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INDUCED EFFECT OF NANOMATERIALS ON THE GROWTH AND YIELD ATTRIBUTES OF BRINJAL (*SOLANUM MELONGENA* L.) VAR. PUSA UTTAM

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ABSTRACT

India's population pressure makes it imperative to boost vegetable output to meet the country's minimal dietary requirements. Brinjal is grown all over the country and main vegetable of plains where it is available around the year. The use of nanotechnology to nanoscale fertilizer particles has produced new methods for enhancing current crop management practices. The present investigation was conducted during the *Rabi* season of 2023-24 in the polyhouse condition, with 14 numbers of treatments with 3 replications in RBD design. Combination and single doses of nanoparticles were used for study the effects over crop growth and yield. Treatment T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF) showed the significantly lowest number of days needed for the first flowering (37.42). Treatment T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF) had the significantly largest fruit output per plant (1721.52 g), which was comparable to treatments T_9 (CuO-NPs 50 ppm + ZnO-NPs 50 ppm) and T_{12} (CuO-NPs 50 ppm + ZnO-NPs 50 ppm + RDF). However, treatment T_0 (no nanoparticles and RDF) showed the lowest fruit yield per plot (2.52 kg/plot) as a control. It has been shown that applying fertilisers containing both zinc and copper together can greatly increase brinjal output by improving growth indices and lowering the incidence of disease Growth and yield are increased when zinc increases nutrient absorption, photosynthetic efficiency, and enzyme activity.

Key words : Zinc Oxide nanoparticles, Copper oxide Nanoparticles, Growth, Yield, Brinjal.

Introduction

Brinjal or eggplant (*Solanum melongena* L.), is a self-pollinated crop belonging to the family, Solanaceae. is one of the most popular and principal vegetable crops grown in India and other parts of the world. It is a perennial plant but grown as an annual. The somatic chromosome number in the domesticated species is 24. Berries can be borne individually or in clusters. It is a herbaceous, semi-spreading, erect.

Brinjal has Ayurvedic medicinal properties. The fruits of brinjal are excellent remedies for those suffering from liver troubles. White brinjal is good for diabetic patients. Brinjal is a good source of vitamins like A, B and C. Micronutrients such as zinc, copper, and boron help to increase the output of brinjal fruit as well as seeds. Micronutrients are those components needed in lesser quantities yet crucial for plant growth. Different responses to trace element deficiencies were seen in the development and yield of crop species and cultivars (Fageria, 2009). The use of nanotechnology to nanoscale fertilizer particles has produced new methods for enhancing current crop management practices (Ghafari and Razmjoo, 2013). According to Nel *et al.* (2006), nanoparticles smaller than 100 nm are found in the transitional region between individual molecules and the equivalent bulk materials, which can have both beneficial and detrimental biological impacts on live cells. ZnO has garnered the most interest among metal oxide nanoparticles thus far due to its potential applications in agriculture. Plant availability may be impacted by the solubility, diffusion, and smaller size, higher specific area, and reactivity of nanoparticulate zinc oxides in comparison to bulk zinc oxides (Scrinis and Lyons, 2007). Copper is a micronutrient that is widely distributed in plant tissues, plays a key role in many physiological processes and is necessary for growth (Sommer, 1931; Chibber *et al.*, 2013). Using metal particles as fertilizers could boost agricultural yield and growth (Raliya and Tarafdar, 2013). Henceforth keeping the above facts in view, the present study was conducted.

Materials and Methods

The present investigation entitled "Induced effect of nanomaterial on growth and yield attributes of Brinjal (*Solanum melongena* L.) var. Pusa Uttam" was conducted during the *Rabi* season of 2023-24 in the polyhouse at Crop Research Center 3 (CRC-3), Gwalior (M.P.) under the Department of Horticulture, School of Agriculture, ITM University, Gwalior (M.P.). This chapter provides a full description of the materials and techniques utilized, as well as the experimental location, soil, climate, and weather during the crop season.

