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Research Article

Effect of titanium dioxide nanoparticles on morphological growth and chlorophyll content of *Solanum lycopersicum* L.

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Background: This study examined the effects of TiO_2 NPs on the morphological growth and chlorophyll content of *Solanum lycopersicum* plants. The nanoparticles either promoted or inhibited early plant growth, including shoot length, root development, and total biomass. Changes in chlorophyll a and b levels were examined to determine the physiological effects of NPs on plants.

Methods: TiO_2 NPs was synthesized using a chemical precipitation method and characterized to evaluate their structural and optical properties. UV-Vis spectroscopy confirmed the optical transmittance of the NPs, while X-ray diffraction (XRD) verified their crystalline phase. Particle size analysis (PSA) and scanning electron microscopy (SEM) were used to determine the precise size distribution and surface morphology of the NPs. To investigate their subsequent biological effects on *S. lycopersicum* seeds, the seeds were treated with different concentrations of 15, 30, 60, 120, and 240 mgL^{-1}. This exposure was designed to systematically evaluate the phenotypic changes caused by the nanoparticles.

Results: The study showed a concentration-dependent effect on plant growth, with lower treatments enhancing growth, but higher concentrations of 60, 120, and 240 mgL^{-1} causing phytotoxicity and morphological abnormalities in vegetative parts. While physiological such as seed germination, plant height, and root and shoot growth initially increased in conditions, Fourier-transform infrared spectroscopy (FTIR) analysis revealed clear biochemical changes in plant tissue, particularly an additional functional group, alkyl nitrites, characterized by an asymmetric NO_2 stretch, which was particularly evident at a concentration of 60 mgL^{-1}.

Conclusion: Nanoparticle phytotoxicity is typically observed with higher concentrations and exhibited both positive and negative growth responses by altering plant morphology and chlorophyll content chlorophyll a, b, and carotenoid levels increased at concentrations of 15 and 120 mgL^{-1}, but decreased at all other treatment levels compared to the control group. TiO_2 NPs can actively regulate plant growth depending on the dose.

Abbreviations:

TiO_2	-	Titanium Dioxide
NPs	-	Nanoparticles
S. lycopersicum	-	*Solanum lycopersicum*
NM	-	Nanomaterials

Keywords: *Chlorophyll, Phytotoxicity, Solanum lycopersicum, TiO_2 nanoparticles*

Introduction

Nanotechnology is believed by many scientists to be a revolution in space, sport, biology, physics, medical science, and chemistry, etc. (Gottschalk et al., 2013; Sun et al., 2015). Nowadays in daily life, titanium dioxide nanoparticles are being used in cosmetics, solar cells, paints, glass and water treatment products, etc. and after their use of the products, TiO_2 NPs get into the air, soil and water in large quantities (Verma et al., 2021). TiO_2 NPs have been shown to be toxic to many species including bacteria, algae, invertebrates and vertebrates (Kushwah et al., 2021b). According to the European Union's Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), NPs are not dangerous, but there are many uncertainties about their safety.

Many problems may arise in future due to excessive use of NPs. TiO_2 NPs is more preferred for research work because of their high photostability, high photon activity, affordable and easy availability. TiO_2 works as a photocatalyst in water treatment, and photocatalysts contribute to water treatment by oxidizing organic pollutants into harmless materials (Verma et al., 2020). Compounds of TiO_2 nanoparticles can compensate for nitrogen deficiency and promote various growths in crops such as plant biomass and activity of various enzymes, and chlorophyll content (Kushwah and Verma 2021a).

Most reports available in the literature indicate synthesized phytotoxicity. Recent research studies in plant science have many studied, effect of many nanoparticles on plants (Sytar et al., 2019). TiO_2 NPs has prolonged facilitates plant growth, inequality and availability in media (Costa et al., 2019). Several sizes of nanoparticles are used in plant science research studies, but smaller size of nanoparticles always produces maximum toxicity to plants than larger nanoparticles (Jiang et al., 2017). Hou et al. (2019) reported TiO_2 NPs in living organisms gave three aspects of the mechanism of toxicity TiO_2 changed the electron-hole pair. Damage to the cell wall and lipid peroxidation damage to the cell membrane and attachment on intracellular organelles. TiO_2 nanoparticles control and improve the growth rate of spinach and other plants (Zheng et al., 2005). Yu et al., 2019 reported that nanoparticles have positive and negative effects on chlorophyll content in plants. TiO_2 nanoparticles are used as indicators of photosynthesis, nitrogen metabolism, plant growth, eukaryotes and chromosomal mutations in higher plants, it has been found in various research studies to cause chromosome aberrations, cytotoxicity, DNA damage and micronucleus formation (Song et al., 2013). Titanium is considered an essential element for plant growth and the role of TiO_2 in crops is useful in stimulating the activities of certain enzymes, increasing chlorophyll content and photosynthesis, improving crop morphology and growth. High amounts of nanoparticles prove to be functionally useful. However, high concentrations of TiO_2 NPs have been shown to be toxic to plants in both in vivo and in vitro systems (Rafique et al., 2014). High amounts of TiO_2 NPs support the adhesion of beneficial bacteria present in the roots of oilseed plants and protect the plants from infection (Palmqvist et al., 2015). Improved chlorophyll concentration, fruit yield, Rubisco activity, as well as improved plant growth in *Solanum lycopersicum* were observed in photosynthesis with TiO_2 NPs leaf treatment (Raliya et al., 2015). Some of the larger NPs enter them through pores in the plant cell walls (Rastogi et al., 2017).

