JOURNAL OF HORTICULTURE AND POSTHARVEST RESEARCH
2021, VOL. 4(SPECIAL ISSUE: RECENT ADVANCES IN SAFFRON), 33-42

Journal of Horticulture and Postharvest Research

Journal homepage: http://www.jhpr.birjand.ac.ir

University of Birjand

Magnetic fields and titanium dioxide nanoparticles promote saffron performance: A greenhouse experiment

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ARTICLE INFO

Original Article

Article history:
Received 9 November 2020
Revised 2 January 2021
Accepted 8 January 2021
Available online 8 April 2021

Keywords:
Corm
Physical treatment
Stigma
TiO_2

DOI: 10.22077/jhpr.2021.3886.1182
P-ISSN: 2588-4883
E-ISSN: 2588-6169

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ABSTRACT

Purpose: Plants are naturally influenced by magnetic fields. On the other hand, the application of titanium dioxide (TiO_2) nanoparticles may improve the quantitative and qualitative traits of plants. **Research method:** The effect of magnetic field and nano and bulk-TiO_2 was studied on the yield of saffron in Nishabur County, Iran. The treatments included 5-mT magnetic field (at three levels of control, exerted magnet tapes into substrate, and the 24-hour exposure of the corms to the magnets) and TiO_2 (at five levels of 0 as control, 1000 and 2000 ppm nanosized-TiO_2, and 1000 and 2000 ppm bulk TiO_2). During the growing season petal fresh and dry weight, flower fresh weight, stigma dry weight and corm weight were recorded. **Findings:** The results showed that studied traits were significantly ($p < 0.01$) influenced by the magnetic field and nano-TiO_2. The highest stigma dry weight was related to the treatment of 2000 ppm nano-TiO_2 and 48-hour exposure to the magnetic field, showing an insignificant difference with 1000 ppm nano-TiO_2. Application of TiO_2 nanoparticles in 2000 ppm increased stigma dry weight by 14.7 % and corm weight by 51 % compared to the control. Exposure of corms to magnetic field in planting media and pretreatment with it, increased corm weight by 13.6 and 26 % in comparing to control, respectively. **Limitations:** No limitations were founded. **Originality/Value:** According to the results, it is possible to use magnetic fields and TiO_2 nanoparticles to stimulate the growth of corms and flower of saffron.

INTRODUCTION

Saffron (*Crocus sativus* L.) is known as the most valuable agricultural crop in Iran and the most expensive spice in the world. This crop is called 'red gold' because of its high value and price (Abrishami, 2004). Among crops, saffron is a plant that has succeeded to tolerate the problem of water scarcity in these regions (Kafi et al., 2006). Averaged across the last 35 years, the yield of saffron has been 4.83 kg ha^{-1} in Iran. Its average production has, however, declined sharply in recent years due to the use of traditional practices and inattention to modern agronomic management practices (Molafilabi & Shourideh, 2009).

Excessive application of chemical fertilizers has influenced global water resources and has brought about the phenomenon of swamp development in aquatic ecosystems (Vattani et al., 2012). Nowadays, sustainable agricultural systems around the world try to find out environmental friendly technologies based on physical and biological treatments to increase the seedling vigor, crop establishment and crop production (Feizi et al., 2012). Recently, specific studies have been addressed to test if physical methods, including ionization and/or application of ultraviolet rays, electric fields, and magnetic fields are able to improve the quality of the seeds. Unlike chemical methods, they cause less environmental harm. Using magnetic fields as a way for increasing quality and quantity of crops yield has been taken in consideration (Feizi et al., 2020b). Further advantage in the use of magnetic field is in relation to increasing the seed germination rates and the possible increase in membrane permeability, simplifying the process of water absorption by seeds. Also, helpful effect of magnetic field on increasing seed germination, seedling vigor, photosynthetic pigments, the efficiency of photosystem II (PSII), and performance index based on the absorption of light energy, as well as in encouraging efficient photosynthesis and alleviating the opposing effects of salt, water, and UV-B stress (Sarraf et al., 2020).

The nanotechnology is gradually transiting from laboratory phase to operational and practical phase and this has expanded its presence in the agricultural sector. Nanoparticles refer to atoms and molecules with diameters of 1-100 nm (Ditta, 2012). In this respect, the use of nanofertilizers for more precise control of nutrient release can be a significant step towards accomplishing sustainable and environmentally-friendly farming. Nanoparticles have enhanced reactivity due to a greater proportion of surface atoms relative to the interior of a structure (Handy et al., 2008). As such, insoluble substances can exhibit drastically enhanced solubility when particle size is less than 100 nm. In addition, materials with dimensions less than 5 nm exhibit unique magnetic/optical properties, electronic states, and catalytic reactivity that differ from equivalent bulk materials (Feizi et al., 2013b).

