http://agriprojournal.com

JOURNAL OF AGRICULTURAL PRODUCTION

ISSN: 2757-6620

PRENSIP

https://prensip.gen.tr

RESEARCH ARTICLE

The Effect of Pre-Applied Titanium Dioxide Nanoparticles on Germination in *Carthamus tinctorius* L. Varieties

Volkan Gul[1]✉ • Burcu Seckin Dinler[2] • Fırat Sefaoglu[3] • Hatice Cetinkaya[2] • Fatma Nur Koc[2]

[1]Bayburt University, Aydıntepe Vocational School, Food Technology Program, Bayburt/Türkiye
[2]Sinop University, Faculty of Arts and Sciences, Department of Biology, Sinop/Türkiye
[3]Kastamonu University, Faculty of Engineering and Architecture, Department of Genetic and Bioengineering, Kastamonu/Türkiye

ARTICLE INFO

Article History
Received: 13.02.2024
Accepted: 03.03.2024
First Published: 31.03.2024

Keywords
Germination index
Germination percentage
Safflower
Seed
Titanium dioxide nanoparticles

ABSTRACT

In the present study, to promote sustainable nano-farming, the apparent effects of different concentrations (0, 100, 200, 300, 400, 500 ppm) of titanium dioxide nanoparticle (TiO_2NPs) solutions on the germination percentage, index and duration of seeds belonging to Balcı, Dincer, Hasankendi, Koc, Olas, and Zirkon safflower varieties were investigated. Moreover, scanning electron microscopy (SEM) was employed to analyze TiO_2NPs in germinated safflower varieties. Germination performance was TiO_2NPs concentration and variety depended. It was determined that the seed samples displayed different responses to TiO_2NPs concentrations; germination percentages were between 20.0±1.15 and 82.9±0.44%, germination durations were between 2.01±0.021 to 3.82±0.017 days, and germination indices were between 9.97±0.606 and 38.97±0.959. While the highest germination percentage (82.9±0.44%) was obtained from Dincer variety with 100 ppm TiO_2NP pre-application, the lowest germination percentage (20.0±1.15% and 20.0±1.92%) was obtained from Balcı and Hasan Kendi varieties with 100 and 300 ppm TiO_2NP pre-application. According to this result, although the highest germination percentage based on variety was obtained from the Dincer variety, the Balcı variety with the lowest germination percentage provided the most significant increase in the 200 ppm TiO_2NPs application dose compared to the control. According to the germination percentage, it can be said that the most effective TiO_2NPs application dose in Safflower varieties is 200 ppm. Further research on nanoparticles is needed to determine both the economical doses of TiO_2NP pre-application and its uptake by the plant.

Please cite this paper as follows:

Gul, V., Seckin Dinler, B., Sefaoglu, F., Cetinkaya, H., & Koc, F. N. (2024). The effect of pre-applied titanium dioxide nanoparticles on germination in *Carthamus tinctorius* L. varieties. *Journal of Agricultural Production*, *5*(1), 41-49. https://doi.org/10.56430/japro.1436131

1. Introduction

Fats and lipids are sources of energy storage and important in human and animal nutrition (Gürsoy, 2019). Vegetable oils are the sources of the most widely used lipids in human nutrition as they are rich in polyunsaturated omega fatty acids and do not contain cholesterol (Roccisano et al., 2016; Zhou et al., 2020). Safflower (*Carthamus tinctorius* L.) is an important oil seed plant for oil production due to its deep root system, which helps its tolerance to drought where dry farming is carried out (Omidi et al., 2012). Safflower seeds contain 30-50% oil and provide quality edible oil owing to its high (63-75%) linoleic acid (omega-6) content (Toma et al., 2014; Conte et al., 2016). The growth and yield of crop plants depend on rapid seed germination and emergence and good seedling formation. Seed germination is the first growth stage of a plant

✉ Correspondence
E-mail address: volkangul555@gmail.com

to limit its development under stress (Jabeen & Ahmad, 2013). Therefore, it is important to investigate effective seed treatment methods such as TiO_2NP to improve the germination percentage and seedling growth is of great importance.

Titanium dioxide nanoparticles (TiO_2NPs) are widely used catalysts in areas such as sewage treatment, food preservation, and environmental improvement, thanks to their low toxicity and high chemical stability (Arezoo et al., 2020; Li et al., 2021; Wu et al., 2018). Titanium dioxide nanoparticles are the most used nanomaterials in agricultural production thanks to their wide range of benefits in plants, such as promoting nutrient absorption in plants, increasing stress resistance, stimulating antioxidant enzyme activity, and increasing product yield and quality (Torres et al., 2020; Kamal & Mogazy, 2021; Shoja et al., 2022). Because nanoparticles (NP_S) are very small, they affect very wide areas in chemical and biological applications (Khalil et al., 2017; Rizvi & Saleh, 2018). Nanotechnology is the production of structures with completely new physical, chemical and biological properties, developed by working at the level of atoms with sizes of 1-100 nm. Since nanomaterials can be produced from many different materials, such as metals (Ni, Pt, Au), semiconductors (Si, InP, GaN) and insulators (SiO_2, TiO_2), they can be used in various industries, including the mechanical, medical, pharmaceutical, manufacturing and environmental sectors (Ateş et al., 2015; Castillo et al., 2020). In recent years, many studies have indicated that they are involved in the main metabolic events that control plant growth and development (Arora et al., 2012; Regier et al., 2015). Seed applications are an important field for the potential usage of NPs (Mahakham et al., 2016), where NPs can affect seed germination, seedling establishment, root and shoot growth, and photosynthesis (Paparella et al., 2015; Guha et al., 2018). They stated that titanium dioxide nanoparticle (TiO_2NP) applied to spinach leaves improved the growth of spinach (*Spinacia oleracea* L.) by promoting the reduction of nitrogenous fertilizer in the form of NH_3 to ammonium (NH_4) and nitrate (NO_3) for nitrogen (N) adsorption (Yang et al., 2008). They stated that TiO_2NPs significantly reduce salt stress and H_2O_2 concentration, increase antioxidant enzyme activity, and reduce disease index and biological stress in plants (Gohari et al., 2020; Satti et al., 2021). It was also reported that titanium application from seed reduced cadmium (Cd) stress in safflower plants (Sardar et al., 2022). Pre-treatment methods (such as a nanoparticle, gibberellic acid and salicylic acid) have been developed for seeds to minimize environmental stresses by increasing the germination quality of seeds (Liu & Lal, 2015). The pre-application method applied to seeds is determined by factors such as the osmotic state of plants, water potential, temperature, light conditions, oxygen availability, soil moisture, and seed quality (Hussain et al., 2016). Nanoparticle applications in the seed are promising techniques in the agricultural sector under normal conditions (Rastogi et al., 2019), and it was tested under environmental stress factors (Ahmad & Akhtar, 2019).

