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Original Research Paper

# Growth response of zinc as nano-fertilizer in tomato (*Solanum lycopersicum* L.) and sweet pepper (*Capsicum annuum* L.)

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## ABSTRACT

The study was carried out to determine ideal zinc concentration for its use as nano-fertilizer, through application of zinc oxide (ZnO) nanoparticles in tomato and sweet pepper. Two-years pot experiment was carried out in completely randomized block design, comprised of seven treatments with three replications. ZnO nanoparticles were applied as seed treatment [$T_2$ (50 mg/L), $T_4$ (100 mg/L), and $T_6$ (150 mg/L)] and foliar application [$T_3$ (50 mg/L), $T_5$ (100 mg/L), and $T_7$ (150 mg/L)], respectively, and control with no nanoparticles application. Results revealed that plant height, root length, number of primary branches, plant biomass, yield, and nutrient uptake of tomato and sweet pepper showed the highest significant response to ZnO nanoparticles (50 mg/L) applied through foliar application. On the other hand, seed treatment of ZnO nanoparticles (50 mg/L) registered significant higher nutrient content. Study concluded that 50 mg/L was ideal concentration of ZnO nanoparticles that proved to be effective in enhancing sustainability by improving growth, yield, nutrient content and uptake of tomato and sweet pepper.

**Keywords:** Growth, nutrient content, sweet pepper, tomato, yield, ZnO

## INTRODUCTION

Zinc oxide (ZnO) nanoparticles are the most prevalent nano-Zn formulations that have been developed, applied, and studied for plant growth-promoting parameters in recent years (Esper Neto et al., 2020). ZnO nanoparticles are emerging as a potential tool in plant science offering promising possibilities of improved plant development and yield which could provide an effective solution to the ever-increasing demand of the world's rapidly growing population (Thounaojam et al., 2021). Understanding their influence, mechanisms and essential interactions with the physico-chemical and biological environment of soil is required for their efficient utilization (Lv et al., 2022). Administering ZnO nanoparticles through seed treatment enhanced plant biomass and germination by promoting adsorption of ZnO nanoparticles on seed coat surfaces and their penetration and transportation through seed tissues (Elhaj & Unrine, 2018). As a result, seed treatment is a targeted delivery method for increasing the availability of macro & micronutrients during plant growth (Acharya et al., 2020). Foliar application, on the other hand, involves administering liquid fertilizer or nutrients to plant leaves or stems rather than to the soil and is useful in case of problems related to leaching, soil fixing, obstructions, and other losses (Ahmed et al., 2021).

ZnO nanoparticles are widely used in agriculture, have the potential to improve the food and agricultural sectors (Zhou et al., 2023). Findings showed that flavonoid content in melon increased by 50 mg/L ZnO nanoparticle (Riverra-Gutierrez et al., 2021). Similarly, 50 and 100 mg/L of ZnO nanoparticles also improved the growth characteristics of eggplant (Semida et al., 2021). Furthermore, plants in the Solanaceae family have also demonstrated the positive impacts of ZnO nanoparticles (Panwar et al., 2021). Hence, the current study aimed to investigate the optimum concentration and method of application of ZnO nanoparticles and to to examine the effectiveness of ZnO nanoparticles on growth, yield, nutrient content and uptake under tomato (*Solanum lycopersicum* L.) and sweet pepper (*Capsicum annuum* L.).

## MATERIALS AND METHODS

A pot experiment comprised of seven treatments and three replications set up in completely randomized design, conducted in polyhouse of Department of Soil

Science and Water Management, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh, India, during 2020-21 to 2021-2022. The potting mixture was analyzed before the execution of experiment *viz*., soil pH 7.07, electrical conductivity 0.69 dS/m, organic carbon 0.57%, available N 249.57 kg/ha, available P 21.60 kg/ha and available K 115.13 kg/ha. Recommended dose of nutrients for the cultivation of tomato and sweet pepper in Himachal Pradesh, India are N: 100 kg/ha, $P_2O_5$: 75 kg/ha and $K_2O$: 55 kg/ha (Anonymous, 2014).

In this study, RDN was supplied indiscriminatory to all treatments through vermicompost (N: 1.60%, $P_2O_5$: 1.20%, $K_2O$: 0.88%). On the basis of 10 kg of potting mixture in each pot, quantity of vermicompost was calculated and doubled (55.81 g/pot) which was further mixed in potting mixture one week before sowing of seeds of both crops. Tomato variety 'Solan Lalima' and sweet pepper variety 'California Wonder' were taken for experiment.

Zinc oxide (ZnO) nano-powder with particle size <50 nm (BET) and purity >97% was used in study. Three concentrations of ZnO nanoparticles were applied to plants by two ways i.e. through seed treatment ($T_2$: 50 mg/L; $T_4$: 100 mg/L and $T_6$: 150 mg/L) and foliar application ($T_3$: 50 mg/L; $T_5$: 100 mg/L and $T_7$: 150 mg/L). Treatment $T_1$ was taken as control i.e. no application of ZnO nanoparticles. In seed treatment, seeds were dipped for overnight in respective concentration of ZnO nanoparticles and in treatments comprising foliar applications, three spray with respective concentration of ZnO nanoparticles was given from one month old plant with 4-5 leaves at the interval of 15 days, in both crops.