Experimental site and Geographical Situation

The field experiment was carried out in a polyhouse during the Rabi season of 2023–24 at Crop Research Centre 3 (CRC-3), which is part of the Department of Horticulture at the School of Agriculture, ITM University, Gwalior (M.P.). Gwalior is situated in the northern part of Madhya Pradesh. Crop Research Centre 3 (CRC-3) of ITM University lies between 26°13' and north latitude and 78°20' east longitude and at an altitude of 317 m above mean sea level. It has an average elevation of 197 meters (646 feet). Most of it comes under the Gird area.

Polyhouse- Naturally ventilated polyhouse (NVPH)

The experiment was carried out in a Naturally ventilated polyhouse of 1950 m^2 area in North-South direction. Its frame was made up of galvanized iron pipe and the 200-micron low-density polyethylene (LDPE) was used as a cladding material. An area of 200 m^2 with 3 beds of 32 m length and 1 m breadth was used for the experiment purpose. The insect-proof net to protect against insect pests and a rollable flap of polyethylene sheet were provided over the insect net on the four sides of the polyhouse for natural ventilation and to regulate the requirement of temperature and humidity depending on the weather conditions.

Experimental details

Name of crop	Brinjal (*Solanum melongena* L.)
Variety	Pusa Uttam
Year	2023-24
Season	*Rabi*
Experimental Design	RBD (Randomized Block design)
No. of Treatments	14
No. of Replication	3
Total No. of plots	42
Planting Distance (cm)	60 × 50 cm
Bed-to-bed spacing	60 cm
No. of plants per plot	4
Total no. of plants	168
Plot size	1m^2
Type of plot	Raised bed
Date of nursery raising	17/08/2023
Date of transplanting	11/10/2023
Time of application of Nanomaterials	**Three foliar applications** 1. 30 days after transplanting 2. 60 days after transplanting 3. 90 days after transplanting

Treatment Details

Treatments	Treatment Combination
T_0	Control (no nanoparticle)
T_1	RDF
T_2	ZnO-NPs (25 ppm) RD&FS
T_3	ZnO-NPs (50 ppm) RD&FS
T_4	ZnO-NPs (100 ppm) RD&FS
T_5	CuO-NPs (25 ppm) RD&FS
T_6	CuO-NPs (50 ppm) RD&FS
T_7	CuO-NPs (100 ppm) RD&FS
T_8	CuO-NPs + ZnO-NPs (25 ppm) RD&FS
T_9	CuO-NPs + ZnO-NPs (50 ppm) RD&FS
T_{10}	CuO-NPs + ZnO-NPs (100 ppm) RD&FS
T_{11}	CuO-NPs + ZnO-NPs (25 ppm)+RDF RD&FS
T_{12}	CuO-NPs + ZnO-NPs (50 ppm)+RDF RD&FS
T_{13}	CuO-NPs + ZnO-NPs (100 ppm)+RDF RD&FS

RDF – Recommended dose of fertilizer ZnO-NPs – Zinc Oxide nanoparticle CuO-NPs – Copper Oxide nanoparticleRD&FS - Root dip and foliar spray

Varietal characteristic of Variety

Pusa Uttam was purchased from NHRDF (National Horticultural Research and Development Foundation) in Indore Madhya Pradesh. It is also a progeny selection of cross GR x 91-2. Plants non-spiny; fruits are slightly oval, glossy, dark purple, medium-sized fruits, 4-5 fruits in 1 kg. First picking 85 days after sowing and yield is 400 - 420 q /ha.

Application of nano-materials

The nano-materials used in treatments were purchased from Nano Research Lab, Jamshedpur, Jharkhand. Zinc Oxide nanoparticles are milky white powder having a density of 6g/cm^2 and Copper Oxide Nanoparticles are black to brown powder having a density of 6.4g/cm^2. These materials were used in 25, 50 and 100 ppm concentrations.