To increase the yield in safflower production, one of the most important considerations is that the seeds show good germination and emergence. Therefore, it is necessary to develop different methods against unfavorable environmental factors affecting the germination and exit process. it was added also above. In the study, it was investigated how titanium dioxide (TiO_2) nanoparticle pretreatment in different doses will have an effect between varieties to break the dormancy and increase productivity that occurs depending on genetic characteristics and promote germination in the germination performance of safflower seeds.

2. Materials and Methods

2.1. Material Procurement

Safflower seeds of six varieties; Balcı (Average yield: 1500-2500 kg ha^{-1}; 1000 grain weight: 40-48 g; oil content is 38-40%), Dincer (Average yield: 1000-2500 kg ha^{-1}; 1000 grain weight: 45-49 g; Oil content: 25-28%), Hasankendi (Average yield: 1600-2800 kg ha^{-1}; 1000 grain weight: 36-48 g; oil rate: 36-38%), Koc (Average yield: 2000-4000 kg ha^{-1}; 1000 grain weight: 40-50 g; oil content: 37-39%), Olas (Average yield: 1500-2800 kg ha^{-1}; 1000 grain weight: 45-50 g; oil content: 39-40%), and Zirkon (Average yield: 2500-3500 kg ha^{-1}; 1000 grain weight: 34-53 g; oil content: 28-35%) were obtained from institutes affiliated with the Turkish Republic Ministry of Agriculture and Forestry. Titanium dioxide nanoparticles (20 nm in size, 99.9% purity) were purchased from a company (Nanografi Nanotechnology, Ankara/Türkiye).

2.2. Experimental Setup

The seeds were kept in a 1% sodium hypochlorite (HClO) solution for 10 min. Then washed five times with distilled water for surface sterilization. After washing, the seeds were placed on filter papers and dried at room temperature. Titanium oxide concentrations at different doses applied to safflower seeds were determined by a preliminary experiment (0-500 ppm no germination) and the most appropriate doses were selected according to this range. Sterilized seeds were incubated in 0, 100, 200, 300, 400, and 500 ppm NP solutions for 18 h. Control treatment was incubated in distilled water without TiO_2 and NP solutions were prepared using distilled water. To prevent heat increases due to ultrasonic treatment, the seeds were subjected to “ultrasonic vibration (Frequency: 40 kHz and power: 180 W)” twice, 1 h at the beginning of the incubation and 30 min before at the end of the incubation. After 18 h, the seeds were washed three times with distilled water and left to dry on filter papers. Filter papers were placed in the Petri dishes and 3 ml of distilled water was added. The experiment was set up with three replications and each replication contained 50 seeds in petri dishes. The seeds were placed in a dark environment with a temperature of 25±2 ºC and a relative humidity of 50±5% for germination. Initial germination data were obtained two days after planting (germination durations differed among varieties). The experiment was terminated seven days after sowing when germination data were obtained (Figure 1).

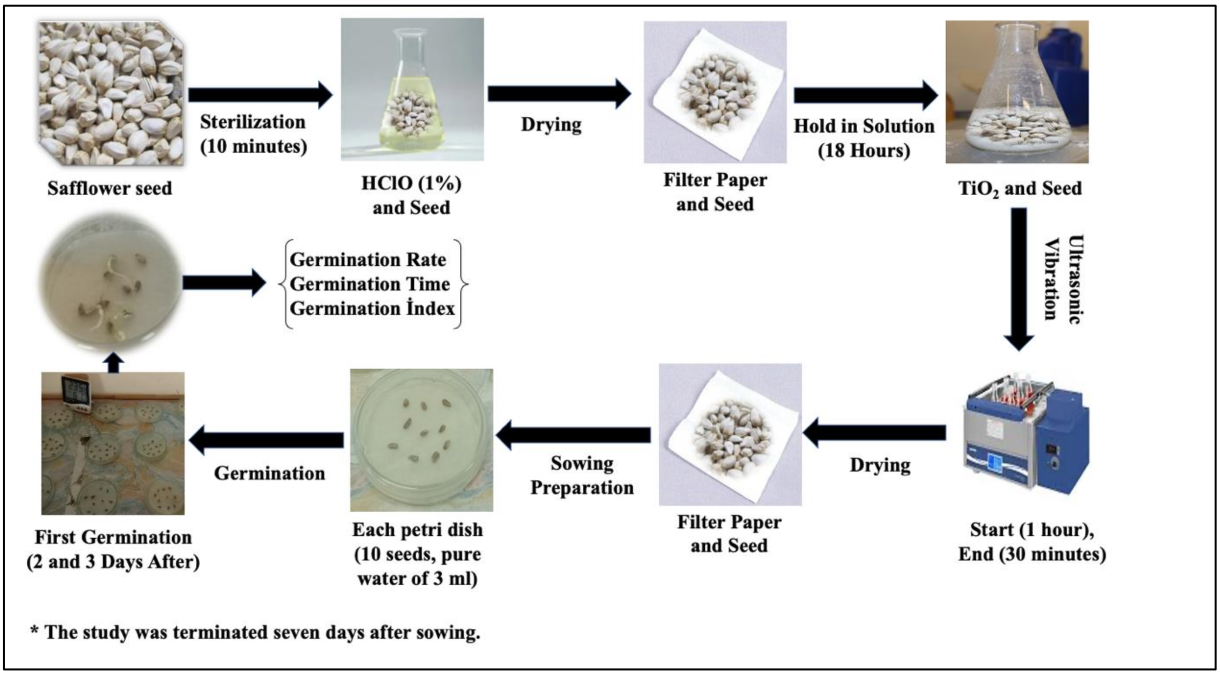


Figure 1. Scheme of preparation of the experiment.