The plant growth parameters of tomato and sweet pepper were computed by choosing plants of specific treatments for calculating plant height, root length, number of primary branches, plant biomass; and 3 pickings were taken for calculating the yield. For estimating plant nutrient content, digestion of the samples was carried out by taking grounded plant samples (0.5 g) further digested in di-acid mixture prepared by mixing concentrated $HNO_3$ and $HClO_4$ in the ratio of 4:1 as laid down by Piper (1966) for P, K, Zn, Cu, Fe and Mn. Separate digestion was carried out for N estimation using concentrated $H_2SO_4$ and digestion mixture ($K_2SO_4$: 480 parts, $CuSO_4$: 20 parts, HgO: 3 parts, Selenium powder 1 part) as suggested by Jackson (1973). The total nitrogen was analyzed by the Micro-Kjeldahl's method as outlined in AOAC (1980) and expressed in per cent. The total phosphorus content was estimated by Vanado-molybdate phosphoric yellow color method formulated by Jackson (1973) and was expressed in per cent on dry weight basis. Potassium in the di-acid extract was estimated on the flame photometer and was expressed in per cent (Jackson, 1967). The estimation of micronutrients was carried out on Atomic Absorption Spectrophotometer (Vogel, 1978) and were expressed in mg/kg on dry weight basis.

Nutrient uptake (g/plant): Nutrient uptake by plant was calculated using the following formula:

$$Nutrient\ uptake\ (g/plant) = \text{Nutrient content (\%)} \times \text{Plant Biomass (g/plant)}/100$$

### Statistical analysis

The data generated from these two-year experiments of both crops were tabulated, pooled and analyzed by applying completely randomized design (Panse & Sukhatme, 2000) and analysis of variance were used to determine significance at $p \leq 0.05$ using Microsoft Excel and OPSTAT packages (Sheron et al., 1998). The least significant difference (LSD) was determined among the means at $p \leq 0.05$.

## RESULTS AND DISCUSSION

### Growth parameters

The highest plant height (213.83 and 70.00 cm), root length (28.07 and 14.28 cm), number of primary branches (6.17 and 5.33), plant biomass (160.00 and 85.50 g/plant) and yield (1.49 and 1.36 kg/plant), respectively, were recorded for tomato and sweet pepper was recorded under treatment $T_3$ (Fig. 1). These effects may have been caused by an increase in inter-nodal length and the growth-promoting properties of ZnO nanoparticles. Also, the use of ZnO-NPs may accelerate the plants' rate of photosynthesis, which in turn leads to more cell division, higher plant growth and development. Our findings are consistent with earlier studies which concluded that application of ZnO nanoparticles as fertilizers promoted the growth and development of plants (Faizan et al., 2018). ZnO nanoparticles at optimal doses promote plant development (Lv et al., 2022). Because of their long-term solubility, ZnO nanoparticles have drawn more attention (Pullagurala et al., 2018). The application of ZnO nanoparticles have been shown to boost plant development features (Raliya & Tarafdar 2013).

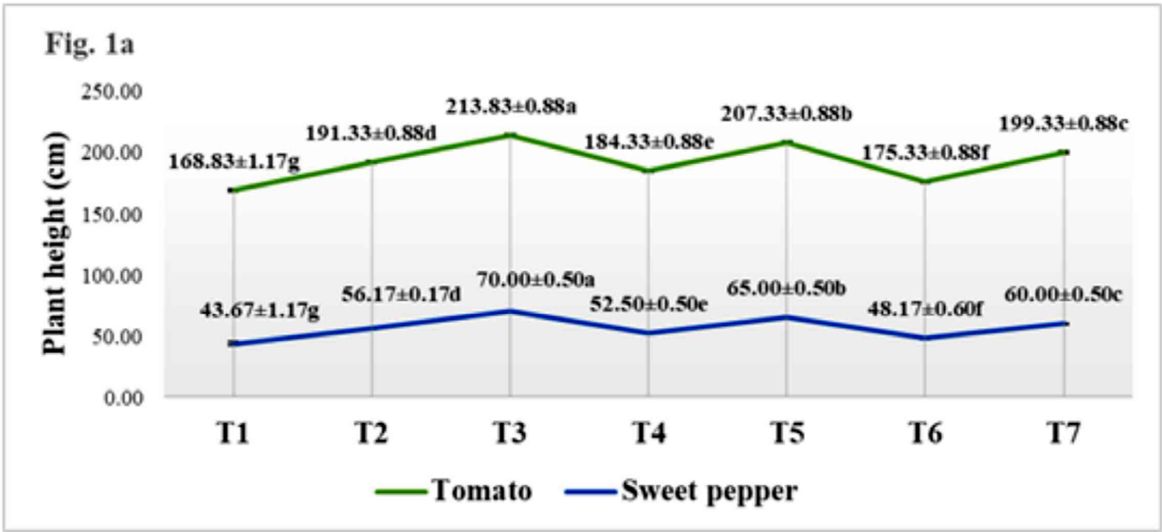


Fig. 1a
Plant height (cm)
250.00
200.00
150.00
100.00
50.00
0.00
168.83±1.17g
191.33±0.88d
213.83±0.88a
184.33±0.88e
207.33±0.88b
175.33±0.88f
199.33±0.88c
43.67±1.17g
56.17±0.17d
70.00±0.50a
52.50±0.50e
65.00±0.50b
48.17±0.60f
60.00±0.50c
T1
T2
T3
T4
T5
T6
T7
Tomato
Sweet pepper

