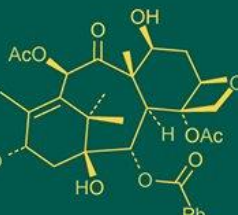
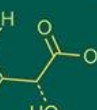
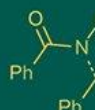


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(8): 1371-1377
www.biochemjournal.com
Received: 10-06-2026
Accepted: 13-07-2026

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Application of nano fertilizer for improving yield of pumpkin (*Cucurbita Moschata* L.) under Balaghat Region

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i8Sp.9614>

Abstract

A field experiment titled “Application of Nano fertilizer for improving yield of pumpkin (*Cucurbita moschata* L.)” was conducted during the Rabi season 2024-25 at the Student Research Farm, Department of Horticulture, Sardar Patel University, Balaghat (M.P.). The study evaluated nine treatments including a control (no fertilizer), recommended nitrogen dose (100 kg N/ha), foliar sprays of nano urea (1 and 2 ml/L), nano zinc oxide (0.5 and 1 g/L), their combinations at different doses, and a reduced nitrogen dose (50% RDN) combined with nano urea. The objective was to assess the individual and combined effects of nano fertilizers on pumpkin growth, yield, and economics. The combined nano fertilizer treatment T8 (nano urea 2 ml/L + nano zinc oxide 1 g/L) showed the most significant improvements in plant height (95.2 cm at 90 DAS), leaf area (558.4 cm²), fruit number (4.5 fruits/plant), average fruit weight (850 g), and total fruit yield per plant (3.83 kg). It also improved fruit quality parameters like size and flesh thickness and reduced days to first harvest to 50.2 days. Economically, T8 achieved the highest gross returns (Rs. 1,02,500/ha), net returns (Rs. 76,500/ha), and benefit-cost ratio (3.94) despite a slightly higher cultivation cost (Rs. 26,000/ha). Treatment T9 (50% RDN + nano urea) also demonstrated good profitability, indicating that nano fertilizers can reduce chemical fertilizer use while maintaining or enhancing yield and profit, making them a promising option for sustainable pumpkin cultivation.

Keywords: Nano, pumpkin, planting, harvest, spray, parameters

Introduction

Pumpkin (*Cucurbita pepo* L.) is a widely cultivated crop known for its nutritional value and versatility in culinary applications. In India, especially in regions like Uttar Pradesh, pumpkin cultivation is integral to the agricultural landscape. However, challenges such as nutrient deficiencies, water scarcity, and soil degradation often hinder optimal growth and yield. Addressing these issues is crucial for enhancing pumpkin productivity and ensuring food security (FAOSTAT, 2024; Ministry of Agriculture & Farmers Welfare, 2024).

Pumpkin (*Cucurbita* spp.) holds significant economic importance in India, contributing to both domestic consumption and international trade. In 2024, India cultivated pumpkins on approximately 45,000 hectares, producing around 3.1 million metric tons, making it one of the largest producers globally. Major producing states include Madhya Pradesh, Odisha, Uttar Pradesh, and West Bengal. The adoption of improved agronomic techniques and disease-resistant varieties has enhanced productivity. Additionally, India's pumpkin export industry has witnessed remarkable growth, reflecting the country's ability to meet international quality standards (FAOSTAT, 2024; APEDA, 2024).

Nano fertilizers are innovative agricultural inputs engineered at the nanoscale (typically <100 nm) to enhance nutrient delivery and uptake in plants. Their unique properties, such as high surface area, increased solubility, and controlled-release mechanisms, make them superior to conventional fertilizers in terms of nutrient use efficiency and environmental sustainability (Subramanian *et al.*, 2015; Solanki *et al.*, 2015; Dimkpa & Bindraban, 2018) [5, 22,, 23]. In the context of pumpkin cultivation, these fertilizers offer promising avenues to improve crop growth, yield, and fruit quality.

Nano fertilizers improve nutrient use efficiency (NUE) by facilitating better nutrient uptake through their small particle size and high surface area. This leads to enhanced root penetration and nutrient absorption, thereby promoting healthier plant growth. Studies have demonstrated that nano fertilizers can increase NUE by reducing nutrient losses and improving nutrient availability to plants (Samrat *et al.*, 2020; Dimkpa & Bindraban, 2018) [5, 16, 17].

