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Research article

Impact of synthesized metal oxide nanomaterials on seedlings production of three Solanaceae crops

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ABSTRACT

Prospective involvement of metal oxide nanomaterials as a prominent agriculture practice for improving existing crop production directed the present investigation for synthesizing of ZnO and TiO_2 nanomaterials as an attempt to enhance the transplants production of some Solanaceae crops. The morphological characterizations of the prepared nanomaterials indicated that the hydrothermal synthesized ZnO was produced in nanorod structure with an average aspect ratio of 7. However, SEM and TEM micrographs of microwave prepared TiO_2 evident that it has a nanoparticle structure with an average diameter of 43 nm. The BET results confirmed the high specific areas of the two prepared metal oxide nanomaterials. The two synthesized metal oxide nanomaterials were coated in gel and mixed with the seeds of eggplant, pepper and tomato crops at four concentrations 0, 50, 100 and 150 mg/L, whilst the control seeds were germinated in distilled water without gel-coating. The results pointed to the outstanding effect of TiO_2 and ZnO nanoparticles on germination characters and seedlings growth. The maximum transplants lengths, fresh and dry weight were recorded at the level 100 mg/L whatever the crop plant used. Hastening germination operation of nanomaterials-gel coated seedlings compared to control plants may be ascribed to the reduction of mean germination time and coefficient variation of the germination process besides increasing the mean germination rate and the synchrony of germination traits. Overall, better performance of growing transplants has been accredited for nanoparticles-gel coated seedlings more than the control treatments which could be efficient for the safer production of transplants in an innovative way.

1. Introduction

Nanotechnology is a versatile topic which included most scientific approaches due to the massive work that being proceeded. Nanotechnology is able to revolutionize agriculture with creative ways for boosting the absorptivity of plants to nutrients. Furthermore, the unique properties of nanomaterials and its utilization in scientific and technological fields have enriched recently this study area (Younes et al., 2019). The applications of nanotechnology included many fields, from electronics to energy, medicine, agriculture, food production and so on. The development of agricultural output with plant growth and preservation condition is outstanding challenge in agriculture, while minimizing the utility of risky agrochemicals.

Nanotechnology provides an outstanding position in transforming agriculture by developing existing crop management techniques and food production experiences (Elkady and Shokry, 2015) especially the production of nanopesticides and nanofertilizers. The use of nanotechnology as a plant nutritional mediator and as modern nanofertilizers are

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coined as controlled release fertilizers which prepared for governing nutrient liberation behaviors that depend upon thermal post-treatment criteria, can mitigate the nutrient use efficiency of crops. The joint reaction of nanoparticles with the living cell occurs at the molecular level, thus nano-agriculture could confer some profitable impacts to the crop (Nair et al., 2010). In this regard, the application of water-holding polymers, gels, nanoclays and nanozeolites had been participated in developing the soil water quality and their water-holding capacity. For the soil remediation, the organic polymers, inorganic metals, metal oxide nanomaterials, and carbon nanotubes have the utilized which save the time and cost. Furthermore, the engineered iron oxide nanoparticles (hematite and ferrihydrite) increased the growth and the chlorophyll content of maize plants (Pariona et al., 2017).

The number of researches encompasses the biological effects of metal oxide nanoparticles (CeO_2, NiO, Fe_2O_3, In_2O_3, Al_2O_3, CuO, La_2O_3, ZnO, ZrO_2, MgO, TiO_2, SnO_2, Cu_2O) and organic ones as fullerenes and carbon nanotubes on plants germination and seedling growth has been astonishingly increasing. For instance, multi-walled carbon nanotubes (MWCNTs) enhance the growth photosynthesis and growth of plants, as MWCNTs can elevate the efficacy of photochemical quantum yield and activate the expression of photosynthesis proteins (Chen et al., 2017, 2019; Fan et al., 2018). Graphene nanosheets which localized inside the chloroplast activated photosynthetic pigments, growth, primary metabolism, antioxidants as well as yield performance of peppers and eggplants (Younes et al., 2019). TiO_2 extensively used in photocatalytic reactions; upon exposure to ultraviolet light, it mineralizes the organic chemicals in rivers to water and CO_2 with the potency to devastate microorganisms (Lei et al., 2007; Giahi et al., 2019). Nowadays, TiO_2 NPs are used vastly in paints, plastics, cosmetics, and catalysts, thus its participation in agriculture fields will be prospected. For instance, TiO_2 NPs increased the photosynthesis, plant growth and enhanced the absorption and transmission of the sun's energy to electron energy and activates chemical energy (Lei et al., 2007; Dawood et al., 2019).

Naderi and Abedi (2012) coined that the application of micronutrient fertilizers in NPs form is a convenient way to stepwise supply required nutrients in managed manner, which is important to alleviate the issues of fertilizer pollutions. Laware and Raskar (2014) stated that the prescence of Zn for a prolonged time is not proven with the utility of $ZnSO_4$ fertilizer because under elevated temperatures $ZnSO_4$ has a large salt index, thereby it may be account for burning injury if the plants are susceptible. In addition, the farmers' trials for applying both zinc sulfate and EDTA-Zn chelate for soil and foliar applications have low efficacy. Thus, efforts for instead utilizing synthesized ZnO-nanomaterials are strikingly increasing because bulk ZnO is highly insoluble. However, the reduction of the particle size to the nanoscale, induced the increment of surface/volume ratio, making it more soluble and bioavailable (Shokry et al., 2017a). Studies included the impact of ZnO nanomaterials on plants (Pramod et al., 2011; Prasad et al., 2012; Rizwan et al., 2019).

Recently, the plant breeders have become astonishing in nano-agriculture via the utilization of nanoparticles which may exert benefits to the crops as well as providing tolerance to various biotic and abiotic factors (Sallam et al., 2019). As scientific investigations on nanoparticles are still in its rudimentary stage and the majority of nanoparticles-related germination experiments were based on priming technique as well as demonstration phytotoxic impacts of nanoparticles at the seedling stage. The present study included the delivery of nanoparticle to seeds by coating the tested seeds with nanoparticles impeded in an inert material such as gel. Furthermore, sowing the treated seeds in peetmoss to warn off nanoparticles from the direct contact to the growing medium. So, preventing their distribution to the ecosystem and lessen any bad effect on the micro-flora. Even though several studies are concerned with the synthesis of nanomaterials using biological and chemical routes, only limited studies included the promoter effects of nanoparticles on plants at low concentration. Hence, the present study had an attempt to test the effect of chemically synthesized ZnO and TiO_2 nanomaterials on seed germination and transplant growth of three Solanaceae crops.