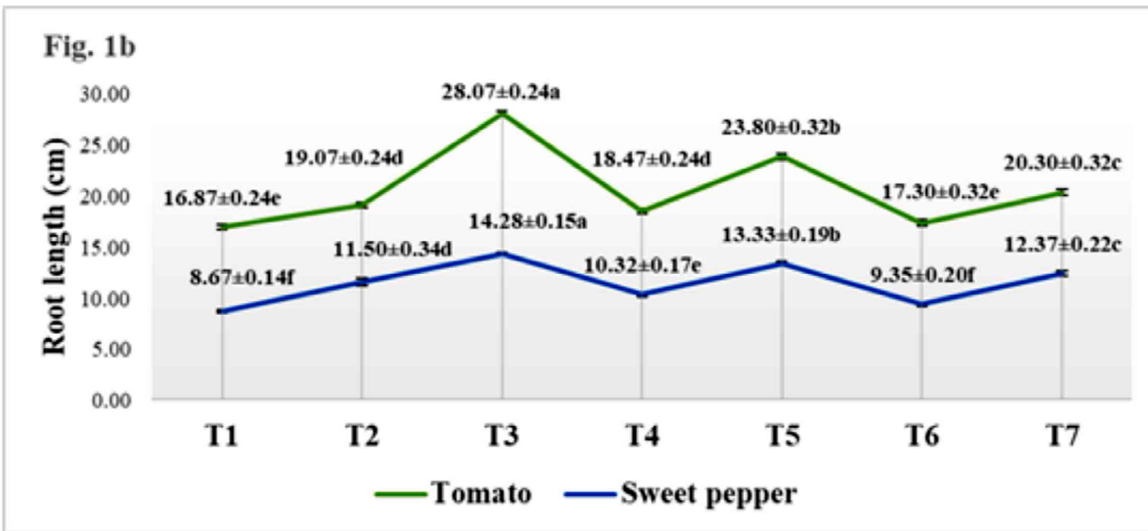


Fig. 1b
Root length (cm)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
16.87±0.24e
19.07±0.24d
28.07±0.24a
18.47±0.24d
23.80±0.32b
17.30±0.32e
20.30±0.32c
8.67±0.14f
11.50±0.34d
14.28±0.15a
10.32±0.17e
13.33±0.19b
9.35±0.20f
12.37±0.22c
T1
T2
T3
T4
T5
T6
T7
Tomato
Sweet pepper

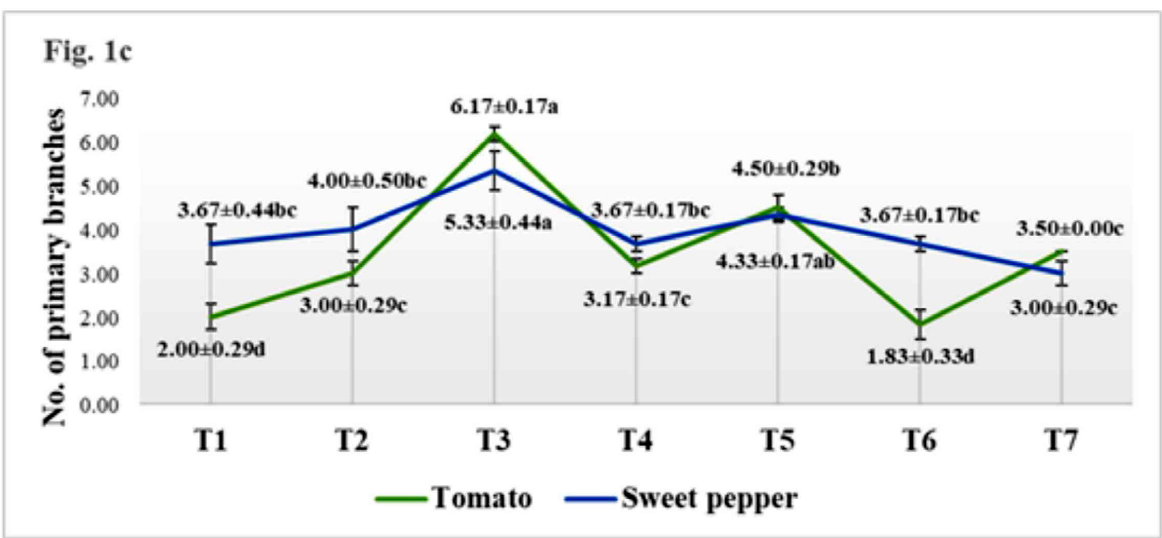


Fig. 1c
No. of primary branches
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.67±0.44bc
4.00±0.50bc
6.17±0.17a
5.33±0.44a
3.67±0.17bc
4.50±0.29b
4.33±0.17ab
3.67±0.17bc
3.50±0.00c
2.00±0.29d
3.00±0.29c
3.17±0.17c
1.83±0.33d
3.00±0.29c
T1
T2
T3
T4
T5
T6
T7
Tomato
Sweet pepper

