial role of organic manure in Khasi mandarin production. However, integrated organic management practices were more effective than sole vermicompost application in improving fruit crop productivity, likely due to their synergistic effects on

nutrient cycling, soil microbial activity, and plant growth (Ali *et al.*, 2024; Sande *et al.*, 2024). On the other hand, reduction of vermicompost to 50% RDF equivalent even with addition of *Azotobacter chroococcum* resulted in comparatively lower yield performance, indicating that inadequate nutrient supply may limit the beneficial effects of microbial inoculants. (Shahwar *et al.*, 2023).

Fruit Quality

The organic nutrient management practices exerted significant influence on fruit quality parameters of Khasi mandarin, particularly juice content and total soluble solids (TSS) and ascorbic acid content whereas acidity and shelf life were not significantly affected by the treatments (Table 2). Among the different treatments, application of 75% vermicompost on nitrogen equivalent basis of recommended dose of fertilizer (RDF) along with *Trichoderma harzianum*, azadirachtin and *Pseudomonas fluorescens* recorded the highest juice content (48.7%), which was significantly superior to the control (42.7%) and other treatments. The improvement in juice percentage under integrated organic practices may be attributed to enhanced nutrient availability, improved soil biological activity and better physiological functioning of plants due to combined application of organic manure and beneficial microorganisms (Srivastava *et al.*, 2021). Similar findings have been reported in citrus where integrated organic nutrient management improved fruit quality through enhanced uptake of nutrients and better translocation of photosynthates (Srivastava, 2012, Abobatta *et al.*, 2020).

The same treatment also recorded the highest TSS (9.7 °Brix), which was significantly higher than the control (7.5 °Brix). Increased TSS under organic treatments

Table 2: Effect of organic nutrient management practices on Fruit quality of khasi mandarin (pooled data for 2019–2023).

Treatments	Juice (%)	Acidity (%)	TSS (°Brix)	AA	SL
Control	42.7	0.42	7.5	42.2	14.2
100% Vermicompost (on N equivalent basis of RDF)	43.9	0.41	8.5	44.7	15.2
75% Vermicompost (on N equivalent basis of RDF) + <i>Trichoderma harzianum</i> (30-40 ml/plant) + Azadirachtin (1% at 3-4 ml/litre as spray)	45.6	0.39	8.7	45.2	16.2
75% Vermicompost (on N equivalent basis of RDF) + <i>Trichoderma harzianum</i> (30-40 ml/plant) + Azadirachtin (1% at 3-4 ml/litre as spray) + <i>Pseudomonas fluorescens</i> (30-40 ml/plant)	48.7	0.38	9.7	46.1	16.2
50 % Vermicompost (on N equivalent basis of RDF) + <i>Trichoderma harzianum</i> (30-40 ml/plant) + Azadirachtin (1% at 3-4 ml/litre as spray) + <i>Pseudomonas fluorescens</i> + <i>Azotobacter chroococcum</i> (30-40 ml/plant)	42.6	0.41	7.6	44.8	15.6
CD	2.09	NS	0.69	2.1	NS
SE(m)	0.691	0.005	0.227	0.156	0.205
C.V.	3.423	3.008	6.031	0.784	2.960
AA: Ascorbic acid (mg/100ml); SL: Shelf life (Days)					

might be due to enhanced carbohydrate synthesis and accumulation of sugars in fruits as a consequence of improved microbial activity and nutrient mineralization (Negi *et al.*, 2021). The synergistic effect of vermicompost with bio-agents and biofertilizers possibly improved metabolic activities leading to better conversion of starches and insoluble carbohydrates into soluble sugars, which directly increases TSS in the fruit (Singh *et al.*, 2020, Sharma *et al.* 2026). Pawar *et al.*, (2020) also observed significant increases in TSS, juice content, and total sugars in sweet orange with vermicompost and microbial inoculants.

