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Effects of different levels of nano-mixed micronutrients on the growth and flowering of tomato (*Lycopersicon esculentum* Mill.) cv. Heemsona

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Abstract
A field study was conducted to evaluate the impact of nano-fertilizer and nano-mixed micronutrients on the growth, and flowering of tomato (*Lycopersicon esculentum* Mill.) cv. Heemsohna under open field conditions at the Horticulture Research Farm, Department of Horticulture, Sam Higginbottom University of Agricultural, Technology and Science, Prayagraj, over two consecutive years, 2021-22 and 2022-23. The aim was to identify the most effective treatment using nano NPK and nano-mixed micronutrients for optimizing tomato growth and flowering. The experiment employed a factorial randomized block design with two factors and three replications. The different applications of nano NPK and nano-mixed micronutrients significantly influenced the growth, flowering, of tomato cultivation. Specifically, the treatment involving 4 ml of Nano NPK and 6 ml of nano-mixed micronutrients per litter of water as foliar applications (FA) demonstrated superior performance across various parameters including plant height, number of branches per plant, number of leaves per plant, leaf area, internode length, number of flowers per plant, In summary, the study highlights the positive impact of nano-fertilizers and nano-mixed micronutrients on tomato growth and flowering. The identified superior treatment combinations can serve as practical recommendations for enhancing tomato production while ensuring economic viability under similar growing conditions.

Keywords: Tomato, nano NPK, nano mix micronutrient, growth, flowering

Introduction

Tomato (*Solanum lycopersicum* L.), a prominent solanaceous vegetable, is cultivated globally for its adaptability, high yield potential, and versatility in fresh and processed food industries. This crop, which originated in Central and South America, particularly in Mexico, was introduced to Europe in 1554. Today, it is a major component of daily meals in many countries, contributing significantly to both nutrition and income, particularly for small and marginal farmers. Tomato are rich in essential nutrients, including vitamins A, C, E, potassium, folate, and fiber, making them an integral part of a healthy diet. In addition to providing essential nutrients, tomato contain valuable antioxidants, such as lycopene and beta-carotene, which are known to reduce the risk of certain cancers, including prostate cancer (Kucuk, 2001) [12]. With increasing demand for high-quality tomato yields and rising consumption, both fresh and processed tomato products are in high demand year-round. However, intensive cropping practices and imbalanced fertilization have led to nutrient depletion in soils (Bose and Tripathi, 1996) [4]. As tomato are heavy feeders that exhaust soil micronutrients, it is essential to replenish these nutrients through organic and inorganic sources, ensuring sustainability in production and nutritive value. Modern fertilization strategies have focused on optimizing nutrient application through the use of nanotechnology, which offers innovative solutions to nutrient management, enhancing crop yield and quality.

Nanotechnology, a field that operates at scales less than 100 nanometers, has found significant applications in agriculture, including the use of nano-fertilizers, nano-pesticides, and nano-carriers (Belal and El-Ramady, 2016) [3]. Nano-fertilizers, in particular, have shown promise in improving nutrient uptake efficiency in crops (Mousavi and Rezai, 2011; Srilatha, 2011; Ditta, 2012) [16, 26, 5].

Despite their potential, limited research is available on the role of nano-fertilizers and nano-micronutrients in tomato cultivation, particularly in enhancing growth and flowering. This lack of awareness has hindered the widespread adoption of nano-fertilizer technologies. Given the crucial role micronutrients play in plant growth, physiological activities, and enzyme functions, exploring the impact of nano-micronutrients on tomato growth and flowering is imperative. Zinc and boron, two essential micronutrients, are known to influence reproductive processes, sugar translocation, and enzyme activation, thereby enhancing yield and crop quality. Studies have demonstrated the importance of applying zinc-enriched fertilizers for better productivity and nutrient concentration (Khan and Rizvi, 2017) [11]. Boron, similarly, has been recognized for its role in cell division, pollen tube growth, and sugar transport within plants (Memon, 1996) [14]. The integration of these micronutrients at the nanoscale may offer even greater benefits by improving plant nutrient absorption, antioxidant enzyme activity, and stress tolerance. The findings will provide insights into optimizing the use of nano-micronutrients in tomato production, with the goal of improving both yield and crop quality. Additionally, this research will contribute to the growing body of knowledge on the economic viability of nano-fertilizer application in sustainable agriculture.