Preparation of nanoparticle solutions

As per the treatment details, 100 mg of nanoparticles dissolved in 1 liter of distilled water to prepare the concentration of 100 ppm solution of ZnO-NPs and CuO-NPs. Similarly, 50 mg of nanoparticles dissolved in 1 liter of distilled water to prepare the concentration of 50 ppm solution of ZnO-NPs and CuO-NPs and 25 mg of nanoparticles dissolved in 1 liter of distilled water to prepare the concentration of 25 ppm solution of ZnO-NPs and CuO-NPs.

Method of treatment application

Two methods are used for giving treatments

Root dipping : Uniform healthy seedlings were uprooted from the nursery tray without damaging fibrous roots and washed gently in the water. After that roots of the seedlings were dipped in different concentrations of nanoparticle solution (*i.e.* 25, 50, 100 ppm and their combination) according to the treatments for 1 hour before transplanting and then seedlings were transplanted into the plots.

Foliar application : In this method, the solution of nanoparticles was sprayed directly on the plants at 30, 60, and 90 days after transplanting according to their different concentration of treatments using a hand sprayer till the leaves on both sides were completely wet with the solution.

Observations recorded

In each treatment, four plants were chosen and labelled so that observations could be made at various intervals (30, 60 and 90 days) following transplanting. The last observation, which is the 90 days following transplantation, is shown in the data in Tables 1, 2 and 3.

Growth attributes : Plant height (cm)**;** Stem girth (mm)**;** Leaf area per plant (mm^2); Leaf area index (m^2); No. of primary branches per plant; No. of leaves per plant; Chlorophyll content in leaves (SPAD); Days to 1st flowering

Yield and yield attributes : No. of fruit per plant; Fruit length (cm); Fruit circumference (cm); Average Fruit weight (g.); Fruit yield per plant (g.); Fruit yield per plot (kg); Fruit yield per hectare (q/ha)

Statistical analysis

An RBD (randomized block design) was used to organize the experiment. The analysis of variance approach, as outlined by Panse and Sukhatme (1967), was used to examine the data gathered from the parameters under investigation. The "F" test employed a five percent significance level. When the "F" test was significant at the five percent level, the critical difference (CD) values are displayed in the table at the five percent significance level.

Results and Discussion

Vegetative attributes

Plant height (cm.)

At 90 days after transplanting, treatment T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF) showed a considerably greater plant height (45.22 cm), which held steady with treatment T_{12} (CuO-NPs 50 ppm + ZnO-NPs 50 ppm + RDF) and T_9 (CuO-NPs 50 ppm + ZnO-NPs 50 ppm) Table 1. Plant height (30.14 cm) was significantly lower in treatment T_0, or the absolute control (no nanoparticle or RDF). A similar finding was also made by Kalroo *et al.* (2013), who determined that the growth and yield contributing attributes progressively improved with an increase in zinc levels. With a zinc content of 5 ml/l of water, the plants reached a height of 85.66 cm, a spread of 77 cm, 13 branches per plant and flower emergence took 56.33 days.

Stem girth (mm)

Under treatment T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF), the maximum stem girth (13.59 mm) at 90 days after transplanting was recorded. This was statistically comparable to treatment T_{12} (CuO-NPs 50 ppm + ZnO-NPs 50 ppm + RDF) and treatment T_9 (CuO-NPs 50 ppm + ZnO-NPs 50 ppm). Significantly minimum stem girth (6.89 mm) was found in treatment T_0 Control (no nanoparticle or RDF) at the interval of 90 days after transplanting (Table 1). One significant growth parameter that affects the stability and general health of plants is stem girth. When Zn and Cu were applied externally, stem girth increased dramatically in comparison to the control. The largest increase in stem girth was observed with the combined Zn and Cu treatment, suggesting a synergistic effect. Cell wall growth and stem strength depend on zinc and copper (Alloway, 2008; Broadley *et al.*, 2007).

Total leaf area (mm^2)

Remarkably, 90 days after transplanting, T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF) had the highest average leaf area per plant (241.22 mm^2), followed by T_{12} (CuO-NPs 50 ppm + ZnO-NPs 50 ppm + RDF) (226.53 mm^2) and T_9 (CuO-NPs 50 ppm + ZnO-NPs 50

Table 1 : Effect of induced effect of nanoparticles on Growth attributes of Brinjal (*Solanum melongena* L.) var. Pusa Uttam".

