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Integrated nano formulated macro and micro nutrient management enhances yield and quality of turmeric (*Curcuma longa* L.)

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ABSTRACT

A two-year field experiment (2022–23 and 2023–24) was conducted at Horticulture Research Station, Mondouri, BCKV, Nadia, West Bengal, India, to evaluate the effect of nano-formulated macro and micro nutrients integrated with conventional fertilizers in turmeric. The whole experiment was designed in RBD with three replications and eight treatments, including a control. Treatments involved three levels of N, P and K (100%, 75%, and 50%) combined with foliar application of nano NPK (0.4%) and nano Zn+Mn+Cu (0.4%) at 45 and 90 days after planting (DAP). The maximum plant height (160.05 cm), tiller number (3.25), clump weight (442.40 g), plot yield (14.30 kg 3 m^{-2}), dry recovery (24.45%), oleoresin (13.91%), and total phenols (72.14 mg GAE 100 g^{-1}) were recorded under application of 40% N + 75% P (basal) followed by 0.4% nano P at 45 DAP and 0.4% nano N+K+Zn+Mn+Cu at 45 and 90 DAP (T_8). Plants receiving 40% N + 100% P basally with foliar 0.4% nano N+K+Zn+Mn+Cu at 45 and 90 DAP (T_4) recorded highest curcumin content (6.25%). The yield under control (100% NPK+ 0.4% nano Zn+Mn+Cu) was 10.57 kg 3 m^{-2}. Based on the growth, yield and quality T_8 is the best treatment.

Key words: Nano macronutrients, nano micronutrients, curcumin, phenol, oleoresin.

INTRODUCTION

Turmeric (*Curcuma longa* L.) is an ancient and valuable spice, belongs to the Zingiberaceae family. The plant originates from Southeast Asia. Due to its distinctive yellow colour and various uses, it is often called the "Golden Spice of India." The plant produces fleshy, tuberous rhizomes which are modified underground stems, rich in curcumin (1.8–5.4%) and essential oils (2.5–7.25%), responsible for its characteristic colour and medicinal properties. Morphologically, the plant grows up to a height of 90–100 cm, has broad lanceolate leaves and a pale yellow inflorescence emerging from the rhizome. India being the largest producer, consumer and exporter of turmeric accounting for nearly 80% of global production, followed by China, Myanmar, Nigeria, and Bangladesh (Tian *et al*.,12). Traditionally, turmeric has been used in ayurveda to treat inflammatory disorders, infections, metabolic diseases, and cancer (Kunnumakkara *et al.,* 6). Since the COVID-19 pandemic, global demand for turmeric has increased due to its recognized health benefits. Turmeric is a nutrient-exhaustive crop requires balance application of macro and micro nutrients. However, excessive dependence on conventional fertilizers adversely affects soil health and environmental sustainability. In addition, excessive use of chemical fertilizers raises input costs and ultimately lowers farmers' profits. To overcome these challenges, nanofertilizers have emerged as a promising alternative in modern agriculture to improve nutrient management, increase fertilizer efficiency, and reduce losses. Nano-fertilizers are nutrient formulations that contains nano-scale particles (<100 nm) which facilitate slow released and efficient nutrient delivery, aid in improving plant height, leaf area, chlorophyll content, and biomass production (Tang *et al*., 11). Application of nano macro and micronutrients as foliar spray helps in better growth and development as it aid in quick absorption, precise placement, and enhance the synthesis of bioactive compounds (Badawy *et al*., 1). Though nano NPK along with nano Zn, Mn, and Cu have shown effectiveness, there is a scarcity of research on the impact of nano fertilizers on the growth, yield, and quality of turmeric. Considering all these facts and realizing the potentiality of nano fertilizers in sustainable agricultural production system, a two years field study has been undertaken in the gangetic new alluvial zone of West Bengal, India.

MATERIALS AND METHOS

The field experiment was conducted at the Horticultural Research Station, Mondouri, under the Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Nadia, West Bengal. The research farm is located at an elevation of 9.75 m above mean sea level (MSL) and lies at 23°05′ N latitude and 89°00′ E longitude. The soil at the