The application of nano fertilizers has been shown to positively affect various growth parameters of pumpkin plants. Different combinations of conventional urea and nano urea significantly improved plant growth, flowering, fruit development, quality, and yield of pumpkin, highlighting the potential of nano fertilizers in vegetable production (Sharma *et al.*, 2024) [19, 20].

Nano fertilizers contribute to increased pumpkin yield by improving photosynthetic efficiency and promoting better fruit development. The controlled release of nutrients ensures a steady nutrient supply throughout crop growth, reducing nutrient losses while improving fruit size, quality, and marketable yield, thereby increasing farmers' economic returns (Sharma *et al.*, 2024; Kah *et al.*, 2018) [9, 10, 19, 20].

Nano fertilizers function through multiple advanced mechanisms that enhance nutrient efficiency and crop productivity. One of the primary mechanisms is controlled nutrient release, ensuring a slow and sustained supply of nutrients according to crop demand. Their nano-sized particles also facilitate efficient penetration through stomata or the cuticle, resulting in improved nutrient uptake and translocation. Furthermore, nano fertilizers positively influence soil microbial activity, nutrient mineralization, and soil fertility, thereby improving overall plant performance and sustainability (Subramanian *et al.*, 2015; Solanki *et al.*, 2015; Kah *et al.*, 2018) [9, 10, 22, 23].

The use of nano fertilizers aligns with sustainable agricultural practices by minimizing nutrient runoff, reducing excessive fertilizer use, and lowering environmental pollution while improving soil health (Dimkpa & Bindraban, 2018; Kah *et al.*, 2018) [5, 9, 10].

Despite their benefits, the application of nano fertilizers requires careful consideration. Potential challenges include nanoparticle accumulation in soil, possible impacts on soil microbial diversity, production costs, and the lack of standardized application recommendations for different crops and agro-climatic conditions (Kah *et al.*, 2018; Dimkpa & Bindraban, 2018) [5, 9, 10].

With continued research and technological advancements, nano fertilizers have considerable potential to revolutionize pumpkin cultivation. Future developments may include crop-specific and region-specific nano formulations designed to maximize nutrient use efficiency while ensuring environmental safety (Subramanian *et al.*, 2015; Dimkpa & Bindraban, 2018) [5, 23].

The integration of nano fertilizers into pumpkin cultivation offers a sustainable strategy to improve growth, yield, and fruit quality. Although certain challenges remain, their potential to enhance nutrient use efficiency, reduce environmental impacts, and improve farmers' profitability makes nano fertilizers an important component of sustainable vegetable production. Continued research is essential to optimize application methods and ensure their safe and effective use (Dimkpa & Bindraban, 2018; Kah *et al.*, 2018) [5, 9, 10].

Nano zinc oxide (ZnO-NPs) has shown promising effects on pumpkin (*Cucurbita* spp.) growth and development. When applied at appropriate concentrations, ZnO nanoparticles enhance seed germination, plant height, leaf number, chlorophyll content, and overall biomass by improving zinc availability, which is essential for enzyme activation, protein synthesis, auxin metabolism, and photosynthesis. Nano zinc oxide also enhances antioxidant enzyme activities such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), enabling plants to better withstand oxidative stress. However, these effects are concentration-dependent, and excessive ZnO-NP application may induce phytotoxicity, reduce growth, and cause cellular damage. Therefore, optimizing the application dose is essential to maximize the benefits of ZnO nanoparticles in pumpkin cultivation (Raliya & Tarafdar, 2013; Tarafdar *et al.*, 2014; Dimkpa *et al.*, 2017; Dimkpa & Bindraban, 2018; Kah *et al.*, 2018) [5, 6, 7, 9, 10, 14, 24].