2. Materials and methods

This investigation was performed at the experimental farm, Faculty of Agriculture, Al-Azhar University-Assiut branch, Assiut, Egypt during the summer seasons of the years 2016 and 2017.

2.1. Synthesis and characterization of metal oxides nanomaterials

2.1.1. Preparation of nanomaterials

2.1.1.1. Preparation of ZnO nanomaterials. A reaction mixture composed of 14 mM zinc acetate was reacted with 0.25 mM of polyvinyl pyrrolidone as a surfactant for a hydrothermal reaction. The pH of the solution was adapted to 9 using NaOH. The mixture was accomplished at 70 °C and 50 Kpsi using autoclave for 6 h. Ethyl alcohol and distilled water were used for purification of ZnO powde which then separated by centrifugation at 6000 rpm for 30 min. The collected sample was dried at 60 °C overnight (Shokry et al., 2017b).

2.1.1.2. Preparation of TiO_2 nanomaterials. Titanium tetraisopropoxide (1 M) was mixed with acetic acid (40 ml) and polyvinyl alcohol (0.1 M) at Teflon coated autoclave which then preserved in a microwave oven at 90 °C for 4 h. The resulting white powder of TiO_2 was washed many times with distilled water and centrifuged at 6000 rpm for 30 min to discrete the TiO_2 nanomaterial. The produced sample was dried at 60 °C under air atmosphere overnight (Chen and Mao, 2007).

2.1.2. Characterization of the prepared metal oxides nanomaterials

The physicochemical characteristics of the produced ZnO and TiO_2 nanomaterials were explored using different characterization techniques.

2.1.2.1. Assessment of materials crystalline structures. X-ray powder diffractometry (XRD) was detected via (Shimadzu 7000) diffractometer with Cu-K_α radiation beam (nm) to define the crystalline structure of the differently prepared metal oxide nanopowders. The grinded powdered materials were fixed onto smooth aluminum holder and subjected to the rotating anode that represented as X-ray source which operate at 30 kV and 30 mA. The anode was rotated over 2θ of 10° and 80°.

2.1.2.2. Assessment of materials morphological structures. The morphological structures of the prepared metal oxides were recognized after materials sputtering with gold metal and examine using JEOL JSM 6360LA scanning electron microscope. In order to approve the examined material morphology, a slight droplet from ethanol dispersed powder materials were dropped on the copper grid then air dried and scanned over TEM (JEOL JEM-1230, Japan).

2.1.3. Assessment of materials surface area

The typical pore diameter and surface area BET (Brunauer-Emmett-Teller) of the produced metal oxide nanoparticles were measured on a Quantachrome NOVA 1000 (Boynton Beach, FL, USA) in a nitrogen atmosphere.

2.2. Assessment of the performance of prepared nanomaterials on plant seedlings production

2.2.1. Plant material and seeds treatment

2.2.1.1. Plant material. Three Solanaceae crops were conducted for the present investigation i.e., eggplant, *Solanum melongena* L., (CRISTAL F1 importer Mecca TRADE Co. as PETO SEED product, USA), pepper, *Capsicum annum* L., (NARDINE F1 importer Mecca TRADE Co. as Monarch Seed product, China) and tomato, *Lycopersicon esculentum* L., (SALSABEL F1 importer Mecca TRADE Co. as Asia Seed co. Lid product, Korea).

2.2.1.2. Nanomaterials-gel-seed coating preparation. Nanomaterials-gel-seed coating was prepared by adding 2 g of gelatin to one liter of distilled water at 40 °C plus the calculated amounts of nanomaterials under stirring. The seeds of eggplant, pepper, and tomato plants were mixed at four concentrations 0, 50, 100 and 150 mg/L of ZnO and TiO_2 nanomaterials, whilst the absolute control seeds were germinated without gel coating.

2.2.2. Greenhouse experiment layout

The seeds (60 seeds in each replication) of eggplant, pepper, and tomato were placed in trays filled with 100% Peetmoss. The trays were kept in a greenhouse at 25 ± 2 °C with 3 replicates/treatment. The trays were fertilized at the rate of 150 mg/L of water-soluble fertilizer with a composition of (NPK) 20:20:20.

After one day from planting, the data of main germination traits were recorded and then calculated based on the published works of Dawood and Azooz (2019) which adopted by Ranal et al. (2009) as the following:

$$\text{Mean germination time} = \sum_{i=1}^{k} n_i t_i \Big/ \sum_{i=1}^{k} n_i \tag{1}$$

$$\text{Mean germination rate} = \sum_{i=1}^{k} n_i \Big/ \sum_{i=1}^{k} n_i t_i \tag{2}$$

$$\text{Coefficient of variation of the germination time, } CV_t = (S_t/t)\,100 \tag{3}$$

$$\text{Synchrony of germination, } Z = \frac{\sum_{i=1}^{k} C_{n_i,2}}{C_{\sum_{i=1}^{k} n_i,2}} \text{ being } C = n_i(n_i - 1)\Big/2 \tag{4}$$

where t_i: time of the germination beginning to the i^{th} observation (day or h); n_i: the number of seeds germinated in the time i (It indicates the number of germinated seeds correspondent to the i^{th} observation, not cumulative number), k: the end of germination, St: standard deviation of the germination time and *t*: mean germination time.

After 6 weeks from planting, data recorded for each replication on ten plants such as the plant height (cm), the number of leaves/plant, stem thickness (mm) and seedlings fresh and dry weights (dry weight was determined after oven drying at 70 °C for 48 h).

2.3. Statistical analysis

The experiments were laid out as a Completely Randomize Design with 5 replications and 10 plants per replication. All the data were analyzed using ANOVA Mstat-c (MSTAT C, 1991), and means were compared using least significance difference test (LSD) at probability P ≤ 0.05, to identify the treatments whose means are statistically different.