Materials and Methods: This experiment was conducted at Horticulture Research Farm, Department of Horticulture, Naini Agricultural Institute, Sam Higginbottom University of Agricultural Technology and Sciences, Prayagraj, (U.P) in 2021-22 and 2022-23. The experiment was designed in a factorial randomized block design with consisting of two factors with 3 replications. The twenty treatment combinations were allocated randomly to each plot so that each plot received only one treatment within the replication during both years of experimentation. Statistical analysis was conducted using Factorial Randomized Block Design (FRBD) as described by Snedecor and Cochran, 1987.

Details of Factors

Factor A

F_0 – Control (without fertilizer)

F_1- 100% RDF as traditional fertilizer

F_2-5 ml each of Nano NPK/ lit. of water as foliar application

F_3- 4 ml each of Nano NPK/ lit. of water as foliar application

F_4- 3 ml each of Nano NPK/ lit. of water as foliar application

Factor B

M_0- control (Without micronutrient)

M_1- 2 ml of nano mix micronutrient/ lit. of water as foliar application

M_2- 4 ml of nano mix micronutrient/ lit. of water as foliar application

M_3- 6 ml of nano mix micronutrient / lit.of water as foliar application

Table 1: Details of the treatment combinations.

Sr. No.	Treatment symbol	Combination
1.	T_1	Control
2.	T_2	100% RDF as traditional fertilizer
3.	T_3	5 ml each of Nano NPK/lit. of water as foliar application
4.	T_4	4 ml each of Nano NPK/ lit. of water as foliar application
5.	T_5	3 ml each of Nano NPK/lit. of water as foliar application
6.	T_6	2 ml of nano mix micronutrient/ lit. of water as foliar application
7.	T_7	4 ml of nano mix micronutrient/ lit. of water as foliar application
8.	T8	6 ml of nano mix micronutrient / lit. of water as foliar application
9.	T_9	100% RDF as traditional fertilizer + 2 ml of nano mix micronutrient/ lit. of water as foliar application
10.	T_{10}	100% RDF as traditional fertilizer + 4 ml of nano mix micronutrient/ lit. of water as foliar application
11.	T_{11}	100% RDF as traditional fertilizer + 6 ml of nano mix micronutrient / lit. of water as foliar application
12.	T_{12}	5 ml each of Nano NPK of water as foliar application + 2 ml/ lit. of nano mix micronutrient of water as foliar application
13.	T_{13}	5 ml each of Nano NPK of water as foliar application+ 4 ml of nano mix micronutrient/ lit. of water as foliar application
14.	T_{14}	5 ml each of Nano NPK of water as foliar application+ 6 ml of nano mix micronutrient / lit. of water as foliar application
15.	T_{15}	4 ml each of Nano NPK/lit. of water as foliar application + 2 ml of nano mix micronutrient/ lit. of water as foliar application
16.	T_{16}	4 ml each of Nano NPK/ lit. of water as foliar application+ 4 ml of nano mix micronutrient/ lit. of water as foliar application
17.	T_{17}	4 ml each of Nano NPK/ lit. of water as foliar application+ 6 ml of nano mix micronutrient / lit. of water as foliar application
18.	T_{18}	3 ml each of Nano NPK/ lit. of water as foliar application + 2 ml of nano mix micronutrient/ lit. of water as foliar application
19.	T_{19}	3 ml each of Nano NPK/ lit. of water as foliar application+ 4 ml of nano mix micronutrient/ lit. of water as foliar application
20	T_{20}	3 ml each of Nano NPK/ lit. of water as foliar application + 6 ml of nano mix micronutrient / lit. of water as foliar application

Results and discussions

The responses of tomato to various treatments were measured in term of growth, flowering, i.e. plant height (cm), number of branches per plant, number of leaves per plant, leaf area (cm^2), length of internode (cm), number of days to 50 percent flowering, number of flowers per plant, during the experimentation. On the basis of pooled analysis data of the year 2021 and 2022, the results for the various parameters have been summarized in (table 2, 3, 4, and5 and figure 1and2)as follows.

