J Multidisciplinary Scientific Journal

MDPI

Brief Report

Two-Hour Magneto-Priming with Static Magnetic Fields Ranging from 65 ± 3 to 505 ± 8 mT Does Not Improve the Germination Percentage of Industrial Hemp Seed at a Sub-Optimal Germination Temperature

Kathrin Spendier

UCCS Center of the BioFrontiers Institute and Department of Physics and Energy Science, University of Colorado at Colorado Springs, Colorado Springs, CO 80918, USA; kspendie@uccs.edu; Tel.: +1-719-255-3197

Received: 5 October 2018; Accepted: 5 December 2018; Published: 7 December 2018

check for updates

Abstract: Industrial hemp is a non-psychoactive variety of *Cannabis sativa* L., i.e., it contains less than 0.3% tetrahydrocannabinols (THC). This crop is one of historical importance in the U.S. as manufacturers seek industrial hemp as a renewable and sustainable resource for a wide variety of consumer and industrial products. To help farmers succeed, agronomic research on industrial hemp is needed. In this trial, investigations were performed to determine whether magneto-priming, a form of seed priming that involves magnetic fields, effects the germination percentage of industrial hemp seed. Beneficial effects of magnetic fields on seedling growths and germination have been reported for many different plant species. Dry industrial hemp seed was exposed to static magnetic fields ranging from 65 ± 3 to 505 ± 8 mT for 2 h prior to seed germination. Germination was performed at 13.6 ± 0.7 °C, a temperature that is representative of the germination temperatures of industrial hemp in the U.S. state of Colorado. Magneto-priming of seed had no statistically significant effect on seed germination percentage.

Keywords: hemp; *Cannabis sativa* L.; magneto-priming; magnetic fields; germination

1. Introduction

Industrial hemp is a sturdy crop championed by growers as multifaceted and sustainable, as it requires less water than corn. Industrial hemp is defined as *Cannabis sativa* L. plants with less than 0.3 percent tetrahydrocannabinols (THC) concentration. Colorado-grown industrial hemp makes up more than half of U.S. domestic production. In 2017, Colorado farms harvested 9000 acres of hemp, compared with just 200 acres in 2014 [1].

Industrial hemp growth is influenced by several factors, with soil and air temperatures being among the most important. In Colorado, industrial hemp is typically sown between April and June and harvested in August or September. Fifty of the 64 Colorado counties had registered industrial hemp producers in December 2017, including Broomfield.

The average monthly soil temperature in Broomfield at a depth of 5 inches is 9.9 °C (49.9 °F) in April, when hemp is typically planted, and 21 °C (69.8 °F) in June, when hemp is typically harvested [2]. At soil temperatures above 6 to 8 °C, industrial hemp seed germinates within 24 to 48 h, and emerges in 5 to 7 days with good moisture and warm temperature. Previous research suggests that the optimal temperature for the germination of fire hemp, which belongs to the genus *Cannabis sativa* L., is 25 °C with a percentage of germination of 92.4% at the 4th day of germination [3]. This percentage is significantly higher than the 64.3% at 10 °C [3].

Seed is one of the most important factors influencing crop yield. According to data obtained from the Hemp Feasibility Study by the National Agricultural Marketing Council [4], the cost of seed stock can constitute up to 20% of total production costs. The objective of the presented study was to test whether magneto-priming, a form of seed priming that involves magnetic fields, can increase industrial hemp seed germination percentage above 65% at germination temperatures close to 10 °C. Previous investigations showed that the exposure of soybean and corn seeds for 2 h to low frequency (16 Hz) alternating magnetic fields of 5 mT promoted seed germination at 10 °C [5]. Increased seed germination percentage may help decrease production costs for industrial hemp farmers in Colorado.

Seed priming to increase plant production is a commercially successful practice and includes chemical and physical methods. Among the physical methods available is a method called magneto-priming. Magneto-priming is based on the application of magnetic fields and is an eco-friendly, low cost, non-invasive technique with proven beneficial effects on seed germination, vigor, and crop yield [6]. There are multiple reviews that describe the effects of magnetic fields on plants by considering plant responses to magnetic fields with values higher than the earth's geomagnetic field, ranging from 25 to 65 μT [7,8]. Most of the attention has been focused on seed germination of important crops like wheat, rice, and legumes. Static magnetic fields ranging from 1.5 μT to 250 mT applied to different types of seeds were found to increase the rate of seed germination at room temperature (see Table 1). Increased seed germination due to the pre-exposure of seed to magnetic fields was also found in okra (99 mT), chickpea (1–250 mT), Japanese parsley (0.5 or 0.75 mT), common bean (2 or 7 mT), pea (60 mT, 120 mT, or 180 mT), common wheat (4 mT or 7 mT), mung bean (87 to 226 mT), and corn (100–250 mT) [7].