2.3. Germination Percentage (%)

The germinated seeds were counted at the same time every day, and the seeds were considered as germinated when the radicle reached 2 mm and germination percentage was calculated according to Sanoubar et al. (2018).

$$Germination\ percentage\ (\%) = \frac{Number\ of\ germinated\ seeds}{Total\ number\ of\ seeds}\ x\ 100 \qquad (1)$$

2.4. Mean Germination Time (day)

Mean germination time was determined following the formula of Ellis and Roberts (1981).

$$Mean\ germination\ duration = \frac{n_1 x\ d_1 + n_2 x\ d_2 + n_3 x\ d_3 + \cdots + n_n x\ d_n}{Total\ number\ of\ days} \qquad (2)$$

Where, n = the number of germinated seeds, d = day.

2.5. Germination Index

The germination index was calculated according to Czabator (1962).

$$Germination\ index = \frac{n_1}{d_1} + \frac{n_2}{d_2} + \frac{n_3}{d_3} + \cdots + \frac{n_n}{d_n} \qquad (3)$$

Where, n = number of germinated seeds, d = day.

2.6. Scanning Electron Microscopy (SEM) And Energy-Dispersive X-Ray Spectroscopy (EDX) Analysis

For SEM imaging, the Examples of germinating safflower were left to dry in the air, fixed on carbon tapes, coated with Au-Pd on the Cressington Sputter Coater for 60 s and then placed on the FEI Quanta FEG 250 SEM (operating at 10 kV and 20 kV) immediately. The elemental analyses of the samples were done by area and point analysis with an EDX detector (Javed & Mashwani, 2020; Javed et al., 2020).

2.7. Statistical Analysis

The two-year data obtained from the research were subjected to analysis of variance with the help of JMP 5.0.1 (SAS institute 2002) package according to the Randomized Complete Blocks Desing. Significant differences among treatments were compared and grouped according to the Duncan Multiple Range Test at the p<0.05 probability level.

3. Results and Discussion

Significant differences were detected at the statistically p<0.01 level in terms of germination percentage, germination duration and germination index variety x TiO_2NPs pre-application. While significant differences were obtained in terms of TiO_2NPs pre-application at the germination index statistically level of p<0.05, significant differences were obtained at the germination percentage and germination duration statistically level of p<0.01 (Table 1).

Table 1. Variance analysis material of the development parameters of safflower varieties germinated in different titanium dioxide nanoparticles pre-applications.

Source Variation	d.f	Germination Percentage	Germination Duration	Germination Index
Variety	**5**	30.529**	54.316**	11.062**
Pre-Application	**5**	2.325*	2.361*	6.040**
Variety x Pre-Application	**25**	116.296**	13.626**	14.506**

**, * Statistically significant at $P<0.01$ and $P<0.05$, d.f: degrees of freedom, the difference between the averages denoted by different letters is significant.

3.1. Germination Percentage

The mean germination percentages of safflower varieties pre-treated with different concentrations of TiO_2NPs varied between 20.0±1.15 and 82.9±0.44 %. While the highest germination percentage (82.9±0.44%) was obtained from Dincer variety with 100 ppm TiO_2NP pre-application, the lowest germination percentage (20.0±1.15% and 20.0±1.92%) was obtained from Balcı and Hasan Kendi varieties with 100 and 300 ppm TiO_2NP pre-application. TiO_2NP pre-application doses had a positive effect on the varieties at different rates compared to the control (Table 2). The mean germination percentages of safflower varieties pre-treated with different concentrations of TiO_2NPs varied between 20.0±1.15 and 82.9±0.44%. This significant difference between varieties may be due to genetic, climate, and environmental factors. It can also be said that the storage life of safflower seeds varies depending on their storage life and conditions (Kumari, 2009). The highest germination percentage on a variety basis was obtained in the Dincer variety at a pre-application dose of 100 ppm TiO_2NP. It was observed that TiO_2NP pre-application doses had a positive effect on other varieties compared to the control. The administration dose of TiO_2NPs may have increased the germination rate by fully penetrating the seed coat and endosperm and acting on the embryo (Song et al., 2013). Dogaroglu and Köleli (2016), stated that the increase in TiO_2 and TiO_2Ag nanoparticle dose increases the germination percentage in lettuce seeds, so the same kind of nanoparticles may have different effects on other plants. (Ravindran et al., 2012), due to AgNP applications to tomato and corn plants, stated that tomato seeds are more sensitive than corn seeds and cause inhibition of 20-40% in germination percentages depending on the increase in concentration. The seed coat protects the embryo against adverse environmental conditions and may not always allow the inhibition of nanoparticles into the seed with its semi-permeable structure (Boonyanitipong et al., 2011; Song et al., 2013). TiO_2NPs, which do not ionize in water, can see the seed coat and endosperm as effective barriers, especially when they become clumped. The germination percentage results we found show similarities with the results of some researchers.

Table 2. The average germination percentage, germination duration and germination index of safflower varieties germinated in different titanium dioxide nanoparticles pre-applications.