The maximum plant height observed in the F_3 (106.45 cm) and followed with F_4 treatment. Significant effect of nano mix micronutrients reported and observed maximum plant height in the M_3 treatment (114.12 cm) and minimum in M_1 at 30 DAS (67.51 cm) and minimum plant height (111.87 cm) was recorded in the M_0 treatment. The interaction effect of nano NPK and nano mix micronutrients observed, and maximum plant height was observed in F_2M_3 treatment combinations. Plant height was substantially affected by the foliar application of nano NPK fertilizers and their mixture with nano micronutrient due to the alteration of sink-source relationships caused by both fertilizers and foliar spray treatments. Plant growth is dependent on the conversion of solar energy into chemical energy during the photosynthesis process in mature (as source organs) organs to assimilate carbon and produce transportable carbohydrates, primarily sucrose and trehalose, for their utilization (Wang *et al*., 2020) [28]. The increase in plant height may have been attributable to internodal elongation by cell division as a result of enhanced carbohydrate metabolism, metabolic and physiological processes in plants and increased cell division (Ashour and Reda, 1972) [2]. Zinc and boron are involved in the biosynthesis of plant hormones, indole acetic acid, auxin metabolism, and cell expansion. Similar observations were confirmed by Faizan *et al*. (2021) [6] in tomato, Liu *et al*. (2005) in peanut seedling and Hemantaranjan *et al*. (2000) [7] in soyabean.

The maximum number of leaves was found in the F_3 treatment, whereas the minimum number of leaves was recorded in F_0 treatment at all stages. Whereas the maximum number of leaves was found in the M_3 treatment and minimum in M_1 treatment at 30 DAS and M_0 treatment shows minimum at 45 and 60 DAS crop growth stages. Interactive effect of both the factors shows significant and the higher number of leaves was observed in the F_2M_3 treatment combination which was found at par with F_2M_2 at 30 DAS and at 60 DAS found at par with F_2M_2 and F_3M_3 treatment combination. The observed increase in leaf numbers is attributed to the positive effects of foliar sprays of nano NPK and nano micronutrients, which enhance vegetative growth by stimulating metabolic and physiological activities such as photosynthesis, cell division, and cell elongation. This could also be linked to positive changes in hormonal profiles, particularly auxins, gibberellins, and cytokinin's, which promote growth. These findings align with previous studies on spinach by Shankramma *et al*. (2016) [21] and Alireza *et al*. (2012) [1].

Application of 4 ml each of Nano NPK/ litre of water as FA (12.31) tomato crop recorded higher number of branches per plant. Among nano mix micronutrient treatments, application of 6 ml of nano mix micronutrient / lit. of water as FA exhibited the highest number of branches per plant (11.14) during the experimentation and lowest was observed with control. The maximum number of branches per plant was found in the application of 5 ml each of Nano NPK of water as FA + 6 ml of nano mix micronutrient / lit. of water as FA (F_2M_3) treatment combinations and found at par with F_2M_2 treatment combinations. The increase in the number of leaves and branches may be attributable to improved nutrient availability. These nutrients play a crucial role in a number of physiological and biochemical processes, including root development, photosynthesis, energy transfer reactions, and symbiotic biological N fixation (Rathinavel and Dharmalingam, 1999) [19]. Furthermore, nano micronutrients such as zinc and boron act on building up the natural auxin (IAA), thereby stimulating cell division and growth. Similar findings were reported by Janmohammadi and Sabaghnia, (2023) [8] in safflower, Singh *et al*. (2021) [22] in tomato and Panda *et al*. (2020) [17] in tomato.

Leaf area maximum was observed in the F_3 treatment and minimum in F_0 treatment. From the perusal data of effect of nano mix micronutrients, the maximum leaf area was recorded in the M_3 treatment (47.49 cm^2) and the lowest in M_0 treatment. From the inspection of pooled data of interaction, the maximum leaf area was recorded in the F_2M_3 treatment (50.36 cm^2) followed with F_2M_2 and F_3M_3 treatment combinations and lowest in F_0M_0. The primary reason for the increased leaf area is the development of epidermal cells, which occurs at the same time as mesophyll cells begin to produce intercellular airspaces (Jiao, 2001) [9]. Positive effects of NPK and micronutrient interactions may be linked to nitrogen augmentation for photosynthetic activity in the presence of sufficient boron nanoparticle levels, as evidenced by the maximum leaf area per plant that was observed (Mahmoud *et al*., 2006) [13]. Zinc nanoparticles are also connected to the production of auxin hormones in leaves, which is positively correlated with the growth of the leaf's surface area since it promotes photosynthesis and accumulates more photosynthetic by-products. These findings are confirmed with results obtained by Alireza *et al*. 2012 [1]; Moghadam *et al.* 2012 [15]; Shankramma*et al*. 2016 [21] in spinach.

