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EFFICACY OF DIFFERENT NANOPARTICLES, NEEM EXTRACT AND FUNGICIDE ON GROWTH AND YIELD ATTRIBUTES OF TOMATO (*SOLANUM LYCOPERSICUM* L.) SEEDLINGS

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ABSTRACT

A field experiment was conducted during the 2023–24 season at the Student Instructional Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur to evaluate the efficacy of various nanoparticles on the growth and yield parameters of tomato seedlings. The study comprised twelve treatments, including silver nanoparticles (AgNP), copper nanoparticles (CuNP), neem extract, and mancozeb fungicide, alongside an untreated control. Performance was assessed based on shoot and root length, shoot and root weight, the number of branches and fruits per plant, and total yield per plot, with observations recorded at 30, 45 and 60 days after transplanting (DAT).

The results indicated significant statistical differences among the treatments, with Treatment T_3 (AgNP @ 100 ppm) demonstrating the highest performance across all recorded metrics at 60 DAT. Specifically, T_3 achieved a maximum shoot length of 41.92 cm, root length of 35.15 cm, shoot weight of 90.40 g, and root weight of 14.30 g. Furthermore, it produced the highest number of branches (6.47) and fruits (53.66) per plant, resulting in a peak yield of 1660 g/plot. In contrast, the lowest performance was consistently observed in the infected control (T_{12}). These findings clearly demonstrate that silver nanoparticles at a concentration of 100 ppm are highly effective in stimulating the growth and enhancing the overall yield of tomato crops.

Key words : Tomato, Neem Extract, Nanoparticles, Growth Parameters, Yield.

Introduction

The tomato (*Solanum lycopersicum* L.) is globally recognized as a premier vegetable crop, valued for its significant nutritional profile, medicinal properties, and high economic returns. Rich in vitamins, minerals, antioxidants, and lycopene, tomato fruits play a vital role in human health and nutrition (Rai *et al.*, 2009). Despite its importance, tomato cultivation faces persistent challenges from various biotic and abiotic stresses that constrain its potential productivity. In response, nanotechnology has emerged as a groundbreaking frontier in agricultural science, offering innovative solutions for enhancing plant growth, optimizing disease management, and bolstering crop yields.

The efficacy of nanoparticles is primarily attributed to their unique physicochemical properties, such as their ultra-small dimensions and high surface-area-to-volume ratio, which facilitate superior interaction with plant systems and stimulate essential physiological processes (Raliya and Tarafdar, 2020). Previous research has indicated that the application of metallic nanoparticles can significantly improve seedling development, nutrient assimilation, photosynthetic efficiency, and overall plant vigor (El-Sayed *et al.*, 2021). Specifically, silver nanoparticles (AgNPs) and copper nanoparticles (CuNPs) have garnered substantial interest due to their potent antimicrobial properties and growth-promoting effects across various botanical species (Jo *et al.*, 2009). Evidence suggests that AgNPs can catalyze plant growth by enhancing enzymatic activity and chlorophyll synthesis while increasing resistance to pathogenic infections (Mukherjee *et al.*, 2014). Similarly, CuNPs have been shown to positively influence biomass accumulation and vegetative development in several crops, including tomatoes (Singh and Kumar, 2022).

Recent advancements further suggest that nano-based formulations outperform conventional agricultural treatments in terms of both yield and crop quality (Gupta *et al*., 2024). While botanical alternatives, such as neem extract, have long been utilized as eco-friendly strategies for disease management and growth promotion (Singh *et al*., 2016), comparative field-scale evaluations between nanoparticles and traditional plant extracts remain limited. Consequently, this investigation was designed to evaluate and compare the impact of silver nanoparticles, copper nanoparticles, neem extract, and mancozeb fungicide on the growth and yield attributes of tomato seedlings under field conditions.

Materials and Methods

The experiment was conducted under field conditions during the *Rabi* season of 2023–24 at the Student Instructional Farm of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, India. To ensure statistical rigor and minimize spatial variability, the field trial was laid out in a Randomized Block Design (RBD). The study incorporated three independent replications for each of the twelve treatments, allowing for a comprehensive comparative analysis of the effects of silver nanoparticles, copper nanoparticles, botanical extracts, and conventional fungicides on tomato seedlings. Standard agronomic practices were uniformly maintained across all plots to ensure that the observed variations in growth and yield parameters were solely attributable to the applied treatments.

