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TITANIUM DIOXIDE NANOPARTICLES AND MAGNETIC FIELD STIMULATE SEED GERMINATION AND SEEDLING GROWTH OF *Cannabis sativa* L.

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ABSTRACT

In order to evaluate the effect of magnetic field intensities and concentrations of TiO_2 nanoparticles on seed germination and seedling growth of *Cannabis sativa* L., this study was conducted. The experimental treatments included magnetopriming at intensities of 0, 30, 60, and 90 mili Tesla (mT), and the second factor included nanopriming at different concentrations of TiO_2 nanoparticles, including 0, 10, 50, and 100 ppm. The results showed that sowing cannabis seeds by the combined use of magnetic fields and TiO_2 nanoparticles had a significant effect on most of the studied traits. The effect of magnetic field levels showed that the highest dry weight of radicle, hypocotyl and seedling, the highest percentage of germination, germination rate, germination index and germination vigor index were related to the magnetic field at the intensity of 90 mT (5.3, 7, 6.8, 54.6, 110.9, 55.4, and 31.5% increase compared to the control, respectively). The results showed that the length and dry weight of radicle, hypocotyl and seedling were affected at the concentration of 10 ppm of TiO_2 nanoparticles (2.84, 0.29, and 1.63, 0.62, 20.55 and 2.37%, respectively increase compared to the control). According to the study results, the decreasing trend of hypocotyl and seedling length was observed with increasing the concentration of nanoparticles. It is suggested to use the magnetic field as a non-invasive and non-destructive growth promoter of the plant and low concentrations of TiO_2 nanoparticles as a useful tool to increase seed permeability through improving morphological and physiological properties for medicinal-industrial plant cannabis.

Keywords: germination index, magnetopriming, nanopriming, seedling vigor.

INTRODUCTION

Today, efforts of modern agriculture seek to find efficient yet harmless technology based on seed priming to increase seed strength and crop yield (Mohammadi et al., 2016). Therefore, agricultural scientists have studied eco-friendly methods affecting the plant production, such as ionization, laser and ultraviolet radiation, magnetic and electric fields etc. (Faqenabi et al., 2009).

Priming using magnetic and electromagnetic fields can meet the needs of organic farming by increasing production efficiency without causing environmental pollution, and since chemical treatments are a concern for the environment, it seems that physical treatments before planting are safer (Jamil et al., 2012). Magnetic and electromagnetic treatments, as a non-invasive and non-destructive method in agriculture, improve seed germination, and increase crop yield, and the magnetic field is one of the factors affecting cell performance (Sunita et al., 2017). The use of magnetic fields, like other environmental stresses such as salinity, drought, light, UV and cold, creates a stressful situation for growth, quality and yield (Najafi et al., 2013).

There are various reports on the role of magnetic fields in growth of various plants. Hosseini et al. (2018) studied the seeds of *Guizotia abyssinica*, which were passed through a magnetic field, and found that the seeds were swollen, resulting in an increase in auxin content, respiration, more uniform germination and production of stress-tolerant plants. In a study on seeds of *Vicia faba* L. treated by a magnetic field, it was shown that significantly increased the amount of 3- indole acetic acid (IAA) and gibberellic acid in germinating seeds in the upper parts and the radicle of the plant (Podleśna et al., 2019).

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In another studies it has been shown that waves at low intensities have stimulatory effects on living cells but at very high intensities they have destructive effects (Barnothy, 2013; Zamiran et al., 2013).

Currently, nanotechnology is used in various fields such as environmental protection, building engineering, medicine, agriculture, food and cosmetics industries (Samat, 2016). In agriculture, they are used for the production of fertilizers and pesticides, which can have a significant effect on soil fertility, plant growth and crop yield (Lim et al., 2015). However, despite the increasing production of nanoparticles, their effect on plant growth is very complex because there are different reports on the effects of nanoparticles on different plants. In the meantime, the improving role of some of them, such as titanium nanoparticles, has been considered by plant physiologists due to their prominent features in most studies (Gao et al., 2013).

Various researchers have studied the effects of TiO_2 nanoparticles on plant germination and growth. Titanium as a beneficial element increases and promotes growth (Pais, 1983), increases plant yield by 10 to 20% (Feizi et al., 2013), and biomass and growth of various plant species (Carvajal and Alcaraz, 1998) and production of free radicals in germinated seeds (Agheli et al., 2016).