Varieties	Germination Percentage (%)					
	Control	100 ppm	200 ppm	300 ppm	400 ppm	500 ppm
Balcı	24.0±1.15qr	20.0±1.15r	47.0±0.58gi	43.0±2.89ij	46.3±0.33gi	37.0±0.58km
Dinçer	78.4±0.96b	82.9±0.44a	63.6±1.94d	70.7±0.67c	81.6±0.96ab	48.6±0.98gh
Hasankendi	47.6±1.24gh	34.8±1.13mo	46.4±0.22gi	20.0±1.92r	28.2±0.97pq	33.1±0.59mo
Koç	50.4±0.44fg	40.01±0.00jl	31.4±0.99op	54.8±0.98e	48.2±0.98gh	36.8±1.93kn
Olas	48.0±1.15gh	36.01±1.55ln	40.3±3.48jk	46.0±2.31hi	54.0±0.00ef	32.7±0.67no
Zirkon	61.4±0.98d	46.7±1.26gi	65.0±2.89d	40.0±3.85jl	73.3±0.87c	50.0±1.92fh
	Germination Duration (day)					
Balcı	3.04±0.151de	3.19±0.097bd	3.36±0.125bd	3.38±0.095bc	3.51±0.017ab	3.82±0.017a
Dinçer	2.39±0.205gi	2.31±0.124gj	2.41±0.011gi	2.33±0.049gj	2.62±0.130fg	3.04±0.119ce
Hasankendi	2.01±0.021j	2.11±0.032hj	2.23±0.071hj	2.30±0.087gj	2.34±0.023gj	2.35±0.115gj
Koç	2.16±0.023hj	2.24±0.017hj	2.20±0.115hj	2.31±0.055gj	2.36±0.031gi	2.38±0.035gi
Olas	2.09±0.060ij	2.16±0.081hj	2.24±0.062hj	2.36±0.086gi	2.34±0.172gj	2.40±0.226gi
Zirkon	2.32±0.072gj	2.40±0.160gi	2.39±0.144gi	2.45±0.072gh	2.45±0.358gh	2.83±0.192ef
	Germination Index					
Balcı	12.94±0.727qr	9.97±0.606r	24.10±0.02in	22.16±1.385ko	24.87±0.069im	18.09±0.382oq
Dinçer	37.48±0.149ab	35.73±1.299ac	27.09±0.823fk	30.59±0.247ch	32.60±1.566be	15.57±0.658pq
Hasankendi	28.42±1.727ei	28.34±1.213ei	22.19±0.206ko	31.41±0.535cf	27.19±7.459fk	18.99±2.994np
Koç	23.94±0.050in	18.96±0.147np	14.71±0.618pr	26.23±0.461gl	21.76±1.404lo	14.33±0.919pr
Olas	33.63±1.307bd	27.37±0.637fj	22.34±5.502jo	31.77±0.564cf	38.97±0.959a	25.50±0.316hm
Zirkon	26.79±0.267fl	18.65±0.352op	28.72±1.668di	22.91±1.411jo	30.74±0.399cg	20.84±0.584mo

The difference between the averages denoted by different letters is significant.

3.2. Germination Duration

According to the results of the variance analysis, the effect of variety and TiO_2NP applications on germination duration was significant, while the effect of variety x TiO_2NP interaction was insignificant (Table 1). The shortest mean germination duration among TiO_2NP doses was obtained from the control group (2.01±0.021 days) and the shortest germination duration was obtained from the 500 ppm TiO_2NP dose (3.82±0.017 days). Although the effect of different TiO_2NP doses on the germination duration was significant, the germination duration values recorded at the application doses were close (Table 2). The highest germination duration (3.82±0.017 days) was obtained from the 500 ppm TiO_2NP pre-application group in the Balcı variety. In comparison, the shortest germination duration (2.01±0.021 days) was obtained from the control group in the Hasankendi variety. In some cases, adverse effects were observed on some growth parameters, which may indicate a toxic effect of TiO_2NPs doses. The increase in different TiO_2NPs doses have restricted the germination duration compared to the control (Table 2). In this case, the seed pods and endosperm may have acted as filters that absorb metals but pass through the water. Indeed, Song et al. (2013) determined that 2.2 ± 0.6 mg kg^{-1} TiO_2 passed through the TiO_2-treated corn seeds (*Zea mays* L.) and that the nanoparticles did not penetrate the seed coats. (Younes et al., 2020), stated that the mean germination time of seeds belonging to the *Solanaceae* family was reduced when coated with 100 mgbL^{-1} TIO_2NPs. According to the results we obtained, like some researchers, the increase in the pre-application dose of TiO_2NP_s extended the germination duration.