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experimental site belongs to the Gangetic New Alluvial Plains of West Bengal and is characterized by a sandy clay loam texture. The experiment was laid out in randomized block design (RBD) with eight treatments and three replications, namely T_1= 40% N + 100% P (Basal)→ 30% N + 50% K (45 DAP) → 30% N + 50% K (90 DAP) + 0.4% nano Zn + Mn + Cu (45 and 90 DAP), T_2= 40% N + 100% P (Basal)→ 0.4% nano N + 50% K (45 DAP)→ 0.4% nano N + 50% K (90 DAP) + 0.4% nano Zn + Mn + Cu (45 and 90 DAP), T_3= 40% N + 100% P (Basal)→ 30% N + 0.4% nano K (45 DAP) → 30% N + 0.4% nano K (90 DAP) + 0.4% nano Zn + Mn + Cu (45 and 90 DAP), T_4= 40% N + 100% P (Basal)→ 0.4% nano N and K (45 DAP) → 0.4% nano N and K (90 DAP) + 0.4% nano Zn + Mn + Cu (45 and 90 DAP), T_5= 40% N + 75% P (Basal)→ 30% N + 0.4% nano P + 50% K (45 DAP)→ 30% N + 50% K (90 DAP) + 0.4% nano Zn + Mn + Cu (45 and 90 DAP), T_6= 40% N + 75% P (Basal)→ 0.4% nano N and P + 50% K (45 DAP)→ 0.4% nano N + 50% K (90 DAP) + 0.4% nano Zn + Mn + Cu (45 and 90 DAP), T_7= 40% N + 75% P (Basal)→ 30% N + 0.4% Nano P and K (45 DAP)→ 30% N + 0.4% Nano K (90 DAP) + 0.4% nano Zn + Mn + Cu (45 and 90 DAP), T_8= 40% N + 75% P (Basal)→ 0.4% nano N, P and K (45 DAP)→ 0.4% nano N and K (90DAP) + 0.4% nano Zn + Mn + Cu (45 and 90 DAP).

The turmeric variety Suguna was used for the experiment. Raised beds of 3.0 m × 1.0 m diameter with a height of 15 cm were prepared for planting. Seed rhizomes weighing 25–30 g were treated with blitox @ 4 g L^{-1} for 30 minutes prior to planting, and were sown at a spacing of 30 cm × 25 cm in the experimental plots which accommodate 40 plants per bed. In the both years, planting was carried out in the middle of June, while harvesting was completed by the end of January. The recommended fertilizer dose was NPK @ 150:60:150 kg ha^{-1} (Medda and Hore, 8) supplied through urea, single super phosphate, and muriate of potash. The 40% nitrogen along with the full dose of phosphorus were applied as a basal along with FYM @ 25 t ha^{-1}, while the remaining nitrogen and potassium were applied in two split doses at 45 and 90 DAP according to the respective treatment schedules. Mulching was done just after planting with paddy straw at 10 t ha^{-1}. Irrigation, weeding and intercultural operation were done depending on the requirement. Morphological observations like plant height, tiller and leaf number were taken at 180 days after planting. After harvesting and cleaning off the roots and adhere soil the clump weight (g) and yield per plot (kg 3 m^{-2}) were recorded. Quality parameters like dry recovery, oleoresin, curcumin and total phenols were also recorded after harvesting by using standard procedure.

RESULTS AND DISCUSSION

The data presented in Table 1 revealed a significant variation on growth parameters at 180 DAP among all the treatments. The maximum plant height (174.92 cm) was recorded under application of 40% N + 75% P as basal→ 0.4% nano N, P and K at 45 DAP→ 0.4% nano N and K at 90DAP + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP (T_8). The lowest plant height (147.74 cm) was recorded under T_1 (40% N + 100% P as basal→ 30% N + 50% K + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP). The highest number of tillers per plant (3.25) was recorded in treatment combinations of 0.4% nano N + K + Zn + Mn + Cu at 45 and 90 DAP + 0.4% nano P at 45 DAP along with 40% N and 75% P as basal (T_8), closely followed by T_4 (40% N + 100% P as basal→ 0.4% nano N +

Table 1: Influence of nano formulation of macro and micro nutrients on growth parameters of turmeric at 180 DAP.

Treatment	Plant height (cm)			Tillers number			Leaves number		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	146.59	148.89	147.74	2.11	2.54	2.33	16.58	17.92	17.25
T_2	160.17	164.67	162.42	2.41	2.92	2.67	18.91	19.89	19.40
T_3	152.46	160.77	156.62	2.46	2.68	2.57	18.02	19.17	18.60
T_4	169.37	170.04	169.71	3.10	3.15	3.13	19.59	19.86	19.73
T_5	156.28	161.58	158.93	2.57	2.87	2.72	18.36	18.72	18.54
T_6	163.76	168.44	166.10	3.02	3.18	3.10	19.44	19.35	19.40
T_7	169.06	165.85	167.46	2.98	3.04	3.01	19.75	19.13	19.44
T_8	171.14	178.69	174.92	3.22	3.27	3.25	19.71	20.52	20.12
S.Em. (±)	2.062	2.062	2.112	0.040	0.050	0.037	0.241	0.332	0.269
C.D. (P=0.05)	6.315	6.315	6.468	0.123	0.154	0.115	0.739	1.017	0.824