Since the application of nanofertilizers allows matching the timing and rate of nutrient release with plant nutritional requirements, the plants can absorb more nutrients resulting in higher crop yield as well as less leaching of the nutrients. The application of nanotechnology in optimizing the formulation of chemical fertilizers can lead to wonderful accomplishments, such as the reduction of energy use, the saving on production costs, and the prevention of environmental problems (Ditta, 2012). The shift in technologies related to the agriculture industry is the main factor underpinning the establishment of modern farming. In this sense, nanotechnology can be an excellent area of interest in food and agricultural production. Because of the impacts of this technology on other existing technologies, researchers suggest that professionals of different fields will not have an opportunity for growth in coming decades if they do not show interest in issues at a nano scale (Feizi et al, 2013b).

Titanium dioxide (TiO_2) may occur in three shapes: anatase, rutile, and brookite. TiO_2 nanoparticles are in very tiny size, so they have more contact area and higher efficiency than rutile and brookite. TiO_2 is among the main nanoparticles with photocatalyst properties and extensive applications in many countries (Sawhney & Condon, 2008). When exposed to radiation, nano-anatase as a photocatalyst can create the conditions for oxidation-reduction reactions. This compound can be used to decompose NO_x to N_2 and O_2 or to decompose organic matter to CO_2 and water (Li et al., 2020). Titanium is a useful element for plants. It can stimulate the uptake of some elements like N, P, Ca, Mg, Fe, and Mn (Pais, 1983), the extent of which depends on several factors such as plant species and cultivar, pH, moisture, and nutrient status of soil (Kuzel et al., 2003). Nanomatter can improves a plant's ability to absorb and use water and nutrients. It has been reported that some nanoparticles, e.g. TiO_2, have the potential for light absorption and can play a significant role in enhancing photosynthesis efficiency of plants (Zheng et al., 2007). Maleki et al. (2021) reported that foliar application of TiO_2 nanoparticles with 30 ppm concentration caused the stigma yield by 25 % compared to control treatment. In addition, TiO_2 and SiO_2 nanoparticles significantly increased number of corm compared to the control.

In a study on soybean, Lu et al. (2001) concluded that a mixture of nano-TiO_2 and nano-SiO_2 accelerated the germination rate of soybean seeds and the growth of their seedlings. It has, also, been established that nano-TiO_2 improves light absorption, the transfer of light energy to electrons, and their conversion to chemical energy, which finally, increases CO_2 fixation (Gao et al., 2006). Zheng et al. (2005) reported the improved yield and germination of spinach plants treated with nano-TiO_2. Similarly, Yang and Hong (2006) stated that nano-TiO_2 had a remarkable impact on increasing seed weight of spinach towards stimulating its growth. Research has shown that the germination of tomato, lettuce and onion seeds was enhanced in the presence of TiO_2 and the following exposure to radiation (Elghniji et al., 2014).

Specific studies have been addressed to test if physical methods, including ionization and/or application of ultraviolet rays, electric fields, and magnetic fields are able to improve the quality of the seeds. Contrasting chemical methods, they cause less environmental harm. Use of physical treatments as a replacement for chemical fertilizers and supplements could diminish the toxicity of plant raw materials, increasing nutritional and environmental health (Dhawi & Al-Khayari, 2009). Although both stimulatory and inhibitory impacts of nanoparticles on various crop species have been reported in the literature, there is limited information on the impact of TiO_2 bulk and nanoparticles and magnetic field treatment on saffron. In this way, this study aimed to explore impact of magnetic field and bulk and nanosized particles on flower and corm production of saffron in a greenhouse experiment.

