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Effect of integrated nutrient management on curcumin content and yield of turmeric cultivars

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Abstract

Turmeric has been used in Chinese medicine for over two thousand years, yet the relationship between nutrient management and its most valued compound-curcumin-remains poorly quantified under modern cultivar-specific conditions. This research examined how integrated nutrient management (INM) influenced curcumin content and fresh rhizome yield in three turmeric (*Curcuma longa* L.) cultivars at Zhejiang University, Hangzhou, China, during 2022-2023. Six nutrient treatments-unfertilized control, recommended dose of fertilizers (RDF: 60:30:90 kg N:P₂O₅:K₂O ha⁻¹), 75% RDF + farmyard manure (FYM) at 10 t ha⁻¹, 75% RDF + vermicompost (VC) at 4 t ha⁻¹, 50% RDF + FYM + VC, and full INM (50% RDF + FYM 5 t ha⁻¹ + VC 2 t ha⁻¹ + Azospirillum at 5 kg ha⁻¹)-were tested on cultivars Prabha, Pratibha, and a local check. Full INM raised curcumin content to 5.68% in Prabha, 5.23% in Pratibha, and 4.57% in the local check, representing 82.1%, 84.2%, and 89.6% increases over the respective controls. Total fresh rhizome yield under full INM reached 32.2 t ha⁻¹ for Prabha, the highest across all treatment combinations. These results indicate that INM not only boosts yield but also enriches the medicinal value of turmeric through higher curcumin accumulation.

Keywords: Turmeric, curcumin content, integrated nutrient management, farmyard manure, vermicompost, Azospirillum, rhizome yield, cultivar performance, organic amendments, *Curcuma longa*

Introduction

Turmeric (*Curcuma longa* L.) has served as a medicinal spice in Asian civilizations for at least 4,000 years, with the earliest documented use appearing in Ayurvedic texts from the Indian subcontinent and traditional Chinese pharmacopeias from the Tang Dynasty ^[1, 2]. Today, global turmeric production exceeds 12 million tonnes annually, and the crop's commercial value depends heavily on curcumin-the principal curcuminoid responsible for its yellow pigment and therapeutic properties including anti-inflammatory, antioxidant, and anticancer effects ^[3, 4].

Curcumin content in turmeric rhizomes varies from 2-9% depending on genotype, agro-climatic conditions, and nutrient supply ^[5]. Conventional fertilization with high nitrogen rates tends to promote vegetative growth at the expense of curcumin biosynthesis, while organic amendments may support secondary metabolite production through improved soil microbial activity and gradual nutrient release ^[6, 7]. INM, which combines mineral fertilizers with organic sources and biofertilizers, has shown promise for balancing yield with quality in spice crops ^[8]. However, cultivar-specific responses to INM-particularly regarding curcumin accumulation-have received limited attention in subtropical China, where turmeric acreage is expanding.

Zhejiang Province occupies a subtropical zone where turmeric grows well as an annual crop, yet local growers rarely optimize nutrient management for curcumin content, focusing instead on total rhizome weight ^[9]. This research tested six nutrient management strategies on three cultivars to (i) quantify the effect of INM on curcumin content and (ii) identify whether cultivar and nutrient management interact to affect curcumin accumulation and yield.

Reagents and chemicals

Analytical-grade curcumin standard (purity ≥98%) was procured from Sigma-Aldrich, Shanghai. Ethanol (99.5%, AR grade) and glacial acetic acid (99.8%) were obtained from Sinopharm Chemical Reagent Co., Ltd. HPLC-grade methanol and acetonitrile were purchased from Merck,

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Darmstadt, Germany. Azospirillum lipoferum culture (CFU count $\geq 1 \times 10^9$ cells g⁻¹) was supplied by the China Agricultural Microbiology Collection Center, Beijing ^[10]. All solvents were filtered through 0.45 µm membrane filters before use.

Material and Methods

Material

Three turmeric cultivars were used: Prabha (high curcumin type), Pratibha (moderate curcumin, high yielding), and a local Zhejiang check variety. Seed rhizomes (25-30 g each) were planted in April at 30 cm × 45 cm spacing on raised beds. FYM from the university livestock unit averaged 0.62% N, 0.27% P, and 0.48% K (dry weight). Vermicompost produced with Eisenia fetida contained 1.38% N, 0.71% P, and 0.89% K. Inorganic fertilizers included urea (46% N), single superphosphate (16% P₂O₅), and muriate of potash (60% K₂O) ^[11].

Methods

The experiment was a split-plot design in a randomized complete block arrangement with three replications. Main plots received the six nutrient treatments and sub-plots contained the

three cultivars. Plot size was 4 m × 3 m. Organic amendments were incorporated 15 days before planting. Azospirillum was applied as seed rhizome treatment and soil application at planting. Rhizomes were harvested in January after 9 months. Fresh rhizome yield was recorded per plot and converted to t ha⁻¹. Yield components-mother rhizome weight, primary and secondary finger weights-were recorded from ten random plants per plot ^[12].