3. Results and discussion

3.1. Assessment of physicochemical properties of the prepared nanomaterials

3.1.1. Crystalline structures of the metal oxide nanoparticles

The crystalline structure of the two various metal oxide nanomaterials was identified in Figure 1. XRD pattern of the prepared ZnO nanopowder (Figure 1A) was compared with the ZnO wurtzite phase presented at JCPDS card number 01-089-1397 that showed that all the characteristics peaks can be well indexed to the hexagonal phase of ZnO and no other characteristic peaks are detected that confirmed the high purity of prepared ZnO material (Shokry et al., 2014, 2017b). The high intensity of the characteristic peaks of the hydrothermally prepared ZnO sample showed a wurtzite crystal structure with high crystallinity degree and material orientation (Shokry et al., 2018). Figure 1B revealed that the XRD pattern of the microwave produced TiO_2 nanoparticles. It was represented that the XRD spectrum of the material is in accordance with the JCPD card number 21-1272 (anatase TiO_2) that identify its orientation plane as displayed in Figure 1B (Elkady et al., 2017). The strong identified peaks at 2θ of 25° and 48° identify the anatase phase of prepared TiO_2. The absence of bogus diffractions showed the crystallographic structure of the prepared material. The high intensity of XRD peaks of the two prepared materials reflected that the designed nanoparticles were crystalline and the sharp diffraction peaks at their XRD patterns pointed out a very small size crystallite of the prepared materials (Chen and Mao, 2007; Arabi et al., 2019).

3.1.2. Morphological structures of prepared metal oxide nanoparticles

The scanning electron microscope (SEM) micrographs of the two prepared ZnO and TiO_2 nanomaterials are investigated in Figure 2. It was apparent from the Figure 2A and B that ZnO formed in nanorods structure, however, TiO_2 produced in nanoparticles structure with low diameters ranged between 35 to 50 nm (Abbad et al., 2012). The average aspect ratio of the prepared ZnO nanorods using hydrothermal technique was detected from the transmission electron microscope (TEM) image (Figure 2C) to be 7. However, the average particle diameter of microwave prepared TiO_2 illustrated from the TEM image (Figure 2D) is 43 nm.

3.1.3. The surface area of prepared metal oxide nanoparticles

The material surface states demonstrated a significant role in nanomaterials owing to their great surfaces to volume ratio that dimension in particle size (Zhang et al., 2010). The specific surface area (SSA) of the material which represents the surface area (SA) per mass is a derivative scientific term that utilized for determination the material

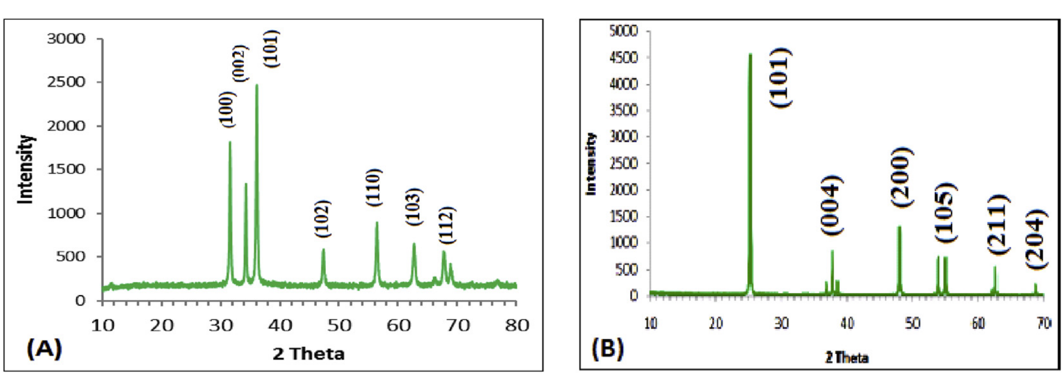


Figure 1. XRD patterns of prepared ZnO (A) and TiO_2 (B) nanomaterials.

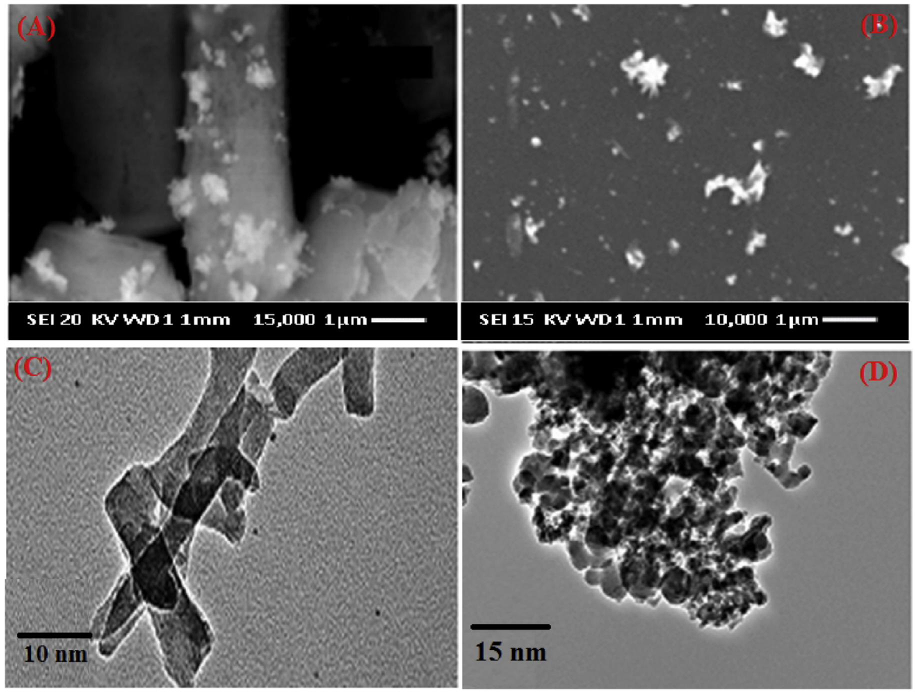


Figure 2. SEM (A and B) and TEM (C and D) micrographs of ZnO and TiO_2 nanomaterials.

characteristics. This property had a significance role for the material applications that depend upon adsorption, catalysis and surfaces reactions. The BET specific surface area of prepared ZnO nanorods is determined as 19.2 m^2/g compared with 14.4 m^2/g for TiO_2 nanoparticles. So, the surface area of prepared ZnO nanorods is comparatively higher than that of TiO_2 nanoparticles. However, their measured average pore volume is almost equivalent, where the pore volume of prepared ZnO is 218.9 nm compared with 216.8 nm for TiO_2 nanoparticles (Abbad et al., 2012).