MATERIALS AND METHODS

The experiment was carried out under hydroponic conditions in a greenhouse in Nishabur city, Iran. Nishabur is located on 36° 21' N and 58° 79' E and has an altitude 1250 m. The planting medium was composed of 50% coco peat (coconut husk) and 50% perlite (volcanic matter turned into swollen glass particles under severe heat). This experiment was conducted as a split plot layout on a randomized complete block design with four replicates. Main factor consisted three levels of magnetic field exerted magnet tapes (5 mT) into substrate, corm pretreatment and control (without magnetic field treatment), and sub factor involved application of five TiO_2 bulk and nanoparticle concentrations of 0, 1000 ppm nanoparticle, 2000 ppm nanoparticle, 1000 ppm bulk particle and 2000 ppm bulk TiO_2 particles. The corms with average weight about 8 g were provided from Torbat Heydarieh landrace and planted at the depth of 10 cm with an inter-corm spacing of 3 cm into pots. In each pot (20 cm diameter, 30 cm height) five corms were planted. Before planting, corms were soaked in water contains TiO_2 concentrations for 24 hours.

Nanosized TiO_2 powder was as AEROXIDE® TiO_2 P25 that was supplied by Evonik Degussa GmbH Company. The size of TiO_2 nanoparticles were determined by Scanning Tunneling Microscope (STM) in Central Laboratory of Ferdowsi University of Mashhad, Iran (Fig. 1). Bulk TiO_2 was provided by AppliChem GmbH Company with 99% purity and particles size was provided by Scanning Electron Microscope (SEM) (Fig. 2).

Some of the corms were exposed to 5 mT magnetic field band for 48 hours. For exerting magnet in planting media treatment, a five number of magnet pieces with 3-4 cm length and 5 mT strength were placed in each pot near to the corms throughout the growing season. The first irrigation was carried out on September. The interval period of irrigation was 7 days. The corms were fed with Hoagland solution for 7 times. Mean temperature in greenhouse was about 20 °C in September and after that it remain 15 °C. The moisture was about 60 %. The first flower emerged on October 23 and the flowering phase terminated on November 9. The flowers were harvested from the individual pots every day to analyze petal fresh and dry weight, flower fresh weight, and stigma dry weight. At the end of growing season on 20 April, corms removed from medium and measured average fresh weight. Data were analyzed by the SAS (Ver. 9.2) software package, and the means were compared by Duncan's test at the $p < 0.05$ level.

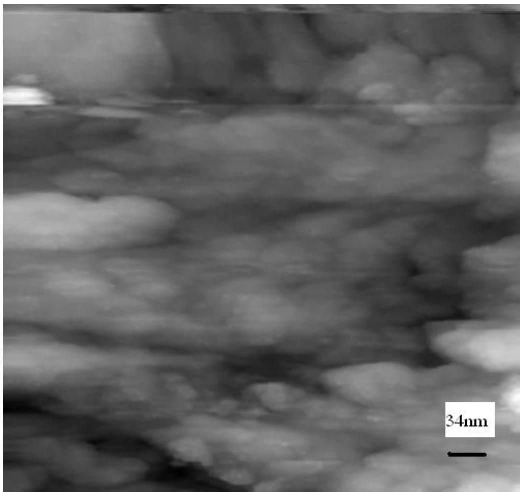

Fig. 1. Image of nanosized TiO_2 by Scanning Tunneling Microscope (STM).

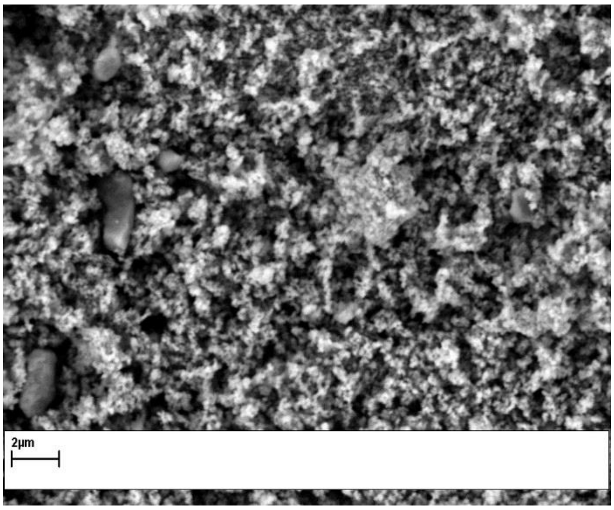

Fig. 2. Image of bulk TiO_2 particles by Scanning Electron Microscope (SEM).