DAP: Days after planting

K + Zn + Mn + Cu at 45 and 90DAP) [3.13], while T_1 (RDF + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP) recorded the lowest number of tillers (2.33). The highest leaf number (20.12) was recorded under T_8 (40% N + 75% P as basal→ 0.4% nano N, P and K at 45 DAP→ 0.4% nano N and K at 90 DAP + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP) which is statistically *at par* with T_4 (40% N + 100% P as basal → 0.4% nano N + K + Zn + Mn + Cu at 45 and 90 DAP) [19.73] and T_7 (40% N + 75% P as basal→ 30% N + 0.4% nano P and K at 45 DAP→ 30% N + 0.4% nano K at 90 DAP + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP) [19.44]. The minimum number of leaves (17.25) was recorded under T_1 (RDF + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP).

The enhancement of various growth parameters, such as plant height, the number of tillers and leaves, may be due to the balanced supply of macro and micronutrients which is essential for key physiological processes during growth (Kalaji *et al*., 5). Foliar application improves nutrient absorption during critical stages, bypassed the limitations associated with soil application and reduced toxicity risks (Solanki *et al.*, 10). Due to small size and large surface area, nano-fertilizers enhance nutrient uptake and ensure efficient, targeted delivery. Major nutrients like N, P, and K support photosynthesis, protein synthesis, and overall biomass, while micronutrients such as Zn, Mn, and Cu regulate chlorophyll formation, enzyme activity and stress resistance (Johnson and Mirza, 3). Nanoparticles also help to minimize oxidative stress, results in better plant growth. The findings of the present study are in good agreement with Manikanta *et al.* (7) who observed that the significant improvement of plant height, branches and leaf number in potato with foliar application of nano nitrogen, zinc, and copper fertilizers @0.4%.

It is revealed from Table 2 that the application of 40% N + 75% P as basal in combination with 0.4% nano N + K + Zn + Mn + Cu at 45 and 90 DAP + 0.4% nano P at 45 DAP (T_8) recorded the highest clump weight (442.40 g), whereas the treatment combinations of RDF + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP (T_1) recorded the lowest weight of clump (276.04 g). The plot yield ranged from 10.57 kg $3m^{-2}$ to 14.30 kg 3 m^{-2} revealed a significant variations among the treatments. Application of 40% N + 75% P as basal→ 0.4% nano N, P and K at 45 DAP→ 0.4% nano N and K at 90 DAP + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP (T_8) recorded the highest plot yield (14.30 kg 3 m^{-2}), whereas the control treatment T_1 (RDF + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP) recorded the lowest yield (10.57 kg 3 m^{-2}). The higher vegetative growth under integrated application of nano macro and micro nutrients may results in better accumulation and translocation of photosynthates to the sink (rhizome), resulting in better yield. The findings of the present investigation are in close agreement with earlier report of Hamed *et al*. (2) who observed that application of nano NPK and micro nutrients at a moderate concentration significantly improved fresh weight of sugar beet roots.

The foliar application of 0.4% nano N + K + Zn + Mn + Cu at 45 and 90 DAP + 0.4% P at 45 DAP along with 40% N and 75% P as basal (T_8) recorded the highest dry recovery (24.45%) while the lowest value (22.74%) was observed in T_2 (40% N + 100% P as basal→ 0.4% nano N + 50% K + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP). The enhanced dry recovery under nano nutrient treatments may be due to increased accumulation of dry matter and reduced moisture content in rhizomes due to improved photosynthetic efficiency and assimilate partitioning. The data presented in Table. 3 showed

Table 2: Influence of nano formulation of macro and micro nutrients on yield parameters.

Treatment	Weight of clump (g)			Plot yield (kg $3m^{-2}$)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	254.31	297.76	276.04	9.63	11.50	10.57
T_2	313.05	335.20	324.13	11.83	12.79	12.31
T_3	299.14	350.58	324.86	11.50	13.23	12.36
T_4	389.23	431.86	410.55	13.34	14.05	13.69
T_5	317.71	354.13	335.92	12.33	13.56	12.95
T_6	399.16	410.34	404.75	12.90	14.08	13.49
T_7	354.60	371.67	363.14	13.26	13.60	13.43
T_8	428.52	456.27	442.40	13.88	14.73	14.30
S.Em. (±)	4.550	4.846	4.651	0.158	0.174	0.167
C.D. (P=0.05)	13.936	14.840	14.244	0.484	0.532	0.510

Table 3: Influence of nano formulation of macro and micro nutrients on quality parameters.