In the past two decades, many scientists have observed the effect of different types of synthesized NPs on different plants. HM (Heavy metals) NPs in excessive amounts in soil are harmful to plants, but NPs of heavy metals (HM) as micronutrients have been reported to play important roles in plant metabolism, growth and development. In addition to NPs in plants nowadays, the effects of HMs are also being studied, as they play an important role in metabolism and support plant growth and development. However, at levels above the threshold, these HMs act as contaminants and are increasing future environmental hazards worldwide (Kushwah and Patel 2018). Many scientists have suggested the positive impact of TiO_2 nanoparticles on thylakoid membranes and photo system II in the plants (Hong et al., 2005). TiO_2 nanoparticles encourage cell division such as increased cell size, changes in cell organelles size, etc., and also stimulate callus induction under dark conditions (Mandeh et al., 2012), and TiO_2 nanoparticles may have similar effects as hormones (cytokinin and gibberellin). Low quantity of nanoparticles can also be used to increase production in agriculture. As such, TiO_2 nanoparticles can improve light absorption and carbon fixation through RuBisCO enzyme activity enhancement and through this the fresh and dry weight of plants can be increased, nitrate can be accelerated and inorganic materials can be converted to organic material (Yang et al., 2006; Mingyu et al., 2007; Nair et al., 2010).

Solanum lycopersicum is commonly referred to as tomato in the world. *S. lycopersicum* is an angiosperm plant that belongs to the family Solanaceae. Tomato is the most important and cultivated crop in worldwide. Tomato plant sprouts are symbiotic, originally highly branched, leafy (mixed leaves) and about 20 to 60 inches in height (Hernández-Fuentes et al., 2017). Tomato plants are vegetable crops and fruits contain a good amount of water, minerals, vitamins (most vitamin C) and some amounts of carbohydrates, fats and proteins (Beecher, 1998). Tomato plants are the most important in the research field; it has many characteristics of genetic formation which are very useful for genetic hybridization of plants (Qi et al., 2013). During the life cycle of a tomato plant, a variety of diseases and pests decrease its yield, pathogenic *Ralstonia solanarum* bacteria present in the soil enter the radicular system by wounding in the plant's xylem and preventing their colonization. Therefore, our research investigated the morphological and phytochemical properties of the effect of TiO_2 nanoparticles on tomato plants, protection against pathogens, enhancing yield productivity.

Materials and Methods

Synthesis of TiO_2 nanoparticles by chemical method

The 0.5 gram of TiO_2 powder phase were dissolved in 1.0 mM of sodium hydroxide and then heated that solution under refluxing at 80-100° C for 3 hours with continuous magnetic stirring on magnetic stirrer. The 1.0 mM HCl added in suspension for maintained 5 pH value of suspension with continues magnetic stirring for 5 hours. After stirring these ions exchange and totally materialized NaCl. The obtained solution centrifuged at 4500 - 5000 rpm for 25 to 30 minutes, discards supernatant and washed with double distilled water. Obtained particles dried in hot air oven for 6 hours at 80-90° C and then again heated at 500-550° C to formed Anatase phase of TiO_2 nanoparticles (Tiwari et al., 2018).

Biological material- The seeds in the present investigation were procured in local farmer, seeds of (a local variety) *S. lycopersicum* being maintained in the lab and the plants were cultivated in the garden of the School of Studies in Botany, were used for the morphology (phytotoxicity) studies and effect of TiO_2 NPs on *S. lycopersicum* (Kushwah et al. 2021a).

Treatment of seeds and collection- Dry seeds of *Solanum lycopersicum* (6.64 % moisture) were sterilized with 4% Sodium hypochlorite solution for 5 minutes and washed with distilled water. Different concentrations 15, 30, 60, 120 and 240 mgL^{-1} of nanoparticles were prepared and sonicated for 3 hrs. The seeds were treated with different concentrations and kept for 24 hours. Seed dose control and concentration (10 seeds/dose) were performed prior to treatment and detected an average weight of three replicates (n = 3 or 10 X 3 = 30) of each dose. These seeds were sown (10 seeds) in each in Petri plates and transferred to pots in the first week of January at 22 ± 6 °C. The treated plants were kept under observed in morphological changes such as root, shoot, leaves, size of flowers and seeds (Kushwah et al., 2018).

Results

PSA (Particles Size Analysis)

The average particle diameter was ranging from 50 to 300 nm as given by the PSA 5 % normalized particle amount of TiO_2 NPs.