Seed Selection and procurement

The tomato cultivar Azad T-6 was selected for this study due to its widespread cultivation and popularity among local farming communities in the Kanpur district (U.P.). Despite its commercial importance, this variety is notably susceptible to late blight (*Phytophthora infestans*), making it an ideal candidate for evaluating the protective and growth-promoting effects of nanoparticles. High-quality seeds were procured from the Vegetable Research Farm at Chandra Shekhar Azad University of Agriculture & Technology, Kalyanpur, Kanpur, to ensure genetic purity and uniformity across all experimental trials.

Treatment details : The treatments included in the study were:

S. no.	Treatments	Concentration
T_1	Seedling treatment and foliar spray with AgNP	50 ppm
T_2	Seedling treatment and foliar spray with AgNP	75 ppm
T_3	Seedling treatment and foliar spray with AgNP	100 ppm
T_4	Seedling treatment and foliar spray with CuNP	50 ppm
T_5	Seedling treatment and foliar spray with CuNP	75 ppm
T_6	Seedling treatment and foliar spray CuNP	100 ppm
T_7	Seedling treatment and foliar spray with Neem extract	250 ppm
T_8	Seedling treatment and foliar spray with Neem extract	500 ppm
T_9	Seedling treatment and foliar spray with Neem extract	750 ppm
T_{10}	Foliar spray with Mancozeb fungicide	2000 ppm
T_{11}	Control (Healthy)	
T_{12}	Control (Infected)	

Data collection and Yield attributes

Growth and yield parameters were systematically monitored at three critical developmental stages: 30, 45, and 60 days after transplanting (DAT). Physiological growth metrics included shoot length (cm), root length (cm), shoot fresh weight (g) and root fresh weight (g). Additionally, the number of primary branches per plant was recorded to assess vegetative vigor. To evaluate reproductive performance and productivity, yield attributes—specifically the number of fruits per plant and the total yield per plot (g)—were meticulously documented at each interval.

Statistical analysis

The experimental data were subjected to statistical analysis using OPSTAT software, following the standard procedure for a Randomized Block Design (RBD). To determine the significance of the treatments, the Critical Difference (CD) was calculated at a 5% level of significance (P = 0.05). Furthermore, the Standard Error of the Mean (SEm±) and the Coefficient of Variation were computed to assess the precision of the experimental results and the degree of variation between treatments.

Results and Discussion

Impact on shoot and Root morphogenesis

Analysis of the experimental data revealed that the application of various treatments significantly influenced the vegetative architecture of tomato plants across all growth stages. At 60 days after transplanting (DAT),

Table 1 : Effect of different nanoparticles on shoot length (cm) and root length(cm) of tomato seedlings.

Treatments	2023-24					
	Shoot length after transplanting			Root length after transplanting		
	30 days	45 days	60 days	30 days	45 days	60days
T_1	15.28	23.87	34.28	11.09	24.62	31.66
T_2	16.43	26.14	38.11	12.70	25.16	33.78
T_3	20.31	31.36	41.92	14.41	28.50	35.15
T_4	14.99	23.19	31.77	10.83	24.44	29.80
T_5	16.03	25.65	36.00	12.12	25.02	31.90
T_6	18.90	28.93	40.37	13.28	26.36	34.22
T_7	12.38	19.49	22.69	9.90	19.44	27.13
T_8	12.76	20.89	24.45	10.10	22.51	28.14
T_9	13.80	22.71	28.90	10.68	23.85	28.75
T_{10}	11.98	15.58	24.32	9.25	17.63	26.90
T_{11}	10.84	12.88	22.08	9.94	13.60	22.20
T_{12}	9.65	11.37	20.91	7.80	11.13	18.38
CD at 5%	2.911	4.438	6.171	0.446	1.150	1.500
SE(m)	0.986	1.503	2.090	0.151	0.390	0.508
SE(d)	1.395	2.126	2.956	0.214	0.551	0.719
CV	11.823	11.925	11.878	2.377	3.088	3.036

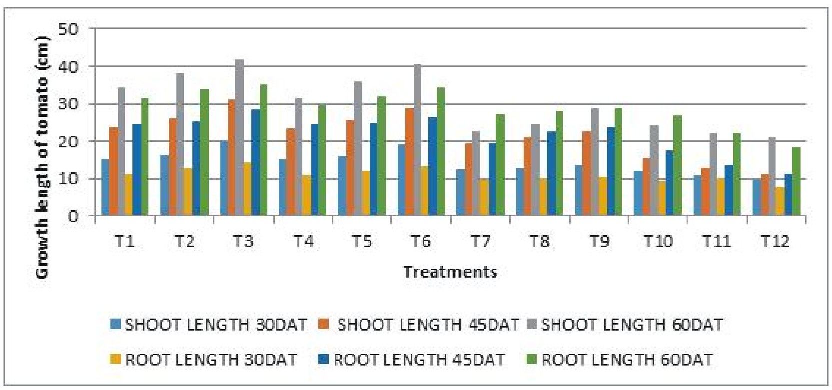

Fig. 1 : Effect of different nanoparticles on shoot and root length(cm) of tomato seedling.