Feizi et al. (2020) found that combined use of the magnetic field and TiO_2 nanoparticles has led to an increase in growth indices and germination parameters of Okra (*Abelmoschus esculentus*) plants. The inconsistent results obtained from the use of TiO_2 nanoparticles can indicate the positive and negative impacts of this matter (Khan et al., 2019). The same author reported that TiO_2 nanoparticles inhibited chlorophyll and carotenoids at optimal temperatures.

Qi et al. (2013) believed that if titanium nanoparticles were used at an appropriate concentration, not only it did not have a toxic effect, but also due to its photocatalytic properties, it induced positive effects such as improving photosynthetic yield and increasing gas exchange in leaves of tomato.

Cannabis (*Cannabis sativa* L.) is a member of Cannabaceae family that due to its valuable agricultural properties, such as easy cultivation and biodiversity has been considered as a product with high yield by the scientific community around the world (Chandra et al., 2017). Cannabis is a medicinal-industrial plant native to Central Asia and has been used by humans as a source of food, fuel, fiber, medicine and drug for thousands of years (Wills, 2003; Russo, 2004).

Since production of nanoparticles and their application in various aspects of plant and agricultural sciences is increasing and due to positive and negative impacts of biochemical priming of seeds using nanoparticles such as TiO_2 and the application of various types of physical priming, including magnetopriming ecological importance and lack of negative impact on the environment, therefore, the present study was designed and conducted to determine the best magnetic field intensity and application of TiO_2 nanoparticles to stimulate germination and growth of cannabis seedlings.

MATERIAL AND METHODS

This study was conducted in the research laboratory of the Faculty of Agriculture, Torbat Heydariyeh University, Iran. The experiment was as factorial layout in a randomized completely block design with three replications. The experimental treatments included sowing the seeds in a magnetic field exposure at intensities of 0, 30, 60, and 90 mT for 30 minutes, and the second factor included seed treatment at different concentrations of TiO_2 nanoparticles, including 0, 10, 50 and 100 mg/l for 2 hours. The required cannabis seeds were provided from Pakan Bazr, Isfahan Seed Production Company. The seeds were disinfected with 5% sodium hypochlorite solution for 5 minutes and then washed three times with distilled water.

The TiO_2 nanoparticle powder was AEROXIDE® TiO_2 P25 prepared from Evonik Degussa GmbH Company of Germany. The purity of nanoparticle powder was 99.8% and the mean particle size was 21 nm

(Feizi et al., 2012). In order to obtain properly dispersed and stable TiO_2 suspensions of each concentration, an ultra-sonication treatment was applied for 15 min. After preparation, the nanoparticles were poured in different concentrations at separate Erlenmeyer flasks and the seeds were soaked in each concentration for 2 hours.

The seeds were placed in a thin plastic tube between the poles of the magnet with the required magnetic field intensity for 30 minutes. 4 CC of distilled water was added to Petri dishes, and then transferred to a dark growth room with a temperature of 23 ± 1ºC and relative humidity of 75% (ISTA, 2009). During the experiment, the seeds were inspected daily for germination. The seedlings were counted in 24-hour periods. The criterion for seed germination was the emergence of two-millimeter radicle length (Miller and Chapman, 1978). Germination lasted for 7 days, and at the end of germination, 10 seedlings were randomly selected from each Petri and traits was measured. Some traits were calculated using the following equations:

Eq. 1: Germination Percentage (GP) (Ellis and Roberts, 1981):

$$GP = \frac{\sum n_i}{N} \times 100$$

n_i is the number of seeds germinated and N is the total number of seeds per treatment.

Eq. 2: Germination Rate (GR) (Maguire, 1962):

$$GR = \sum(\frac{n_1}{t_1} + \frac{n_2}{t_2} + \frac{n_i}{t_i})$$

n_i is the number of germinated seeds per day and t_i is the number of germination days of given seeds.

Eq. 3: Razeghi Yadak and Tavakkol Afshari (2011):

$$GI = \frac{7n_1+6n_2+5n_3+4n_4+3n_5+2n_6+1n_7}{7 \times N}$$

n is the number of germinated seeds per day and N is the total number of seeds.