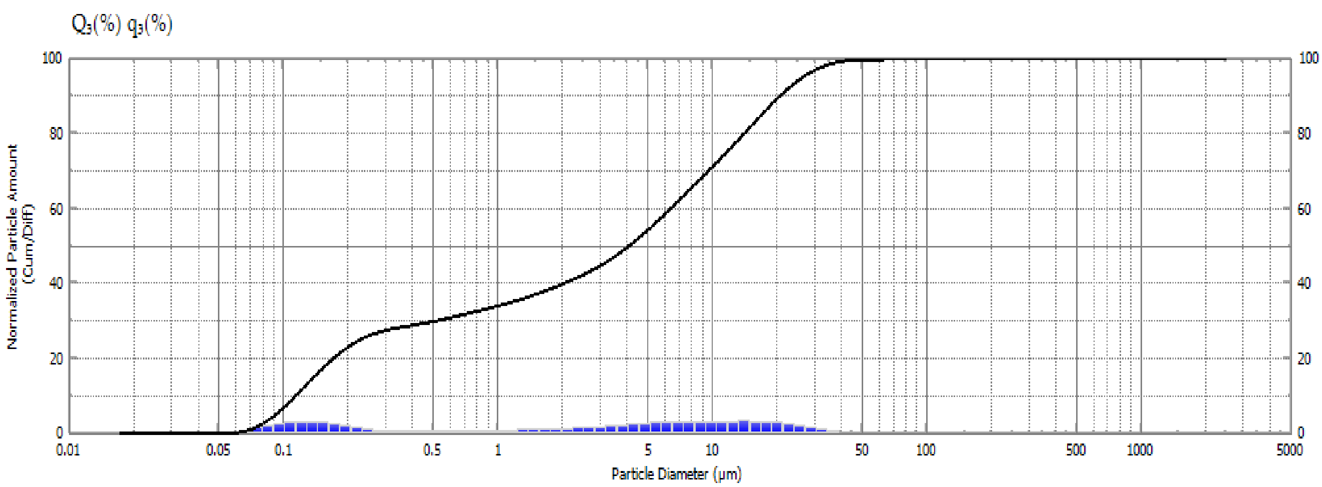

Figure 1. Showed the TiO_2 nanoparticles range and size by PSA

XRD (X-Ray Diffraction)

The analysis of TiO_2 nanoparticles by XRD was 2θ range of 24° to 64°. The XRD peaks generated confirmed that the crystalline nature of TiO_2 nanoparticles. The peaks generated at 25.28, 37.8, 48.04, 53.89, 55.06 and 62.68 which were corresponding to (101), (004), (200), (211) and (204) planes reflections of anatase phase of TiO_2 nonmaterial and confirmed anatase phase of nanoparticles. The obtained data matched from the Joint Committee on Powder Diffraction Standards (JCPDS card no 21-1272) this is to confirm that the anatase phase (Figure 2).

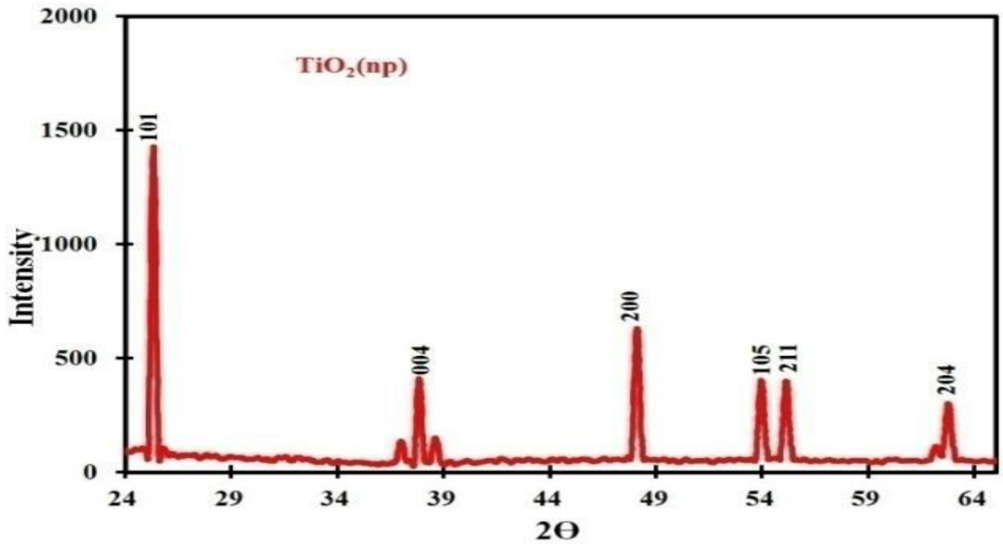

Figure 2. XRD pattern of TiO_2 nanoparticles and synthesized by chemical

UV-Vis Spectroscopy

The UV-Vis Spectroscopy is one of the absorption spectroscopy tools in which UV light (200 – 750 nm) is absorbed by particles or molecules. The TiO_2 nanoparticles were analyzed by UV-Vis Spectroscopy (Cary 60 UV-Vis Spectrometer) and the graph shows the transmission spectra on the TiO_2 nanoparticles. The wavelength of spectrum was 250 nm and spectrums were transmitted ground state to higher energy state and the energy band gap was found 1.75 eV to 2.5 eV. The result was matched by a plotting graph which was the same as previously recorded data and this was confirmed that TiO_2 nanoparticles were nano size structure (Figure 3).