Treatment	Plant height (cm)	Stem girth (cm)	No. of leaves	Chlorophyll (SPAD)	Leaf area per plant (mm^2)	LAI (m^2)	No. of primary branch
T_0	30.14 ± 0.10^{e}	6.89 ± 0.23^{g}	27.75 ± 4.01^{f}	52.69 ± 1.80^{e}	151.69 ± 0.48^{h}	0.51 ± 0.03^{g}	4.00 ± 0.00^{f}
T_1	34.82 ± 0.10^{cd}	7.83 ± 0.43^{fg}	42.70 ± 1.25^{de}	55.54 ± 0.31^{cde}	172.66 ± 1.68^{g}	0.60 ± 0.04^{f}	4.92 ± 0.82^{def}
T_2	33.38 ± 0.57^{cde}	8.87 ± 0.33^{ef}	37.00 ± 4.21^{ef}	54.30 ± 2.03^{de}	211.21 ± 14.41^{cd}	0.70 ± 0.04^{de}	5.83 ± 0.44^{abcd}
T_3	35.34 ± 1.21^{cd}	8.00 ± 0.07^{fg}	37.92 ± 1.88^{ef}	54.75 ± 1.77^{cde}	211.39 ± 6.92^{bcd}	0.74 ± 0.01^{cd}	5.33 ± 0.20^{bcde}
T_4	31.08 ± 0.88^{de}	7.18 ± 0.18^{g}	35.59 ± 0.31^{ef}	54.09 ± 1.29^{de}	193.60 ± 0.68^{ef}	0.62 ± 0.01^{f}	5.03 ± 0.09^{cde}
T_5	32.64 ± 1.10^{cde}	9.41 ± 0.56^{de}	45.50 ± 6.08^{cde}	54.29 ± 0.69^{de}	220.05 ± 11.86^{bc}	0.73 ± 0.04^{cd}	5.58 ± 0.33^{abcde}
T_6	35.25 ± 0.20^{cd}	10.19 ± 0.75^{cd}	54.47 ± 0.54^{bc}	56.05 ± 1.13^{cde}	188.42 ± 1.18^{ef}	0.82 ± 0.03^{b}	5.67 ± 0.08^{abcde}
T_7	34.64 ± 0.08^{cd}	9.34 ± 0.39^{de}	42.20 ± 1.37^{de}	55.80 ± 0.95^{cde}	184.77 ± 0.35^{fg}	0.62 ± 0.04^{ef}	5.33 ± 0.08^{bcde}
T_8	34.47 ± 1.41^{cde}	$9.92 \pm 0.60^{cd}e$	51.42 ± 6.87^{bcd}	56.49 ± 0.32^{bcd}	215.72 ± 3.96^{bcd}	0.71 ± 0.01^{d}	6.00 ± 0.38^{abc}
T_9	36.92 ± 0.10^{bc}	10.56 ± 0.33^{bc}	57.07 ± 0.08^{b}	57.92 ± 2.03^{abc}	226.05 ± 1.48^{abc}	0.79 ± 0.02^{bc}	6.33 ± 0.09^{ab}
T_{10}	32.52 ± 2.96^{cde}	9.39 ± 0.48^{de}	45.40 ± 0.40^{cde}	57.10 ± 1.56^{bcd}	200.65 ± 0.49^{de}	0.62 ± 0.01^{ef}	4.67 ± 0.58^{ef}
T_{11}	45.22 ± 1.22^{a}	13.59 ± 0.274^{a}	69.51 ± 1.69^{a}	61.15 ± 1.96^{abc}	241.22 ± 0.51^{a}	0.96 ± 0.01^{a}	6.58 ± 0.2^{a}
T_{12}	40.91 ± 4.32^{ab}	11.54 ± 0.33^{b}	60.67 ± 3.28^{ab}	59.91 ± 1.62^{ab}	226.53 ± 0.60^{ab}	0.84 ± 0.01^{b}	6.42 ± 0.22^{a}
T_{13}	32.55 ± 0.53^{cde}	9.93 ± 0.43^{cde}	54.30 ± 8.48^{bc}	57.44 ± 0.99^{bcd}	214.57 ± 0.63^{bcd}	0.76 ± 0.04^{bcd}	5.58 ± 0.22^{abcde}
C.D. (p=0.05)	**4.44**	**1.14**	**10.80**	**3.60**	**15.27**	**0.08**	**1.02**
SE(m)	**1.52**	**0.39**	**3.70**	**1.23**	**5.22**	**0.03**	**0.35**

