

Original Research Paper

Effect of titanium dioxide nanoparticles on growth, yield, and nutrient uptake in *Capsicum annuum* L.

Brar P.S., Bhardwaj G.* and Kaushal R.

Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan - 173 230, India

*Corresponding author Email: bhardwajgitika93@hotmail.com

ABSTRACT

In order to test the effective concentration of titanium dioxide (TiO₂) nanoparticles on growth, yield and nutrient uptake in bell pepper, two-year open field experiment was conducted with three replications and seven treatment combinations. TiO₂ nanoparticles (size<25 nm) was applied with three levels (50, 100 and 150 mg/L) by using two methods *i.e.* through seed treatment and foliar application and one control without application of TiO₂ nanoparticles. The full recommended dose of nutrients was applied uniformly to all treatments through urea, single super phosphate and muriate of potash (94, 202.50 and 39.60 g/plot, respectively). The results revealed that treatment comprised of TiO₂ nanoparticles (100 mg/L) through foliar application produced the best outcomes and brought significant increment for all the growth parameters. Whereas, application of TiO₂ nanoparticles (50 mg/L) through seed treatment improved macro & micronutrient content and number of primary branches in bell pepper. Also, application of TiO₂ nanoparticles (50 mg/L) through foliar spray improved average fruit weight and NPK uptake in bell pepper. The findings concluded that application of TiO₂ nanoparticles (50 mg/L) through seed treatment as well as foliar application and 100 mg/L through foliar application have the potential to enhance growth, yield and nutrient uptake in bell pepper.

Keywords: Bell pepper, growth, titanium dioxide, uptake, yield

INTRODUCTION

Bell pepper (*Capsicum annuum* L.), belongs to Solanaceae family, is a high-value and popularly grown as commercial crop among large number of small and marginal farmers of North-Western hilly areas, especially Himachal Pradesh, India. Nanotechnology provides novel approaches offering innovative solutions to address complex challenges across multiple fields, including agriculture (Pramanik et al., 2020). In the present era, metal oxide nanoparticles offer enormous potential for usage as agricultural inputs to reduce the adverse effects of various factors on crop growth and development (Diaz-Parra et al., 2025). By merging nanotechnology in agriculture, new opportunities have emerged for boosting plant growth, enhancing crop resilience and ensuring sustainable farming techniques (El-Saadony et al., 2022). Due to the evident, unique and amazing capabilities of nanoparticles, efforts have been made to employ nanotechnology and nanomaterials to improve the agricultural system (Grillo et al., 2015). With their special physicochemical characteristics, nanoparticles improved the nutritional status of plants

by raising nutrient uptake and nutrient utilization efficiency, which further improved plant metabolism as well as growth (Brar et al., 2023; Bhardwaj et al., 2024). Previous studies have also demonstrated that titanium dioxide (TiO₂) nanoparticles particularly in anatase form, at low to moderate concentrations can positively impact seed germination, seedling strength and early growth stages in multiple plant species (Zainab et al., 2024). Additionally, it has been noted that TiO₂ nanoparticles enhance plant growth and production (Kumar et al., 2025). Because of their ability to boost metabolic activity and microbial activity, TiO₂ nanoparticles hold great promise as an effective source of nutrients for plants to improve biomass (Aqeel et al., 2022).

In this study, TiO₂ nanoparticles were selected due to its widespread application as one of the most popular but less exploited nanoparticles for agricultural interventions (Soran et al., 2021). Their potential to penetrate and interact with plant cells is enhanced by their nanoscale size. Seed treatment and foliar spraying are common application methods of nanoparticles. Increased yield, improved levels of essential elements



in plant tissues, and increased chlorophyll content in pepper (*Capsicum annuum* L.) are the three main impacts of titanium element on plants' physiology (Pérez-Velasco et al., 2023). So, the purpose of this study is to examine how seed treatment and foliar spraying of TiO₂ nanoparticles affect bell pepper growth, yield, and nutrient absorption.

MATERIALS AND METHODS

Field experiments were conducted at experimental farm of Department of Soil Science and Water Management, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh, during 2021 and 2022. The area is located in mid-hills, sub-humid, agro-climate zone-II of Himachal Pradesh, India at 30° 52' North latitude and 77° 11' East longitude. The initial soil status before experiment revealed that soil pH 7.20, electrical conductivity 0.40 dS/m and organic carbon 0.55%. The soil available NPK was 349.41, 21.20 and 239.76 kg/ha, respectively. The soil was sandy loam in texture and belongs to order Inceptisol and sub group Eutrochrept.