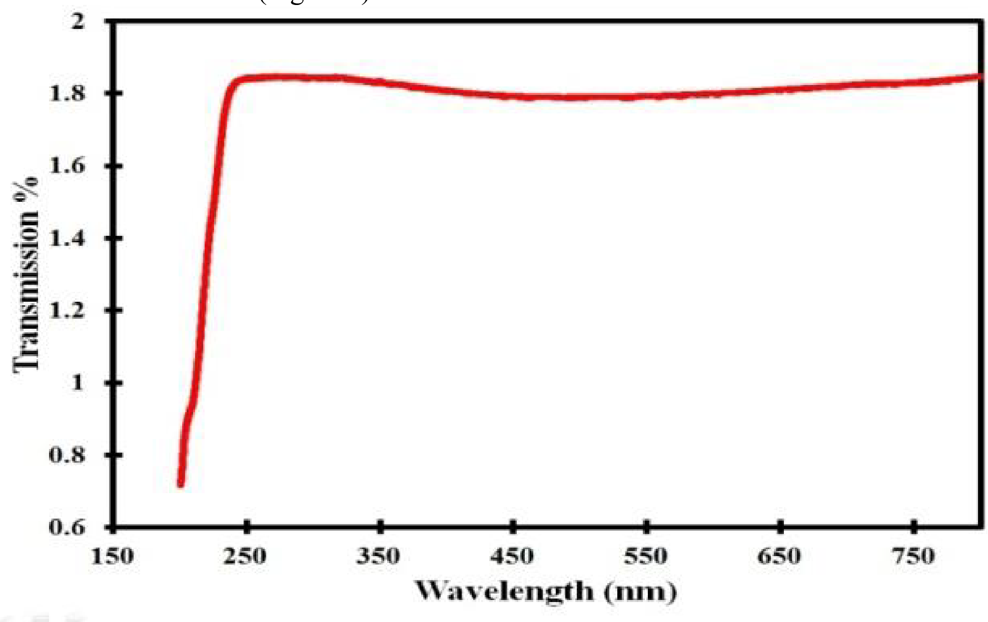

Figure 3. Image of UV-vis Spectroscopy of TiO_2 nanoparticles

Scanning Electron Microscope (SEM)

The SEM (Zeiss EVO MA10) micrograph shows that TiO_2 nanoparticles are more or less spherical in shape or core – shell structure. The electron beam is constructed with the help of an electron gun. The electron gun is kept in a vacuum. The vacuum is created through a vacuum pump (rotary and oil diffusion pump). SEM uses a beam of electrons to create a surface pattern in a 2-dimensional photo of the sample. The secondary electron emitted from the sample is collected in a CCD camera. The chemical composition of the sample can be determined by analyzing the secondary electrons. The TiO_2 nanoparticles range in size from 50 to 200 nm as shown in the Figure 4.

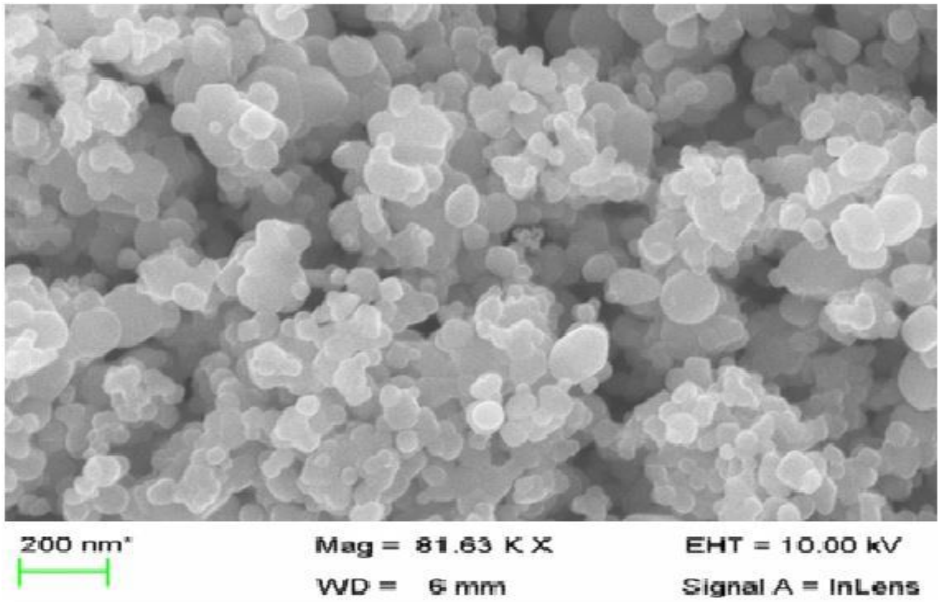

Figure 4. SEM micrograph of TiO_2 nanoparticles

Germination of seeds: This work perform on *S. lycopersicum* plants and normal temperature was 22 to 28 °C. Control and concentration of the seed dose (10 seeds / dose) were detected by weighing three replicates (n = 3 or 10 X 3 = 30) of each dose before treatment. The average weight of the control seeds (10 seeds / dose) was 21 mg whereas the dried seed had the highest average weight 20 mg at 120 and 240 mgL^{-1} concentrations of treated seeds and the lowest average weight 19 mg at 15, 30 and 60 mgL^{-1} concentrations. Aerated soil, temperature above 10 °C, water and oxygen is required for better germination of tomato seeds. After the treatment of seeds were germinated in Petri plates and it was observed that germination started from 4th day of treatment at 15 mg, 60 mg and 120 mgL^{-1} concentration, 5th days seeds germinated at 30 and 240 mgL^{-1} concentrations. In untreated seed, the germination started on 6th day. The treated seed germination percentage rate was found in lower concentrations to higher concentrations of nanoparticles, as compared to control seeds. The highest seeds germinations were 90 % in 15 and 60 mgL^{-1} and lowest seeds germination 70 % in 30 mg and 240 mgL^{-1} concentrations of nanoparticles and 100% in control.