From the perusal of pooled data, the maximum length of internode was recorded in the F_3 treatment (8.09 cm) and the lowest in F_0 treatment. The effect of nano mix micronutrients shows significant and maximum length of internode was recorded in the M_3 treatment (7.70 cm) and minimum in M_0 treatment. The interaction effect of nano NPK and nano mix micronutrients reported significant and maximum length of the internode was recorded in F_2M_3 treatment (8.27 cm) which was at par with F_2M_2, F_3M_3 and F_3M_2 treatments and minimum (6.73 cm) was noted in F_0M_0. NPK and nano micronutrients (Zn, B, and Fe) are very effective for normal plant growth and development as carbohydrates and protein metabolism and help with auxin synthesis, which ultimately enhances cell wall development and cell differentiation in plants. These activities inside the plant metabolism enhance the length of the internodes. Similar findings were reported by Janmohammadi and Sabaghnia, (2023) [8] in safflower, Singh *et al*. (2021) [22] in tomato and Panda *et al*. (2020) [17] in tomato.

The higher number of flowers (108.65) was noted in the F_3 treatment, and it was found at par with the F_4 treatment and lowest number of flowers was recorded in the F_0 treatment. The application of different nano-mixed micronutrients and interaction effect of nano-NPK and nano mixed micronutrients was not shown a significant effect on the number of flowers during the experimentation. The foliar application of nano NPK and nano micronutrients helps to enhance the number of flowers by ensuring that sufficient amounts of major and minor nutrients are available for the flowers' growth and development. This may be attributed to better synthesis of cytokinin with optimum supply of N and phosphorus resulting in more number of flowers and fruits (Premsekhar and Rajashree, 2009) [18]. Similar findings were reported by Kazemi *et al*. (2014) [10]; Sivaiah *et al*. (2013) [23]; Swetha *et al*. (2018) [26] in tomato.

Table 2: Effect of nano fertilizer and nano mixed micronutrient on plant height, Number of leaves/plant and Number of branches/plants of tomato

Treatments	Plant height (cm)			Number of leaves/plants			Number of branches/plants		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Factor A (Nano NPK)									
F_0	104.92	107.99	106.45	29.65	30.45	30.05	9.13	9.27	9.20
F_1	105.30	108.39	106.85	30.38	31.35	30.86	8.85	8.96	8.91
F_2	109.52	112.52	111.02	31.86	33.18	32.52	10.64	10.91	10.77
F_3	121.56	124.65	123.11	35.18	36.81	35.99	12.16	12.46	12.31
F_4	116.26	119.54	117.90	34.22	35.62	34.92	11.78	12.04	11.91
F – test	S	S	S	S	S	S	S	S	S
SEm±	0.73	0.89	0.58	0.25	0.28	0.17	0.09	0.08	0.06
CD at 5 %	2.10	2.55	1.67	0.73	0.81	0.50	0.24	0.24	0.17
Factor B (Micronutrient)									
M_0	112.02	115.32	113.67	31.75	32.82	32.29	9.94	10.11	10.03
M_1	111.11	114.10	112.61	31.63	32.80	32.22	10.24	10.47	10.35
M_2	110.24	113.50	111.87	32.48	33.78	33.13	10.83	11.09	10.96
M_3	112.68	115.55	114.12	33.16	34.52	33.84	11.03	11.24	11.14
F – test	NS	NS	S	S	S	S	S	S	S
SEm±	0.65	0.79	0.52	0.23	0.25	0.16	0.08	0.07	0.05
CD at 5 %	NS	NS	1.49	0.65	0.72	0.45	0.22	0.21	0.15