3.2. Assessment of the performance of prepared nanomaterials on plant seedlings production

The following results demonstrated the phytoimpact of the prepared nanomaterials on the transplants production of eggplant, pepper and tomato crops during the two studied seasons.

3.2.1. Germinability as affected by the prepared metal oxide nanoparticles

The data of mean germination time (MT) or the time spent to germinate or emerge as well as mean germination rate (MR, days) or speed to germinate or emerge and it is a concept of seedlings vigor, were given in Figure 3A–C and D–F and calculated based on Eqs. (1) and (2) where significant difference among the three tested crops and the nanoparticles levels compared with the control plants in the two successive seasons was registered. Coating the seeds of eggplant, pepper, and tomato with ZnO and TiO_2 NPs lessened MT whatever the concentration used, but more obviously at 100 mg/L where MT reached, on average, 5.01 and 5.41 days for seasons 2016 and 2017, respectively compared to control plants which accomplished MT at 11.97 and 12.11 days in both seasons. Such acceleration of MT could be associated with the increasing speed of seeds germination of the studied crops as recommended by the mean germination rate trait which displayed significant increment with the application of both nanoparticles especially at 100 mg/L and for eggplants compared to the other two crops. MR increased, on average, 0.197 and 0.185 in 2016 season as well as 0.188 and 0.194 in 2017 season at the level of 100 mg/L ZnO NPs and TiO_2 NPs, respectively. Meanwhile, the control treatment kept the values of MR by means 0.087 in both seasons.

The acceleration and speed of germination process could be ascribed to the capability of ZnO and TiO_2 nanomaterials to penetrate seed coat and may be activated the embryo differentiation by triggering the enzymes related to seed dormancy breaking down, hence enhancing the speed of germination. Similarly, Azimi et al. (2014) stated that activation of respiration and rapid ATP production could be the major metabolic events induced by faster seed germination. This might be the reason for the decrement of mean germination time, thereby higher mean germination rate in the present work. The data also revealed the effectiveness of ZnO NPs compared to TiO_2 NPs in the acceleration of germinability. As zinc is an essential micronutrient for metabolic activities in plants. The releasing of Zn^{+2} from ZnO NPs may probably occur as was reported by Lin and Xing (2007) and its high content in seeds could act as a starter fertilizer for improving seed germination and early seedling growth (Laware and Raskar, 2014; Rizwan et al., 2019). In this respect, ZnO and Fe NPs have been used as a source of fertilizers in numerous studies (Munir et al., 2018; Rizwan et al., 2019). On the other hand, Titanium is investigated as a beneficial element for plant growth, which qualified for promoting crop performance, nutrient uptake when present at low levels. TiO_2 nanomaterials accelerated the germination of tomato, radish and onion (Haghighi and da Silva, 2014). The increase in seed germination and better establishment of seedlings due to lower concentrations of TiO_2 NPs might be due to accelerated water and oxygen uptake. Sufficient quantity of water and oxygen in imbibed onion, tomato and radish seeds might have accelerated the amylase and protease activities and produced soluble sugars and amino acids required for early seed germination and seedling growth (Laware and Raskar, 2014). Different concentrations of titanium dioxide nanoparticles (0, 0.025, 0.05, 0.1, 0.2, and 0.5%) were used to identify the concentration which stimulated the seeds germination percentage and seedling vigor of four wheat cultivars (Shafea et al., 2017). The similar positive impact of TiO_2 NPs on different plants has been also manifested (Jiang et al., 2017; Lyu et al., 2017; Dawood et al., 2019).

In this sense, the efficiency of ZnO and TiO_2 nanomaterials gel-coated seeds on germination appeared obviously through raising coefficient