Table 1. Germination of first seed and seedlings in days, values Mean ± SE of root and shoot growth of germinated seeds

S.no	Concentrations in (mgL^{-1})	First seed germination time from seed sowing (in days)	First seedlings time from seed sowing (in days)	Root growth after 10 days in cm (Mean ± SE)	Shoot growth after 15 days in cm (Mean ± SE)
1.	Control	6	10	2.53 ± 0.03	2.66 ± 0.11
2.	15	4	9	2.26 ± 0.24	4.86 ± 0.23
3.	30	5	9	2.96 ± 0.18	5.06 ± 0.54
4.	60	4	8	4.13 ± 0.86	4.33 ± 0.76
5.	120	4	8	3.16 ± 0.37	2.93 ± 0.56
6.	240	5	9	3.63 ± 0.66	2.83 ± 0.81

Survival percentage of plants was 60 % in 15 mgL^{-1}, 40 % in 30 and 60 mgL^{-1}, 30% in 120 and 240 mgL^{-1}concentrations and 100 % in control. The higher concentration of TiO_2 nanoparticles decreases germination and survival percentage of plants (Figure 5).

The measurement of root growth after 10 days and shoot growth after 15 days were from seed sowing of treated and untreated seeds show a significant variation. The treated plants show increased growth as compared to control plants (untreated plants). The highest root growth was 4.13 cm at 60 mgL^{-1} concentration and the highest shoot growth was 5.06 cm at 30 mgL^{-1} concentration of TiO_2 nanoparticles. Whereas, in control plants root and shoot growth was 2.53 cm and 2.66 cm respectively (Table 1). The efficiency of root and shoot growth was enhanced by all concentrations of TiO_2 nanoparticles. Plants were transferred in pots (soil pH 6.7) for further growth and development (Figure 6, Table 1).

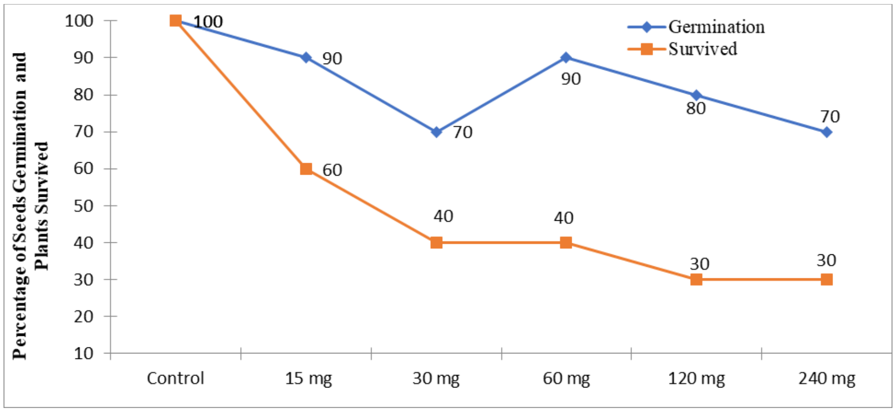

Figure 5. Seeds germination and plants survival percentage of *S. lycopersicum* treated with different concentrations of TiO_2 nanoparticles and control

Figure 6. This figure showed the roots and shoots growth of control and treated with different concentrations of TiO_2 NPs

Figure 7. Images of matured leaves of control and treated *S. lycopersicum*, A = Control, B = 15 mg, C = 30 mg, D = 60 mg, E = 120 mg and F = 240 mgL^{-1} TiO_2 concentrations

Spectrophotometric analysis of chlorophyll: The chlorophyll content of matured *S. lycopersicum* plant leaves was analyzed by spectrophotometer absorbance reading at a different wavelength. Chlorophyll-a, and carotenoid was increased 1.25 and 0.22 at 15 mgL^{-1} and 1.26, 016 at 120 mgL^{-1} concentration of treated plants compared to control plants (Table 2), while chlorophyll-b content was decreased in all treated plants than control. The control plants chlorophyll- a, b and carotenoid content was 1.15, 1.46 and 0.13 respectively of *Solanum lycopersicum* (Table 2).

Height of plants: The 90 days matured *S. lycopersicum* plant height was found increased as compared to control plants. The highest height of plants increases at 112.66 cm at 60 mgL^{-1} compared to control (90.66 cm) plants and highly decreased 64.33 cm at 240 mgL^{-1} concentration treated plants (Table 3).

Number of leaves: The leaves is the most important photosynthetic part for the growth rate of the plant. The TiO_2 nanoparticles concentrations showed great enhancement in leaves 29.66 at 60 mgL^{-1} and highly decreased 14.0 at 240 mgL^{-1} treated plants compared to control plants. The number of leaves was 23.66 in control plants. TiO_2 nanoparticles increase development of plant leaves with low concentration. The structure of the leaves was changed to the surface area structures in 30 mgL^{-1} concentration treated plants. At the 240 mgL^{-1} concentration treated plants leaves color was yellowish due to deficiency of chlorophyll content (Table 3). Compound leaves of *S. lycopersicum* plants have many small and large leaflets but leaflets in treat plants less than 30 mgL^{-1} were smaller and much smaller in number than control and other concentrations (Figure 7 and Table 3).

Table 2. Values are Mean ± SE of Chlorophyll- a, b and carotenoid of *S. lycopersicum*

S. no	Concentrations in mgL^{-1}	Chlorophyll- a (663 nm wavelength) Mean ± SE	Chlorophyll- b (646 nm wavelength) Mean ± SE	Carotenoid (470 nm wavelength) Mean ± SE
1.	Control	1.15 ± 0.08	1.46 ± 0.08	0.13 ± 0.00
2.	15	1.25 ± 0.01	1.40 ± 0.06	0.22 ± 0.03
3.	30	1.05 ± 0.04	1.15 ± 0.04	0.13 ± 0.00
4.	60	1 ± 0.04	1.10 ± 0.03	0.13 ± 0.01
5.	120	1.26 ± 0.07	1.44 ± 0.02	0.16 ± 0.02
6.	240	1.06 ± 0.01	1.26 ± 0.03	0.11 ± 0.00

Number of flowers: In the treated plants the number of flowers found decreased from lower concentration to higher concentrations. The total number of flowers under control was 16.33 while the total number of flowers at 15, 30, 60, 120 and 240 mgL^{-1} respectively were 14.66 11.0, 12.66, 13.0 and 9.33 respectively. The total number of flowers in 240 mgL^{-1} treated plants decreased (Table 4).