Treatment T_3 (AgNP @ 100 ppm) exhibited the most pronounced effect, recording a maximum shoot length of 41.92 cm and a root length of 35.15 cm. These values were found to be statistically superior to all other treatments, as detailed in Table 1 and Fig. 1. Conversely, the minimum growth parameters were consistently recorded in the Infected Control (T_{12}), highlighting the restrictive impact of untreated biotic stress on plant development.

The observed enhancement in vegetative growth following AgNP application aligns with the findings of Khan *et al*. (2020), who reported a significant increase in plant height and root development in nanoparticle-treated crops. The positive influence of nanoparticles on root architecture and elongation—critical for efficient resource acquisition—has also been documented by El-Sayed *et al*. (2021). This improvement in shoot and root metrics is likely attributed to the unique ability of silver nanoparticles to stimulate cell division, facilitate superior nutrient absorption, and catalyze essential enzymatic activities within the plant system. These results are further corroborated by Khodakovskaya *et al*. (2012), who noted increased plant height and root proliferation in treated subjects, and Mukherjee *et al*. (2014), who suggested that AgNPs optimize physiological processes to drive robust vegetative growth.

Impact on Biomass accumulation (Shoot and Root Weight)

The application of nanoparticle treatments exerted a significant influence on biomass accumulation, measured as shoot and root fresh weight. At the 60 DAT interval, Treatment T_3 (AgNP @ 100 ppm) achieved the highest recorded biomass, with a shoot weight of 90.40 g and a root weight of 14.30 g. This was followed by Treatment T_6 (CuNP @ 100 ppm), which also showed substantial gains compared to the traditional treatments. In contrast, the Infected Control (T_{12}) exhibited the lowest biomass production, as evidenced by the data presented in Table 2 and Fig. 2.

The marked increase in biomass among nanoparticle-

Table 2 : Effect of different nanoparticles on shoot and root weight(g) of tomato seedlings.

Treatments	2023-24					
	Shoot weight after transplanting			Root weight after transplanting		
	30 days	45 days	60 days	30 days	45 days	60days
T_1	46.68	59.87	77.47	5.00	8.51	12.72
T_2	50.39	66.76	87.13	5.96	9.20	13.35
T_3	60.88	73.44	90.40	6.87	10.04	14.30
T_4	44.20	58.49	70.09	4.80	8.12	12.01
T_5	49.39	62.36	85.51	5.72	8.86	13.00
T_6	52.40	69.67	89.10	6.53	9.78	14.08
T_7	31.00	47.15	55.90	3.67	6.39	10.46
T_8	36.37	50.10	63.23	4.29	7.06	11.24
T_9	40.25	53.27	68.80	4.71	7.43	11.90
T_{10}	27.16	41.36	52.22	3.33	5.27	9.31
T_{11}	24.38	33.16	51.22	2.34	4.89	7.28
T_{12}	18.49	28.92	38.14	2.19	3.11	6.07
CD at 5%	2.114	2.171	3.053	0.199	0.355	0.415
SE(m)	0.716	0.735	1.034	0.068	0.120	0.141
SE(d)	1.013	1.040	1.463	0.096	0.170	0.199
CV	3.090	2.371	2.592	2.534	2.818	2.152

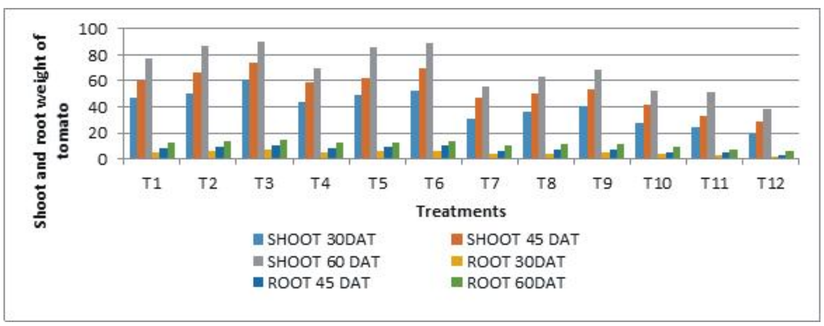

Fig. 2 : Effect of different nanoparticles on shoot and root weight(g) of tomato seedling.