Material and Methods

The study titled "Application of Nano fertilizer for improving yield of pumpkin (*Cucurbita moschata* L.)" have been carried out at Horticulture Research farm, Sardar Patel University, Balaghat (M.P.) during Rabi season of 2024-25. The experiment followed a Randomized block design (RBD) with nine treatment combinations replicated thrice at the student Research farm of the Department of Horticulture (Vegetable Science), School of Agriculture Science, Technology & Research, Sardar Patel University, Balaghat (M.P.). The experiment were taken The treatments included a control (T1), full recommended dose of nitrogen (100 kg N/ha) as T2, and foliar applications of nano urea at two concentrations: 1 ml/L (T3) and 2 ml/L (T4). Treatments T5 and T6 involved foliar sprays of nano zinc oxide at 0.5 g/L and 1 g/L, respectively. Combined applications of nano urea and nano zinc oxide were studied under T7 (1 ml/L nano urea + 0.5 g/L nano zinc oxide) and T8 (2 ml/L nano urea + 1 g/L nano zinc oxide). Lastly, T9 involved an integrated approach with 50% recommended nitrogen dose (50 kg N/ha) supplemented by combined foliar sprays of nano urea (1 ml/L) and nano zinc oxide (0.5 g/L), representing a balanced strategy for nutrient optimization. The experiment was laid out in a randomized block design comprising nine treatments with three replications. Biometric observations were obtained from the selection of five random plants within each plot. Analysis of Variance approach was employed to analyze the gathered data at 5 % level of significance.

Results and Discussion

Growth parameters

The application of nano fertilizers significantly enhanced various growth parameters of pumpkin, as observed across multiple stages of crop development. The most effective treatment consistently across all parameters was T8, which combined nano urea (2 ml/L) with nano zinc oxide (1 g/L). For plant height, T8 recorded the tallest plants at 30, 60, and 90 DAS with values of 29.7 cm, 61.5 cm, and 95.2 cm, respectively, outperforming both the control and conventional RDN treatments. This increase is attributed to the superior foliar absorption and nutrient use efficiency of nano particles, which support rapid cell division and elongation. Similarly, in terms of the number of leaves per plant, T8 again recorded the highest counts (8.7, 16.5, and 22.1 at 30, 60, and 90 DAS), reflecting improved

photosynthetic surface area, early canopy establishment, and vegetative vigor, which are essential for reproductive success. A consistent trend was observed in leaf area, where T8 recorded 173.8 cm², 372.5 cm², and 558.4 cm² across the three stages. These improvements highlight that nano fertilizers are capable of enhancing the plant's ability to intercept light and perform efficient photosynthesis due to their precise and timely nutrient availability. Furthermore, the vine length followed a similar pattern, where T8 had the longest vines at all stages 69.3 cm (30 DAS), 143.6 cm (60 DAS), and 218.7 cm (90 DAS) indicating that stem elongation and internodal growth are highly responsive to nano nutrient inputs. Lastly, the number of branches per plant, which influences the overall productivity, was highest in T8 at both 45 DAS (5.5) and 60 DAS (7.8). This could be due to the synergistic effect of nitrogen and zinc in promoting shoot development and hormonal balance. Overall, the application of nano fertilizers, especially in combination, showed consistent and superior performance across all growth parameters, underscoring their potential to improve crop vigor, reduce reliance on bulk fertilizers, and enhance sustainable pumpkin production. These findings are supported by previous studies (Chhipa, 2017; Adhikari *et al.*, 2021) reporting that nano nitrogen and zinc enhance nutrient uptake efficiency, photosynthetic rate, and early plant vigor by minimizing losses and improving bioavailability.

The application of nano fertilizers significantly enhanced key growth parameters of pumpkin, including plant height, number of leaves per plant, and fruit dimensions, owing to improved nutrient availability and uptake efficiency. The superior performance of combined nano urea and nano zinc oxide treatments can be attributed to the nanoscale properties higher surface area and solubility that promote better absorption and translocation of nutrients (Kah *et al.*, 2018) ^[9, 10]. This supports earlier studies where nano urea application increased plant height and biomass in crops like tomato and maize (Sharma *et al.*, 2020; Prasad *et al.*, 2017) ^[13, 18]. Increased leaf number under nano fertilizer application indicates enhanced photosynthetic potential, supported by zinc's crucial role in chlorophyll synthesis and auxin regulation, which govern leaf development (Cakmak, 2008) ^[3]. The synergistic effect of nitrogen and zinc under combined treatments likely stimulated balanced cellular activity, facilitating robust vegetative growth (Raliya *et al.*, 2016) ^[15]. Similar trends were observed in cucumber and wheat, where nano zinc enhanced leaf area and chlorophyll content (Khan *et al.*, 2020; Tripathi *et al.*, 2019) ^[11, 25]. Additionally, fruit dimensions such as length and diameter improved markedly under nano fertilizer application, likely due to sustained nutrient supply during critical growth phases that promote cell enlargement and fruit development (Singh *et al.*, 2019) ^[21]. Controlled nutrient release from nano fertilizers ensures continuous availability, improving fruit quality and size, as also reported in bitter melon with nano urea foliar spray (Ahmad *et al.*, 2021) ^[1]. Overall, nano fertilizers' enhanced adherence to leaf surfaces and efficient penetration result in better nutrient use efficiency compared to conventional fertilizers, reducing nutrient losses and supporting sustainable crop production systems (DeRosa *et al.*, 2010) ^[14].