Figure 8. Matured *S. lycopersicum* plants treated with TiO_2 nanoparticles

Table 3. Values are Mean ± SE of height, number of leaves and root length of harvested *S. lycopersicum*

S.no	Concentrations in mgL^{-1}	Height of matured plants in cm (Mean ± SE)	Number of leaves in plants (Mean ± SE)	Root length of harvested plants in cm (Mean ± SE)
1.	Control	90.66 ± 4.66	23.66 ± 1.44	28.33 ± 2.59
2.	15	81.66 ± 8.0	19.33 ± 2.33	28.66 ±3.17
3.	30	73 ± 4.35	17 ± 2.64	26.33 ± 3.70
4.	60	112.66 ±12.5	29.66 ± 5.2	39.66 ± 4.90
5.	120	79.66 ± 6.11	19.33 ± 2.72	22.33 ± 2.96
6.	240	64.33 ± 5.17	14 ± 2.51	30.66 ± 5.88

Number of seeds obtained: The total numbers of seeds/fruit were collected in the fully ripened fruits of *S. lycopersicum* from all treated plants. There was the number of seeds 129.0 at 15 mgL^{-1} followed by 125.66 at 30 mgL^{-1}, 127.66 at 60 mgL^{-1}, 125.33 at 120 mgL^{-1} and decreased number of seeds 106.33 at 240 mgL^{-1} concentration treated plants. At the 240 mgL^{-1} treated plant seeds highly reduced due to small fruits compared to control. The control plant seeds were 129.33 (Table 4).

Number of fruits: The maximum number of fruits was counted 14.33 (fruits) in the control plants, whereas the decreased fruit number in all treated plants. The largest fruit in all treated plants was 12.0 (fruit) at 15.0 mgL^{-1} while the smallest fruit was 8.66 at 240 mgL^{-1} concentrations and showed shrinkage. Fruit color and pigmentation were affected in treated plants. Delayed ripening of the fruits was treated plant with 240 mgL^{-1} concentrations. High concentrations of nanoparticles reduce the number of fruits and dyes and damage the structure of fruits in *S. lycopersicum* plants (Table 4).

Weight of obtained seed: The weight of dry seed, 10 seed reduced at minute level such as 20 (mg) at 15 mgL^{-1}, followed by 19 at 30 mgL^{-1}, 19.66 at 60 mgL^{-1}, 18.33 at 120 mgL^{-1} and 18.33 at 240 mgL^{-1} concentration of treated plants respectably. The seeds weight at 120 mgL^{-1} and 240 mgL^{-1} concentration was equal on average. The TiO_2 nanoparticles affect the seed weight at higher concentrations due to their toxic effects (Table 4).

Table 4. Values are Mean ± SE of number of flowers, number of fruits, number of obtained seeds and weight of seeds of *S. lycopersicum*

S. no	Concentrations in mgL^{-1}	Number of flowers/plant (Mean ± SE)	Number of fruits/plant (Mean ± SE)	Number of obtained seeds/fruit (Mean ± SE)	Weight of seed/10seeds (mg) (Mean ± SE)
1.	Control	16.33 ± 1.45	14.33 ± .87	129.33 ± 4.91	20.33 ± 0.88
2.	15	14.66 ± 2.18	12.0 ± 2.51	129 ± 5.13	20.0 ± 0.57
3.	30	11.0 ± 2.89	9.0 ± 2.07	125.66 ± 4.48	19.0 ± 0.33
4.	60	12.0 ± 2.85	10.0 ± 2.84	127.66 ± 4.37	19.66 ± 0.57
5.	120	13.0 ± 2.31	11.33 ± 2.02	125.33 ± 3.53	18.33 ± 0.33
6.	240	9.33 ± 2.02	8.66 ± 2.18	106.33 ± 7.84	18.33 ± 0.66

Root length of harvested plants: The roots harvested (after life cycle completed) from fully matured *S. lycopersicum* plants were treated at different concentrations of nanoparticles and the length of the roots was measured. The highest 39.66 cm length of the roots was measured at 60 mgL^{-1} followed by 30.66 cm at 240 mgL^{-1} concentration of treated plants compared to control plants. While other roots lengths were such as 28.66 cm at 15 mgL^{-1}, 26.33 cm at 30 mgL^{-1} and 22.33 cm at 120 mgL^{-1} treated plants, these roots length were reduced compared to control plants. The control plants root length was 28.33 cm. The roots were very thin and cluster type; highly fibrous and adventitious roots recorded in 240 mgL^{-1} concentrations of treated plants. TiO_2 nanoparticles increase the root length and root fibers of matured *S. lycopersicum* plants (Table 3).