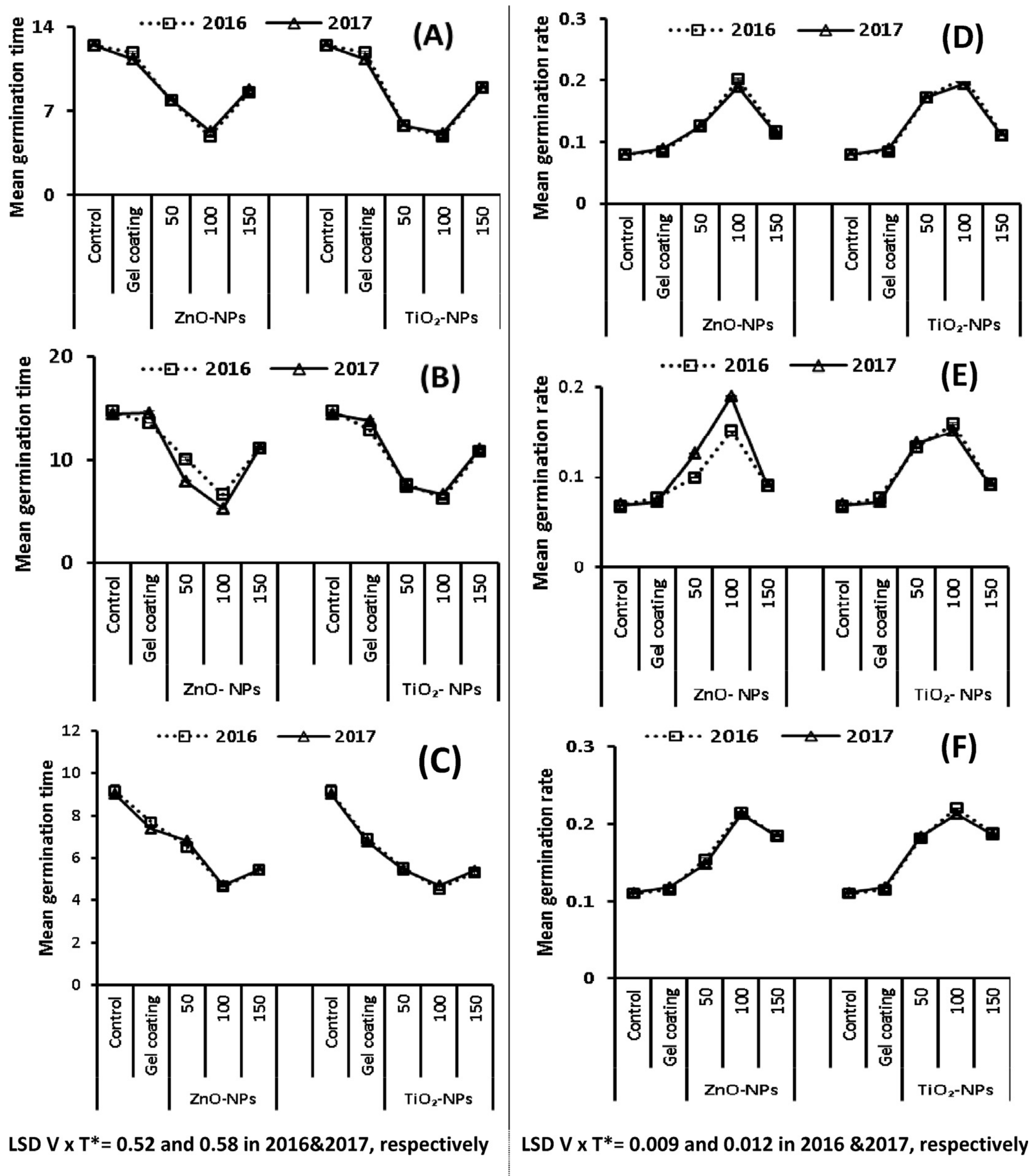


Figure 3. Mean germination time, days (A, B and C) and mean germination rate (D, E and F) for eggplant, pepper and tomato, respectively. Each point in the curve represents a mean value of five replicates, and the vertical bars indicate ± SE. **V x T* = Variety x Treatment.**

variation of mean germination time as calculated in Eq. (3) which gives an indication of the rapidity of germination and increases when the number of germinated seeds increases, and the time required for germination decreases (Jones and Sanders, 1987). Regarding to control which registered values of CV_t by about 7.67%, 7.20% and 20.77% for eggplants, pepper and tomato, respectively, whilst 100 mg/L of ZnO NPs and TiO_2 NPs gel-coated seeds attained the highest mean values of CV_t by about 11.88%, 48.40% and 50.39% in season 2016 and 11.89%, 41.22% and 51.27% in season 2017, respectively for the same crops. The data of CV_t also revealed that eggplants were the highest crop responded to nanomaterials-gel seeds coating compared to the rest tested crops. The same results were denoted under the interaction effect among the different levels of the prepared nanomaterials and Solanaceae species as presented in Figure 4D–F.

In the current investigation, ZnO and TiO_2 nanomaterials affected positively the homogeneity of germination process in terms of synchrony of germination as was depicted in Figure 4A–C which calculated based on Eq. (4), so higher synchronous germinated seeds were produced at the level of 100 mg/L relative to control whatever the crop tested. The application of ZnO NPs (22.4 nm, 10 mg L^{-1}) increased shoot and root length of *Vigna radiate* parallel to triggering in phosphorus mobilizing enzymes and phosphorus uptake by 10.8% (Raliya et al., 2016). Tumburu et al. (2015) reported an increase in seed germination on *Arabidopsis thaliana* upon exposure to TiO_2 nanomaterials at lower concentrations (up to 500 mg/L; 33 nm).

3.2.2. Seedlings growth characters as affected by the metal oxide nanoparticles

Phytotoxic impacts or stress in the early growth of tomato, pepper and eggplants seedling in terms of stunt growth or morphogenesis malformation were not observed on the nanomaterials-gel coated treated plants. The growth characters of eggplant, pepper, and tomato treated