3.3. Germination Index

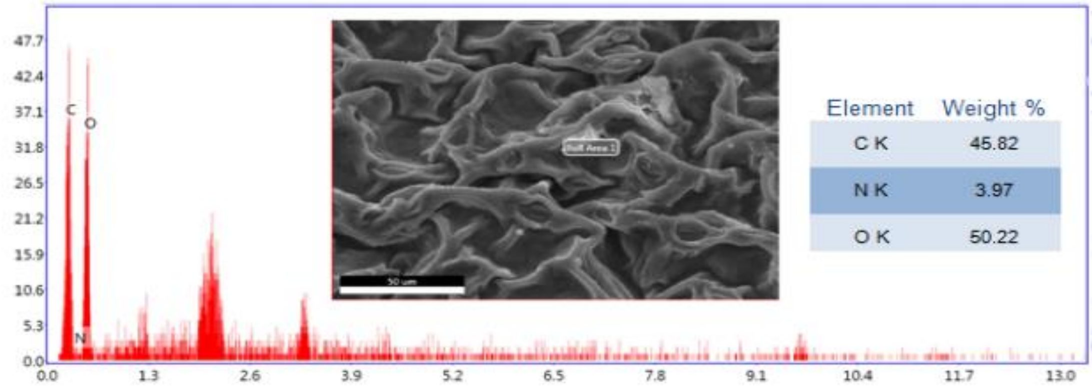
In the present study, 300 and 400 ppm concentrations of TiO_2NPs applied to safflower seeds showed a positive effect by increasing the germination index compared to normal conditions by 8.6%, respectively. However, 100, 200, and 500 ppm concentrations negatively affected the germination index by 14.76, 14.72, and 30.03%, respectively. The germination indexes of safflower seeds varied, and the highest mean index was obtained in Dincer (37.48±0.149) and Olas (38.97±0.959) varieties, whereas the lowest mean germination index was obtained in Balcı (9.97±0.606) varieties. Although the germination indexes of the Dincer and Olas varieties were the highest, as the pre-treatment concentrations of TiO_2NPs increased, the germination indexes decreased to a certain extent. Furthermore, although there were increases in 300 and 400 ppm concentrations, these were not extremely high compared to the standard conditions. In the Balcı variety, which had the lowest germination index, a 23.1% decrease occurred in the 100 ppm treatment compared to the control (12.94±0.727) group. In contrast, increases of 84.6, 69.2, 93.3 %, and 38.5% occurred in the pre-treatments of 200, 300, 400, and 500 ppm TiO_2NP, respectively. Differences were determined between varieties regarding their germination indices depending on the titanium dioxide nanoparticle concentration increase. Different responses to the pre-treatment concentrations of TiO_2NPs caused variety x pre-treatment interaction to be significant in terms of the germination index. Although the germination index of Dincer and Olas cultivars was the highest, germination indexes decreased at certain rates as TiO_2NPs pre-application doses increased. Although there are very few studies on the effect of TiO_2NPs on seed germination, the results of different studies show that each plant is affected differently by TiO_2NPs. Differences were determined in terms of the germination index of varieties depending on the increase in TiO_2NPs dose. (Mehrian et al., 2016), reported that the germination index of some tomato seeds increased with AgNP application, while there was no change in some. (Hatami et al., 2014), reported that applying different doses of TiO_2NPs to five different medicinal species seeds stimulated seed germination, but this response was dependent on the application of TiO_2NP_S and plant species (Faraji et al., 2018).

3.4. Scanning Electron Microscopy (SEM-ED) Analysis

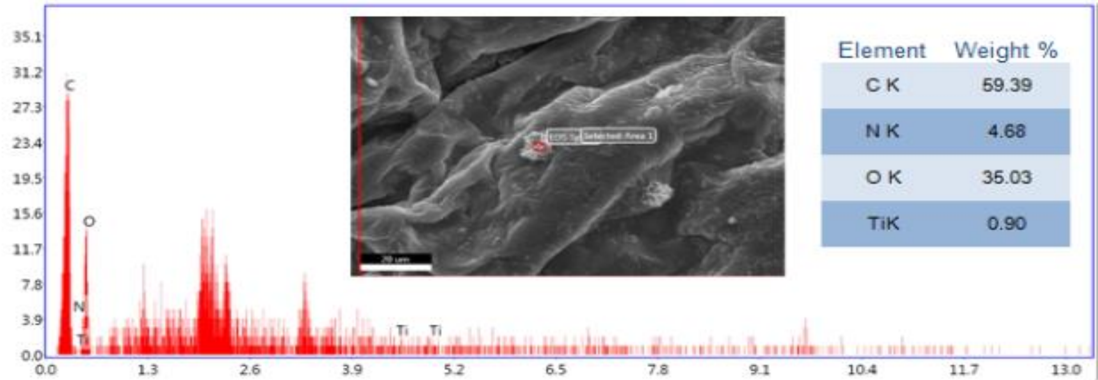
Surface morphology and topography of the TiO_2NPs were observed by using SEM. When the SEM images in Figure 2 were examined, it was observed that the particles appeared in cubic shapes and were located in the radicle and plumule of the seeds that were treated with TiO_2NPs. While nanoparticles were spread on the surface in both the radicle and plumula in the Balcı variety, it was determined that there was an agglomeration in the Dincer variety.

As seen in Figure 2, it shows that the morphology of TiO_2NP residues in the germinating safflower samples is close to spherical in shape and is in an aggregated state. Elemental detection of TiO_2NPs was observed with an energy-dispersive X-ray. Energy dispersive X-ray detector confirms the presence and purity of TiO_2NPs. While TiO_2NPs were detected at a rate of 0.90% in the Balcı variety and 0.28% in the Dincer variety in the applied groups, TiO_2NPs could not be seen on the surface of control plants. TiO_2NPs are less detected in Dincer than Balcı variety, which can be interpreted as the better development of this variety.

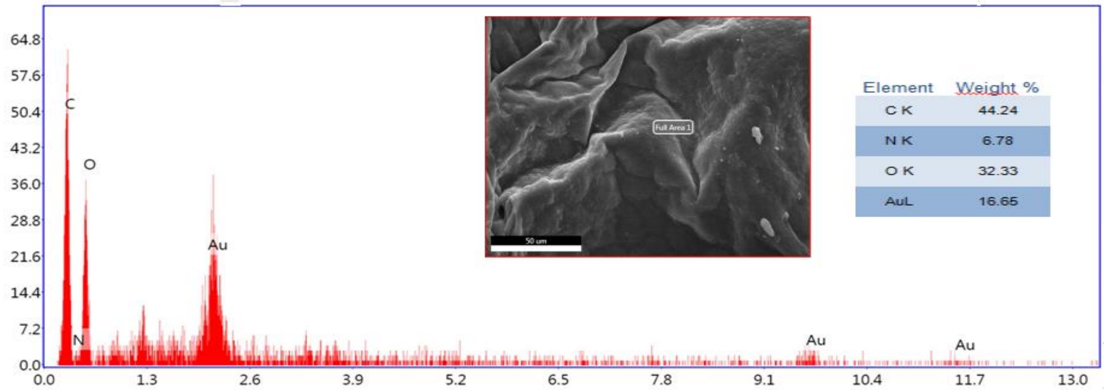
EDS spectra recorded from the TiO_2 nanoparticles are shown in Figure 2, respectively. SEM image showed that the TiO_2NP_S were spherical in shape or cubic (Figure 2). The qualitative and quantitative elemental profile involved in materialized synthesis was ascertained using EDS microanalysis of numerous distinct particles. EDS profile shows a strong Ti signal along with oxygen and carbon peak, which may originate from the biomolecules bound to the TiO_2 nanoparticles' surface. Observation of some peaks in the vicinity of the Ti and O other than C and O were Au peaks used in the coating of plant material.