Table 1. Increase in seed germination (SG) percentage due to static magnetic field pretreatment of seed and temperature (*T*).

Species	Static Magnetic Field Treatment	Increase in SG	*T* in °C	Source
Onion	1.5 μT for 12 h	36.6%	NR	[9]
Rice	1.5 μT for 12 h	16.5%	NR	[9]
Rice	150–250 mT chronically	12–18%	20 ± 4 °C	[10]
Salvia	125 or 250 mT for 1, 10, 20 min, 1, 24 h, chronic	30%	20 °C	[11]
Sunflower	50–250 mT for 1–4 h	5–11%	RT	[12]
Corn	150 mT for 10 min	17%	NR	[13]

Note: NR stands for Not Reported and RT stands for Room Temperature.

The effects of magnetic fields on industrial hemp seed germination is unknown. The results of this study showed that there was no effect on industrial hemp seed germination percentage and mean germination time when dry seed was exposed to static magnetic fields ranging from 65 ± 3 to 505 ± 8 mT for 2 h prior to seed germination at 13.6 ± 0.7 °C.

2. Materials and Methods

2.1. Plant Material

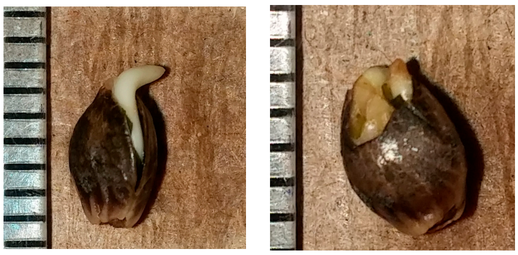
Industrial hemp seed of non-specified variety from the Colorado 2015 crop year was obtained from the Colorado Department of Agriculture (CDA). Seed was stored under cool and dry conditions. Seeds were visually checked for quality. Only seeds of uniform size and shape without visible defects and malformation were selected for this study.

2.2. Magnetic Field Generation and Magnetic Treatment

A 7.62 cm × 7.62 cm disc neodymium magnet (grade N48) was used to apply static magnetic fields. Field strength was controlled by placing dry seed at 2 ± 1 mm, 22 ± 1 mm, 42 ± 1 mm, or 62 ± 1 mm above the surface of the permanent magnet. The magnetic field at each position was measured using a F.W. Bell Gaussmeter Model 9200. The measured magnetic field amplitudes were 505 ± 8 mT, 241 ± 18 mT, 119 ± 8 mT, and 65 ± 3 mT, respectively.

2.3. Germination Tests

Three replications with 40 visibly firm, mature, healthy seeds were exposed to a 65 ± 3 mT, 119 ± 8 mT, 241 ± 18 mT, 505 ± 8 mT, or no static magnetic field (0 mT) for 2 h, immediately prior to starting the germination tests. During magnetic field exposure, each replication was kept in a Petri dish (6.0 cm in inner diameter). The magnetic field amplitudes were selected based on previous research on other plant seed (see Table 1). After the treatment of dry seed with magnetic fields, seeds of each replication were kept in their Petri dish and placed between two layers of moist, circular germination paper (Qualitative Filter Paper, Grade 615, VW). Approximately 0.11 mL of distilled water was used per square centimeter of dry media (or approximately 3.1 mL of water per Petri dish). Each Petri dish was covered by a sheet of plastic wrap to reduce surface evaporation. Seeds were placed in a mini fridge at 13.6 ± 0.7 °C. This temperature is close to the germination temperatures of industrial hemp in Colorado at planting time. Additionally, a control was performed to test the viability of the seed. For this viability test, three replications with 40 seeds were not exposed to a static magnetic field and placed in an incubator at 26 ± 0.1 °C. Germination at this temperature should allow for almost full germination (i.e., a germination percentage greater than 90%). After 45 h and then daily afterwards, the seed germination percentage was calculated. Germination percentage, $G(\%)$ (see Equation (1)), is the percentage of seed in which the germination process reached its conclusion under the experimental conditions, resulting in the protrusion (or emergence) of a growing embryo [14]. Only normal seedlings with well-developed radicles or white sprouts (Figure 1a) were counted as germinated. Abnormal seedlings with stunted radicles (Figure 1b) were not counted.



(**a**) (**b**)

Figure 1. Representative examples of (**a**) a normal industrial hemp germinated seed with a well-developed radicle or white sprout and (**b**) an abnormal germinated seed with a stunted radicle. The distance between scale bar ticks represents 1.0 mm.