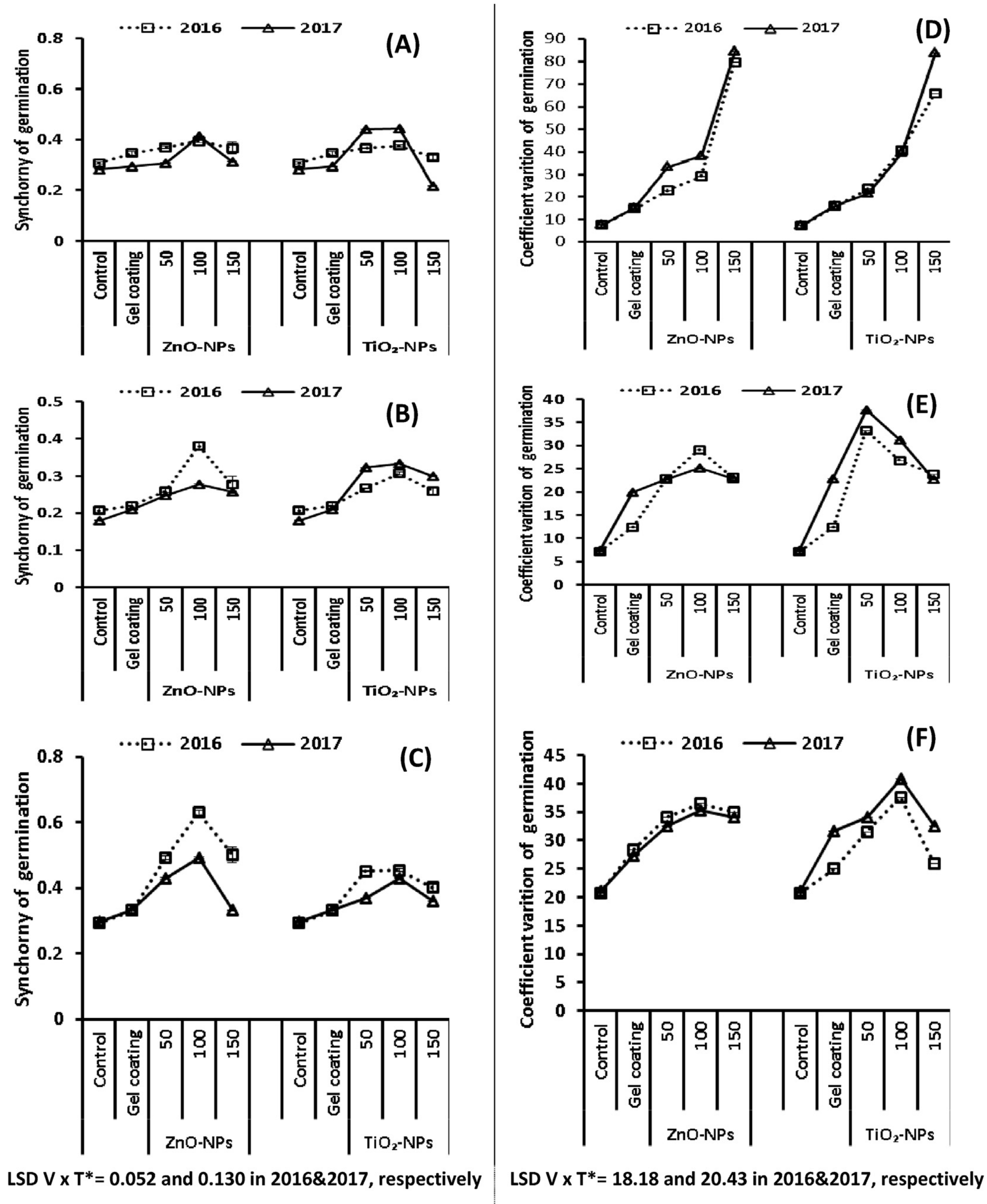
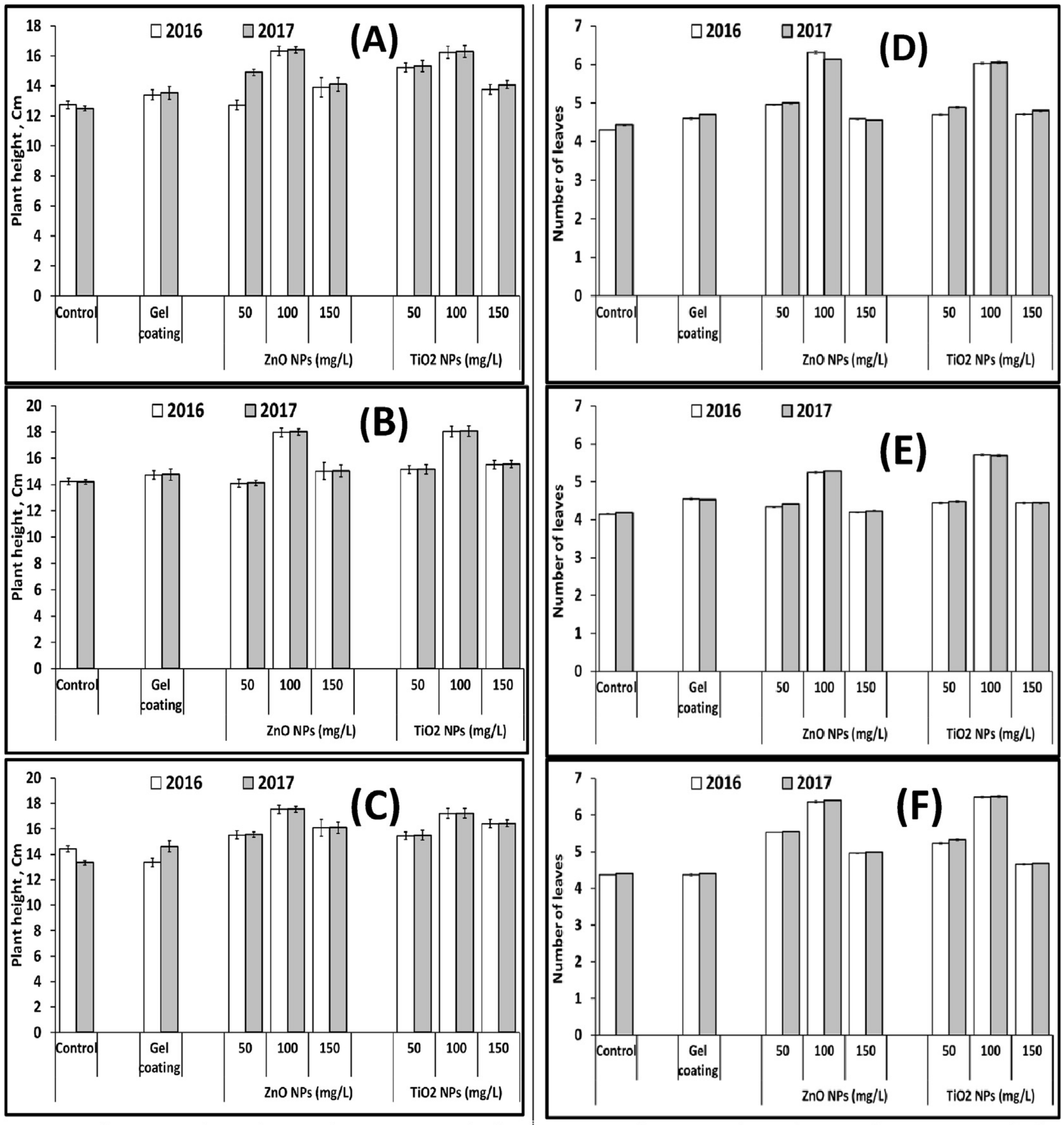


Figure 4. Synchrony of germination (A, B and C) and coefficient variation of germination (D, E and F) for eggplant, pepper and tomato, respectively. Each column represents a mean value of five replicates, and the vertical bars indicate ± SE. **V x T* = Variety x Treatment.**

with ZnO and TiO_2 nanomaterials and the control is presented in Figures 5, 6, and 7. The data indicated a highly significant difference for all tested crops at various nanomaterials concentrations and the interaction effect between them in both seasons.

A positive affect highly significantly was detected for 100 mg/L of ZnO and TiO_2 nanomaterials on the plant height (Figure 5A–C), number of leaves/plant (Figure 5D–F) and stem thickness (Figure 6A–C) in both seasons for eggplant, pepper and tomato seedlings, hence better morphogenesis and organs differentiation was triggered by the both applied nanomaterials. The results of the interaction effect among the three Solanaceae crops and nanomaterials levels, herein, revealed that low and high levels of ZnO and TiO_2 nanomaterials (50 and 150 mg/L) in the two successive seasons recorded lower growth criteria compared to 100 mg/L, but generally higher than hydro-primed seedlings. The seeds primed with TiO_2 nanoparticles enhanced germination rates, promoted root lengths as well as improved seedling growth (Andersen et al., 2016; Szymanska et al., 2016). On the other hand, the promoter impact of nanoscale ZnO may be associated with Zn's activity as a precursor in the formation of auxins that increase elongation and cell division (Teale et al., 2006), thus higher transplants lengths.