The experiment was laid out in randomized block design comprised of seven treatments with three replications; in plot size of 2.40×1.80 m (4.32 m²) with spacing 60×45 cm. Each plot accommodated 16 plants, with a total of 336 plants in 21 plots. The full amount of recommended dose of nutrients (N: 100 kg/ha, P₂O₅: 75 kg/ha and K₂O: 55 kg/ha) (Anonymous, 2014) was applied uniformly to all treatments through chemical fertilizers (urea: 94 g/plot; single super phosphate: 202.50 g/plot and muriate of potash: 39.60 g/plot); 15 days prior to the transplanting of seedlings. Treatments include different concentrations (mg/L) of TiO₂-NPs such as T1: control (without application of TiO₂-NPs), T2: ST 50, T3: FS 50, T4: ST 100, T5: FS 100, T6: ST 150 and T7: FS 150.

Titanium dioxide nano powder (TiO₂; anatase; Sigma-Aldrich Co., St Louis, MO, USA) with particle size <25 nm, white in color, poorly water soluble, and has 99.7% purity, was used for the experiment. TiO₂ nano-powder was first dissolved in ethanol and then further mixed in distilled water to prepare final solution of desired concentration. Titanium dioxide nanoparticles (TiO₂-NPs) was applied by two methods *i.e.* seed treatment (ST) and foliar application (FS), with concentration of 50, 100 and 150 mg/L, respectively.

For seed treatment, the seeds were dipped in respective concentration for overnight and in case of foliar application, one foliar spray of respective concentration was given after 15 days of transplanting.

Plant growth attributes were recorded at maturity by selecting five random plants from each plot and 3 pickings (*i.e.* 60, 75 and 90 days after transplanting) were taken for calculating the total yield. Digestion of the samples was carried out by method laid down by Piper (1966) for P, K, Zn, Cu, Fe and Mn. The total nitrogen was analyzed by Micro-Kjeldahl's method (AOAC, 1980). The total phosphorus by Vanado-molybdate phosphoric yellow colour method (Jackson, 1973). Total potassium was estimated in flame photometer (Jackson, 1967). The estimation of Zn, Cu, Fe and Mn was carried out on atomic absorption spectrophotometer (Vogel, 1978). Nutrient uptake by plant was calculated using the following formula:

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{Plant biomass (kg/ha)}}{100}$$

The benefit cost ratio was computed using the given formula:

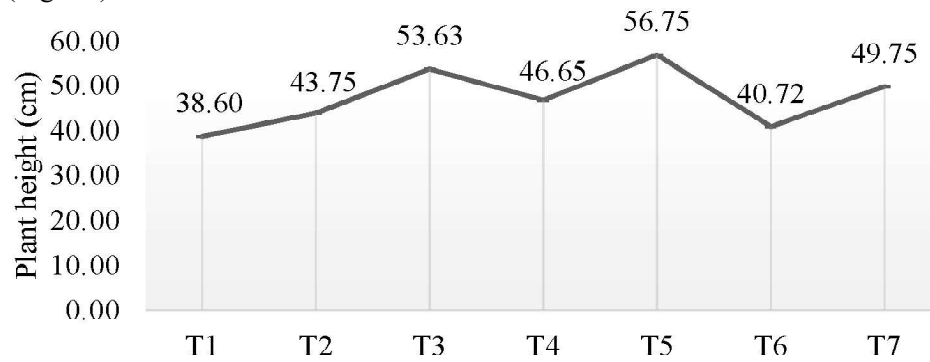
$$\text{Benefit Cost Ratio} = \frac{\text{Gross Return (₹)}}{\text{Total Cost (₹)}}$$

The data generated from both the years were pooled and analyzed by applying randomized block design (Panse & Sukhatme, 2000). The analysis of variance (ANOVA) of pooled data was performed using Microsoft Excel 2016 and OPSTAT packages (Sheron et al., 1998). The least significant difference (LSD) was determined among the treatment means at $p \leq 0.05$.