Eq. 4: Seedling Vigor Index (SI) (Abdul-baki and Anderson, 1973):

$$SI = \frac{GP \times LSh}{100}$$

GP is germination percentage and LSh is mean seedling length (cm).

Finally, data analysis of variance was performed by software SAS version 9.2 and the calculation of mean comparison was performed using Duncan's multiple range test at the 5% probability level.

RESULTS AND DISCUSSION

Germination percentage (GP)

Results showed that the highest percentage of germination occurred in 90 mT treatment and the lowest percentage of germination occurred in 60 mT treatment (72.667 and 45.667%, respectively). Using 90 mT treatment showed a significant difference compared to other treatments (Table 1). Hydration and swelling of seeds are associated with lateral elongation of cell membranes, and this may mainly change electrostatic interactions of peripheral proteins with the polar groups of membrane lipids and facilitate their separation. The elongation of the membrane can depend on the amount of absorbed water, in which case the release of proteins undoubtedly determines the germination process. The stimuli produced by the magnetic field may improves this process and significantly improve germination (Mohammadi Milasi, 2010). It has also been suggested that seed metabolism in the face of an active magnetic field changes pH and protein is released from the seed more rapidly, which increases germination (Huseynova et al., 2014).

According to the results of Table 3, the treatment of 50 ppm TiO_2 nanoparticles determined the largest percentage of germination, which did not differ from the control treatment, while increasing the concentration of nanoparticles, from 50 to 100 ppm, significant reduced the seeds germination. As the concentration of nanoparticles increases, their uptake by the seed coat increases and toxicity is created in the seed, which in turn reduces germination by reducing water uptake (Eskandarinasab et al., 2019) or due to changes in the metabolic activity of cells (Khan et al., 2019). On the contrary the results of Sayaedena et al. (2019) showed that in the treatment of 500 mg of titanium nanoparticles, about 65% improvement in germination percentage compared to control seeds occurred.

The results of interaction between magnetic field and nanoparticle levels showed that the concentration of 50 ppm of nanoparticles and 90 mT magnetic field treatment had the highest percentage of germination and the lowest percentage was for 60 mT magnetic field at the concentration of 10 ppm of TiO_2 nanoparticles, with a difference of 58.06%, showing a significant reduction compared to the highest percentage of germination. Application of 90 mT intensity magnetic field accounted for the highest percentage of germination. In the 100 ppm of TiO_2 nanoparticles, the lowest percentage of germination was observed in the control treatment, which in other magnetic field treatments, this result was observed in the treatment of 60 ppm of TiO_2 nanoparticles. In general, at all concentrations of TiO_2 nanoparticles, a decreasing trend was observed at the intensity of 60 mT and an increasing trend was observed at 90 mT treatment (Table 5).

Germination rate (GR)

The results showed that the highest germination rate (8.9 seeds per day) occurred at 90 mT intensity magnetic field and the lowest germination rate (3.36 seeds per day) occurred at 30 mT intensity. The germination rate at the highest intensity of the magnetic field increased by 111% compared to the control (Table 1). The opinion is that the magnetic field reduces surface tension and water viscosity (Pang and Deng, 2008) and reduces the latent heat of evaporation, which finally leads to rapid evaporation of water. The changes in these indices lead to faster water infiltration into the seed, which causes the seed to germinate faster and more efficiently (Galland and Pazur, 2005).

The concentrations of 50 and 10 ppm of TiO_2 nanoparticles had the highest and lowest germination rates, respectively. The germination rate reduced and this means that with increasing the concentration, the effect of toxicity on seedlings was created which has reduced germination rate compared to the control (Table 2). The increase in seed germination rate of nanoparticle-treated seeds may be due to the increase in cell division rate in seed radicle meristem cells should be treated with nanoparticles from the beginning (Ghasemi Sarab Badieh et al., 2017). The positive effects of TiO_2 nanoparticles to increase germination rate of *Salvia officinalis* (Hatami et al., 2014), onions (Laware and Raskar, 2014) and fennel (Feizi et al., 2013) seeds confirmed this.