Yield parameters

The growth, yield, and quality parameters of pumpkin were significantly influenced by the application of nano fertilizers, as detailed across various developmental stages.

Regarding fruiting traits, the number of fruits per plant was notably highest in the T8 treatment (combined nano urea at 2 ml/L + nano zinc oxide at 1 g/L) with 4.5 fruits/plant, significantly surpassing both the control (T1 - 2.1) and the conventional fertilizer treatment (T2 - 3.6), indicating the positive role of nano nutrients in enhancing reproductive success. Similarly, T8 also recorded the highest average fruit weight (850 g) and total fruit yield per plant (3.83 kg), reflecting a synergistic effect of improved nutrient use efficiency, photosynthesis, and vegetative vigor. In terms of fruit dimensions, T8 again stood out with the maximum fruit length (25.1 cm) and diameter (20.1 cm), which were considerably greater than those in the control and conventional treatments, highlighting the effectiveness of nano fertilizers in improving physical fruit quality. The beneficial impact extended to internal quality traits as well, with T8 achieving the highest fruit volume (5600 cm³) and flesh thickness (4.8 cm), indicating enhanced biomass accumulation and consumer appeal. When evaluating overall productivity, T8 recorded the maximum total yield of 26,700 kg/ha, followed by T7 and T4, all of which outperformed the conventional 100% RDN treatment (22,300 kg/ha), underlining the potential of nano formulations in boosting crop yields. The harvest index, a measure of economic yield efficiency, also peaked in T8 (50.7%), indicating optimal partitioning of assimilates towards fruit development. Additionally, nano fertilizer treatments significantly accelerated crop maturity, with T8 reaching first harvest at 50.2 days compared to 58.3 days in the control, thereby offering scope for early marketability and increased cropping intensity. Remarkably, T9 (50% RDN + nano urea 1 ml/L) performed better than the full RDN (T2) in several parameters, suggesting the feasibility of reducing chemical fertilizer usage through strategic nano fertilizer integration. Across all measured indicators growth, yield attributes, fruit quality, harvest index, and days to harvest nano fertilizers, particularly in combined formulations and higher doses, consistently demonstrated superior performance, reinforcing their role as a promising nutrient management strategy in sustainable pumpkin production.

The application of nano fertilizers significantly improved the yield parameters of pumpkin, including total fruit yield, fruit volume, and fruit flesh thickness, by enhancing nutrient availability and uptake due to the nano-sized particles' high surface area and solubility. The combined treatment of nano urea and nano zinc oxide recorded the highest yield, indicating a synergistic effect of nitrogen and micronutrients on productivity. These findings are consistent with Dimkpa *et al.* (2017) and Kah *et al.* (2018) ^[6, 7, 9, 10], who reported that nano fertilizers enhance nutrient use efficiency, resulting in increased yields across various crops. In addition to yield, nano fertilizers also positively influenced fruit quality attributes such as volume and flesh thickness, which are critical for market value and consumer preference. Zinc, applied as nano zinc oxide, is essential for enzyme activation and protein synthesis, contributing to better fruit firmness and size (Cakmak, 2008) ^[3]. The sustained and controlled nutrient release from nano formulations ensures a continuous nutrient supply during critical growth phases, improving fruit development (Ahmad *et al.*, 2021) ^[1]. Similar benefits on yield and fruit quality have been reported in vegetables by Raliya *et al.* (2016) ^[15] and Sharma *et al.* (2020) ^[18], reinforcing the efficacy of nano fertilizers in enhancing both quantity and quality of produce. Overall, the increased yield parameters

under nano fertilizer treatments reflect improved nutrient assimilation and physiological efficiency compared to conventional fertilizers, making nano fertilizers a promising tool for sustainable intensification of pumpkin cultivation with enhanced economic returns.