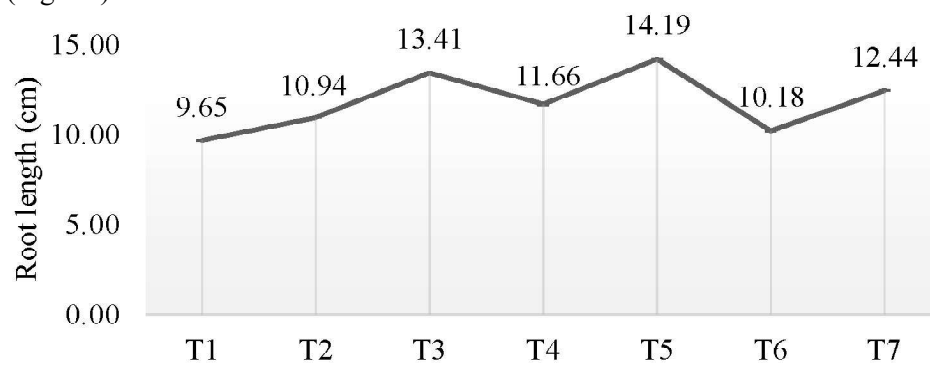
RESULTS AND DISCUSSION

The results revealed that the highest plant height (56.75 cm), root length (14.19 cm), plant biomass (63.87 g/plant) and yield (18.40 t/ha) were noted under treatment T5. Seed treatment of TiO₂ nanoparticles 50 mg/L (T2) recorded the highest number of primary branches (4.88), whereas treatment T3 *i.e.* foliar application of TiO₂ nanoparticles 50 mg/L registered maximum average fruit weight (65.33 g). Compared to control treatment (T1), foliar application of TiO₂ nanoparticles 100 mg/L showed the best outcome for all growth parameters (Fig. 1).

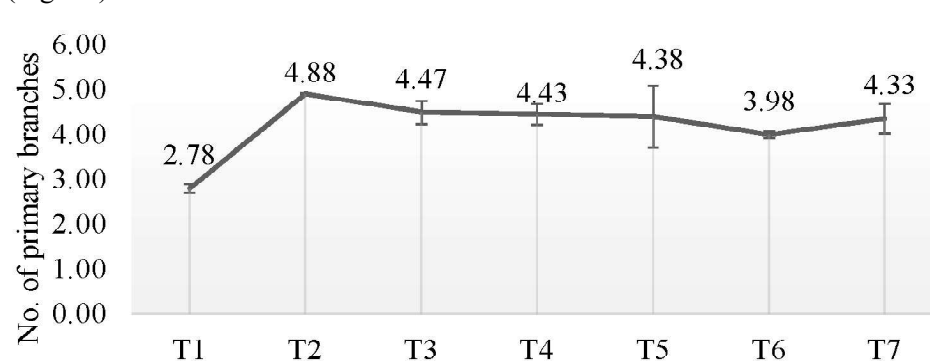
(Fig. 1a)



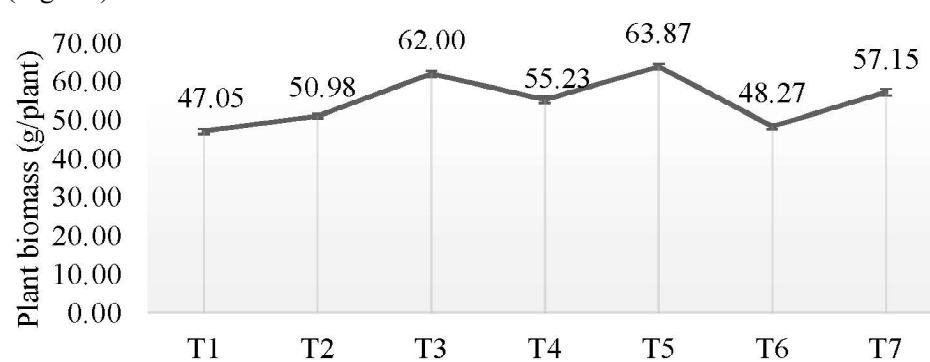
(Fig. 1b)



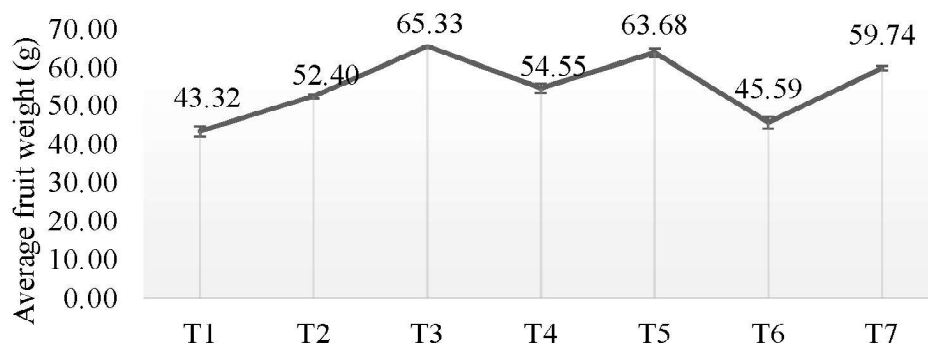
(Fig. 1c)