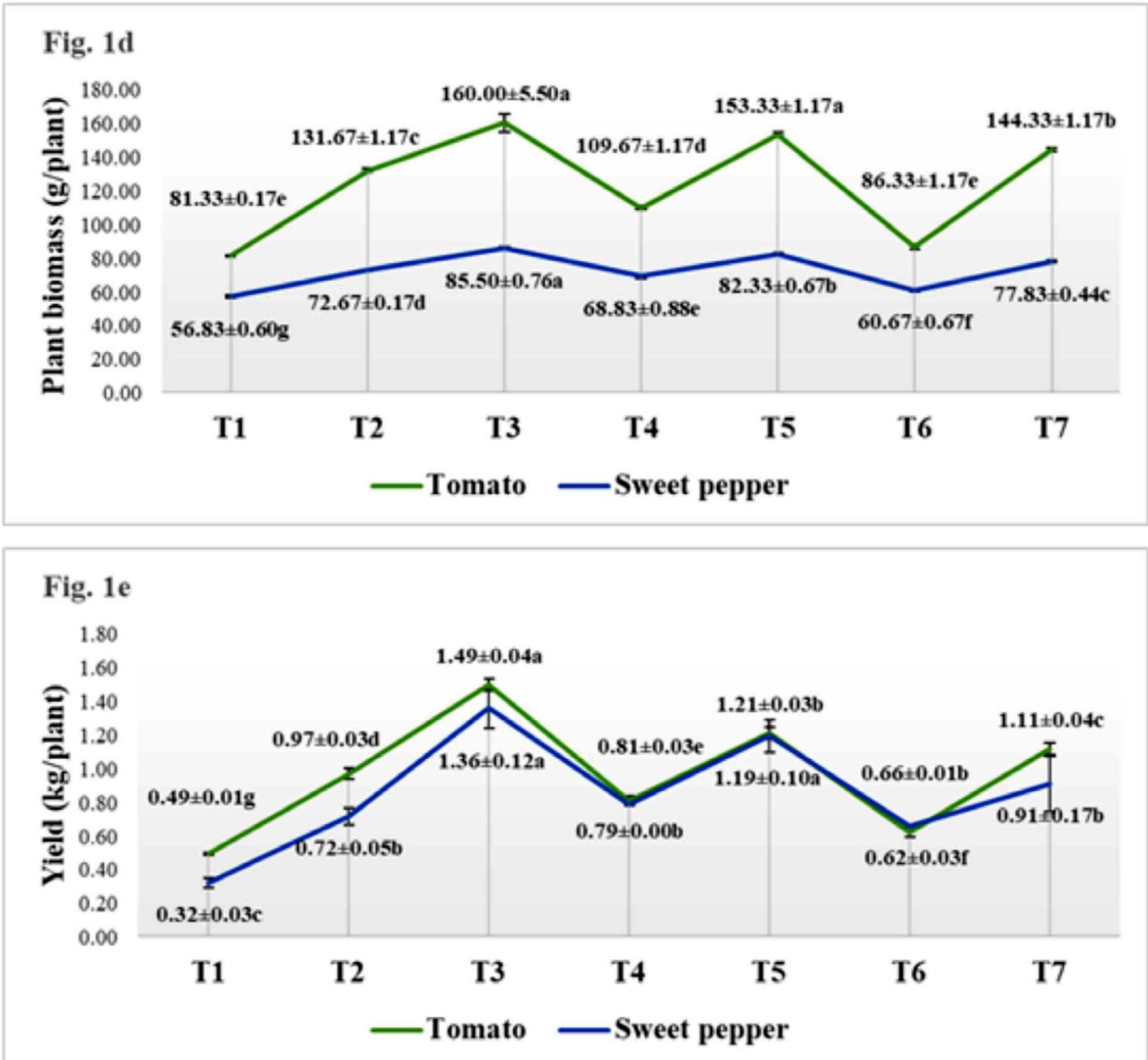



Fig. 1 : Effect of ZnO nanoparticles on growth parameters of tomato and sweet pepper

The sequence of data depicted in Fig. 2 reflects significant improvement in total N (3.54 and 3.39%), total P (0.73 and 1.37%) and total K (4.57 and 10.94%) content in tomato and sweet pepper under treatment comprised of 50 mg/L ZnO nanoparticles as seed treatment ($T_2$) over control. The significant increase in total Fe (254.75 mg/kg and 432.83 mg/kg) and total Zn (24.50 mg/kg and 84.25 mg/kg) content was recorded under treatment $T_3$ and $T_2$, respectively in tomato and sweet pepper. Maximum significant value of total Mn (220.67 mg/kg) was recorded in treatment $T_2$ under sweet pepper. However, the total Mn content and total Cu content remained non-significant in tomato. Also, total Cu content was recorded non-significant for sweet pepper under the influence of ZnO nanoparticles application. The nutrient content of both solanaceous crops in our data may have increased due to the use of ZnO nanoparticles, which may be positively influenced by increased photosynthetic pigment levels as well as growth parameters (Bhardwaj et al., 2024). Increased microbial biomass or activity around developing roots supported by vermicompost may be the cause of the rise in macronutrient contents. This activity was further boosted by seed treatment with zinc oxide nanoparticles (Bageshwar et al., 2017). The use of ZnO nanoparticles through seed treatment led to an increased total potassium content in maize plants (Tondey et al., 2021). The foliar spray of ZnO nanoparticles ranging from 50 to 200 mg/L in lettuce plants resulted in an increase in Fe absorption (Liang et al., 2021).

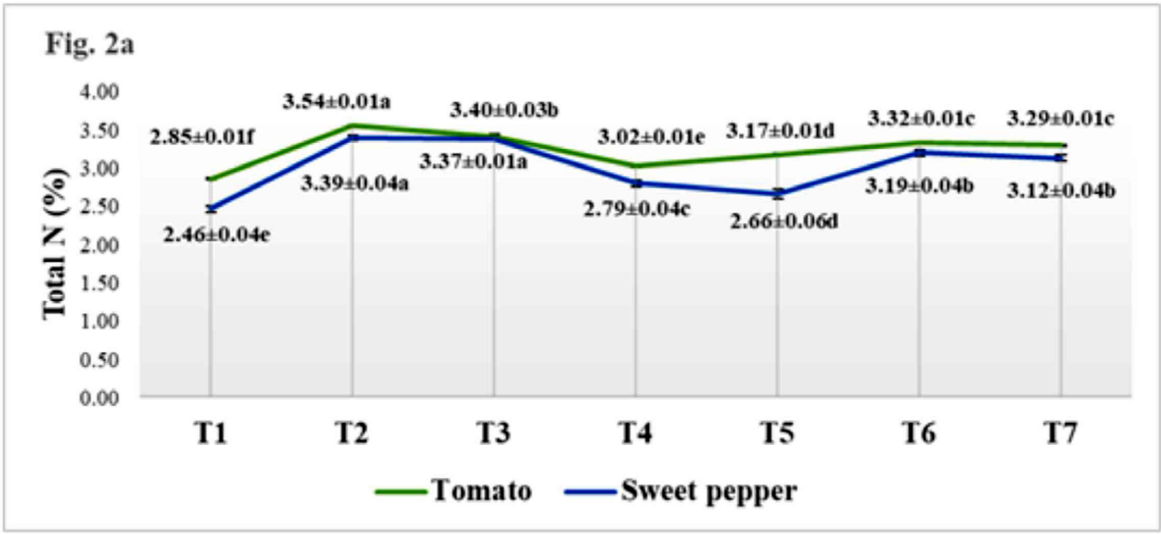


Fig. 2a
Total N (%)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2.85±0.01f
3.54±0.01a
3.40±0.03b
3.02±0.01e
3.17±0.01d
3.32±0.01c
3.29±0.01c
2.46±0.04e
3.39±0.04a
3.37±0.01a
2.79±0.04c
2.66±0.06d
3.19±0.04b
3.12±0.04b
T1
T2
T3
T4
T5
T6
T7
Tomato
Sweet pepper