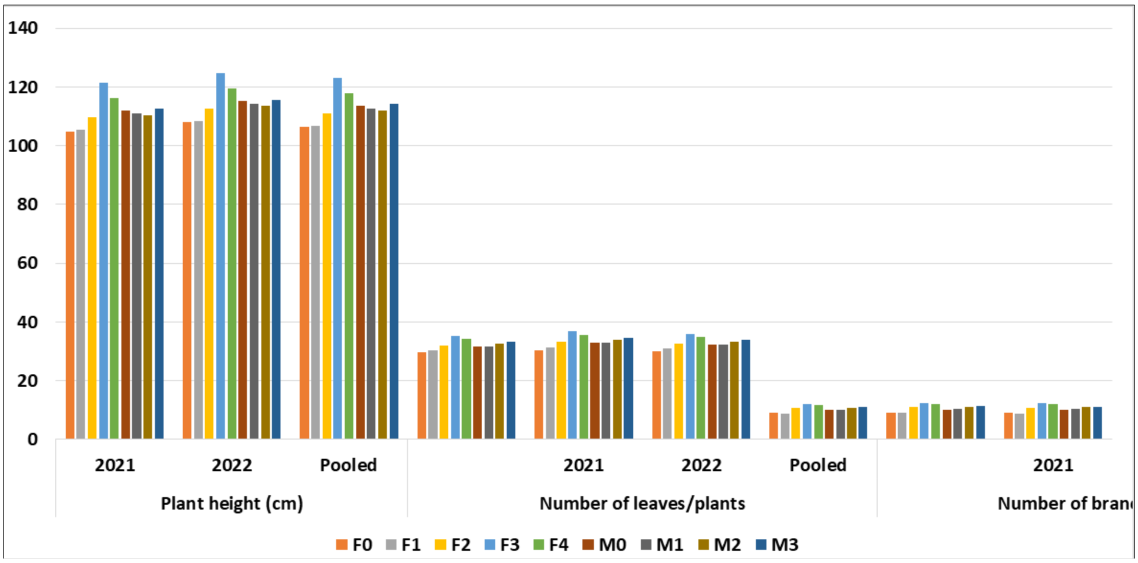

Fig 1: Effect of nano fertilizer and nano mixed micronutrient on plant height, Number of leaves/plant and Number of branches/plants of tomato

Table 3: Interaction effect of nano-fertilizer and nano mixed micronutrient on plant height, Number of leaves/plant and Number of branches/plants of tomato

Treatment combinations	Plant height (cm)			Number of leaves/plants			Number of branches/plant		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
F_0M_0	101.56	101.56	101.56	27.45	27.56	27.51	7.40	7.65	7.53
F_1M_0	102.50	102.50	102.50	27.78	28.30	28.04	7.98	8.12	8.05
F_2M_0	108.00	108.00	108.00	31.76	33.10	32.43	10.90	11.00	10.95
F_3M_0	107.60	107.60	107.60	31.60	32.83	32.22	10.23	10.30	10.27
F_4M_0	104.51	104.51	104.51	29.44	30.50	29.97	8.65	8.76	8.71
F_0M_1	103.70	103.70	103.70	29.30	29.76	29.53	8.21	8.32	8.27
F_0M_2	106.00	106.00	106.00	31.20	32.45	31.83	9.14	9.21	9.18
F_0M_3	107.00	107.00	107.00	31.56	32.67	32.12	9.40	9.56	9.48
F_1M_1	105.88	105.88	105.88	30.00	31.20	30.60	8.92	9.00	8.96
F_1M_2	108.33	108.33	108.33	32.10	33.33	32.72	11.00	11.23	11.12
F_1M_3	109.87	109.87	109.87	32.33	33.87	33.10	11.12	11.50	11.31
F_2M_1	114.00	114.00	114.00	33.00	34.33	33.67	11.50	11.89	11.70
F_2M_2	124.65	124.65	124.65	35.98	37.54	36.76	12.42	12.67	12.55
F_2M_3	129.70	129.70	129.70	36.52	38.50	37.51	12.87	13.10	12.99
F_3M_1	113.00	113.00	113.00	32.89	34.20	33.55	11.23	11.76	11.50
F_3M_2	118.90	118.90	118.90	35.32	37.00	36.16	12.13	12.32	12.23
F_3M_3	123.50	123.50	123.50	35.87	37.32	36.60	12.31	12.47	12.39
F_4M_1	111.30	111.30	111.30	32.45	34.11	33.28	11.15	11.56	11.36
F_4M_2	114.33	114.33	114.33	34.22	35.30	34.76	11.76	12.00	11.88