In the absence of nanoparticle priming, as the magnetic field intensity increased, germination rate reduced significantly compared to the control and the highest germination rate was obtained from non-application of a magnetic field. At the concentration of 100 ppm of TiO_2 nanoparticles, a decreasing trend was observed with increasing the magnetic field intensity. In other concentrations of nanopriming, the highest germination rate was observed at 90 mT, while at 10 and 50 ppm concentrations the lowest germination rate was observed at 60 mT, and for the interaction at the concentration of 100 ppm for non-application of nanoparticles was observed at 0 and 30 mT, respectively. The highest germination rate was observed at 50 ppm and intensity of 90 mT, which was significantly different from the other treatments, while the other treatments were not significantly different (Table 5). Sayaedena et al. (2019) in a study on *Sorbus luristanica* reported that germination rate increased in 500 and 150 ppm of TiO_2 nanoparticles treatments were 73 and 66%, respectively compared to the control.

Table 1. Effect of magnetic field levels on germination parameters and seedling growth of cannabis

Magnetic field (mT)	Germination rate (seed/day)	Germination (%)	Root length (cm)	Shoot length (cm)	Seedling length (cm)
70	4.2233 b	47.00 b	2.6383 a	2.9300 a	5.5683 a
30	3.3667 b	47.00 b	2.2433 c	2.6483 b	4.8917 b
60	3.4767 b	45.667 b	2.3908 bc	2.3250 c	4.7158 b
90	8.9092 a	72.667 a	2.5283 ab	2.2941 c	4.8225 b

**Use of different letters in each column indicates significant difference based on Duncan's Multiple Range Test at 5% level*

Germination index (GI)

The highest germination index belonged to 90 mT, which increased by 55.4% compared to other treatments (Table 2). In the case of non-application of nanoparticles and at the concentration of 10 ppm, the lowest germination index was obtained from the treatment of 60 mT. The highest germination index was obtained from application all nanoparticle concentrations and 90 mT magnetic field (Table 5). The study results of Abdollahi et al. (2020) on two varieties (cultivars) of almonds showed that low-intensity static magnetic fields had no effect on germination properties of Iranian almonds, including germination index.

Seed vigor index (SI)

In the study of the mean comparisons, due to the placement of seeds in the magnetic field of 90 mT, the highest germination vigor index was obtained, which showed an increase of 31.45% compared to the treatment of non-placement in the magnetic field (Table 2). It seems that the increase in germination vigor index due to magnetic field priming has increased the activity of hydrolyzing enzymes such as alpha-amylase, dehydrogenase and protease, which leads to increased seed germination and improved seed vigor (Vashisth and Nagarajan, 2010).

Length of radicle, hypocotyl and seedling

The results illustrated that increasing magnetic field intensity reduced length of the hypocotyl. The lowest length of radicle, hypocotyl and seedlings was observed in treatments of 90, 30, and 60 mT, by 2.2941, 2.2433 and 5.5683 cm, respectively (Table 3). The low intensity magnetic fields may have a greater stimulating effect than high intensity magnetic fields and/or even high intensity magnetic fields have an inhibiting effect on seed germination, which can be due to the positive or negative properties of para-magnetism of most atoms in plant cells and pigments such as chloroplasts (Aladjadjiyan, 2010).

In the case of applying 10 ppm of TiO_2 nanoparticles, the highest length of radicle, hypocotyl and seedlings was obtained. The decreasing trend in hypocotyl and seedlings length with increasing nanoparticle concentration was seen. The highest radicle length was obtained from the concentration of 50 ppm of TiO_2 nanoparticles and non-application of magnetic field and the highest hypocotyl length was obtained from the concentration of 10 ppm and non-application of magnetic field (3.03 and 3.42 cm, respectively). In non-priming treatment with nanoparticles, the highest length of radicle and hypocotyl was obtained from non-application of magnetic field treatment (2.79 and 3.31 cm, respectively). At the concentration of 10 ppm TiO_2 nanoparticles, the highest length of radicle and hypocotyl was observed in 90 mT treatments and no magnetic field. The highest seedling length was obtained from non-priming of TiO_2 nanoparticles and magnetic field treatments and the lowest seedling length was obtained from the concentration of 50 ppm TiO_2 and 90 mT (6.11 and 3.39 cm, respectively) (Table 5).