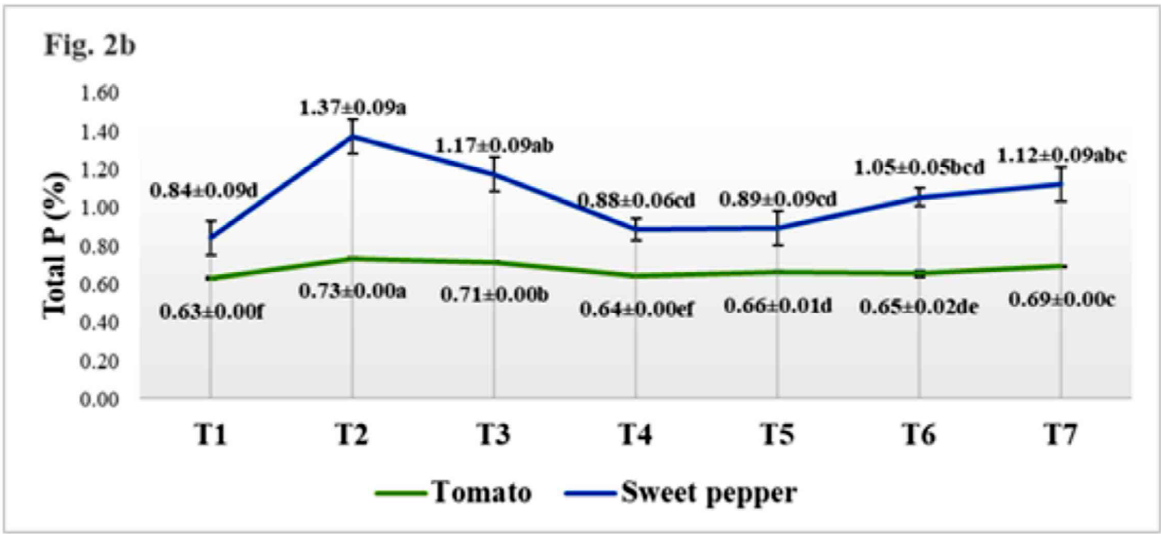


Fig. 2b
Total P (%)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1.37±0.09a
0.84±0.09d
1.17±0.09ab
0.88±0.06cd
0.89±0.09cd
1.05±0.05bcd
1.12±0.09abc
0.63±0.00f
0.73±0.00a
0.71±0.00b
0.64±0.00ef
0.66±0.01d
0.65±0.02de
0.69±0.00c
T1
T2
T3
T4
T5
T6
T7
Tomato
Sweet pepper

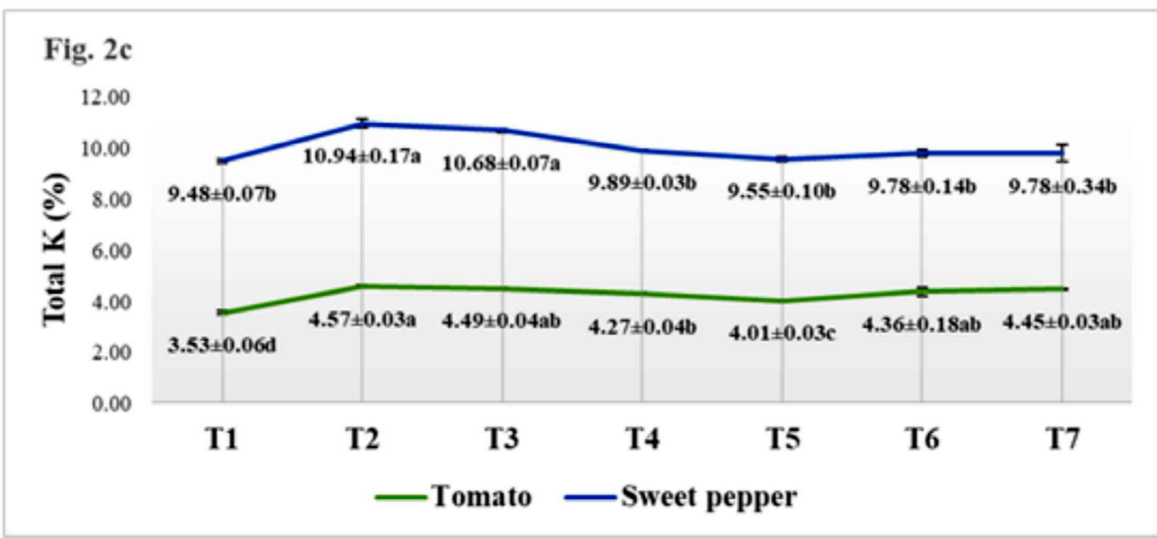


Fig. 2c
Total K (%)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
9.48±0.07b
10.94±0.17a
10.68±0.07a
9.89±0.03b
9.55±0.10b
9.78±0.14b
9.78±0.34b
3.53±0.06d
4.57±0.03a
4.49±0.04ab
4.27±0.04b
4.01±0.03c
4.36±0.18ab
4.45±0.03ab
T1
T2
T3
T4
T5
T6
T7
Tomato
Sweet pepper