Fourier Transform Infrared Spectroscopy (FTIR): A sample of 5.0 g dried plant was grinded and the extract was extracted with distilled water with the help of Soxhlet. Liquid extracts were used to identify the functional group of the active compounds of *S. lycopersicum*. The absorption spectrum of FTIR on the Control plants sample exhibited peak at 3341.91 cm^{-1} (Transmission 51.16%) represented the presence of Alcohol (H bonded) (O-H stretch), Primary amines (Asym NH_2 stretch), Aliphatic alcohol (OH stretch), Primary amides (Asym NH_2 stretch), and Secondary amides (NH stretch). The next peak at 1634.7 cm^{-1} (Transmission 71.24%) showed the presence of Tertiary amides (Amide 1 bond), Hydrazones (C=N stretch), Primary amides (NH_2 scissors) and Alkyl derivatives (C=C stretch). The 60 mgL^{-1} treated plant sample exhibited peak at 3340.59 cm^{-1} (Transmission 51.57%) represented the presence of Alcohol (H bonded) (O-H stretch), Primary amines (Asym NH_2 stretch), Aliphatic alcohol (OH stretch), Primary amides (Asym NH_2 stretch), and Secondary amides (NH stretch). The next peak at 1634.00 cm^{-1} (Transmission 71.35%) showed the presence of Tertiary amides (Amide 1 bond), Hydrazones (C=N stretch), Primary amides (NH_2 scissors) and Alkyl derivatives (C=C stretch) and Alkyl nitriles (Asym NO_2 stretch*)*. In the 60 mgL^{-1} treated plant alkyl nitriles (Asym NO_2 stretch) functional group was extra which was formed from the negative or positive effects of nanoparticles. The interaction of TiO_2 with the cellular metabolism of plants formed additional compounds for the cells to defend themselves. The FTIR data interpretation with the help of (https://www.protea.ltd.uk/ir-search.html).

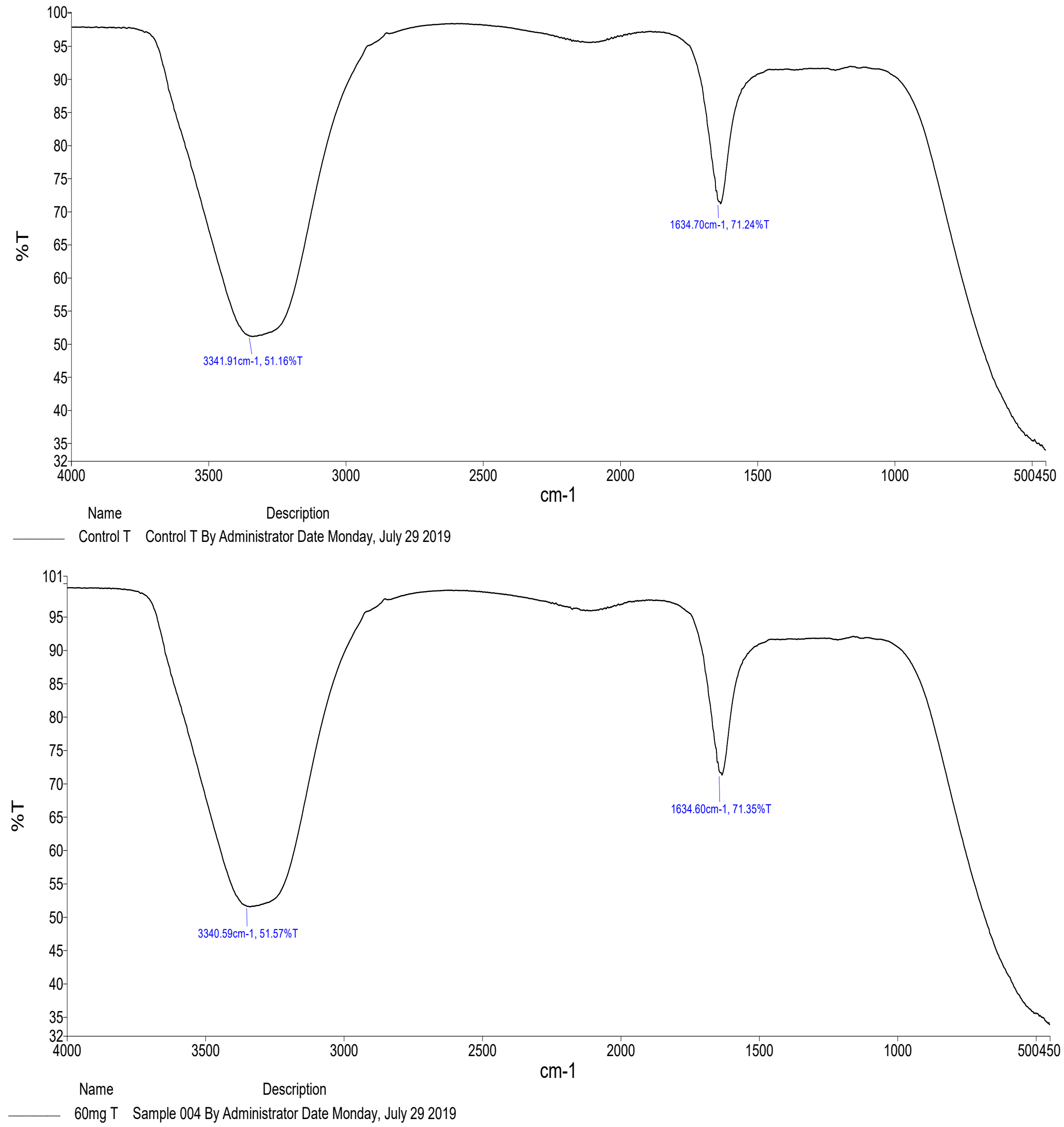

Figure 9. FTIR analysis of extract of Control and 60 mgL^{-1} concentration treated *S. lycopersicum*