Table 2. Effect of magnetic field levels on germination parameters and seedling growth of cannabis

Magnetic field (mT)	Vigor index	Germination index	Seedling dry weight (g)	Root dry weight (g)	Shoot dry weight (g)
30	2.6358 b	0.0587 b	0.1993 b	0.0208 ab	0.1784 b
30	2.2756 bc	0.0587 b	0.2069 ab	0.0190 b	0.1878 ab
60	2.1296 c	0.0587 b	0.1978 b	0.0198 b	0.1780 b
90	3.4650 a	0.0912 a	0.2128 a	0.0219 a	0.1909 a

**Use of different letters in each column indicates significant difference based on Duncan's Multiple Range Test at 5% level*

Table 3. Effect of TiO_2 nanoparticle concentrations on seed and seedling growth parameters of cannabis

TiO_2 nanoparticles (ppm)	Germination rate (seed/day)	Germination (%)	Root length (cm)	Shoot length (cm)	Seedling length (cm)
0	5.1308 b	56.333 ab	2.5375 a	2.7808 a	5.3183 a
10	3.4742 c	47.667 c	2.5450 a	2.8600 a	5.4050 a
50	6.7325 a	57.333 a	2.3508 a	2.3191 b	4.6700 b
100	4.6383 bc	51.000 bc	2.3675 a	2.2375 b	4.6050 b

**Use of different letters in each column indicates significant difference based on Duncan's Multiple Range Test at 5% level*

Dry weight of radicle, hypocotyl and seedling

Application of 90 mT magnetic field had the most significant increase in dry weight of radicle, hypocotyl and seedling (Table 2). Compared to the control, nanoparticles at the lowest concentration (10 ppm) had a clear effect on dry weight of the specified traits. However, at high concentrations (50 and 100 ppm), it caused a significant reduction in dry weight of hypocotyl and seedlings (Table 4). Khan et al. (2019) found that dry weight of the seedling had a small increase at the lowest concentration and reduced with increasing concentration (the highest reduction was obtained from the concentration of 200 μg/ml).

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 intensity (0.2254 and 0.2490 g, respectively). The highest dry weight of radicle was obtained from the treatment of 50 ppm TiO_2 nanoparticles under non-application of magnetic field conditions (0.0251 g). In the case of non-application of nanoparticles, the highest dry weight of hypocotyl and seedlings was measured at 60 mT (12.89 and 12.39% increase, respectively, compared to the control) and the highest dry weight of radicle was observed at 90 mT magnetic field. At the concentration of 10 ppm of TiO_2 nanoparticles, the highest dry weight was obtained at 90 mT. At the concentration of 50 ppm, the highest dry weight of hypocotyl and seedling was obtained from 30 mT (7.4 and 3.36% increase, respectively, compared to the control). At the concentration of 100 ppm TiO_2 nanoparticles, the highest dry weight of hypocotyl and seedling was obtained from the treatment of 30 mT and dry weight of radicle was obtained from the treatment of 90 mT (Table 5). In a study on the effects of TiO_2 nanoparticles and magnetic field on *Abelmoschus esculentus*, it was found that the combined use of 30 mT intensity magnetic field and 50 ppm TiO_2 nanoparticles significantly increased the length of radicle compared to the control (Feizi et al., 2020).

The opinion is that increasing the level of nanoparticles increases uptake and deposition of this element in the cell wall, strengthens the wall (cell wall thickness) and prolongs the cell at the early stages of growth. As a result, the plant cell size and flexibility and length reduces (Liang et al., 2007), and this increase in the cell wall thickness in the stem increases plant weight (Eskandarinasab et al., 2019).

Table 4. Effect of TiO_2 nanoparticle concentrations on seedling growth parameters of cannabis

TiO_2 nanoparticles (ppm)	Vigor index	Germination index	Seedling dry weight (g)	Root dry weight (g)	Shoot dry weight (g)
0	3.0111 a	0.0708 a	0.2106 a	0.0180 b	0.1926 a
10	2.5547 b	0.0595 b	0.2156 a	0.0217 a	0.1938 a
50	2.5577 b	0.0716 a	0.1945 b	0.0205 a	0.1739 b
100	2.3826 b	0.0637 b	0.1962 b	0.0213 a	0.1748 b

**Use of different letters in each column indicates significant difference based on Duncan's Multiple Range Test at 5% level*

Table 5. Interaction effect of TiO_2 nanoparticle and magnetic field on seedling growth parameters of cannabis