treated plants can be attributed to several physiological advantages, including enhanced photosynthetic efficiency, elevated chlorophyll concentrations, and more effective nutrient translocation within the vascular system. These findings are consistent with the work of Nair *et al*. (2010) and Prasad *et al*. (2017), who observed similar biomass augmentation following nanoparticle application. Furthermore, Raliya and Tarafdar (2020) noted that nanoparticles stimulate biomass production by optimizing the underlying physiological and metabolic processes of crop plants. Similar trends were documented by Singh and Kumar (2022), specifically regarding tomatoes and other high-value vegetable crops, reinforcing the role of nanotechnology in driving plant productivity.

Impact on Lateral Branching

The number of branches per plant serves as a critical growth indicator, as it directly determines the canopy architecture and the subsequent yield potential of the crop. In this study, the branching density was significantly enhanced by nanoparticle application, with the maximum number of branches at 60 DAT recorded in Treatment T_3 (6.47). This was closely followed by T_6 (6.10) and T_2 (5.87). Consistent with other growth metrics, the minimum branching frequency was observed in the Infected Control (T_{12}), as illustrated in Table 3 and Fig. 3.

The proliferation of lateral branches in AgNP-treated plants is likely a result of enhanced metabolic activity and a more favorable hormonal balance induced by the nanoparticles. These results align with the observations of Sharma *et al*. (2012), who noted a positive correlation between nanoparticle application and increased vegetative branching. Furthermore, Ahmed *et al*. (2021) suggested that silver nanoparticles stimulate vegetative growth and lateral development by modulating phytohormone levels and activating antioxidant enzyme systems within tomato plants. These findings are further supported by Verma *et al*. (2023), confirming that nano-interventions can effectively modify plant morphology to support higher productivity.

Impact on Reproductive success (Number of Fruits per plant)

Reproductive performance, characterized by the

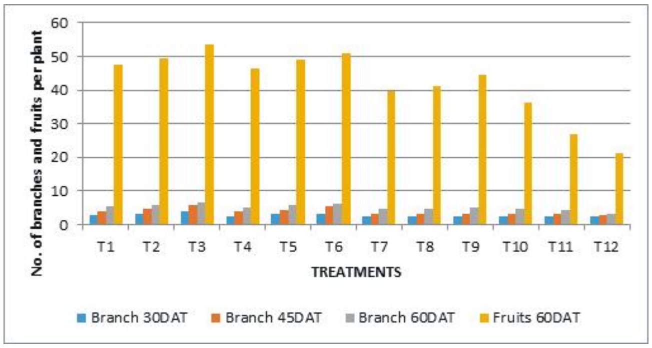

Fig. 3 : Effect of different nano-particles on number of branches and fruits.

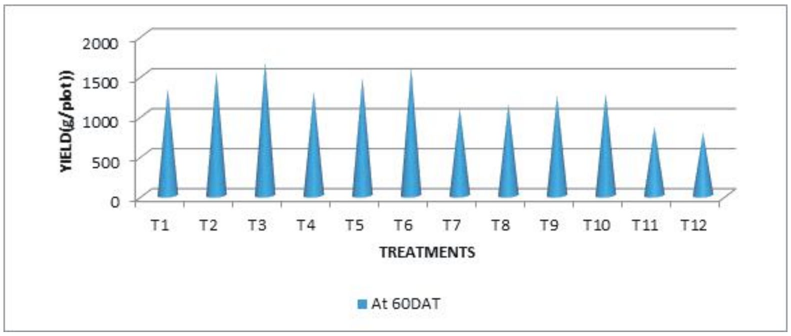

Fig. 4 : Effect of different nanoparticles on shoot yield (g/plot) of tomato seedling.

Table 3 : Effect of different nanoparticles on yield attributes of tomato seedlings.