Solanaceae seedlings derived from seeds gel coated with ZnO or TiO_2 at concentrations of 100 mg/L was the best promoter to seedlings fresh (Figure 6D–F) and dry (Figure 7A–C) weight compared to the lower and higher concentrations or control treatments. The reason could be that



LSD V x T*= 0.97 and 1.08 in 2016&2017, respectively

LSD V x T*= 0.56 and 0.58 in 2016 &2017, respectively

V x T* = Variety x Treatment

Figure 5. Shoot length (A, B and C) and number of leaves (D, E and F) for eggplant, pepper and tomato, respectively. Each column represents a mean value of five replicates, and the vertical bars indicate ± SE.

ZnO or TiO_2 nanomaterials at these concentrations may be produced new pores on seed coat during penetration which may help to move the nutrients inside the germinating seed or NPs may carry the nutrients along causing rapid germination and growth rate. The increased seedling growth may be due to enhancing the water and nutrient uptake by the treated seeds. In addition, uptake of NPs led to their accumulation in subcellular locations (Schwab et al., 2016), the changes in various physiological processes thereby induced plant growth and development (García-Sánchez et al., 2015). Furthermore, seed soaking can proportionally influence the seedlings vigor via triggering beneficial metabolic system which is necessary for seedling growth (Paparella et al., 2015; Rizwan et al., 2019).

Better transplants growth traits under TiO_2 nanoparticles may be ascribed to activating light absorbance, speeding up the transport and conversion of the light energy, and extending the photosynthetic half life time of the chloroplasts (Yang et al., 2006; Dawood et al., 2019). Ti has several biological effects. Ti able to increases Fe and Mg contents in plant tissues by chelating with ascorbic, citric and malic acid as well as it induces chlorophyll a and b production and affects many enzymatic activities as NiR that confer defense mechanism of plant (Kužel et al., 2003). Raliya et al. (2015) reported that the areosol of TiO_2 nanoparticles could significantly improve phenological criteria, chlorophyll content and soluble leaf protein of mung bean plants. Moreover, the low concentrations of TiO_2 nanomaterial improved the development and chlorophyll content of linseed under water deficit stress conditions (Baiazidi-Aghdam et al., 2016).

The seed presowing with ZnO NPs may change the nutrient contents in seeds affecting plant growth, yield and quality (Rui et al., 2018; Rizwan et al., 2019). For instance, the application of ZnO NPs (22.4 nm, 10 mg L^{-1}) increase the shoot and root length of *Vigna radiate* concomitant with activation of phosphorus mobilizing enzymes and phosphorus uptake by 10.8% (Raliya et al., 2016). Rizwan et al. (2019) stated that Zn