Acidity of fruits varied from 0.38 to 0.42%, however, the differences among treatments were statistically non-significant. Nevertheless, comparatively lower acidity was observed in fruits receiving 75% vermicompost along with *Trichoderma harzianum*, azadirachtin and *Pseudomonas fluorescens* (0.38%), indicating a tendency towards improved palatability and fruit quality. Reduction in acidity under organic treatments may be associated with increased conversion of organic acids into sugars during fruit ripening, leading to a higher TSS-to-acidity ratio and improved fruit quality characteristics (Albertini *et al.*, 2006; Lin *et al.*, 2015; Liao *et al.*, 2019).

Ascorbic acid content ranged from 42.2 to 46.1 mg/100 ml juice with the highest value recorded under the combined application of 75% vermicompost with *Trichoderma harzianum*, azadirachtin and *Pseudomonas fluorescens* (46.1 mg/100 ml). The higher ascorbic acid content under integrated organic management may be attributed to enhanced microbial activity, improved nutrient availability, and increased enzymatic activity involved in ascorbic acid synthesis. The combined application of organic manures and

biofertilizers promotes balanced nutrition and physiological efficiency, leading to greater accumulation of vitamin C in citrus fruits (Abobatta and El-Azazy, 2020; Barooah *et al.*, 2022; Duarte *et al.*, 2010, Kumar *et al.*, 2024). Similar results were also reported by Malsawmkimi and Hazarika (2018) who recorded that khasi mandarin fruits from organic production system had higher TSS and ascorbic acid content than fruits from inorganic fruit production system.

Shelf life of fruits varied from 14.2 to 16.2 days and the treatment differences were statistically non-significant. However, fruits from organically managed treatments exhibited relatively longer shelf life compared to the control. The enhanced shelf life under integrated organic treatments may be attributed to improved fruit firmness, balanced nutrient uptake and reduced physiological deterioration due to better plant health and microbial interactions (Gautam *et al.*, 2024).

Conclusion

The findings of the present study demonstrated that integrated organic management involving 75% vermicompost combined with *Trichoderma harzianum*, azadirachtin and *Pseudomonas fluorescens* was highly effective in enhancing fruit yield and productivity of Khasi mandarin under organic production systems. The findings of the present study also demonstrate that the integrated use of vermicompost, beneficial microorganisms, and botanical pesticides constitutes an efficient and sustainable nutrient management strategy for organic Khasi mandarin cultivation, capable of improving fruit productivity and quality under organic production systems while supporting long-term soil health and ecological sustainability.