ppm) (226.05 mm^2) shown in Table 1. Significantly at the same interval T_0 Control (no nanoparticle or RDF) shows the lowest leaf area per plant (151.69 mm^2). Similar findings were reported by Karthick *et al.* (2018), who found that the maximum mean values for morphological and growth parameters, such as vine length, node count, total leaf area per plant and leaf area index in bitter gourd, were considerably recorded upon the use of $ZnSO_4$+ $FeSO_4$+ $MgSO_4$ each at 0.5% at 35 and 45 DAS.

Leaf area index (m^2)

Light interception, photosynthesis and yield are all impacted by the leaf area index. Higher LAI values often correspond to higher productivity and photosynthetic potential. In comparison to the other treatments, A considerably greater leaf area index (0.96 m^2) was reported at 90 days after transplanting in T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF) as compared to T_{12} (CuO-NPs 50 ppm + ZnO-NPs 50 ppm + RDF) and T_{13} (CuO-NPs 50 ppm + ZnO-NPs 50 ppm). significantly smaller leaf area index (0.51 m^2) was recorded in treatment T_0 Control. A higher Leaf area index was obtained from combined Zn oxide and Cu oxide treatments that enhanced plant vigor and leaf area (Prasad *et al.*, 2012).

Number of primary branches

Periodic observations about the number of primary branches per plant during 30, 60, and 90 days, final data (90 days) are shown in Table 1. The T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF) treatment had a majority of primary branches per plant (6.58 respectively) at 90 days after transplanting. This was statistically similar to the T_{12} treatment, which had (6.42) numbers of primary branches per plant respectively, of CuO-NPs 50 ppm + ZnO-NPs 50 ppm + RDF. However, at 90 DAT, the minimum number of primary branches per plant (4.00) was seen under treatment T_0 (No. nanoparticles and RDF) control. Ullah *et al.* (2015) In an experiment, observed similar results: among various Zn 0.4% levels, there was a considerable rise in the number of flowers cluster plants (27.45), flowers 1 cluster (5.66), fruits cluster (4.57), branches plant (7.36), and yield (t/ha) (23.40).

Number of leaves per plant

The treatment with the largest number of leaves per plant (69.51) at 90 days post-transplantation was T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF), followed by T_{12} (CuO-NPs 50 ppm + ZnO-NPs 50 ppm + RDF) and T_9 (CuO-NPs 50 ppm + ZnO-NPs 50 ppm). T_0 (no nanoparticles and RDF) had the considerably lowest number of leaves per plant (27.75) observed at 90 days after transplanting. Plants use photosynthesis to transform light energy into chemical energy, and leaves are the main organ for this process. The photosynthetic capacity of the plant can be improved by having more leaves, which will increase biomass accumulation and yields. Research has demonstrated that applying zinc to crops like tomato and brinjal can greatly enhance the number of leaves (Prasad *et al*., 2012). Similar results were also achieved by Shnain *et al.* (2014), who observed that, in tomato plants grown in Allahabad's agroclimatic conditions, simultaneous applications of 1.25 g/l of zinc and 1.93 g/l of boron produced the highest plant height (2.93 m) and number of leaves per plant (39.33).