RESULTS AND DISCUSSION

According to the results of analysis of variance in Table 1, the simple and interaction effects of magnetic field and TiO_2 were significant ($p < 0.01$) on petal fresh and dry weight, flower fresh weight, and stigma dry weight. The simple effects of magnetic field and nano-TiO_2 were significant on corm weight, but their interaction was not significant for this trait (Table 1). The simple effects of the magnetic field showed that the highest flower fresh weight of 0.34 g, petal fresh weight of 0.204 g, and stigma dry weight of 0.0077 g were obtained from the corms exposed to 5-mT magnetic field for 48 hours. The highest petal dry weight was obtained from the placement of magnet next to the corms in medium (Table 2). Also exposure of corms to magnetic field in planting media and pretreatment with it, increased corm weight by 13.6 and 26 percent in comparing to control, respectively. Surprisingly exerting of pretreatment of magnetic field improved stigma dry weight from 0.0044 in control to 0.0077 g in this treatment (by 75 percent increase compared to control). Although impact of magnetic field on saffron growth and yield has not been reported but these positive results has been proved on other crops such as muskmelon (*Cucumis melo* L.) (Feizi et al., 2013b), artichoke (*Cynara scolymus* L.) (Bagherifard & Ghasemnezhad, 2014), and adjowan (*Carum copticum*) (Seghatoleslami et al., 2015). Alexander and Doijode (1995) showed that a 36.6 % increase in seed germination of onion (*Allium cepa* L.) compared with control. Fernandez et al. (1996) stated that exerting 120-150 mT of magnetic field on onion plant increased the amount of phosphorus in leaves and lowered soil alkalinity which resulted in yield enhancement.

Table 1. Analysis of variance for the simple and interactive effects of magnetic field and nano-TiO_2 on yield components of saffron

Sources of variations	Degrees of Freedom	Means of squares				
		Petal fresh weight	Petal dry weight	Flower fresh weight	Stigma dry weight	Corm weight
Replication	3	0.0003	0.000001	0.00009	0.0000002	0.042
Magnetic field (A)	2	0.0052^{**}	0.0076^{**}	0.0331^{**}	0.000063^{**}	6.56^{**}
Error 1	6	0.0001	0.000003	0.00009	0.0000005	0.11
TiO_2 (B)	4	0.0028^{**}	0.00034^{**}	0.015^{**}	0.0000015^{**}	6.62^{**}
A × B	8	0.0006^{**}	0.00043^{**}	0.002^{**}	0.0000014^{**}	0.07^{ns}
Error 2	36	0.0001	0.00000058	0.00026	0.00000007	0.03
Coefficient of variation (%)		6.35	5.04	5.23	9.38	3.92

* and ** show significance at the $p < 0.05$ and $p < 0.01$ levels, respectively.

Table 2. The simple effects of magnetic field on yield components of saffron

Treatment	Mean petal fresh weight (g)	Mean petal dry weight (g)	Flower fresh weight (g per flower)	Stigma dry weight (g per flower)	Mean corm weight (g)
Control	0.165 c	0.025 c	0.26 c	0.0044 b	4.42 c
Magnet in soil	0.189 a	0.062 a	0.32 a	0.0073 a	5.02 b
Pretreatment with magnetic field	0.204 b	0.056 b	0.34 b	0.0077 a	5.57 a

Similar letter in each column show non-significance.

It was shown that the effect of pre-sowing magnetic field treatment on melon led to increase in vigor index and dry weight of plant by 40.6 %, 28.8 %, and 12.9 %, respectively (Iqbal et al., 2016). With respect to the simple effects of TiO_2, the highest petal fresh weight of 0.193 g and stigma dry weight of 0.007 g were obtained from the application of 2000 ppm nano-TiO_2 (Table 3). Recently Feizi et al. (2020a) proved that the concentrations of titanium dioxide nanoparticles (100 and 300 ppm) significantly increased the lentil seedling length compared to the control. The seedling length in the 100 ppm nanoparticle treatment was 12.9 % higher than control and increased its length from 4.04 to 4.56 cm in lentil seedling. In another experiment on the sage (*Salvia officinalis* L.) they have illustrated that the concentration of 60 ppm of nanoparticles and non-nanoparticles of TiO_2 improved germination percentage and mean germination time compared to control (Feizi et al., 2013a).

Based on the data in Table 3, employing TiO_2 nanoparticles in 2000 ppm illustrated the highest petal fresh weight. This treatment enhanced petal fresh weight by 17 % comparing to control. But the greatest petal dry weight was seen in TiO_2 nanoparticles in 1000 ppm with 33.3 % increment to the control. The highest flower fresh weight was observed in the plants treated with 2000 ppm nano-TiO_2, showing insignificant differences with 1000 ppm nano-TiO_2. Furthermore, it was revealed application of TiO_2 nanoparticles in 2000 ppm increased stigma dry weight by 14.7 % compared to the control (Table 3). Using TiO_2 nanoparticles also improved corm weight. The highest corm weight was seen in applying TiO_2 nanoparticles in 2000 ppm. This treatment increased corm weight from 3.99 g in control to 6.05 g (Table 3). The highest corm weight of 6.05 g was produced by those exposed to the magnetic field for 48 hours (Table 2). Also, the impact of nano-TiO_2 showed that the highest corm weight was obtained from the plants treated with 2000 ppm nano-TiO_2 (Table 3).