F_4M_3	115.91	115.91	115.91	34.33	35.76	35.05	11.90	12.14	12.02
F – test	S	S	S	S	S	S	S	S	S
SEm±	1.46	1.46	1.46	0.51	0.56	0.35	0.17	0.17	0.12
CD at 5 %	4.20	4.20	4.20	1.46	1.62	1.00	0.49	0.47	0.35

Table 4: Effect of nano fertilizer and nano mixed micronutrient on Leaf area (cm^2), Length of internode (cm) and Number of flowers/ plant of tomato

Treatments	Leaf area (cm^2)			Length of internode			Number of flowers/ plant		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Factor A (Nano NPK)									
F_0	43.37	44.02	43.70	7.03	7.10	7.07	37.32	36.91	37.11
F_1	44.31	44.19	44.25	7.01	7.15	7.08	37.35	36.95	37.15
F_2	46.11	46.82	46.46	7.40	7.51	7.45	37.93	37.50	37.71
F_3	48.60	49.39	48.99	8.06	8.11	8.09	38.58	38.12	38.35
F_4	47.87	48.81	48.34	7.84	8.00	7.92	38.39	37.95	38.17
F – test	S	S	S	S	S	S	S	S	S
SEm±	0.30	0.35	0.21	0.05	0.05	0.03	0.29	0.27	0.19
CD at 5 %	0.87	1.00	0.62	0.15	0.15	0.09	0.82	0.77	0.54
Factor B (Micronutrient)									
M_0	45.18	45.61	45.40	7.40	7.43	7.41	37.72	37.29	37.51
M_1	45.24	45.92	45.58	7.35	7.50	7.42	37.77	37.35	37.56
M_2	46.63	47.21	46.92	7.49	7.62	7.56	38.02	37.57	37.80
M_3	47.15	47.84	47.49	7.64	7.75	7.70	38.14	37.72	37.93
F – test	S	S	S	S	S	S	NS	NS	NS
SEm±	0.27	0.31	0.19	0.05	0.05	0.03	0.26	0.24	0.17
CD at 5 %	0.78	0.89	0.55	0.14	0.13	0.08	NS	NS	NS