Quality parameters

The application of nano fertilizers positively influenced the quality parameters of pumpkin fruits, including fruit dimensions (length and diameter), fruit volume, and flesh thickness. These improvements can be attributed to enhanced nutrient uptake efficiency and balanced nutrition provided by nano formulations. Nano zinc oxide, in particular, plays a critical role in enzymatic processes and protein synthesis, which contribute to better cell division and enlargement, thereby increasing fruit size and flesh thickness (Cakmak, 2008) [3]. The controlled nutrient release and better foliar absorption associated with nano fertilizers ensure continuous nutrient availability during fruit development, leading to improved fruit quality traits (Dimkpa *et al.*, 2017) [6, 7].

Moreover, combined nano fertilizer treatments resulted in superior fruit characteristics compared to individual nano applications or conventional fertilization. This synergistic effect of nano urea and nano zinc oxide enhances physiological processes such as photosynthesis and metabolic activity, which are vital for fruit growth and quality (Ahmad *et al.*, 2021) [1]. Enhanced fruit volume and flesh thickness improve marketability and consumer acceptance, directly impacting the economic value of the produce. Similar improvements in fruit quality were reported in other horticultural crops following nano fertilizer application, confirming their potential in boosting both yield and quality sustainably (Sharma *et al.*, 2020; Raliya *et al.*, 2016) [15, 18].

Economics of different treatments in pumpkins

The economics of different nutrient management treatments in pumpkin cultivation revealed that nano fertilizers significantly enhanced profitability and cost-efficiency over the control and conventional fertilization. Gross monetary returns were the lowest in the control (T1 - Rs. 48,500/ha), correlating with its poor yield performance. Conventional fertilization (T2 - Rs. 89,200/ha) showed substantial improvement, but all nano fertilizer treatments surpassed this, with the highest gross return observed in T8 (Rs. 1,02,500/ha), highlighting the superior impact of combined nano urea and nano zinc oxide applications on marketable

yield. While cost of cultivation increased across fertilized treatments, with T8 also having the highest input cost (Rs. 26,000/ha) due to the expense of nano formulations and spraying operations, the gains in productivity justified these investments. Net monetary returns mirrored the trends in gross returns, with T8 leading at Rs. 76,500/ha, followed closely by T7 (Rs. 74,100/ha), while the control lagged at Rs. 33,400/ha. Interestingly, T9, which involved 50% RDN plus nano urea, yielded Rs. 68,900/ha in net returns outperforming the full RDN treatment indicating potential for input cost reduction without sacrificing profit. The benefit-cost (B:C) ratio was highest in T7 and T8 (3.94), followed by other nano treatments, all exceeding 3.8, while the control had the lowest B:C ratio (3.21), signaling inefficient resource use. Overall, these findings confirm that nano fertilizers, especially in combined and optimized doses, not only boost yield and quality but also enhance economic returns and input efficiency, making them a sustainable and profitable alternative to traditional fertilization in pumpkin farming.

The economic analysis of pumpkin cultivation under different nano fertilizer treatments demonstrated a clear advantage in profitability over conventional fertilization and control. Although the use of nano fertilizers slightly increased the cost of cultivation due to the additional expenses associated with nano formulations and foliar application, these costs were effectively offset by substantially higher gross returns resulting from improved yield and fruit quality. This trend is consistent with the findings of Raliya *et al.* (2016) [15] and Dimkpa *et al.* (2017) [6, 7], who observed that despite higher input costs, nano fertilizers significantly boost crop productivity, leading to increased economic returns. Net monetary returns were notably higher in treatments involving combined nano urea and nano zinc oxide, indicating greater economic efficiency and profitability. Moreover, the benefit-cost (B:C) ratios of nano fertilizer treatments exceeded those of conventional fertilization and the control, highlighting better returns per unit investment. These observations are in agreement with Kah *et al.* (2018) [9, 10], who emphasized the economic viability of nano fertilizers due to their enhanced nutrient use efficiency and reduced nutrient losses. Overall, the superior net returns and B:C ratios underscore nano fertilizers as a promising, cost-effective strategy for sustainable pumpkin production, offering both agronomic and economic advantages to farmers.