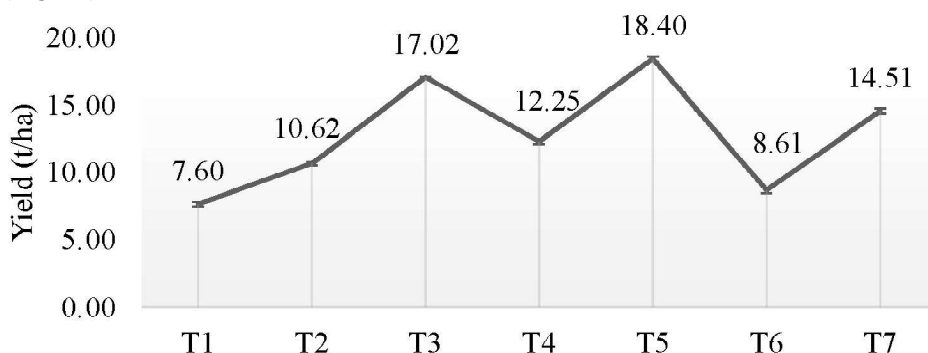
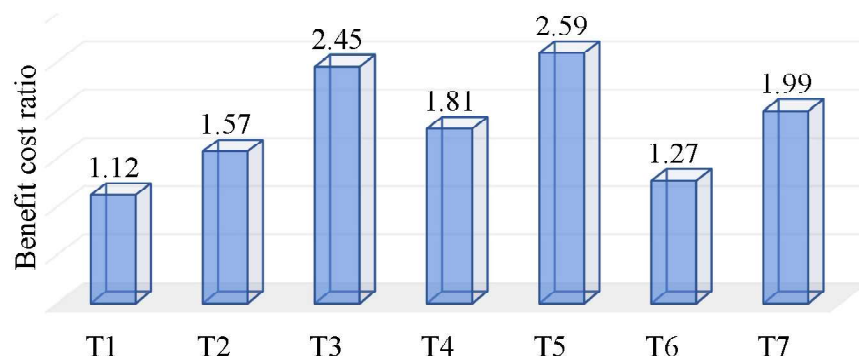
(Fig. 1d)



(Fig. 1e)



(Fig. 1f)


Fig 1 : Effect of TiO₂ nanoparticles on growth parameters of bell pepper

Fig. 2 : Effect of TiO₂ nanoparticles on benefit cost ratio of bell pepper

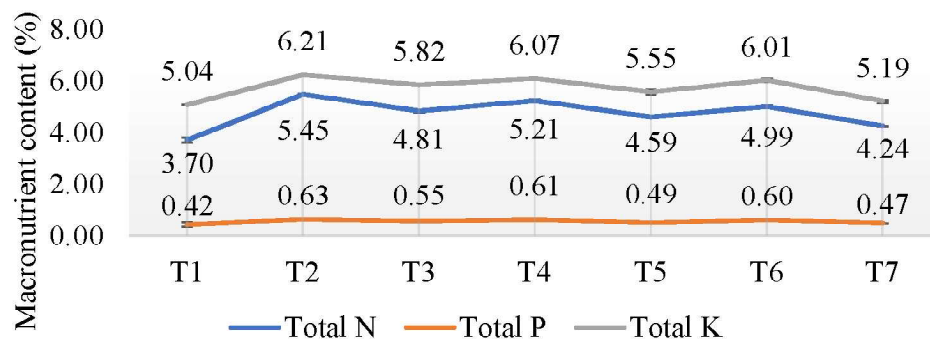
Also, the foliar application of TiO₂ nanoparticles at 100 mg/L (T5) recorded highest benefit-cost ratio (2.59) among all treatments (Fig. 2).

In the present study, foliar application of TiO₂ nanoparticles at 100 mg/L improved plant growth parameters, leading to maximum plant height, root length, plant biomass, yield and benefit-cost ratio. TiO₂ nanoparticles accelerate the conversion of inorganic nitrogen into organic nitrogen and enhances nitrogen

metabolism and increases nitrate absorption, which promotes better plant development (Kaur et al., 2022).

The remarkable capacity of titanium to stimulate plant development may be responsible for the enhanced growth characteristics of bell pepper. These findings are consistent with those of Irshad et al. (2021) who found that foliar application of TiO₂ nanoparticles (100 mg/L) led to increased plant parameters of wheat. Increased transport and photosynthetic life of the plant

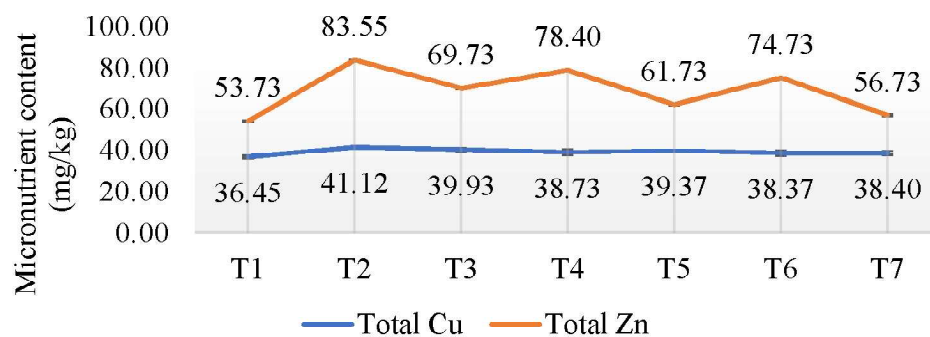
(Fig. 3a)