TiO_2 nanoparticle (ppm)	Magnetic field (mT)	Germination index	Germination rate (seed/day)	Germination (%)	Seedling length (cm)	Root length (cm)	Shoot length (cm)	Seedling dry weight (g)	Root dry weight (g)	Shoot dry weight (g)
0	30	0.0666 c*	5.920 cd	53.333 c	6.1067 a	2.7967 ab	3.3100 ab	0.1960 bcd	0.0168 fg	0.1791 bcde
	30	0.0666 c	4.547 cde	53.333 c	4.9233 def	2.3800 bcd	2.5433 cdef	0.2089 bcd	0.0165 g	0.1923 bcd
	60	0.0650 cd	5.083 cde	52.000 c	4.8200 def	2.5267 bc	2.2933 ef	0.2203 b	0.0180 efg	0.2022 b
	90	0.0850 b	4.973 cde	66.667 b	5.4233 bcd	2.4467 bc	2.9767 bc	0.2174 b	0.0208 bcdef	0.1966 bc
10	30	0.0500 de	3.620 cde	40.00 cd	5.9067 ab	2.4900 bc	3.4167 a	0.2008 bcd	0.0194 cdefg	0.1813 bcde
	30	0.0533 cde	2.162 e	42.667 cd	5.2067 cde	2.5900 abc	2.9433 bc	0.2108 bc	0.0226 abc	0.1882 bcd
	60	0.0433 e	2.003 e	34.667 d	5.3567 bcd	2.2633 cde	2.7667 cd	0.2017 bcd	0.0214 abcde	0.1803 bcde
	90	0.0916 ab	6.113 c	73.333 ab	5.1500 cdef	2.8367 ab	2.3133 ef	0.2490 a	0.0236 ab	0.2254 a
50	30	0.0650 cd	4.833 cde	52.000 c	5.6600 abc	3.0300 a	2.6300 cde	0.1993 bcd	0.0251 a	0.1742 cde
	30	0.0533 cde	3.973 cde	52.000 c	5.5733 abc	2.6033 abc	2.9700 bc	0.2060 bcd	0.0189 cdefg	0.1871 bcde
	60	0.0650 cd	3.633 cde	42.667 cd	4.0500 g	1.9533 def	2.0967 f	0.1862 cd	0.0185 defg	0.1677 de
	90	0.1033 a	14.490 a	82.667 a	3.3967 h	1.8167 ef	1.5800 g	0.1864 cd	0.0195 cdefg	0.1669 de
100	30	0.0533 cde	2.520 de	42.667 cd	4.6000 f	2.2367 cde	2.3633 def	0.2013 bcd	0.0221 abcd	0.1792 bcde
	30	0.0616 cd	2.787 cde	49.333 c	3.8600 gh	1.7267 f	2.1367 f	0.2020 bcd	0.01823 defg	0.1838 bcde
	60	0.0550 cde	3.187 cde	44.00 cd	4.6367 ef	2.4933 bc	2.1433 f	0.1829 d	0.0212 abcde	0.1617 e
	90	0.0850 b	10.060 b	68.000 b	5.3200 bcd	3.0133 a	2.3067 ef	0.1986 bcd	0.0238 ab	0.1748 cde

**Use of different letters in each column indicates significant difference based on Duncan's Multiple Range Test at 5% level*

CONCLUSIONS

According to the results, it is possible to use magnetic fields and TiO_2 nanoparticles to stimulate the initial growth of seedlings of cannabis seeds. Using 90 mT intensity magnetic field and 50 ppm TiO_2 nanoparticle treatment showed a superiority in germination percentage, germination rate and germination index compared to other treatments.

The opinion is that the increase in the physiological activity due to higher water uptake by primed seeds with the magnetic field and TiO_2 nanoparticles is responsible for increasing the mentioned traits in this experiment. Given that 90 mT magnetic field treatment and concentrations of 50 and 10 ppm of TiO_2 nanoparticles compared to other levels gained acceptable success in terms of germination, establishment and improvement of seedling growth traits, and on the other hand, due to the medium and low concentrations of nanoparticles, they are also economically effective, so they can be recommended as a successful treatment. Therefore, 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 seed permeability for medicinal-industrial cannabis. Of course, in order to achieve more accurate results, it is recommended to apply TiO_2 nanoparticles and magnetopriming to this plant at different growth stages and levels and in both laboratory and field environments so that a more accurate decision can be made.

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