Table 1: Application of Nano fertilizer for improving yield of pumpkin (*Cucurbita moschata* L.)

Treatment	Plant height (cm)	Number of leaves per plant	Leaf area per plant (cm ²)	Vine Length per Plan (cm)	Number of branches/vines per plant	Number of fruits per plant	Average Fruit Weight (g)	Total Fruit Yield per Plant (kg)	Fruit Dimensions (Length in cm)	Fruit Dimensions (Diameter in cm)	Fruit Volume (cm ³)	Fruit Flesh Thickness (cm)	Total Yield (kg/ha)	B:C ratio
T1 - Control)	59.7	13.2	375.6	153.7	4.5	2.1	610	1.28	18.6	14.5	3450	3.2	12,500	3.21
T2 - 100 % RDN (100 kg N/hectare)	84.2	18.5	496.7	198.5	6.3	3.6	780	2.81	22.3	17.8	4950	4.1	22,300	3.81
T3 - Nano urea at 1 ml/L foliar spray	87.5	19.2	510.5	203.6	6.7	3.8	795	3.02	23.1	18.4	5100	4.3	23,400	3.84
T4 - Nano urea at 2 ml/L	90.1	20.1	525.9	209.3	7.1	4.0	820	3.28	24	19.1	5300	4.5	24,800	3.9

foliar spray														
T5 - Nano zinc oxide at 0.5 g/L foliar spray	85.6	18.8	503.4	200.4	6.6	3.7	790	2.92	22.7	18	5050	4.2	23,100	3.8
T6 - Nano zinc oxide at 1 g/L foliar spray	88.0	19.6	517.2	205.9	6.9	3.9	810	3.16	23.5	18.7	5200	4.4	24,100	3.86
T7 - Combined nano urea (1 ml/L) + nano zinc oxide (0.5 g/L) foliar spray	92.4	21.2	543.8	213.2	7.4	4.2	830	3.49	24.5	19.5	5450	4.6	25,600	3.94
T8 - Combined nano urea (2 ml/L) + nano zinc oxide (1 g/L) foliar spray	95.2	22.1	558.4	218.7	7.8	4.5	850	3.83	25.1	20.1	5600	4.8	26,700	3.94
T9 - 50 % RDN (50 kg N/hectare) + Combined nano urea (1 ml/L)	86.9	19.0	508.6	202.4	6.8	3.9	800	3.12	23.3	18.5	5150	4.3	23,900	3.83
S.Em ±	1.38	0.53	6.38	2.91	0.18	0.08	11.3	0.12	0.38	0.31	110	0.08	350	
CD (P=0.05)	3.97	1.57	18.5	8.42	0.52	0.23	34.2	0.37	1.1	0.89	320	0.23	1,020	

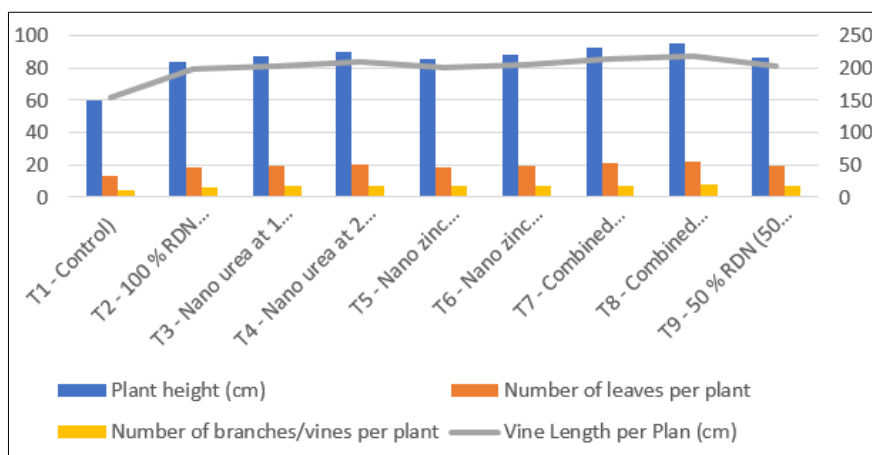


Fig 1: Application of Nano fertilizer for vegetative growth parameters of pumpkin