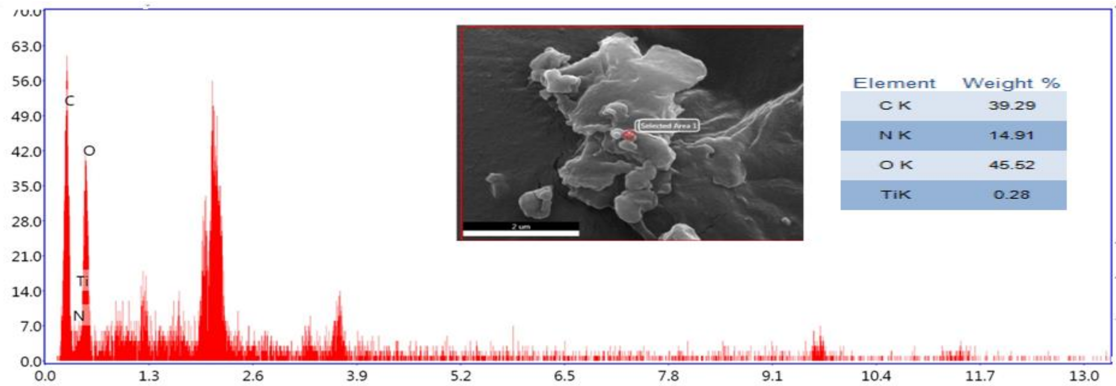
a. Balcı-Control



b. Balcı-Nano



c. Dincer-Control



d. Dincer-Nano

Figure 2. SEM and EDX-based analysis of safflower varieties of Balcı and Dincer (**a.** Balcı-Control, **b.** Balcı-TiO_2NPs, **c.** Dincer-Control, **d.** Dincer-TiO_2NPs). The difference between the averages denoted by different letters is significant.

4. Conclusion

Based on the results obtained, the germination performance of safflower seeds has shown changes depending on the doses of TiO_2NPs and the variety. According to TiO_2NPs concentrations and the variety of safflower seed samples, germination percentages varied between 20.0±1.15-82.9±0.44%, germination duration varied between 2.01±0.021-3.82±0.017 days and germination indexes varied between 9.97±0.606-38.97±0.959. It can be said that the significant differences between safflower varieties in terms of germination rate vary depending on the genetic, climate, and environmental factors of the varieties, as well as the storage life and conditions of the seeds. The highest germination percentage (82.9±0.44%) was obtained from Dincer variety with 100 ppm TiO_2NP pre-application, while the lowest germination percentage (20.0±1.15% and 20.0±1.92%) was obtained from Balcı and Hasankendi varieties with 100 and 300 ppm TiO_2NP pre-application. Different TiO_2NP pre-application doses had a positive effect on the germination percentage of safflower varieties compared to the control. According to this result, although the highest germination percentage based on variety was obtained from the Dincer variety, the Balcı variety with the lowest germination percentage provided the most significant increase in the 200 ppm TiO_2NPs application dose compared to the control. According to the germination percentage, it can be said that the most effective TiO_2NPs application dose in Safflower varieties is 200 ppm. Further research on nanoparticles is needed to determine both the economical doses of TiO_2NP pre-application and its uptake by the plant.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

Ahmad, I., & Akhtar, M. S. (2019). Use of nanoparticles in alleviating salt stress. In M. S. Akhtar (Ed.), *Salt stress, microbes and plant interactions: Causes and solution* (pp. 199-215). *Springer*. https://doi.org/10.1007/978-981-13-8801-9_9

Arezoo, E., Mohammadreza, E., Maryam, M., & Abdorreza, M. N. (2020). The synergistic effects of cinnamon essential oil and nano TiO_2 on antimicrobial and functional properties of sago starch films. *International Journal of Biological Macromolecules*, *157*, 743-751. https://doi.org/10.1016/j.ijbiomac.2019.11.244

Arora, S., Sharma, P., Kumar, S., Nayan, R., Khanna, P. K., & Zaidi, M. G. H. (2012). Gold-nanoparticle-induced enhancement in growth and seed yield of *Brassica juncea*. *Plant Growth Regulation*, *66*(3), 303-310. https://doi.org/10.1007/s10725-011-9649-z

Ateş, H. (2015). Nano parçacıklar ve nano teller. *Gazi Üniversitesi Fen Bilimleri Dergisi Part:C, Tasarım Ve Teknoloji*, *3*(1), 437-442. (In Turkish)

Boonyanitipong, P., Kositsup, B., Kumar, P., Baruah, S., & Dutta, J. (2011). Toxicity of ZnO and TiO_2 nanoparticles on germinating rice seed *Oryza sativa* L. *International Journal of Bioscience, Biochemistry and Bioinformatics*, *1*(4), 282-285.