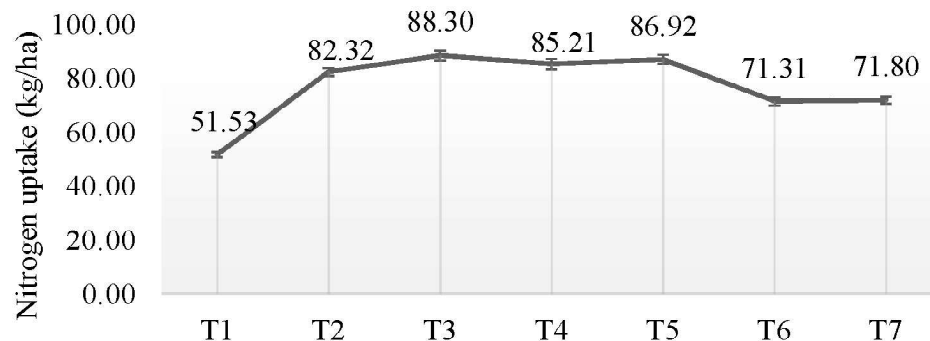
(Fig. 3b)



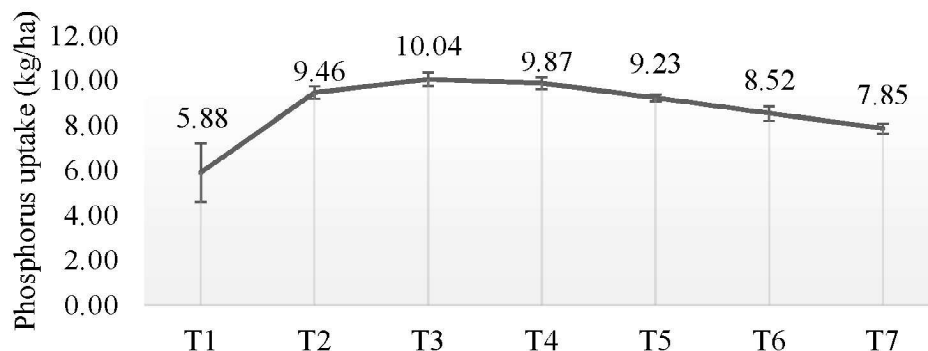
(Fig. 3c)



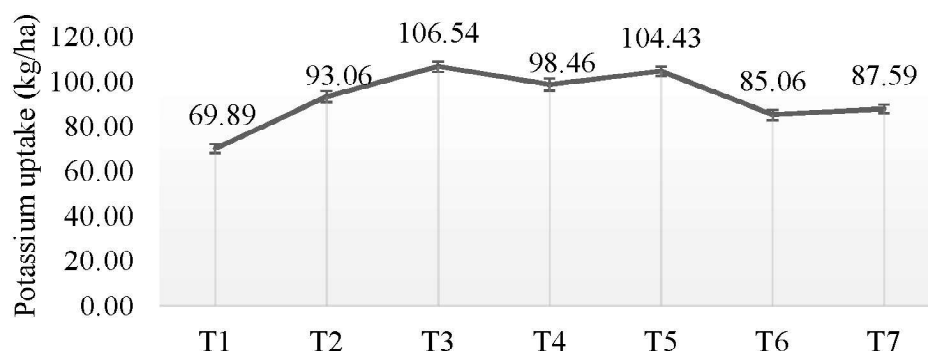
(Fig. 3d)



(Fig. 3e)



(Fig. 3f)


Fig. 3 : Effect of TiO₂ nanoparticles on nutrient content and uptake in bell pepper

may be responsible for the rise in plant growth parameters under foliar application of TiO₂ nanoparticles. Due to improved photosynthetic and enzymatic activities, bell pepper biomass and production also increased (Bhatti et al., 2025). The growth of plants was also enhanced by titanium through increased rates of photosynthesis and nutrient uptake (by increasing root volume) (Morshedloo et al., 2025). Khattak et al. (2021) also reported that foliar treatment of TiO₂ nanoparticles (25 to 300 mg/L) had beneficial effects on sunflower (*Helianthus annuus* L.). In our study, when bell pepper was treated with 100 mg/L through foliar spray of TiO₂ nanoparticles, plant biomass and yield metrics enhanced due to increased enzymatic activities. The foliar spray of TiO₂ nanoparticles increased oxidative enzyme activity (superoxide dismutase, peroxidase and catalase) (Khalid et al., 2024). They have also noted that, the enhanced oxidant enzyme activity scavenges reactive oxygen species (ROS) and reduces plants' stress indicators (Hydrogen peroxide, Malondialdehyde) production. This reduction in stress indicators