Chlorophyll content (SPAD)

When the leaves were examined 90 days after transplanting, treatment T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF) had the considerably highest chlorophyll content (61.15 SPAD), which was comparable to treatment T_{12} (CuO-NPs 50 ppm + ZnO-NPs 50 ppm + RDF) and treatment T_9 (CuO-NPs 50 ppm + ZnO-NPs 50 ppm). The control treatment, T_0, which had no nanoparticles and RDF, had the lowest amount of chlorophyll in their leaves, (52.69 SPAD). An essential component in the production of chlorophyll is zinc. It functions as a cofactor for the protochlorophyllide reductase enzyme, which is required for the synthesis of chlorophyll. It was discovered that one of the possible reasons for the loss of chlorophyll in plants could be the deficiency of vital micronutrients such as zinc and iron, zinc and copper, or zinc and manganese (Sharma *et al*., 2008).

Flowering attributes

Days to first flowering (days)

The treatment T_0 control (no nanoparticles and RDF) had the significantly highest number of days needed for the first flowering (65.90), which was comparable to the treatments T_4 (ZnO-NPs 100 ppm), T_7 (CuO-NPs 100 ppm), and T_{13} (CuO-NPs 100 ppm + ZnO-NPs 100 ppm + RDF). Treatment T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF) showed the significantly lowest number of days needed for the first flowering (37.42) (Table-2). Treatment T_9 (CuO-NPs 50 ppm + ZnO-NPs 50 ppm) followed behind similarly (39.37) days. Indole acetic acid (IAA), a hormone that is essential for the commencement and development of flowers, is derived from tryptophan, which is synthesised with zinc. Plants that are more resistant to stressors such as salt, drought, and pests may develop more robustly and blossom earlier as a result of the application of nanomaterials in their growth. An optimized growth cycle that supports early reproductive stages can result from increased stress tolerance (Dimkpa *et al*., 2017).

Fruit and yield attributes

Number of fruits per plant (nos)

At treatment T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF), the number of fruits per plant was substantially higher (7.42) than in treatment T_9 (CuO-NPs 50 ppm + ZnO-NPs 50 ppm) (6.83) and T_{12} (CuO-NPs 50 ppm + ZnO-NPs 50 ppm + RDF) (6.25). The control treatment, T_0, without RDF and nanoparticles, had the notably lowest quantity of fruits per plant (3.42) (Table 2). The increased production and accumulation of carbohydrates as well as the beneficial effects on vegetative growth and the retention of flowers and fruits may be the cause of the increased number of fruits resulting from the foliar spraying of micronutrients. A similar result was reported by, Elmer *et al.* (2021). In their investigation that CuO NPs applied alone at 500 µg/ml increased fruit yield, biomass and disease suppression. When compared to untreated controls, CuO NPs were linked to increases in fruit yield (17 and 33% increase) and disease suppression (28 and 22% reduction), respectively.

Fruit length and diameter (cm.)

In comparison to treatments T_9 (CuO-NPs 50 ppm + ZnO-NPs 50 ppm) and T_8 (CuO-NPs 25 ppm + ZnO-NPs 25 ppm), treatment T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF) showed the significantly longest fruit length (12.74 cm). Treatment T_0 (no nanoparticles and RDF) as control showed the significantly lowest fruit length (8.70 cm). Treatment T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF) had the maximum fruit diameter (8.26 cm) of all the treatments, with T_9 (CuO-NPs 50 ppm + ZnO-NPs 50 ppm) coming in second (8.10 cm). Concerning fruit diameter, Treatment T_0 (no nanoparticles and RDF) had the considerably lowest result (6.36 cm). Nanoparticles can boost light absorption and chlorophyll content to increase photosynthetic efficiency. Longer fruits can be produced by directing the extra energy produced by better photosynthesis into fruit development (Giraldo *et al*., 2014).

Fruit weight (gm)

Treatment T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF) had the significantly highest fruit weight (229.50 g), which remained at par with treatments T_9 (CuO-NPs 50 ppm + ZnO-NPs 50 ppm), T_{12} (CuO-NPs 50 ppm + ZnO-NPs 50 ppm + RDF), and T_{13} (CuO-NPs 100 ppm + ZnO-NPs 100 ppm + RDF). Fruit weight

Table 2 : Effect of induced effect of nanoparticles on Flowering and fruiting attributes of Brinjal (*Solanum melongena* L.) var. Pusa Uttam".