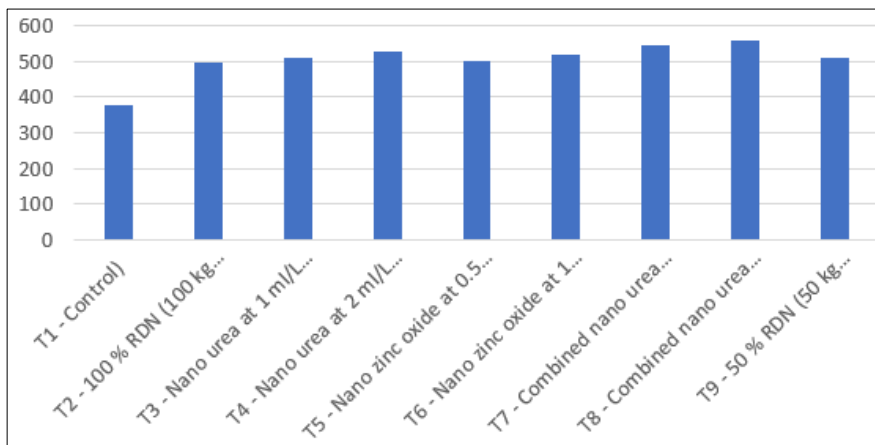


Fig 2: Application of Nano fertilizer for Leaf area per plant (cm²) of pumpkin

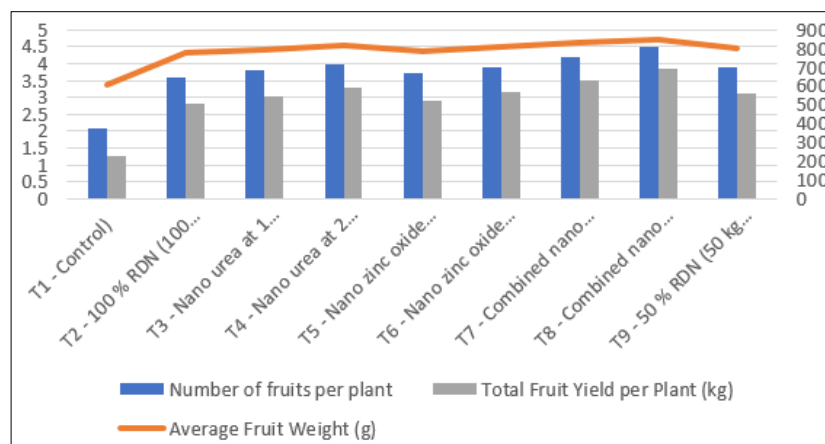


Fig 3: Application of Nano fertilizer for yield attributes of pumpkin

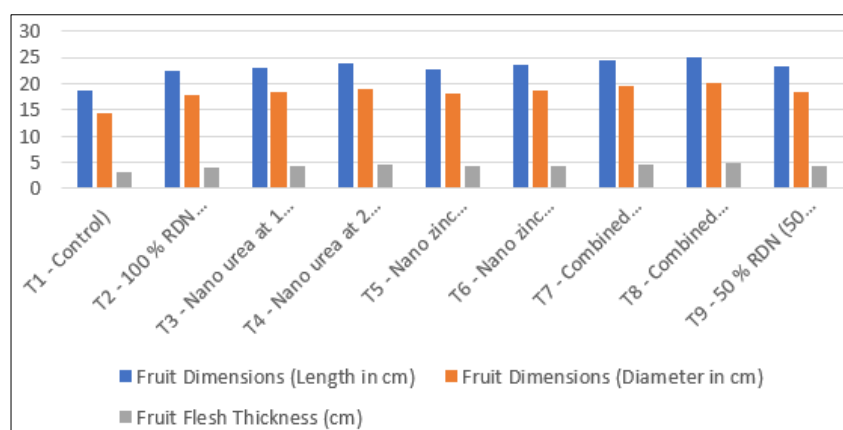


Fig 4: Application of Nano fertilizer for fruit quality parameters of pumpkin

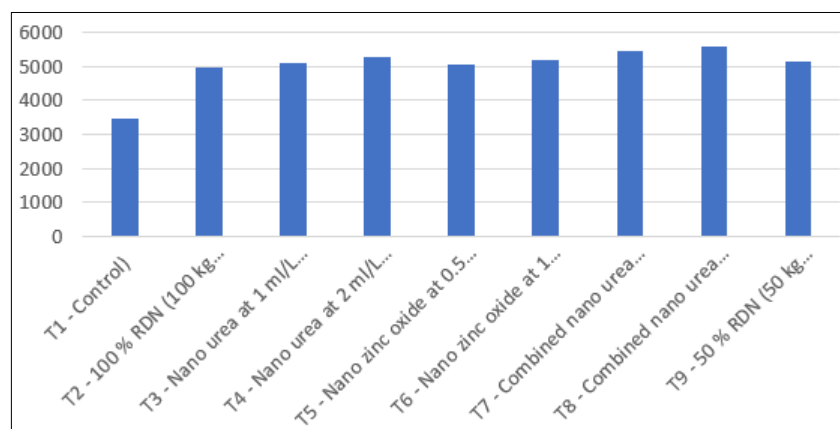


Fig 5: Application of Nano fertilizer for Fruit Volume (cm³) of pumpkin

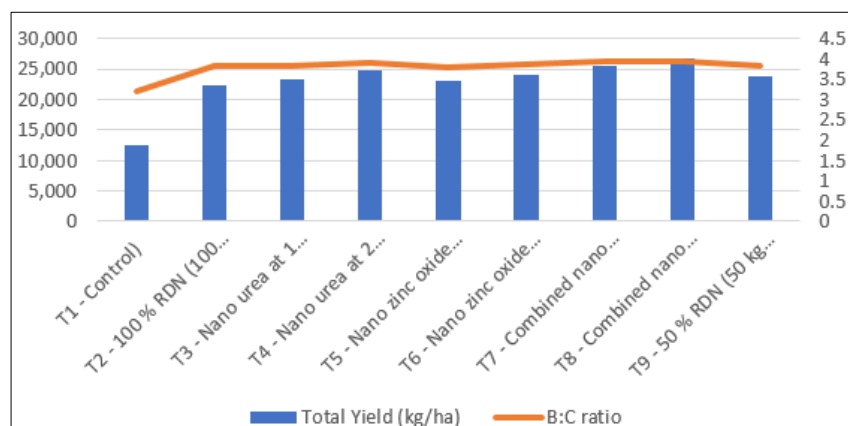


Fig 6: Application of Nano fertilizer for total yield and BC ratio of pumpkin

Conclusion

The application of nano fertilizers significantly enhanced the growth, yield, and economic returns of pumpkin compared to both the control and conventional fertilization. Among all treatments, T8 (combined nano urea 2 ml/L + nano zinc oxide 1 g/L) recorded the highest plant height (29.7 cm, 61.5 cm, and 95.2 cm at 30, 60, and 90 DAS, respectively) and maximum leaf area (173.8 to 558.4 cm²), far surpassing the control. It also produced superior fruit characteristics with 4.5 fruits per plant, an average fruit weight of 850 g, total yield of 3.83 kg per plant, and the largest fruit size and quality parameters (25.1 cm length, 20.1 cm diameter, 5600 cm³ volume, and 4.8 cm flesh thickness). Furthermore, T8 accelerated maturity, reducing the days to first harvest to 50.2 from 58.3 days in the control. Economically, T8 proved most profitable with gross returns of Rs. 1,02,500/ha, net returns of Rs. 76,500/ha, and a benefit-cost ratio of 3.94, outperforming both the control and the conventional 100% RDN treatment. Notably, T9 (50% RDN + nano urea) also delivered encouraging results (net return Rs. 68,900/ha; B:C 3.83), highlighting the potential of nano fertilizers in reducing chemical fertilizer dependency while sustaining yield and profitability. Thus, the study confirms that combined nano nutrient applications, especially in T8, offer an effective, sustainable, and economically viable strategy for pumpkin cultivation.

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