improved plant growth by minimizing oxidative damage, preserving cellular function, enhancing nutrient assimilation in plants. Another study by Mustafa et al. (2022) also revealed that TiO₂ acts as a plant stimulant, activating defense mechanisms against various stress factors. Kolencik et al. (2020) also reported that applying TiO₂ nanoparticles significantly increased sunflower plant growth and yield attributes.

The data sequence presented in Fig. 3 indicated a statistically significant improvement in total N (5.45%), P (0.63%), K (6.21%), Fe (442.08 mg/kg) and Zn (83.55 mg/kg) content by the application of TiO₂ nanoparticles at 50 mg/L through seed treatment (T2) compared to the control. But, the effect of different applied treatments of TiO₂ nanoparticles was remained non-significant for total manganese and copper content in bell pepper. The possible outcomes of metal oxide nanoparticles depend on composition, size, type and concentration of that particular nanoparticle. Even some of the research studies also

showed no appreciable effects by the application of TiO₂ nanoparticles. In a similar way, Rawat et al. (2018) also investigated the impact of metal oxide nanoparticles on growth of capsicum plants and found no significant effect on some of the growth parameters which further signified that the interaction between nanoparticles and biological system might be dependent on several factors specific to the experimental environment. Also, study conducted by Diaz-Parra et al. (2025) revealed the variability of nutrient accumulation and their uptake; and often negligible bioaccumulation by the application of metal oxide nanoparticles in capsicum.

In present study, treatment T2 recorded the highest macro & micronutrient content and number of primary branches. Hu et al. (2020) also found that applying TiO₂ nanoparticles at 50 mg/L increased the nutrient content in coriander. Furthermore, with treatment T3 i.e. foliar application of TiO₂ nanoparticles at 50 mg/L, a noteworthy rise in nitrogen, phosphorus and potassium uptake (88.30, 10.04 and 106.54 kg/ha) were noted (Fig. 3). Similar results were also reported by Sehrish et al. (2024). Their findings concluded that foliar application of 100 mg/L TiO₂ nanoparticles significantly enhanced macro as well as micronutrient uptake in *Brassica napus*.

CONCLUSION

Growth, yield and nutrient uptake parameters of bell pepper was greatly impacted by the use of TiO₂ nanoparticles (50 mg/L) as seed treatment as well as foliar application; and 100 mg/L as foliar application. It has been shown that usage of nanoparticles in plants can enhance fertilization strategies and sustain vital physiological functions including increased plant biomass and net nutrient absorption, which are necessary for the best possible plant development in order to enhance agricultural productivity by stimulating plant metabolism. Further investigation on TiO₂ nanoparticles in bell pepper should explore molecular mechanisms, and analyze environmental safety. TiO₂ nanoparticles can be integrated with biofertilizers and using smart delivery systems might augment nutrient efficiency, boost yield, and support sustainable agriculture with minimal environmental impact. Ensuring safe and sustainable use of nanoparticles requires focused research on their potential residues in edible crops and associated environmental impacts.

ACKNOWLEDGMENT

The authors are thankful to the Department of Soil Science and Water Management, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India for providing necessary research facilities.

REFERENCES

- Anonymous. (2014). Packages of practices for *vegetable crops*. Directorate of Extension Education, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India. 24p.
- AOAC. (1980). *Official methods of analysis*. Association of official analytical chemists, 13th edition, W. Horowitz (eds.). Benjamin Franklin Station, Washington, DC. 1018p.
- Aqeel, U., Aftab, T., Khan, M. M. A., Naeem, M., & Khan, M. N. (2022). A comprehensive review of impacts of diverse nanoparticles on growth, development and physiological adjustments in plants under changing environment. *Chemosphere*, 291, 132672. <https://doi.org/10.1016/j.chemosphere.2021.132672>.
- Bhardwaj, G., Brar, P. S., Chauhan, A., & Bhardwaj M. (2024). Comparison of fruit and quality parameters of tomato and capsicum by using different amount of nano ZnO through foliar and seed application. *Journal of Plant Nutrition*, 47(19), 3767–3776. <https://doi.org/10.1080/01904167.2024.2384572>.
- Bhatti, A., Sanchez-Martinez, A., Sanchez- Ante, G., Jacobo- Velázquez, D. A., Qui-Zapata, J. A., Mahmoud, S. S., Channa, G. M., Lozano, L. M., Mejía-Méndez, J. L., López-Mena, E. R., & Navarro- López, D. E. (2025). Synergistic effect of TiO₂-nanoparticles and plant growth-promoting microorganisms on the physiological parameters and antioxidant responses of *Capsicum annum* cultivars. *Antioxidants*, 14(6), 707. <https://doi.org/10.3390/antiox14060707>.
- Brar, P. S., Bhardwaj, G., & Chauhan, A. (2023). A review on understanding the efficient source of balanced crop nutrition through nanotechnology in agriculture. *Journal of Plant Nutrition*, 46(13), 3221-3231. doi: 10.1080 01904167. 2023.2179923