Discussion

TiO_2 nanoparticles were synthesized in the laboratory by a chemical route using the precipitate method. The average particle size of TiO_2 NPs was investigated by PSA and the average particle size was found to be 60–300 nm. XRD analysis was used to examine the size of crystalline NPs. The crystalline nature of NPs was confirmed by XRD. The physical properties of TiO_2 nanoparticles were investigated using UV – vis spectroscopy. The synthesis of TiO_2 NPs was confirmed by transmission spectra between 150 and 750 nm. The SEM micrograph clarified that TiO_2 NPs were more or less crystalline and spherical. Nano material exhibits excellent growth in plant science in the research sector, which can be synthetic and engineered nanoparticles. In the present research study, we find that TiO_2 nanoparticles produce positive and negative effects on tomato plants. TiO_2 nanoparticles increased seeds germination and root elongation of seeds treated with 60 mgL^{-1} concentration was observed in tomato plants. The agricultural growth area improved TiO_2 nanoparticles such as plant growth, yield, number of seeds, weight and biomass of plants, and agronomic traits with 0.02% nanoparticles (Nair et al., 2016). The TiO_2 nanoparticles have unique properties to boost the growth of plants. TiO_2 nanoparticles affect plant morphology such as increased root and shoot growth, the number of leaves, as well as negative effects, reduce the number and size of fruits of plants in 240 mgL^{-1} concentration. Because previous studies used concentrations up to 5000 mgL^{-1} on nano-TiO_2 solutions and concentrations up to 6000 mg kg^{-1} were used in another previous study on TiO_2 NP solutions and any negative effects (Song et al., 2013; Zheng et al., 2005) were not reported. Concentrations above 6000 mg kg^{-1} have been considered unrealistic in natural systems, as TiO_2 NPs have been reported to contain viruses on plants in other studies at concentrations of 500 mg kg^{-1} or less (Trouiller et al., 2009; Nohynek et al., 2008; Newman et al., 2009). Hajra and Mondal (2017) studied the TiO_2 nanoparticles produce unfavorable effects on growth and development of plants but higher concentrations of TiO_2 nanoparticles decrease the growth rate of plants. Increased absorption of light in TiO_2

nanoparticles, conservation and transmission of light energy, inhibition of chloroplast and increase in photosynthetic period of chloroplast in plant cells were known (Golami et al., 2018). But in this study, the plant treated with 240 mgL^{-1} concentration was found to have very abnormal growth and shrinkage of small leaves, while the 30 mgL^{-1} concentration increased the margin structure, leaf area and petiole length of the treated plant leaves. TiO_2 nanoparticles increase cell division rate, cell size, and callus induction, and affects hormones (Cytokinin and gibberellins) of plants (Hong et al., 2005). In this study, chlorophyll content was increased in 15 mg and 120 mgL^{-1} concentrations, but in the 240 mgL^{-1} concentration the chlorophyll content was reduced. Previous studies reported that TiO_2 nanoparticles induced plant stomata under stress conditions during photosynthesis in summer and stimulated the production of carbohydrates and photosynthetic rates (Qi et al., 2013; Duhan et al., 2017). TiO_2 nanoparticles were shown to have photo-catalytic activity for insecticide degradation and could achieve efficiency of pathogen disinfection. High concentrations of TiO_2 nanoparticles enhanced the activity of glutamate dehydrogenase, nitrate reductase, glutamine synthase, and glutamic-pyruvin transamine in spinach plants (Yang et al., 2006). In this study, concentrations of 240 mgL^{-1} TiO_2 nanoparticles damage the structure of the fruit and decrease the yield and thickness of tomato plant stem. TiO_2 affects biochemulation, damage to mitochondria and cellulose activity was inhibited in soil 5.0 g kg^{-1} at high doses to *Eisenia fetida* (Hu et al., 2010). In this study reported that, the root length of the fully mature plant was exceeded at 60 mgL^{-1} concentration, while the root structure changed to a helical cluster type and the roots were thinner than the controlled plants. The use of TiO_2 nanoparticles accumulates effects on both plants and animals which can be positive or negative.

Conclusion

Toxicity on plants has been demonstrated by NPs of smaller size and greater concentrations. In general, phytotoxicity effects of NPs have been reported from studies of chlorophyll content and plant morphology in plants. In the current research, TiO_2 NPs were synthesized by the chemical precipitation method, and characterized by XRD, PSA, UV-vis and SEM including NPs size, shape, and experimental techniques. The content of chlorophyll a, b and carotenoids was increased at 15 and 120 mgL^{-1} concentrations, but decreased at other concentrations compared to control plants. The length of the roots of the fully mature plant was increased to 60 mgL^{-1} and additive branches increased to 120 mgL^{-1} concentration. In this research experiment, the potential effects of TiO_2 nanoparticles on the life cycle of the tomato plant produce both positive and negative effects on plant growth. In future times, more research is needed for various nanoparticles on plants and their positive potential in plant species for their interactions with cellular organelles to alter plant species.

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Authors' contribution

DKV reviewed the literature and wrote the manuscript. SP conceptualized and supervised the manuscript, and KSK have helped in reviewed and writing the manuscript. All authors read and approved the final manuscript.

Ethical statement

The authors declare that present research work was done only on plants; there was no involvement of any animal species and from this research work has not any harmful effects on animals and human beings.

Conflict of interest

Authors declare that there is no conflict of interest for publication of this article.

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