Treatment	Days to 1st flowering	No. of fruit/plant	Fruit length in (cm)	Fruit diameter (cm)	Fruit weight (g)
T_0	65.90 ± 3.12^{a}	3.42 ± 0.22^{h}	8.70 ± 0.56^{e}	6.36 ± 0.13^{e}	179.58 ± 0.87^{h}
T_1	47.20 ± 0.85^{de}	4.58 ± 0.08^{de}	9.04 ± 0.15^{de}	7.08 ± 0.27^{de}	214.42 ± 0.71^{b}
T_2	$48.65 \pm 0,88^{cd}$	5.08 ± 0.08^{d}	9.97 ± 0.34^{cde}	$7.54 \pm 0,38^{cde}$	193.00 ± 2.88^{ef}
T_3	46.83 ± 0.53^{de}	4.67 ± 0.08^{de}	10.21 ± 0.11^{bcd}	7.64 ± 0.22^{bcd}	193.50 ± 1.28^{ef}
T_4	62.91 ± 1.52^{ab}	4.33 ± 0.08^{efg}	10.78 ± 0.08^{bc}	6.75 ± 0.42^{bc}	191.58 ± 0.65^{fg}
T_5	43.58 ± 1.47^{ef}	4.50 ± 0.25^{ef}	11.04 ± 0.21^{bc}	7.31 ± 0.21^{bc}	192.50 ± 0.52^{fg}
T_6	40.45 ± 0.87^{fg}	4.00 ± 0.14^{fg}	10.94 ± 0.61^{bc}	7.67 ± 0.11^{bc}	190.50 ± 0.90^{fg}
T_7	60.86 ± 1.66^{b}	3.83 ± 0.22^{gh}	10.71 ± 0.43^{bc}	7.14 ± 0.03^{bc}	187.8 ± 0.73^{g}
T_8	42.25 ± 1.16^{f}	4.83 ± 0.08^{de}	11.18 ± 1.24^{bc}	7.32 ± 0.14^{bc}	198.0 ± 1.31^{de}
T_9	39.37 ± 1.21^{fg}	6.83 ± 0.08^{b}	11.50 ± 0.42^{ab}	8.10 ± 0.06^{ab}	215.83 ± 0.80^{b}
T_{10}	51.75 ± 2.66^{c}	4.42 ± 0.33^{ef}	10.68 ± 0.16^{bc}	7.57 ± 0.25^{bc}	191.92 ± 0.88^{fg}
T_{11}	37.42 ± 0.94^{g}	7.42 ± 0.08^{a}	12.74 ± 0.51^{a}	8.26 ± 0.49^{ab}	229.50 ± 4.23^{a}
T_{12}	47.45 ± 1.35^{cde}	6.25 ± 0.38^{c}	10.76 ± 0.42^{bc}	7.12 ± 0.13^{bc}	208.83 ± 1.18^{c}
T_{13}	59.92 ± 3.53^{b}	4.67 ± 0.22^{de}	9.96 ± 0.60^{cde}	7.06 ± 0.25^{cde}	201.00 ± 2.18^{d}
C.D. (p=0.05)	**4.51**	**0.51**	**1.52**	**0.69**	**5.15**
SE(m)	**1.54**	**0.18**	**0.52**	**0.24**	**1.76**

Table 3 : Effect of induced effect of nanoparticles on yield attributes of Brinjal (*Solanum melongena* L.) var. "Pusa Uttam".