Treatment	Dry recovery (%)			Oleoresin content (%)			Total phenol (mg GAE 100 g^{-1})			Curcumin content (%)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	22.63	23.07	22.85	11.62	12.24	11.93	66.25	69.72	67.99	5.20	5.42	5.31
T_2	21.09	24.39	22.74	12.01	12.45	12.23	69.28	71.30	70.29	6.19	5.26	5.73
T_3	23.35	24.29	23.82	14.06	13.31	13.69	71.15	64.95	68.05	5.41	6.22	5.82
T_4	23.90	24.63	24.27	13.43	14.17	13.80	67.06	73.34	70.20	6.18	6.32	6.25
T_5	23.79	24.44	24.12	13.01	13.32	13.17	69.01	67.76	68.39	5.22	5.94	5.58
T_6	24.01	22.51	23.26	13.56	14.25	13.91	65.81	72.37	69.09	6.06	5.95	6.01
T_7	24.28	23.85	24.07	12.78	13.40	13.09	65.30	70.22	67.76	5.56	6.36	5.96
T_8	24.57	24.32	24.45	13.29	14.26	13.78	70.09	74.18	72.14	5.87	6.57	6.22
S.Em. (±)	0.307	0.397	0.380	0.168	0.219	0.182	0.875	1.189	1.148	0.077	0.097	0.077
C.D. (P=0.05)	0.940	1.215	1.164	0.516	0.671	0.557	2.680	3.640	NS	0.236	0.296	0.236

that 40% N + 75% P as basal→ 0.4% nano N and P + 50% K at 45 DAP→ 0.4% nano N + 50% K at 90 DAP + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP (T_6) recorded the highest oleoresin content (13.91%), whereas plants treated with RDF + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP (T_1) recorded the lowest value (11.93%). Increased oleoresin content under nano nutrient treatments may be associated with enhanced secondary metabolite synthesis due to improved nutrient availability, particularly nitrogen, potassium and zinc. These nutrients play a vital role in enzymatic activity, metabolic pathways, and synthesis of essential oils and resins (Nair, 9). The highest phenol content (72.14 mg GAE 100 g^{-1}) was recorded under the application of 0.4% nano N + K + Zn + Mn + Cu at 45 and 90 DAP + 0.4% P at 45 DAP along with 40% N and 75% P as basal (T_8). Whereas application of 40% N + 75% P as basal→ 30% N + 0.4% nano P and K at 45 DAP→ 30% N + 0.4% nano K at 90 DAP + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP (T_7) recorded the lowest value (67.76 mg GAE 100 g^{-1}). The enhancement of phenolic compounds may be due to improved micronutrient-mediated activation of phenyl propanoid pathway enzymes. Application of 40% N + 100% P as basal→ 0.4% nano N + K + Zn + Mn + Cu at 45 and 90 DAP (T_4) recorded the highest curcumin content (6.25%), which is statistically *at par* with T_8 (40% N + 75% P as basal→ 0.4% nano N, P and K at 45 DAP→ 0.4% nano N and K at 90 DAP + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP) [6.22%] while T_1 (RDF + 0.4% nano Zn + Mn + Cu at 45 and 90 DAP) recorded the lowest curcumin content (5.31%). The significant increase in curcumin content under nano nutrient treatments may be attributed to improved metabolic efficiency and enhanced biosynthesis of curcuminoid. Micronutrients such as Zn, Mn and Cu are play a crucial role in enzyme systems involved in secondary metabolite synthesis, while potassium enhances translocation and accumulation of metabolites in rhizomes. The present findings are in good conformity with Khattab *et al*. (5) who reported that application of nano Zn at 40 mg L^{-1} promote the biosynthesis of curcumin in turmeric.

The study demonstrated that 40% N+75% P as basal combined with foliar application of 0.4% nano NPK and nano Zn, Mn, Cu at 45 and 90 DAP (T_8) significantly improved growth, yield, and quality parameters. Overall, integration of nano macro and micronutrients with reduced dose of fertilizer offers an efficient and sustainable strategy for enhancing turmeric productivity and quality.

AUTHOR'S CONTRIBUTION

Field experiment, laboratory analysis, preparation of manuscript and manuscript edit (AS). Conceptualization of research work and methodology, manuscript reviewed (JKH).

DECLARATION

Authors of this manuscript declare that they do not have any conflict of interest.

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