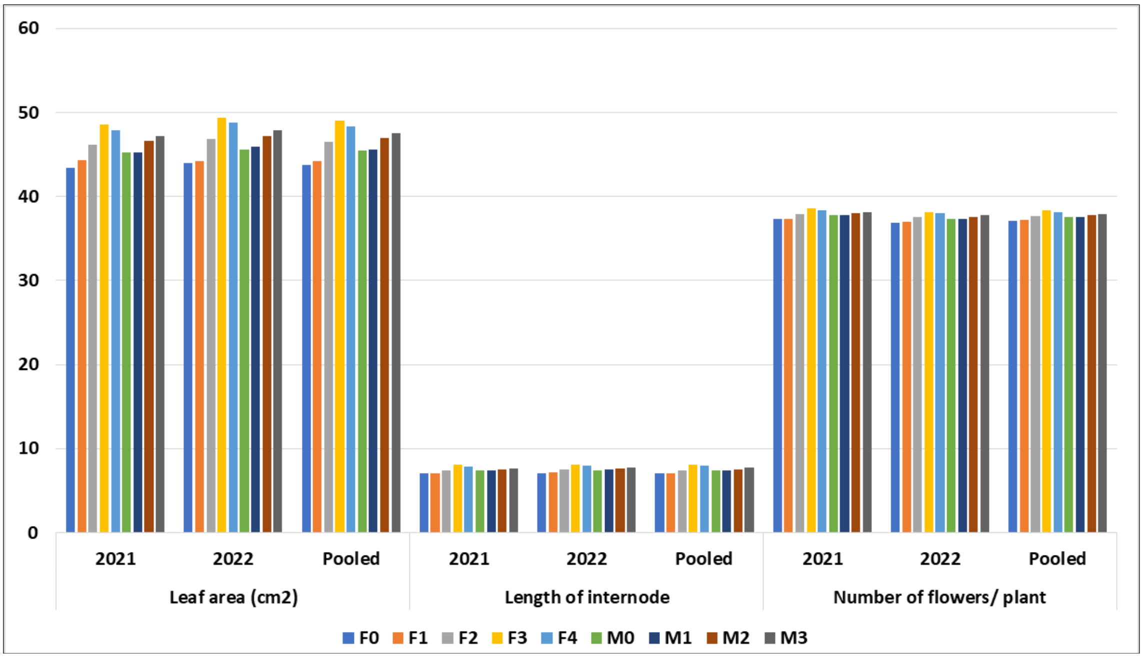

Fig 2: Effect of nano fertilizer and nano mixed micronutrient on Leaf area (cm^2), Length of internode (cm) and Number of flowers/ plant of tomato

Table 5: Interaction effect of nano-fertilizer and nano mixed micronutrient on Leaf area (cm^2) and Length of internode (cm) of tomato

Treatment combinations	Leaf area (cm^2)			Length of internode (cm)			Number of flowers/ plants		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
F_0M_0	40.21	40.87	40.54	6.76	6.70	6.73	100.65	104.87	102.76
F_1M_0	41.10	41.24	41.17	6.87	6.87	6.87	101.18	104.87	103.03
F_2M_0	46.17	47.10	46.64	7.30	7.43	7.37	102.50	107.34	104.92
F_3M_0	46.00	46.87	46.44	7.20	7.40	7.30	101.98	107.04	104.51
F_4M_0	43.60	43.12	43.36	6.95	6.98	6.97	101.53	105.46	103.50
F_0M_1	42.10	42.65	42.38	6.87	6.98	6.93	101.42	105.24	103.33
F_0M_2	45.65	45.10	45.38	7.10	7.30	7.20	101.83	106.23	104.03
F_0M_3	45.87	45.87	45.87	7.12	7.34	7.23	101.90	106.56	104.23
F_1M_1	44.20	44.65	44.43	7.05	7.10	7.08	101.67	105.53	103.60
F_1M_2	46.34	47.20	46.77	7.35	7.50	7.43	102.95	107.66	105.31
F_1M_3	46.67	47.34	47.01	7.40	7.54	7.47	103.34	108.34	105.84

F_2M_1	47.21	48.10	47.66	7.80	7.88	7.84	104.87	109.84	107.36
F_2M_2	49.00	49.76	49.38	8.14	8.20	8.17	106.87	112.04	109.46
F_2M_3	49.87	50.85	50.36	8.23	8.30	8.27	107.01	112.25	109.63
F_3M_1	47.00	47.73	47.37	7.78	7.85	7.82	104.12	109.10	106.61
F_3M_2	48.53	49.20	48.87	8.10	8.10	8.10	106.30	111.53	108.92
F_3M_3	48.90	49.67	49.29	8.10	8.15	8.13	106.53	111.73	109.13
F_4M_1	46.80	47.65	47.23	7.43	7.83	7.63	103.78	108.67	106.23
F_4M_2	47.67	48.76	48.22	7.85	8.00	7.93	105.56	110.71	108.14
F_4M_3	48.12	49.15	48.64	7.98	8.03	8.01	105.95	111.12	108.54
F – test	S	S	S	S	S	S	NS	NS	NS
SEm±	0.61	0.70	0.43	0.11	0.10	0.06	1.52	1.67	1.10
CD at 5 %	1.74	2.00	1.23	0.31	0.30	0.18	NS	NS	NS

Conclusion
Among the various treatments tested, the foliar application of 4 ml of Nano NPK combined with 6 ml of nano-mixed micronutrients per liter of water yielded the most favorable results, including increased plant height, number of branches, leaves, and flowers. These outcomes suggest that nano-fertilizers play a crucial role in improving both physiological and biochemical processes in tomato plants, leading to enhanced growth and productivity. The findings underscore the potential of nanotechnology in agriculture, particularly for optimizing nutrient uptake, improving stress resilience, and boosting overall crop yield.

Reference

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