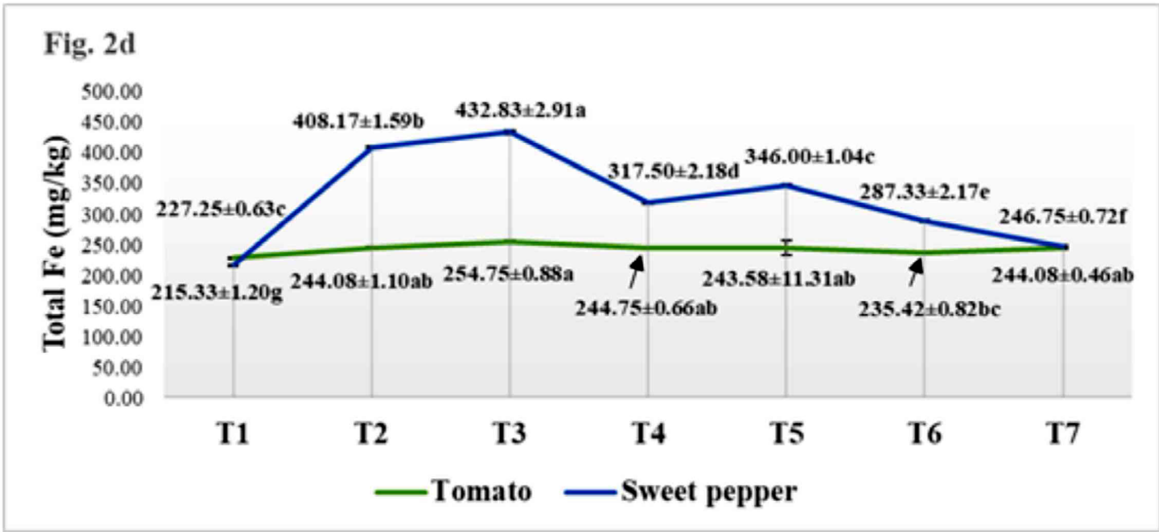


Fig. 2d
Total Fe (mg/kg)
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
408.17±1.59b
432.83±2.91a
317.50±2.18d
346.00±1.04c
287.33±2.17e
246.75±0.72f
227.25±0.63c
215.33±1.20g
244.08±1.10ab
254.75±0.88a
244.75±0.66ab
243.58±11.31ab
235.42±0.82bc
244.08±0.46ab
T1
T2
T3
T4
T5
T6
T7
Tomato
Sweet pepper

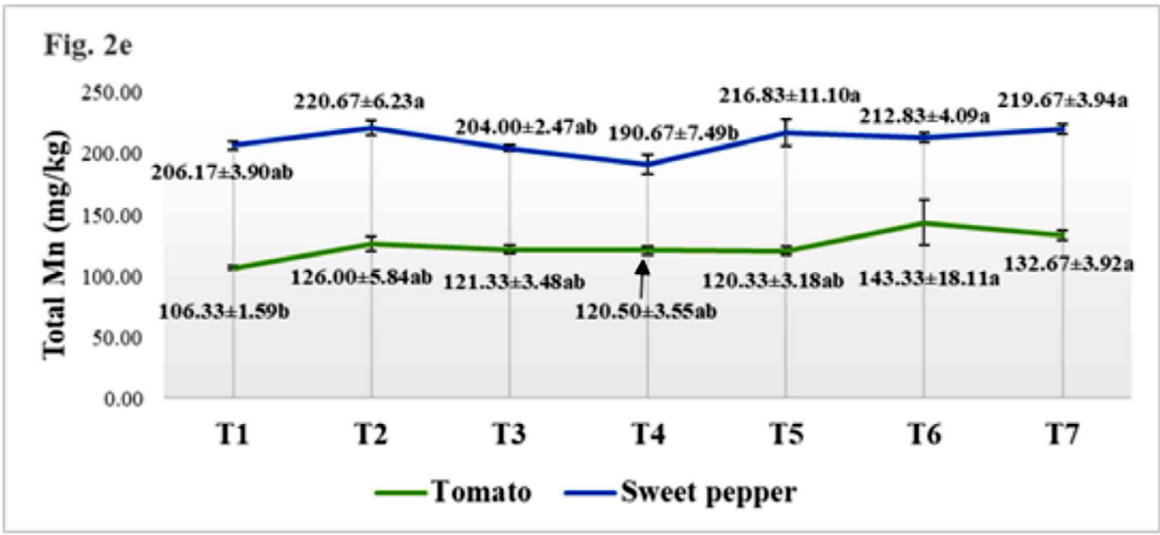


Fig. 2e
Total Mn (mg/kg)
250.00
200.00
150.00
100.00
50.00
0.00
220.67±6.23a
204.00±2.47ab
190.67±7.49b
216.83±11.10a
212.83±4.09a
219.67±3.94a
206.17±3.90ab
126.00±5.84ab
121.33±3.48ab
120.33±3.18ab
143.33±18.11a
132.67±3.92a
106.33±1.59b
120.50±3.55ab
T1
T2
T3
T4
T5
T6
T7
Tomato
Sweet pepper