Treat-ment	Fruit yield /plant (g)	Yield/plot (kg)	Yield quintal/ha
T_0	628.64 ± 27.44^{j}	2.52 ± 0.11^{j}	251.46 ± 10.98^{j}
T_1	1000.38 ± 32.31^{d}	4.00 ± 0.13^{d}	400.15 ± 12.93^{d}
T_2	996.21 ± 16.84^{d}	3.99 ± 0.07^{d}	398.48 ± 6.74^{d}
T_3	902.86 ± 12.91^{defg}	3.61 ± 0.05^{defg}	361.14 ± 5.17^{defg}
T_4	830.11 ± 13.66^{gh}	3.32 ± 0.05^{gh}	332.04 ± 5.46^{gh}
T_5	866.50 ± 50.26^{efg}	3.46 ± 0.20^{efg}	346.60 ± 20.10^{efg}
T_6	762.06 ± 28.45^{hi}	3.05 ± 0.11^{hi}	304.83 ± 11.38^{hi}
T_7	720.17 ± 42.60^{ij}	2.88 ± 0.17^{ij}	288.07 ± 17.04^{ij}
T_8	957.60 ± 22.58^{de}	3.83 ± 0.09^{de}	383.04 ± 9.03^{de}
T_9	1474.73 ± 12.52^{b}	5.90 ± 0.05^{b}	589.89 ± 5.01^{b}
T_{10}	847.52 ± 63.43^{fgh}	3.39 ± 0.25^{fgh}	339.01 ± 25.37^{fgh}
T_{11}	1721.52 ± 51.25^{a}	6.89 ± 0.20^{a}	688.61 ± 20.50^{a}
T_{12}	1305.02 ± 78.89^{c}	5.22 ± 0.32^{c}	522.01 ± 31.56^{c}
T_{13}	938.92 ± 54.01^{def}	3.76 ± 0.22^{def}	375.57 ± 21.60^{def}
C.D. (p=0.05)	**100.71**	**0.40**	**40.29**
SE(m)	**34.45**	**0.14**	**13.78**

(179.58 g) was significantly lowest in treatment T_0 control (no nanoparticles and RDF). Similar results were found by Mishra *et al*. (2023), who noted that treatment T_4 (RDF+$ZnSO_4$ 0.5%) had the greatest fruit weight, the earliest days to first fruit harvest, and the shortest number of days needed for first flower initiation

Yield

Treatment T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF) had the significantly largest fruit output per plant (1721.52 g), which was comparable to treatments T_9 (CuO-NPs 50 ppm + ZnO-NPs 50 ppm) and T_{12} (CuO-NPs 50 ppm + ZnO-NPs 50 ppm + RDF). However, treatment T_0 (no nanoparticles and RDF) showed the lowest fruit yield per plot (2.52 kg/plot) as a control. The treatment T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF) had the considerably largest fruit yield (688.61 q per ha), which was statistically comparable to treatments T_9 (CuO-NPs 50 ppm + ZnO-NPs 50 ppm) and T_{12} (CuO-NPs 50 ppm + ZnO-NPs 50 ppm + RDF). It has been shown that applying fertilisers containing both zinc and copper together can greatly increase brinjal output by improving growth indices and lowering the incidence of disease. Essential micronutrients like zinc and copper have significant effects on brinjal production. Growth and yield are increased when zinc increases nutrient absorption, photosynthetic efficiency, and enzyme activity. Similar findings were obtained by Tawab et al. (2015) in their experiment, which recorded the cultivar Purple brinjal's maximum fruit count (7.42), fruit weight (210.583 g), and total yield (10.21 t/ha). According to the growth and yield metrics, cultivar Purple sprayed with 0.2% zinc produced the greatest results; as a result, producers of brinjal are advised to use it.

Conclusion

From the conducted research trail, it can be concluded that T_{11} (CuO-NPs 25 ppm + ZnO-NPs 25 ppm + RDF), showed the best results in both growth and yield attributes. Using metal particles as fertilizers could boost agricultural yield and growth. Sufficient zinc levels ensure optimal auxin function, which influences the growth of plant. Nanoparticles are having the ability of easy absorption by the plant tissues and stimulate the growth and developments. Combination of CuO-NPs, ZnO-NPs with RDF dose helps the farmers to increase the production of the brinjal.

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