Treatments	2023-24				
	No. of branches/plant after transplanting			No. of fruits/plant and yield after transplanting	
	30 days	45 days	60 days	60 days	Yield (g/plot)
T_1	2.89	4.07	5.53	47.65	1328
T_2	3.11	4.83	5.87	49.33	1535
T_3	3.88	5.67	6.47	53.66	1660
T_4	2.60	3.93	5.03	46.32	1291
T_5	3.03	4.37	5.80	48.99	1461
T_6	3.34	5.31	6.10	51.00	1587
T_7	2.33	3.10	4.67	39.66	1084
T_8	2.46	3.13	4.81	41.33	1133
T_9	2.46	3.33	4.93	44.65	1243
T_{10}	2.38	3.27	4.63	36.32	1267
T_{11}	2.41	3.03	4.20	27.00	850
T_{12}	2.30	2.83	3.17	21.19	780
CD at 5%	0.119	0.210	0.232	1.415	59.381
SE(m)	0.040	0.071	0.078	0.479	20.117
SE(d)	0.057	0.101	0.111	0.678	28.449
CV	2.526	3.157	2.663	1.965	2.747

number of fruits per plant, was significantly enhanced by the various experimental treatments. Treatment T_3(AgNP @ 100 ppm) demonstrated the highest efficacy, producing a maximum of 53.66 fruits per plant, followed by T_6 (51.00) and T_2 (49.33). In stark contrast, the Infected Control (T_{12}) recorded the lowest productivity with only 21.19 fruits per plant, as shown in Table 3 and Fig. 3. This substantial increase in fruit count under nanoparticle treatments can be attributed to a combination of robust vegetative growth, an increased rate of flowering, and a marked reduction in disease incidence.

The results are supported by the findings of Jo *et al.* (2009) and Rai *et al.* (2009), who noted that silver nanoparticles bolster plant health and productivity by providing a protective shield against microbial infections. Furthermore, Patel *et al.* (2022) reported that nano-silver treatments significantly improve both fruit setting and fruit retention in tomatoes. These positive effects on reproductive output are further corroborated by Meena and Rao (2023), whose research underscores the role of nanoparticles in optimizing the transition from vegetative growth to fruit production in vegetable crops.

Influence on Total Yield per Plot

As the definitive indicator of treatment efficacy, the total yield per plot reflected the cumulative benefits of the applied nano-interventions. Statistical analysis revealed that Treatment T_3 (AgNP @ 100 ppm) achieved the highest overall productivity, recording a peak yield of 1660 g/plot. This superior performance was followed by T_6 (1587 g/plot) and T_2 (1535 g/plot). Conversely, the Infected Control (T_{12}) produced the lowest yield at 780 g/plot, representing a significant reduction in productivity compared to the silver nanoparticle-treated plots (Table 3 and Fig. 4).

The substantial yield gain in T_3 can be attributed to the synergistic effects of enhanced physiological growth and robust disease suppression provided by the silver nanoparticles. By optimizing the plant's metabolic sink capacity and ensuring healthier fruit development, the 100 ppm AgNP treatment maximized the harvestable output. These results are consistent with recent agricultural studies suggesting that nano-based formulations significantly outperform conventional treatments by improving the harvest index and overall crop quality.

The significant augmentation in yield observed under the AgNP treatments can be attributed to a synergistic combination of accelerated vegetative growth, increased biomass accumulation and a higher frequency of fruit set. Furthermore, the maintenance of superior plant health throughout the growing season played a pivotal role in maximizing productivity. These observations align with the research of Singh *et al*. (2016), Prasad *et al*. (2017), and Gupta *et al*. (2024), all of whom reported substantial yield enhancements following nanoparticle applications.

Recent literature further confirms that nano-based formulations significantly improve nutrient use efficiency (NUE) and overall crop productivity, particularly in high-demand vegetable crops (Rathore *et al*., 2023). Collectively, these findings provide compelling evidence for the beneficial role of silver nanoparticles as an innovative tool for achieving sustainable and high-yielding tomato production.

Conclusion

The findings of the present study demonstrate that the application of nanoparticle-based treatments significantly enhances both the vegetative growth and reproductive yield of tomato seedlings. Among the various treatments evaluated, silver nanoparticles at a concentration of 100 ppm (T_3) emerged as the most superior intervention, consistently resulting in maximum shoot and root lengths, increased biomass accumulation, and enhanced lateral branching. Most importantly, this treatment significantly boosted the number of fruits per plant and the total yield per plot. Consequently, the application of AgNP @ 100 ppm can be recommended as a highly effective and promising nano-technological strategy for optimizing tomato productivity and improving crop performance under field conditions.

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