Castillo-Henríquez, L., Alfaro-Aguilar, K., Ugalde-Álvarez, J., Vega-Fernández, L., Montes de Oca-Vásquez, G., & Vega-Baudrit, J. R. (2020). Green synthesis of gold and silver nanoparticles from plant extracts and their possible applications as antimicrobial agents in the agricultural area. *Nanomaterials*, *10*(9), 1763. https://doi.org/10.3390/nano10091763

Conte, R., Gullich, L. M. D., Bilibio, D., Zanella, O., Bender, J. P., Carniel, N., & Priamo, W. L. (2016). Pressurized liquid extraction and chemical characterization of safflower oil: A comparison between methods. *Food Chemistry*, *213*, 425-430. https://doi.org/10.1016/j.foodchem.2016.06.111

Czabator, F. J. (1962). Germination value: An index combining speed and completeness of pine seed germination. *Forest Science*, *8*(4), 386-396. https://doi.org/10.1093/forestscience/8.4.386

Dogaroglu, Z. G., & Köleli, N. (2016). Effect of titanium dioxide and titanium dioxide-silver nanoparticles on seed germination of lettuce (*Lactuca sativa*). *Çukurova University Journal of the Faculty of Engineering*, *31*(ÖS2), 193-198. https://doi.org/10.21605/cukurovaummfd.316762

Ellis, R. H., & Roberts, E. H. (1981). The quantification of aging and survival in orthodox seeds. *Seed Science and Technology (Netherlands)*, *9*(2), 373-409.

Faraji, J., Sepehri, A., & Salcedo-Reyes, J. C. (2018). Titanium dioxide nanoparticles and sodium nitroprusside alleviate the adverse effects of cadmium stress on germination and seedling growth of wheat (*Triticum aestivum* L.). *Universitas Scientiarum*, *23*(1), 61-87. https://doi.org/10.11144/Javeriana.SC23-1.tdna

Gohari, G., Mohammadi, A., Akbari, A., Panahirad, S., Dadpour, M. R., Fotopoulos, V., & Kimura, S. (2020). Titanium dioxide nanoparticles (TiO_2NPs) promote growth and ameliorate salinity stress effects on essential oil profile and biochemical attributes of *Dracocephalum moldavica*. *Scientific Reports*, *10*, 912. https://doi.org/10.1038/s41598-020-57794-1

Guha, T., Ravikumar, K. V. G., Mukherjee, A., Mukherjee, A., & Kundu. R. (2018). Nanopriming with zero valent iron (nZVI) enhances germination and growth in aromatic rice cultivar (*Oryza sativa* cv. Gobindabhog L.). *Plant Physiology and Biochemistry*, *127*, 403-413. https://doi.org/10.1016/j.plaphy.2018.04.014

Gürsoy, M. (2019). Importance of some oil crops in human nutrition. *Turkish Journal of Agriculture-Food Science* *and Technology*, *7*(12), 2154-2158. https://doi.org/10.24925/turjaf.v7i12.2154-2158.2916

Hatami, M., Ghorbanpour, M., & Salehiarjomand, H. (2014). Nano-anatase TiO_2 modulates the germination behavior and seedling vigority of some commercially important medicinal and aromatic plants. *Journal of Biological and Environmental Sciences, 8*(22), 53-59.

Hussain, M. I., Lyra, D. A., Farooq, M., Nikoloudakis, N., & Khalid, N. (2016). Salt and drought stress in safflower: A review. *Agronomy for Sustainable Development*, *36*, 1-31. https://doi.org/10.1007/s13593-015-0344-8

Jabeen, N., & Ahmad, R. (2013). Variations in accessions of sunflower and safflower under stress conditions. *Pakistan Journal of Botany, 45*(2), 383-389.

Javed, B., & Mashwani, Z. U. R. (2020). Synergistic effects of physicochemical parameters on bio-fabrication of mint silver nanoparticles: Structural evaluation and action against HCT116 colon cancer cells. *International Journal of Nanomedicine, 15,* 3621-3637. https://doi.org/10.2147/IJN.S254402

Javed, B., Nadhman, A., & Mashwani, Z. U. R. (2020). Photosynthesis of Ag nanoparticles from Mentha longifolia: Their structural evaluation and therapeutic potential against HCT116 colon cancer, Leishmanial, and bacterial cells. *Applied Nanoscience, 10*, 3503-3515. https://doi.org/10.1007/s13204-020-01428-5

Khalil, A. T., Ovais, M., Ullah, I., Ali, M., Shinwari, Z. K., Khamlich, S., & Maaza, M. (2017). *Sageretia thea* (Osbeck.) mediated synthesis of zinc oxide nanoparticles and its biological applications. *Nanomedicine*, *12*(15), 1767-1789. https://doi.org/10.2217/nnm-2017-0124

Li, Q., Duan, M., Liu, L., Chen, X., Fu, Y., Li, J., Zhao, T., & McClements, D. J. (2021). Impact of polyphenol interactions with titanium dioxide nanoparticles on their bioavailability and antioxidant activity. *Journal of Agricultural and Food Chemistry*, *69*(33), 9661-9670. https://doi.org/10.1021/acs.jafc.1c01970

Liu, R., & Lal, R. (2015). Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. *Science of the Total Environment*, *514*, 131-139. https://doi.org/10.1016/j.scitotenv.2015.01.104

Mahakham, W., Theerakulpisut, P., Maensiri, S., Phumying, S., & Sarmah, A. K. (2016). Environmentally benign synthesis of phytochemicals-capped gold nanoparticles as nano priming agent for promoting maize seed germination. *Science of the Total Environment*, *573*, 1089-1102. https://doi.org/10.1016/j.scitotenv.2016.08.120

Kamal, R., & Mogazy, A. M. (2021). Effect of doping on TiO_2 nanoparticles characteristics: Studying of fertilizing effect on cowpea plant growth and yield. *Journal of Soil Science and Plant Nutrition*, *23*, 325-337. https://doi.org/10.1007/s42729-021-00648-0

Kumari, A. (2009). Germination behaviour, viability and longevity of safflower (*Carthamus tinctorius* L.) seeds. *Biosciences*, *3*(1), 11-15.

Mehrian, K. S., Heidari, R., Rahmani, F., & Najafi, S. (2016). Effect of chemical synthesis silver nanoparticles on germination indices and seedlings growth in seven varieties of *Lycopersicon esculentum* Mill (tomato) plants. *Journal of Cluster Science, 27,* 327-340. https://doi.org/10.1007/s10876-015-0932-4

Omidi, A. H., Khazaei, H., Monneveux, P., & Stoddard, F. (2012). Effect of cultivar and water regime on yield and yield components in safflower (*Carthamus tinctorius* L.). *Turkish Journal of Field Crops*, *17*(1), 10-15.