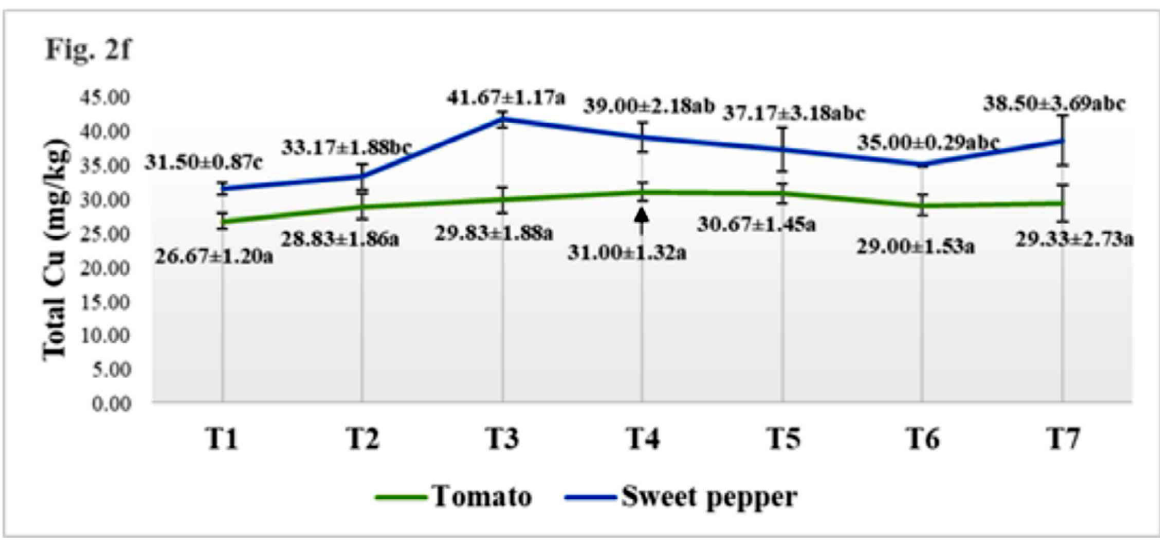


Fig. 2f
Total Cu (mg/kg)
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
41.67±1.17a
39.00±2.18ab
37.17±3.18abc
38.50±3.69abc
31.50±0.87c
33.17±1.88bc
35.00±0.29abc
26.67±1.20a
28.83±1.86a
29.83±1.88a
31.00±1.32a
30.67±1.45a
29.00±1.53a
29.33±2.73a
T1
T2
T3
T4
T5
T6
T7
Tomato
Sweet pepper

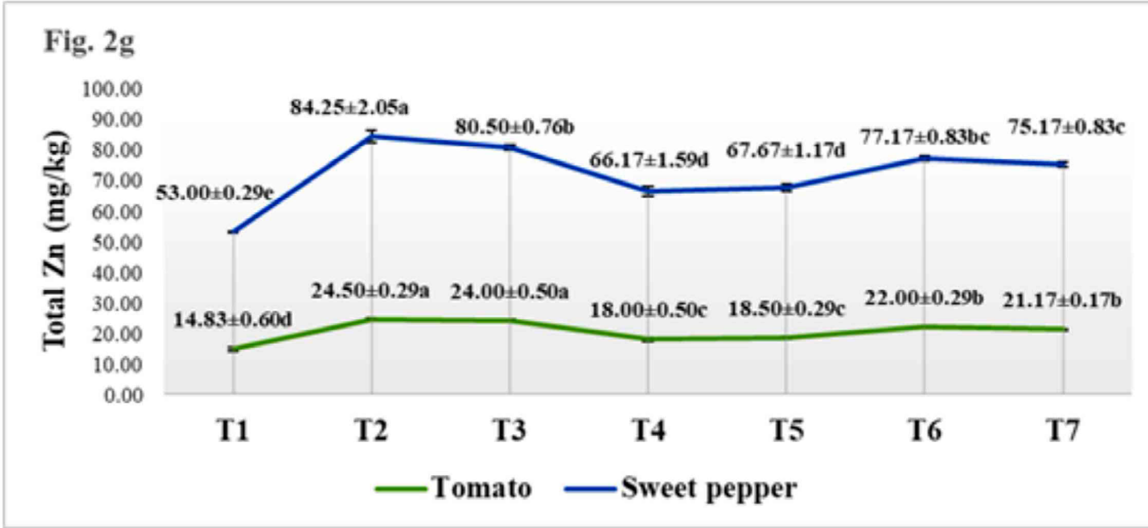
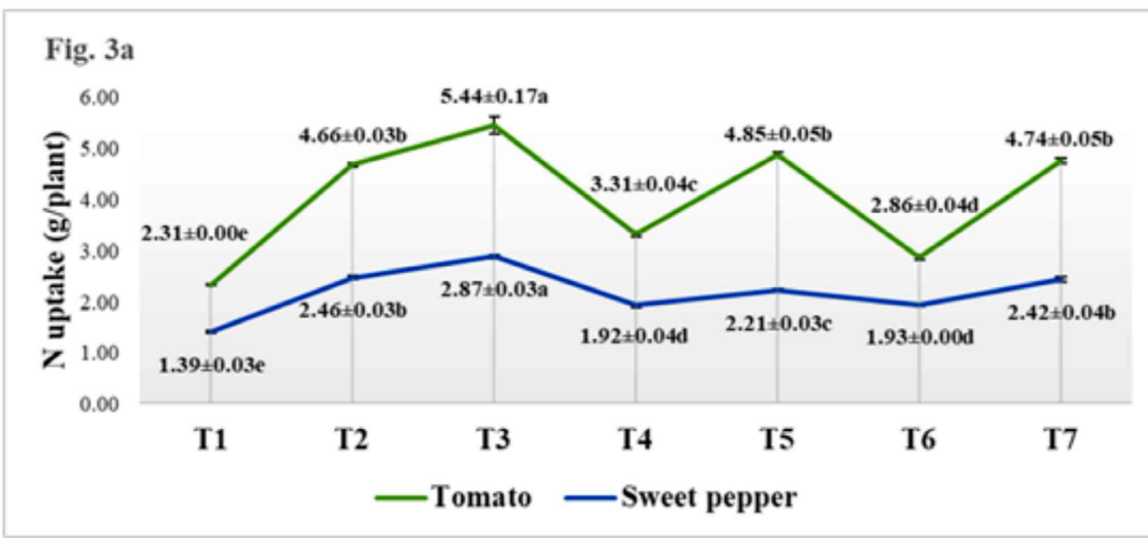