It has been reported that some nanoparticles, e.g. TiO_2, have the potential for light absorption and can play a significant role in enhancing photosynthesis efficiency of plants (Zheng et al., 2007). Application of titanium as foliar application caused an increase in ascorbic acid. Titanium affects the biochemical activity of the plant and increases the activity of catalase, nitrate reductase and peroxidase enzymes (Maleki et al., 2020).

The interaction of the two studied factors revealed that the plants exposed to the magnetic field for 48 hours and treated with 2000 ppm nano-TiO_2 had the highest stigma dry weight of 8.5 mg, but they did not differ from those exposed to the magnetic field for 48 hours and treated with 1000 ppm nano-TiO_2 significantly (Fig. 3). In a study on the effect of magnetic field on germination and yield of Adjowan, Marghaeezadeh et al. (2012) stated that the magnetic field at the rate of 5000 Gs for 30 minutes improved the yield. Based on research conducted by Feizi et al. (2020b) on mustard (*Sinapis alba* L.), plants exposed to a magnetic field up of 50 mT achieved a significant statistically increase of the germination rate and radicle length, compared to the control. They confirmed that the application of a magnetic field of the intensity of 100 mT can have inhibitory effects on seed and its performance. Feizi et al. (2020a) reported that application of TiO_2 nanoparticles had the highest significant effect on seminal root mass of lentil. So that application of concentration of 100 and 300 ppm TiO_2 nanoparticles caused a significant increase of 34 % and 43 % respectively.

In the present study, the application of 2000 ppm nano-TiO_2 along with 48-hour exposure of corms to the magnetic field increased petal dry weight versus control, significantly (Fig. 4). This finding shows that the higher efficacy of nanoparticle in comparison to bulk particles on growth and flower production system in saffron. In the most cases, combination of use of magnetic field with nano-TiO_2 result in the greatest stigma dry weight of saffron (Fig. 3). Recently, Feizi and Javedanipour (2021) demonstrated that the highest dry weight of cannabis hypocotyl and seedling was obtained from the interaction between 10 ppm concentration of TiO_2 nanoparticles and 90 mT magnetic field intensity. The opinion is that raising the level of nanoparticles increases uptake and deposition of this element in the cell wall, strengthens the wall (cell wall thickness) and elongates the cell at the early stages of growth. Consequently, the plant cell size and flexibility and length reduces, and this increase in the cell wall thickness in the stem increases plant weight (Eskandarinasab et al., 2019). Seghatoleslami et al. (2015) indicated that treatments with magnetic field had higher yields compared to the control and nano silver treatments on adjowan (*Carum copticum*). They stated magnetic field may play an important role in plant cation uptake capacity as well as having a positive effect on immobile plant nutrient.

Table 3. The simple effects of TiO_2 on yield components of saffron

Treatment	Mean petal fresh weight (g)	Mean petal dry weight (g)	Flower fresh weight (g per flower)	Stigma dry weight (g per flower)	Mean corm weight (g)
Control	0.165 c	0.039 d	0.25 c	0.0061 b	3.99 d
1000 ppm nano-TiO_2	0.188 b	0.052 a	0.33 a	0.0067 ab	5.06 b
2000 ppm nano-TiO_2	0.193 a	0.05 b	0.334 a	0.007 a	6.05 a
1000 ppm bulk TiO_2	0.192 b	0.05 ab	0.31 b	0.0062 b	4.75 c
2000 ppm bulk TiO_2	0.192 b	0.047 c	0.32 ab	0.0064 b	5.17 b

Similar letter(s) in each column show non-significance.