- Díaz-Parra, D. G., García-Casillas, L. A., Velasco-Ramírez, S. F., Guevara-Martínez, S. J., Zamudio-Ojeda, A., Zuñiga-Mayo, V. M., Rodríguez-Guzmán, E., Melchor-González, A., Lomeli-Rosales, D. A., & Velázquez-Juárez, G. (2025). Role of metal-based nanoparticles in *Capsicum* spp. plants. *ACS Omega*, 10(11), 10756–10768. <https://doi.org/10.1021/acsomega.4c11102>.
- El-Saadony, M. T., Saad, A. M., Soliman, S. M., Salem, H. M., Desoky, E.-S. M., Babalghith, A. O., El-Tahan, A. M., Ibrahim, O. M., Ebrahim, A. A. M., Abd El-Mageed, T. A., Elrys, A. S., Elbadawi, A. A., El-Tarabily, K. A., & AbuQamar, S. F. (2022). Role of nanoparticles in enhancing crop tolerance to abiotic stress: A comprehensive review. *Frontiers in Plant Science*, 13, 946717. <https://doi.org/10.3389/fpls.2022.946717>.
- Grillo, R., Rosa, A. H., & Fraceto, L. F. (2015). Engineered nanoparticles and organic matter: A review of the state of the art. *Chemosphere*, 119, 608-619. <https://doi.org/10.1016/j.chemosphere.2014.07.049>.
- Hu, J., Wu, X., Wu, F., Chen, W., White, J. C., Yang, Y., Wang, B., Xing, B., Tao, S., & Wang, X. (2020). Potential application of titanium dioxide nanoparticles to improve the nutritional quality of coriander (*Coriandrum sativum* L.). *Journal of Hazardous Materials*, 389, 121837. <https://doi.org/10.1016/j.jhazmat.2019.121837>.
- Irshad, M. A., Nawaz, R., Ur-Rehman, M. Z., Adrees, M., Rizwan, M., Ali, S., Ahmad, S., & Tasleem, S. (2021). Synthesis, characterization and advanced sustainable applications of titanium dioxide nanoparticles: A review. *Ecotoxicology Environmental Safety*, 212, 111978. <https://doi.org/10.1016/j.ecoenv.2021.111978>.
- Jackson, M. L. (1967). *Soil chemical analysis* prentice. New Delhi: Hall of India Private Limited.
- Jackson, M. L. (1973). *Soil chemical analysis*. Prentice Hall of India Pvt. Ltd., New Delhi. 111-126p.
- Kaur, H., Kalia, A., Sandhu, J. S., Dheri, G. S., Kaur, G., & Pathania, S. (2022). Interaction of TiO₂ nanoparticles with soil: Effect on microbiological and chemical traits. *Chemosphere*, 301, 134629. <https://doi.org/10.1016/j.chemosphere.2022.134629>.
- Khalid, M. F., Jawaid, M. Z., Nawaz, M., Shakoor, R. A., & Ahmed, T. (2024). Employing titanium dioxide nanoparticles as biostimulant against salinity: improving antioxidative defense and reactive oxygen species balancing in eggplant seedlings. *Antioxidants*, 13(10), 1209. <https://doi.org/10.3390/antiox13101209>.
- Khattak, A., Ullah, F., Shinwari, Z. K., & Mehmood, S. (2021). The effect of titanium dioxide nanoparticles and salicylic acid on growth and biodiesel production potential of sunflower (*Helianthus annuus* L.) under water stress. *Pakistan Journal of Botany*, 53, 1987–1995. [https://doi.org/10.30848/pjb2021-6\(42\)](https://doi.org/10.30848/pjb2021-6(42)).
- Kolencík, M., Ernst, D., Urik, M., Durisova, L., Bujdos, M., Sebesta, M., Dobrocka, E., Ksinan, S., Illa, R., & Qian, Y. (2020). Foliar application of low concentrations of titanium dioxide and zinc oxide nanoparticles to the common sunflower under field conditions. *Nanomaterials*, 10, 1619. <https://doi.org/10.3390/nano10081619>.
- Kumar, S., Suman, S., Muthukumar, M., Mishra, K., Bajpai, A., Tiwari, A. K., Srivastava, G., Bansal, S., Chaturvedi, K., Maurya, S., Damodaran, T., Killadi, B., & Ranjan, D. (2025). Technical review on different metal nanoparticles and their formulations on growth, agronomic and economic traits of crop plants. *Frontiers in Nanotechnology*, 7, 1576582. <https://doi.org/10.3389/fnano.2025.1576582>.
- Morshedloo, M. R., Jabbari, N., Azizi, M., Nazari, M., Zahedi, S. M., & Viapiana, A. (2025). Enhancing salt tolerance in *Mentha × gracilis* through foliar applications of titanium and nano-titanium. *BMC Plant Biology*, 25(1), 1088. <https://doi.org/10.1186/s12870-025-07056-x>.
- Mustafa, N., Raja, N. I., Ilyas, N., Abasi, F., Ahmad, M. S., Ehsan, M., Mehak, A., Badshah, I., & Proćków, J. (2022). Exogenous application of green titanium dioxide nanoparticles (TiO₂ NPs) to improve the germination, physiochemical,