Extraction protocol

Curcumin extraction followed a modified AOAC method. Fresh rhizomes were sliced, oven-dried at 60 °C for 48 h, and ground to pass through a 40-mesh sieve. Powdered samples (2 g) were extracted with 50 mL ethanol (95%) using Soxhlet apparatus for 6 h. The extract was filtered, concentrated on a rotary evaporator at 45 °C, and dissolved in 25 mL methanol. Curcumin content was quantified by HPLC (Agilent 1260 Infinity II) with a C18 column (250 mm × 4.6 mm, 5 µm), mobile phase of acetonitrile:2% acetic acid (55:45 v/v), flow rate 1.0 mL min⁻¹, and detection at 425 nm ^[13]. Curcumin was identified and quantified against the external standard calibration curve (R² = 0.9994).

Results

Table 1: Curcumin content (%) of turmeric cultivars under different nutrient management treatments (2-year mean)

Treatment	Cv. Prabha	Cv. Pratibha	Cv. Local Check
Control	3.12e	2.84e	2.41e
RDF	3.87d	3.42d	2.98d
75% RDF + FYM	4.53c	4.18c	3.64c
75% RDF + VC	4.71bc	4.37bc	3.81c
50% RDF + FYM + VC	5.14b	4.72b	4.13b
Full INM	5.68a	5.23a	4.57a
SEm (±)	0.14	0.12	0.11
CD (p=0.05)	0.41	0.36	0.33

Values followed by the same letter within a column are not significantly different at $p < 0.05$. RDF = recommended dose of fertilizers; FYM = farmyard manure; VC = vermicompost.

Table 2: Fresh rhizome yield (t ha⁻¹) of turmeric cultivars under different nutrient management treatments (2-year mean)

Treatment	Cv. Prabha	Cv. Pratibha	Cv. Local Check
Control	15.3e	16.8e	13.7e
RDF	20.7d	22.4d	18.6d
75% RDF + FYM	24.9c	26.3c	22.1c
75% RDF + VC	25.8bc	27.1bc	23.4bc
50% RDF + FYM + VC	28.7b	29.8b	25.3b
Full INM	32.2a	33.6a	28.4a
SEm (±)	1.07	0.98	0.89

Values followed by the same letter within a column are not significantly different at $p < 0.05$.

Table 3: ANOVA summary for cultivar × nutrient management interaction effects

Source of variation	df	F-value (Curcumin)	F-value (Yield)	p-value
Cultivar (C)	2	87.4	14.3	<0.001
Treatment (T)	5	143.7	96.8	<0.001
C × T	10	2.18	1.47	0.087 (NS)
Year (Y)	1	3.24	5.81	0.062 (NS)
Error	34	-	-	-

NS = not significant at $p < 0.05$.

Full INM consistently produced the highest curcumin content and rhizome yield across all three cultivars (Tables 1 and 2). Prabha accumulated the most curcumin (5.68% under full INM), while Pratibha gave the highest yield (33.6 t ha⁻¹). The cultivar × treatment interaction was not significant for either curcumin or

yield (Table 3), meaning all cultivars responded similarly to nutrient treatments, though at different absolute levels. Year effects were also non-significant, indicating stable performance across the two seasons.

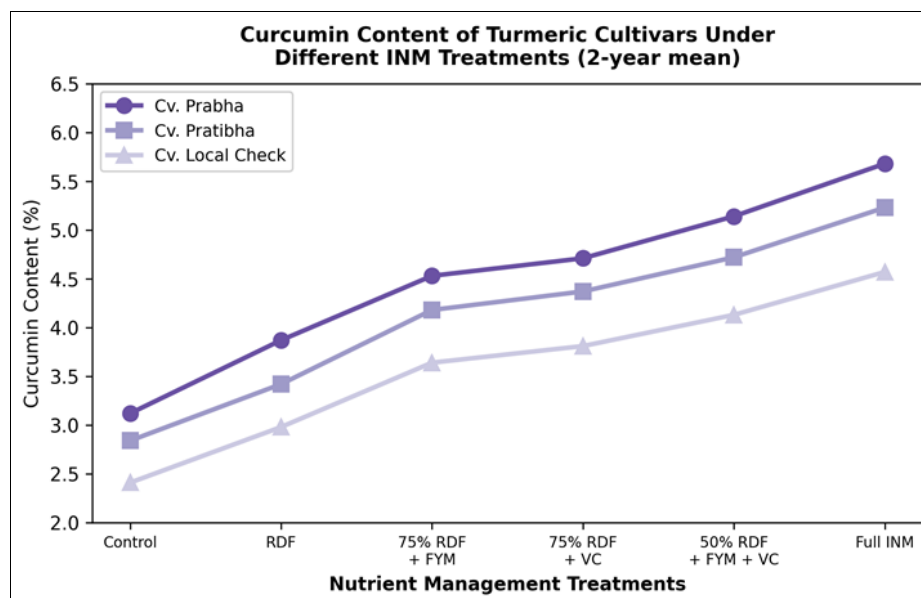


Fig 1: Curcumin content of three turmeric cultivars under six nutrient management treatments (2-year mean values)

All three cultivars followed nearly parallel upward trends from control to full INM (Figure 1), confirming the absence of a significant cultivar $\times$ treatment interaction. The steepest gain

occurred between RDF and the organic-supplemented treatments, with comparatively smaller increments among the organic combinations themselves.