Fig. 2 : Effect of ZnO nanoparticles on nutrient content in tomato and sweet pepper

The NPK uptake was increased as the growth progressed along with the application of 50 mg/L ZnO nanoparticles as foliar application. The ZnO nanoparticles had a substantial effect on these parameters with maximum N uptake (5.44 and 2.87 g/plant), P uptake (1.14 and 1.00 g/plant) and K uptake (7.17 and 9.12 g/plant) recorded under the treatment $T_3$ in tomato and sweet pepper (Fig. 3). Improved root system, led to longer roots and better nutrient uptake, may be responsible for higher nutrient uptake in treatment that included 50 mg/L ZnO nanoparticles as foliar spray. Moreover, ZnO nanoparticles also reported in increasing the efficiency of nutrient uptake in tomato and beans (Chanu & Upadhyaya, 2019). The beneficial effects of nanosized zinc on plant growth have been demonstrated by previous studies, including pepper (Deore et al. 2010) and chilli (Datir et al. 2012). The uniform dispersion of nanoparticles throughout plant parts may be the cause of the enhanced plant growth and development (Salama et al. 2019).



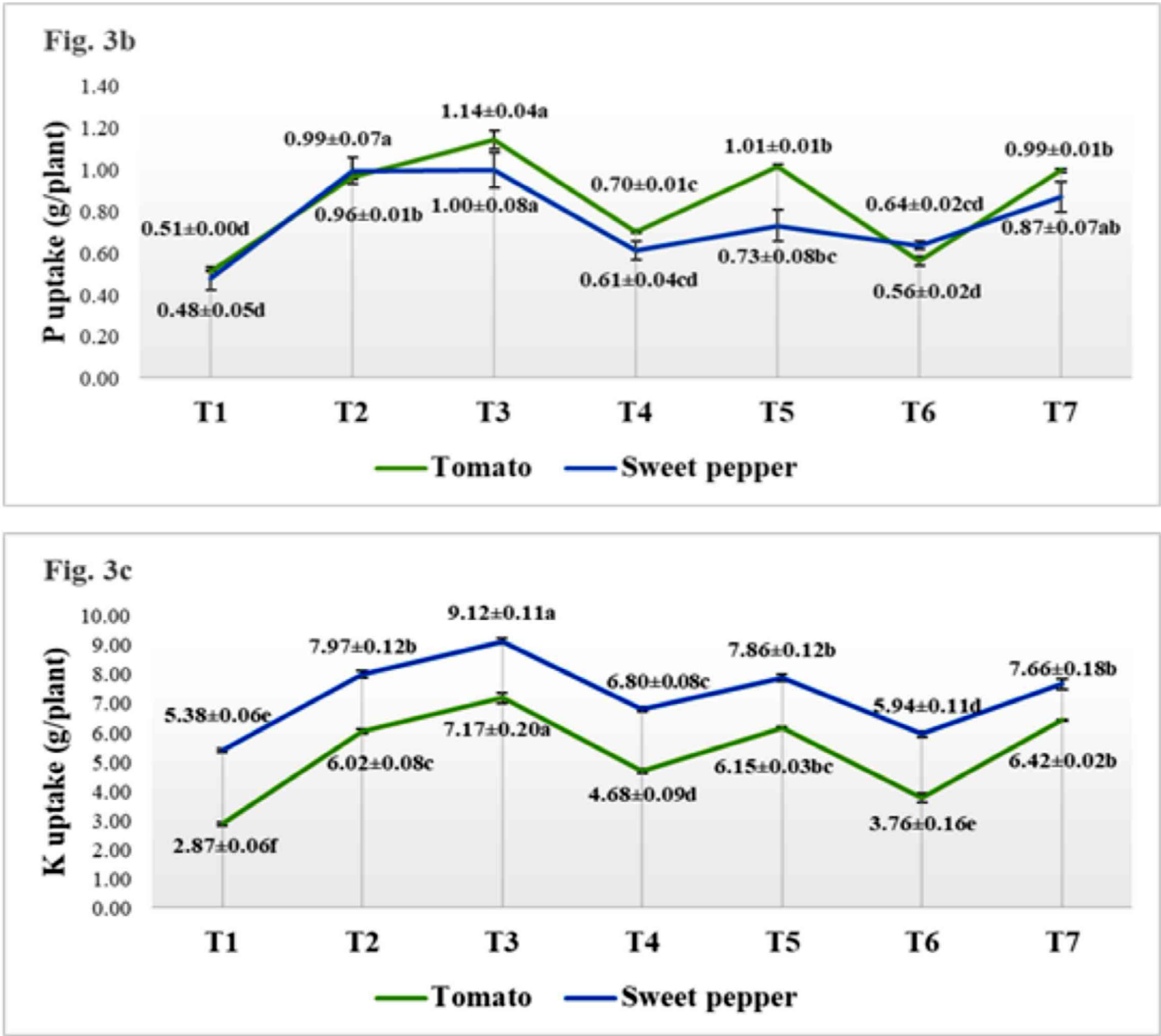



Fig. 3 : Effect of ZnO nanoparticles on nutrient uptake in tomato and sweet pepper

## CONCLUSION

The application of ZnO nanoparticles at 50 mg/L administered via seed treatment and foliar spray exerted a substantial influence on the growth, yield, and nutrient dynamics of tomato and sweet pepper crops. The study identified 50 mg/L as the optimal dosage, with foliar application specifically maximizing plant height, biomass, and fruit yield, while seed treatments significantly boosted internal nutrient content. These nanoparticles appear to optimize fertilization efficiency and physiological health. However, as these findings were obtained under controlled conditions, future research must prioritize multi-location field trials to validate performance across diverse environments. Additionally, long-term investigations into soil accumulation and molecular mechanisms are essential to address ecological safety and clarify plant-nanoparticle interactions.

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