Paparella, S., Araújo, S. S., Rossi, G., Wijayasinghe, M., Carbonera, D., & Balestrazzi, A. (2015). Seed priming: State of the art and new perspectives. *Plant Cell Reports*, *34*, 1281-1293. https://doi.org/10.1007/s00299-015-1784-y

Rastogi, A., Tripathi, D. K., Yadav, S., Chauhan, D. K., Živčák, M., Ghorbanpour, M., El-Sheery, N. I., & Brestic, M. (2019). Application of silicon nanoparticles in agriculture. *Biotech*, *9*, 1-11. https://doi.org/10.1007/s13205-019-1626-7

Ravindran, A., Prathna, T. C., Verma, V. K., Chandrasekaran, N., Mukherjee, A. (2012). Bovine serum albumin mediated decrease in silver nanoparticle phytotoxicity: Root elongation and seed germination assay. *Toxicological & Environmental Chemistry*, *94*(1), 91-98. https://doi.org/10.1080/02772248.2011.617034

Regier, N., Cosio, C., Von Moos, N., & Slaveykova, V. I. (2015). Effects of copper-oxide nanoparticles, dissolved copper and ultraviolet radiation on copper bioaccumulation, photosynthesis, and oxidative stress in the aquatic macrophyte *Elodea nuttallii. Chemosphere*, *128*, 56-61. https://doi.org/10.1016/j.chemosphere.2014.12.078

Rizvi, S. A., & Saleh, A. M. (2018). Applications of nanoparticle systems in drug delivery technology. *Saudi Pharmaceutical Journal*, *26*(1), 64-70. https://doi.org/10.1016/j.jsps.2017.10.012

Roccisano, D., Kumaratilake, J., Saniotis, A., & Henneberg, M. (2016). Dietary fats and oils: Some evolutionary and historical perspectives concerning edible lipids for human consumption. *Food and Nutrition Sciences*, *7*(8), 689-702. https://doi.org/10.4236/fns.2016.78070

Sanoubar, R., Calone, R., Noli, E., & Barbanti, L. (2018). Data on seed germination using LED versus fluorescent light under growth chamber conditions. *Data in Brief.*, *19*, 594-600. https://doi.org/10.1016/j.dib.2018.05.040

Sardar, R., Ahmed, S., & Yasin, N. A. (2022). Titanium dioxide nanoparticles mitigate cadmium toxicity in *Coriandrum sativum* L. through modulating the antioxidant system, stress markers and reducing cadmium uptake. *Environmental Pollution*, *292*(Part A), 118373. https://doi.org/10.1016/j.envpol.2021.118373

Satti, S. H., Raja, N. I., Javed, B., Akram, A., Mashwani, Z.-u.-R., Ahmad, M. S., & Ikram, M. (2021). Titanium dioxide nanoparticles elicited agro-morphological and physicochemical modifications in wheat plants to control *Bipolaris sorokiniana*. *Plos One*, *16*(2), e0246880. https://doi.org/10.1371/journal.pone.0246880

Shoja, A. A., Çirak, C., Ganjeali, A., & Cheniany, M. (2022). Stimulation of phenolic compounds accumulation and antioxidant activity in in vitro culture of *Salvia tebesana* Bunge in response to nano-TiO_2 and methyl jasmonate elicitors. *Plant Cell, Tissue and Organ Culture (PCTOC)*, *149*(1-2), 423-440. https://doi.org/10.1007/s11240-022-02251-2

Song, U., Shin, M., Lee, G., Roh, J., Kim, Y., & Lee, E. J. (2013). Functional analysis of TiO_2 nanoparticle toxicity in three plant species. *Biological Trace Element Research*, *155*, 93-103. https://doi.org/10.1007/s12011-013-9765-x

Toma, W., Guimarães, L. L., Brito, R. M. S., Santos, A. R., Cortez, F. S., Pusceddu, F. H., Cesar, A., Júnior, L. S., Pacheco, M. T. T., & Pereira, C. D. S. (2014). Safflower oil: An integrated assessment of photochemistry, antiulcerogenic activity, and rodent and environmental toxicity. *Revista Brasilera de Farmacognosia*, *24*(5), 538-544. https://doi.org/10.1016/j.bjp.2014.09.004

Torres, J. A., Nogueira, A. E., da Silva, G. T., Lopes, O. F., Wang, Y., He, T., & Ribeiro, C. (2020). Enhancing TiO_2 activity for CO_2 photoreduction through MgO decoration. *Journal of CO_2 Utilization*, *35*, 106-114. https://doi.org/10.1016/j.jcou.2019.09.008

Wu, J., Zhan, M., Chang, Y., Su, Q., & Yu, R. (2018). Adaption and recovery of *Nitrosomonas europaea* to chronic TiO_2 nanoparticle exposure. *Water Research*, *147*, 429-439. https://doi.org/10.1016/j.watres.2018.09.043

Yang, L., Jiang, X., Ruan, W., Zhao, B., Xu, W., & Lombardi, J. R. (2008). Observation of enhanced Raman scattering for molecules adsorbed on TiO_2 nanoparticles: Charge-transfer contribution. *The Journal of Physical Chemistry*, *112*(50), 20095-20098. https://doi.org/10.1021/jp8074145

Younes, N. A., Hassan, H. S., Elkady, M. F., Hamed, A. M., & Dawood M. F. A. (2020). Impact of synthesized metal oxide nanomaterials on seedlings production of three Solanaceae crops. *Heliyon*, *6*(1), e03188. https://doi.org/10.1016/j.heliyon.2020.e03188

Zhou, Y., Zhao, W., Lai, Y., Zhang, B., & Zhang, D. (2020). Edible plant oil: Global status, health issues, and perspectives. *Frontiers in Plant Science*, *11*, 1315. https://doi.org/10.3389/fpls.2020.01315