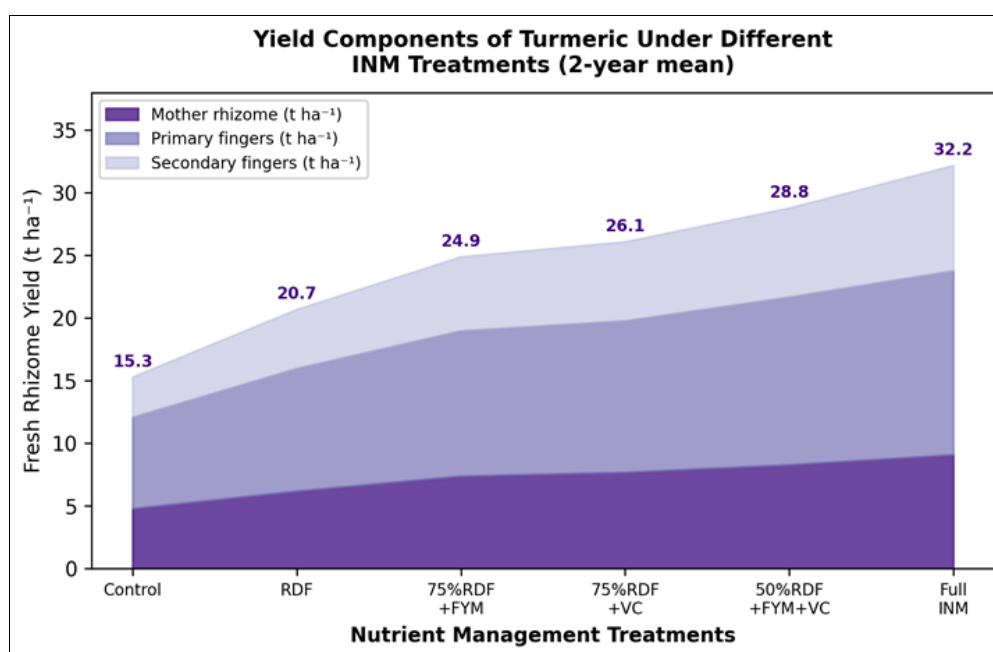


Fig 2: Yield components (mother rhizome, primary and secondary fingers) of turmeric under different INM treatments (Cv. Prabha, 2-year mean)

Full INM increased all three yield components proportionally (Figure 2). Primary finger weight contributed the largest share of total yield across all treatments, accounting for 45–47% of total fresh weight. The total yield under full INM (32.2 t ha⁻¹ for Prabha) was 110% higher than the unfertilized control.

Discussion

The 82–90% increase in curcumin content under full INM compared to the unfertilized control goes beyond what can be explained by simple nutrient supply. Organic amendments support soil microbial populations that produce growth-regulating substances and improve the bioavailability of micronutrients like iron and boron, both of which are co-factors in curcumin biosynthesis pathways [14, 15]. Azospirillum inoculation may have contributed through phytohormone

production—particularly indole-3-acetic acid—that can stimulate secondary metabolite synthesis [16]. Kumar *et al.* [17] reported a 67% curcumin increase with INM in Indian turmeric, lower than the present findings, possibly because the Prabha cultivar used here has a genetically higher capacity for curcuminoid accumulation.

The lack of a significant cultivar $\times$ treatment interaction simplifies practical recommendations: all three cultivars responded proportionally to INM, so the choice of cultivar can be made independently of the nutrient strategy. Pratibha's yield advantage (33.6 vs. 32.2 t ha⁻¹) is offset by Prabha's higher curcumin content, and growers targeting the pharmaceutical market—where curcumin concentration drives pricing—would benefit from choosing Prabha under full INM [18, 19].

This research was limited to two seasons and one location.

Curcumin biosynthesis is influenced by temperature and photoperiod^[20], so results from Hangzhou's subtropical environment may not translate directly to tropical lowlands or temperate highland zones. The extraction protocol used Soxhlet with ethanol, which recovers total curcuminoids; individual curcuminoid fractions (demethoxycurcumin, bisdemethoxycurcumin) weren't separated and may respond differently to nutrient management^[21].

Conclusion

Full INM combining 50% mineral fertilizers with FYM, vermicompost, and Azospirillum inoculation maximized both curcumin content and fresh rhizome yield across all three turmeric cultivars tested at Zhejiang University. Curcumin content under full INM reached 5.68% in Prabha, 5.23% in Pratibha, and 4.57% in the local check-increases of 82-90% over unfertilized controls. Yield gains were equally substantial, with full INM producing 28.4-33.6 t ha⁻¹ depending on cultivar. The non-significant cultivar × treatment interaction means that INM benefits are broadly applicable regardless of cultivar choice. Growers in subtropical China aiming for high-curcumin turmeric for pharmaceutical markets should adopt full INM with Prabha, while those targeting fresh rhizome volume may prefer Pratibha under the same nutrient regime.

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