- and yield parameters of wheat plants under salinity stress. *Molecules*, 27(15), 4884. <https://doi.org/10.3390/molecules27154884>.
- Panse V. G., & Sukhatme, P. V. (2000). *Statistical methods for agricultural workers*, 359. New Delhi: ICAR.
- Pérez-Velasco, E. A., Valdez-Aguilar, L. A., Betancourt-Galindo, R., González-Fuentes, J. A., & Baylón-Palomino, A. (2023). Covered rutile-TiO₂ nanoparticles enhance tomato yield and growth by modulating gas exchange and nutrient status. *Plants*, 12(17), 3099. <https://doi.org/10.3390/plants12173099>.
- Piper, C. S. (1966). *Soil and Plant Analysis*. Hans Publication, Bombay, India. 368p.
- Pramanik, P., Krishnan, P., Maity, A., Mridha, N., Mukherjee, A., & Rai, V. (2020). Application of nanotechnology in agriculture. *Environmental Nanotechnology*, 4, 317–348. https://doi.org/10.1007/978-3-030-26668-4_9.
- Rawat, S., Pullagurala, V. L. R., Hernandez-Molina, M., Sun, Y., Niu, G., Hernandez-Viezcas, J. A., Peralta-Videa, J. R., & Gardea-Torresdey, J. L. (2018). Impacts of copper oxide nanoparticles on bell pepper (*Capsicum annum* L.) plants: A full life cycle study. *Environmental Science: Nano*, 5(1), 83–95. <https://doi.org/10.1039/c7en00697g>.
- Sehrish, A. K., Ahmad, S., Alomrani, S. O., Ahmad, A., Al-Ghanim, K. A., Alshehri, M. A., Tauqeer, A., Ali, S., & Sarker, P. K. (2024). Nutrient strengthening and lead alleviation in Brassica Napus L. by foliar ZnO and TiO₂-NPs modulating antioxidant system, improving photosynthetic efficiency and reducing lead uptake. *Scientific Reports*, 14, 19437. <https://doi.org/10.1038/s41598-024-70204-0>.
- Sheron, O. P., Tonk, D. S., Kaushik, L. S., Hasija, R. C., & Pannu, R. S. (1998). Statistical software package for agricultural research workers. In *Recent advances in information theory, statistics and computer application*, ed. D. S. Hooda & R. C. Hasija, 139-43. Hisar, Haryana, India: Department of Mathematics Statistics, CCS HAU.
- Soran, M.-L., Lung, I., Opri', O., Culicov, O., Ciorîă, A., Stegarescu, A., Zinicovscaia, I., Yushin, N., Vergel, K., Kacso, I., & Borodi, G. (2021). The effect of TiO₂ nanoparticles on the composition and ultrastructure of wheat. *Nanomaterials*, 11(12), 3413. <https://doi.org/10.3390/nano1112341>.
- Vogel, A. (1978). *Textbook of quantitative inorganic analysis*. 4th ed. London: Longman.
- Zainab, L., Tahir, A., Naeem, E. U., Rafaqat, A., Ahmad, A., Malik, D., & Ejaz, H. (2024). Impact of titanium dioxide nanoparticles on agricultural crops performance: A Review of efficacy and mechanisms. *Futuristic Biotechnology*, 4(04), 12-20. <https://doi.org/10.54393/fbt.v4i04.145>.

(Received: 18.2.2025; Revised: 17.2.2026; Accepted: 21.2.2026)