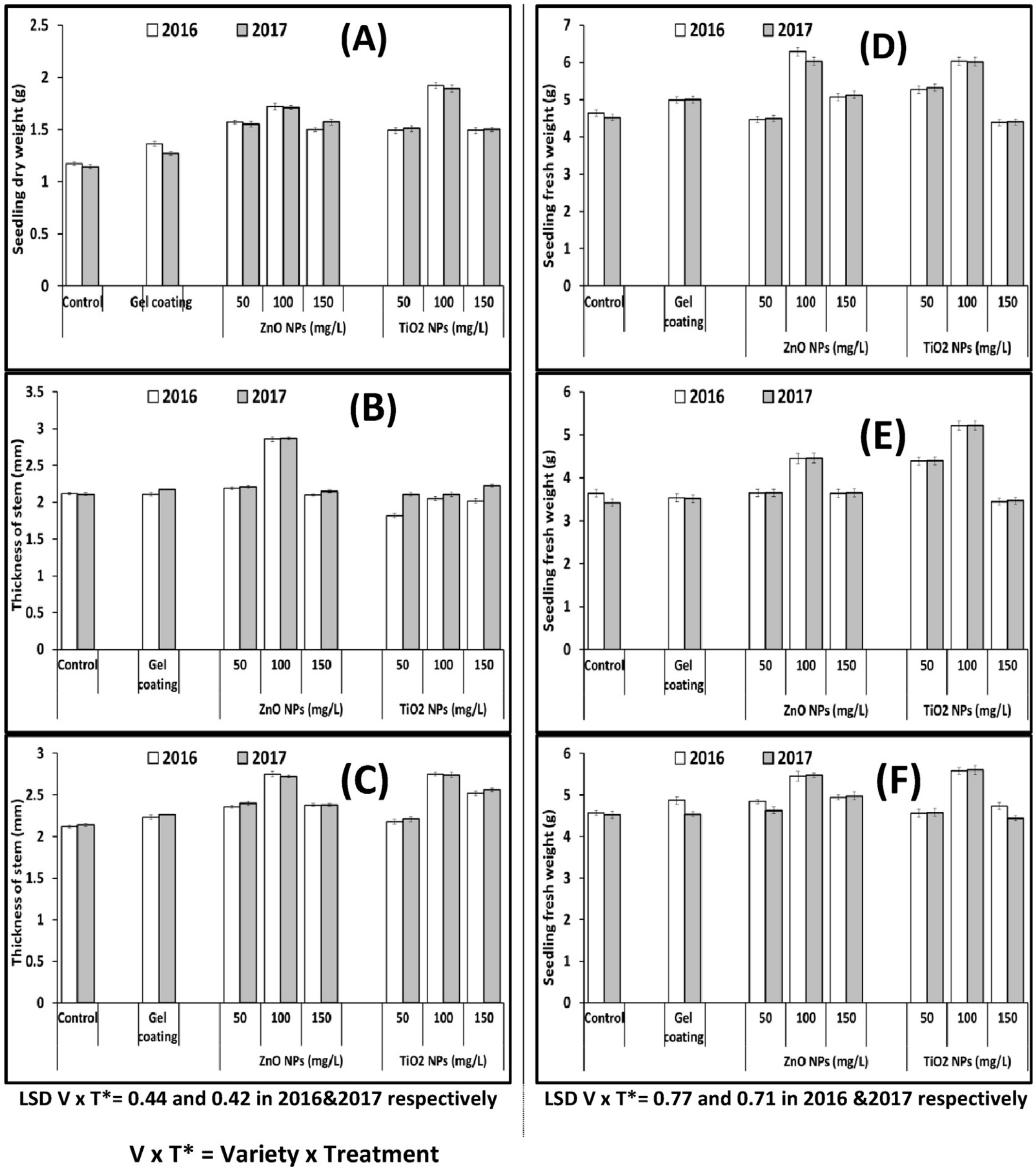


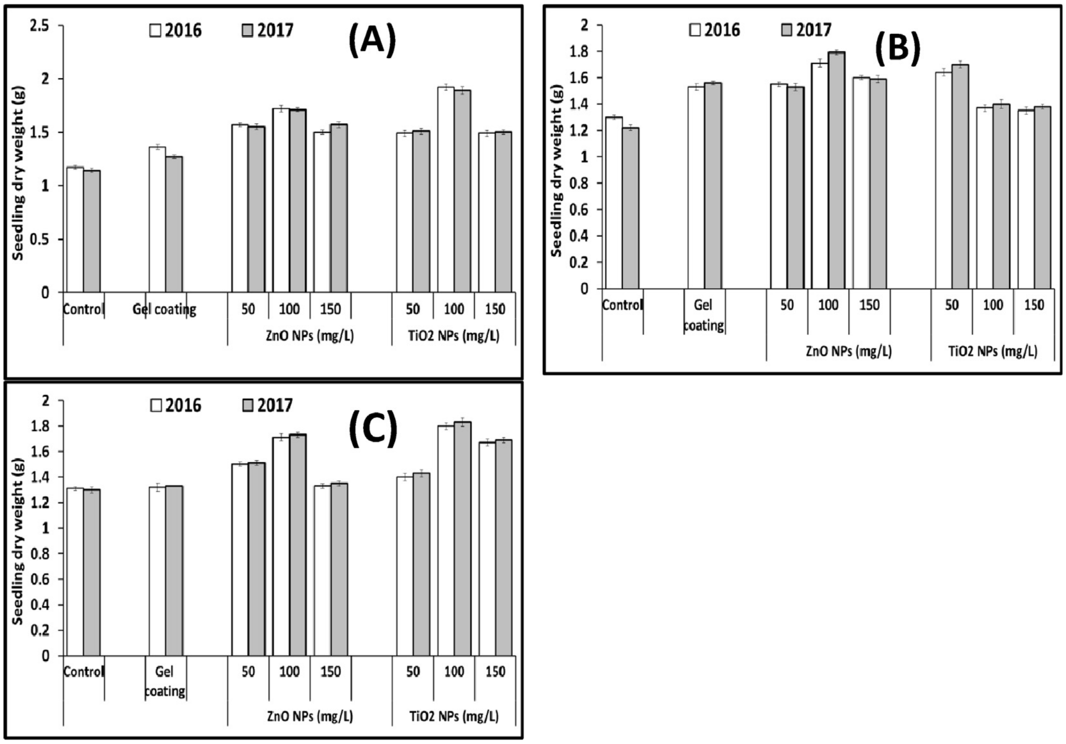
Figure 6. Thickness of stem (A, B and C) and seedling fresh weight (D, E and F) for eggplant, pepper and tomato, respectively. Each column represents a mean value of five replicates, and the vertical bars indicate ± SE.

NPs alleviated cadmium stress in wheat by enhancing growth, chlorophyll contents, gas exchange as well as curtailing the oxidative stress. Furthermore, zinc and copper nanoparticles promoted the drought resistance of two wheat cultivars at seedling stage via stabilizing the photosynthetic pigments, enhancing leaf water content, rising of antioxidative enzyme activity and slow down lipid peroxidation (Taran et al., 2017). Various studies recommended that ZnO NPs at a size lower than100 nm positively promoted biomass, yield, and nutrient content of many crops as cucumber (Zhao et al., 2013); peanuts (Prasad et al., 2012); cauliflower, cabbage, and tomato (Singh et al., 2013); and common chickpea (Pandey et al., 2010).

These works come in agreement with the beneficial effect of both nanomaterials illustrated in this research. Thus, we recommended gel coating of TiO_2 and ZnO nanomaterials at the level of 100 mg/L to produce vigor transplants of the main daily used vegetables as eggplants, pepper and tomato to be applied in the field and further studies should be conducted to evaluate their prospective role on yield. The seed soaking with NPs could be an alternative way which can be used for commercial purposes and the rest nanopriming solution can be re-applied owing to its antimicrobial characters which make it cost-effective (Mahakham et al., 2016).

4. Conclusion

Better transplants traits, plant height, number of leaves, fresh and dry weight as well as stem thickness, of tomato, pepper, and eggplants were displayed in the presence of TiO_2 and ZnO nanomaterials over the respective controls in order of $100 > 150 \geq 50$ mg/L. This may be attributed to the positive effect of ZnO and TiO_2 nanomaterials, especially at 100 mg/L, on germinability where attained higher mean germination rate, the best coefficient variation of mean germination time and synchronous germination to maximize the advantages of the applied nanomaterials and betting for well-establishment in their earliest life stage. Thus, the present investigation provided evidences on the ability of



LSD V x T*=0.19 and 0.21 in 2016&2017 respectively

V x T* = variety x treatment

Figure 7. Seedling dry weight (A, B and C) for eggplant, pepper and tomato, respectively. Each column represents a mean value of five replicates, and the vertical bars indicate ± SE.

production well established main vegetables transplants in a short time by gel coating of seeds with TiO_2 and ZnO nanoparticles, thereby accelerated germination by the used nanoparticles may be open the chance for breaking down the seeds dormancy of plants well known by their high dormancy or long germination period. Therefore, this technique might be a green alternative to conventional technologies used to produce vigorous transplants able to withstand harsh environmental conditions. Numerous applications for TiO_2 and ZnO nanoparticles can estimate the future increase in the manufacturing of these nanoparticles by improving economical synthesis methods of low costs. Hence, the economical application of nanoparticles as fertilizers can be practically applied in large scale worldwide.

Declarations

Author contribution statement

M. F. A. Dawood, N. A. Younes: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

H. Shokry Hassan, M. F. Elkady, A. M. Hamed: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

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