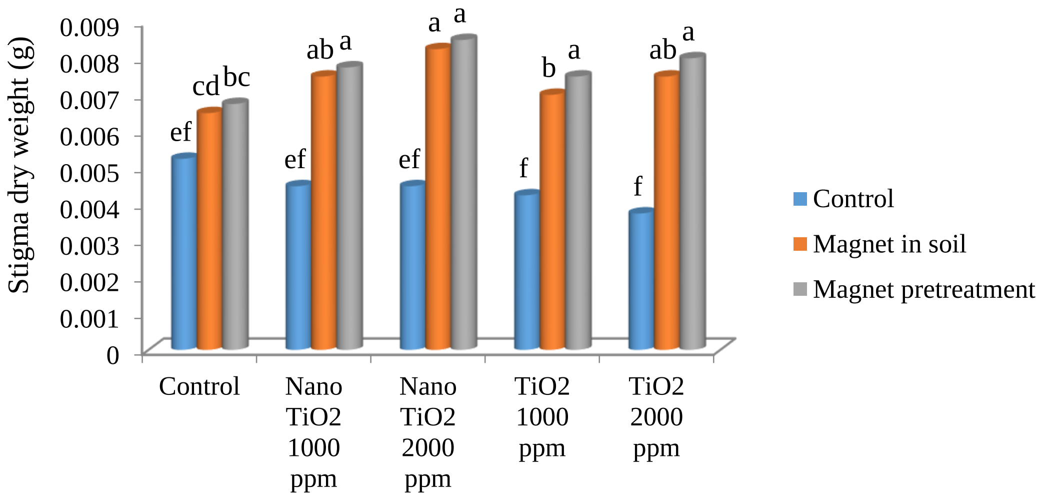

Fig. 3. The interaction effect of magnetic field and TiO_2 on stigma dry weight.

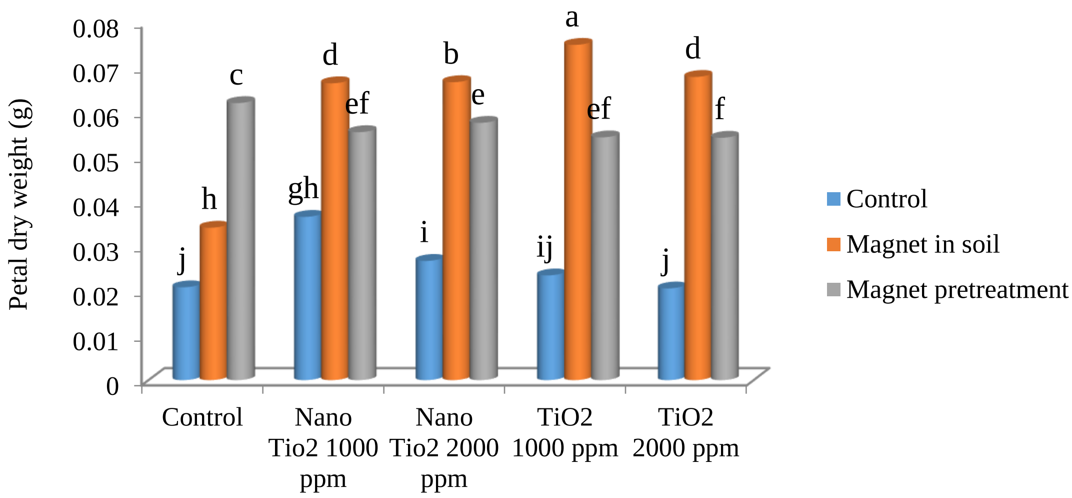

Fig. 4. The effect of magnetic field and TiO_2 on petal dry weight.

CONCLUSION

In this work, we checked the impact of magnetic field and two kinds of TiO_2 particles consisted bulk and nanosized on growth and flower production on saffron for first time. Furthermore, we assessed combination effect of them. Both of corm pretreatment with low intensity of magnetic field and applying magnet tape into the soil improved studied traits of saffron significantly. On the other hand, application of TiO_2 nanoparticles increased saffron traits compared to the bulk TiO_2 particles and control. In addition, it was seen that combination employment of magnetic field and nanoparticle have an interesting effect on saffron growth. Magnetic field exposure, probably through increasing nutrients uptake efficiency and other positive effects, could be used to saffron production system. According to the results, it is possible to use magnetic fields and TiO_2 nanoparticles to stimulate the growth of corms and flower of saffron. Hence, the magnetic field can be used as a non-invasive and non-destructive growth promoter of the plant and nanoparticles can be used to increase corm permeability for medicinal saffron plant. Plant exposed to the magnetic field for 48 hours and treated with 2000 ppm nano-TiO_2 had the highest recommended treatment. However, more extensive exploration trials are needed concerning plant growth when exposed to numerous nano particles or a magnetic field.

Conflict of interest

The authors declare that there is no conflict of interest.

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