References

- Abobatta, W.F. and El-Azazy A.M. (2020). *Role of organic and biofertilizers in citrus orchards*. *Aswan University Journal of Environmental Studies*, **1**(1), 13–27.
- Albertini, M.V., Carcouet E., Pailly O., Gambotti C., Luro F. and Berti L. (2006). Changes in organic acids and sugars during early stages of development of acidic and acid less citrus fruit. *Journal of Agricultural and Food Chemistry*, **18,54(21)**, 8335–9. doi: 10.1021/jf061648j. PMID: 17032048.
- Ali, A., Niu G, Masabni J., Ferrante A. and Cocetta G. (2024). Integrated nutrient management of fruits, vegetables and crops through the use of bio stimulants, soilless cultivation and traditional and modern approaches—A mini review. *Agriculture*, **14**, 1330.
- Barooah, A., Chakravarty M. and Hazarika B. (2022). *Response of nutrient management on growth, yield and quality of citrus crop: A review*. *Journal of Pharmacognosy and Phytochemistry*, **11(5)**, 291–297
- Duarte, A., Caixeirinho D. and Miguel M.G. (2010). Vitamin C content of citrus from conventional versus organic farming systems. *Acta Horticulturae*, **868**, 389–394.
- Gautam, D.K., Vikram B., Chandra V., Sengupta J.D., Singh V., Pandey A., Tiwari S.K. and Singh S.K. (2024). Role of Biofertilizer in Fruit Crops. *Journal of Advances in Biology and Biotechnology*, **27(7)**, 547–54. <https://doi.org/10.9734/jabb/2024/v27i71015>
- Ghosh, S.P. (2007). Citrus fruits. ICAR, New Delhi.
- Hazarika, T.K. (2012). *Citrus genetic diversity of northeast India, their distribution Eco geography and Ecobiology*. *Genetic Resources and Crop Evolution*, **59**, 1267–1280.
- Kumar, R., Manisha K. and Kaur K. (2024). *Pre and post-harvest influences on the Vitamin C (Ascorbic acid) content in citrus: A review*. *International Journal of Research in Agronomy*, **7(12S)**, 517–525.
- Lin, Q., Wang C. and Dong W. (2015). *Transcriptome and metabolome analyses of sugar and organic acid metabolism in Ponkan (Citrus reticulata) fruit during fruit maturation*. *Gene*, **554(1)**, 64–74. <https://doi.org/10.1016/j.gene.2014.10.025>
- Malsawmkimi and Hazarika T.K. (2018). Influence of organic manures and bio-dynamic preparations on growth, yield and quality of Khasi mandarin (*Citrus reticulata* Blanco) in Mizoram, North East India. *Indian Journal of Agricultural Research*, **52(5)**, 576–580.
- Negi, Y.K., Sajwan P., Uniyal S. and Mishra A.K. (2021). Enhancement in yield and nutritive qualities of strawberry fruits by the application of organic manures and biofertilizers. *Scientia Horticulturae*, **283**, 110038.
- Paramanik, B., Mahanta S., Das B., Patra P. S., Choudhury A., Ghatak P. and Biswakarma N. (2024). Enhancing rice productivity through holistic nutrient management: integrating vermicompost and Azolla for improved agronomic performance and sustainability. *Journal of Plant Nutrition*, **47(17)**, 2866–2880.
- Pawar, P.S., Garande V.K. and Bhite B.R. (2020). *Effect of vermicompost and biofertilizers on growth, yield and fruit quality of sweet orange (Citrus sinensis L. Osbeck) cv. Mosambi*. *Journal of Pharmacognosy and Phytochemistry*, **9(4)**, 3370–3372.
- Sande, T.J., Tindwa H.J., Alovise A.M.T., Shitindi M.J. and Semoka J.M. (2024). Enhancing sustainable crop production through integrated nutrient management: A focus on vermicompost, bio-enriched rock phosphate, and inorganic fertilizers. *Frontiers in Agronomy*, **6**, 1422876.
- Shahwar, D., Mushtaq Z. and Mushtaq H. (2023). Role of microbial inoculants as biofertilizers for improving crop productivity: A review. *Heliyon*, **9(6)**, e16134.
- Sharma, L.D., Bhupenchandra I. and Choudhary A.K. (2025). Synergistic Implications of Soil supportive, Sustainable Integrated Nutrient Management Protocols Leverage Cowpea Growth and productivity, and Optimizes Crop physiology, Soil Fertility and Quality in Acidic Inceptisols of Northeast India. *Journal of Plant Growth Regulation*, 1–25.
- Sharma, R., Kumar R., Bakshi P. and Maanik (2026). Organic nutrient combinations for enhancing nutrient uptake and fruit quality in Sardar guava (*Psidium guajava* L.) cv. L-49. *Frontiers in Plant Science*, **17**, 1830499. doi: 10.3389/fpls.2026.1830499.
- Singh, A., Reddy K.S. and Singh J. (2020). Phenological stages of guava: A review. *International Journal of Current Microbiology and Applied Sciences*, **9**, 735–736. doi: 10.20546/ijcmas.2020.912.089
- Singh, K.K., Kumar A., Singh S.K., Prasad R., Gupta S.K. and Kumari S. (2025). Improving soil fertility and wheat (*Triticum aestivum*) productivity through precision nutrient management in North Bihar, India. *Research Perspective on Biological Science*, **2**, 133–145.
- Srivastava, A.K. (2012). *Integrated Nutrient Management in Citrus*. In: Lal, R. & Stewart, B.A. (Eds.), *Soil Fertility Management for Sustainable Development*. Springer. https://doi.org/10.1007/978-94-007-4171-3_25
- Srivastava, A.K., Wu Q.S., Mousavi S.M. and Hota D. (2021). *Integrated Soil Fertility Management in Fruit Crops: An Overview*. *International Journal of Fruit Science*, **21(1)**, 413–439.