Germination percentage, $G(\%)$,

$$G(\%) = \left(\frac{\sum_{i=1}^{k} n_i}{N}\right)100, \tag{1}$$

was calculated following Labouriau [14]. Here, n_i is the number of germinated normal seedlings in the ith time (not the accumulated number, but the number corresponding to the ith observation), N = 40 is the total number of seeds in each experimental unit, and k is the last time of observation. The germination count of incubated seeds was taken until no more seeds appeared to germinate.

3. Results

Dry industrial hemp seed was exposed to a 65 ± 3 mT, 119 ± 8 mT, 241 ± 18 mT, 505 ± 8 mT, or no static magnetic field (0 mT) for 2 h prior to germination. After exposure to a specific static magnetic field at room temperature, the germination process was started, and seed was germinated at 13.6 ± 0.7 °C. First seeds germinated within 48 h. A germination count was taken until 211 h or 8.8 days, when no more seeds appeared to germinate. Figure 2 shows the effect of static magnetic fields on the germination percentage calculated from Equation (1).

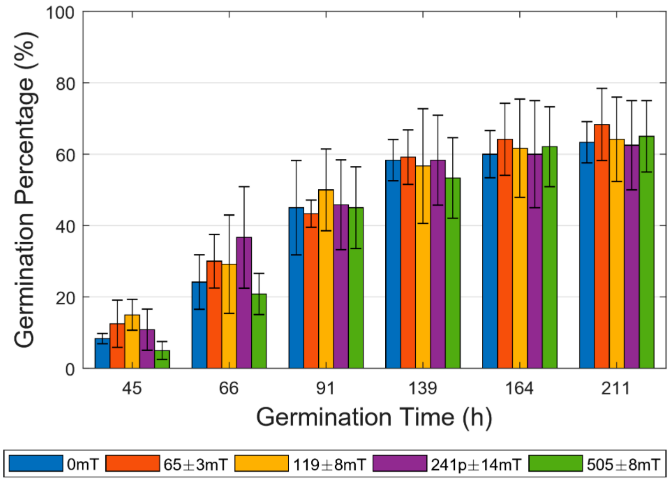


Figure 2. Effect of 0 mT (blue), 60 ± 3 mT (orange), 119 ± 8 mT (yellow), 241 ± 18 mT (violet), and 505 ± 8 mT (green) static magnetic field strength on germination percentage of industrial hemp seed as a function of germination time. Error bars represent the standard deviation of three experiments.

A total of 24 two-sample *t*-tests were performed to determine if the population means for 0 mT at each time point were different from the population means of any of the four magnetic field treatments. The results indicated that the null hypothesis ("means are equal") could not be rejected at the 5% significance level. One-way ANOVA was also performed on seed germination percentage to compare the means of 0 mT and the four magnetic field treatments within each time point. *p*-values obtained from one-way ANOVA also indicated that the differences between treatment means were not statistically significant at $p = 0.05$. Therefore, the performed magneto-priming of seed had no significant effect on seed germination percentage. The average germination percentage of magnetically treated seed was 65 ± 10% at 13.6 ± 0.7 °C after 211 h or 8.8 days.

The average germination percentage obtained from the viability test of magnetically untreated seed at 26° ± 0.1 °C was 93 ± 2% after 2 days and 95 ± 2% after 9 days. This germination percentage above 90% indicated that seeds from the Colorado 2015 crop year maintained acceptable viability.

4. Discussion

The objective of the presented study was to test if magneto-priming, a form of seed priming that involves magnetic fields, can increase industrial hemp seed germination percentage above 65% at germination temperatures close to 10 °C. Beneficial effects of magnetic fields on seedling growths and germination have been reported for many different plant species; see the review by Maffei [7]. The performed 2-h magneto-priming of dry industrial hemp seed with static magnetic fields ranging from 65 ± 3 to 505 ± 8 mT had no statistically significant effect on seed germination. The average germination percentage of magnetically treated seed was 65 ± 10% at 13.6 ± 0.7 °C after 8.8 days. The average germination percentages for magnetically untreated seed at 13.6 ± 0.7 °C and 26° ± 0.1 °C were 63 ± 6% (8.8 days) and 95 ± 2% (9 days), respectively.

It remains to be investigated if static magnetic fields below 65 ± 3 mT or above 505 ± 8 mT, as well as a chronic exposure to different magnetic fields, effect the seed germination percentage of industrial hemp. Besides static magnetic fields, a future research direction may include the investigation of the effect of different time-varying magnetic fields on the seed germination percentage. For example, magneto-primed tomato seed with a dynamic magnetic field ranging from 0.3–300 mT for one minute at

60 Hz resulted in a 1.1–2.8-fold increase in germination percentage [15]. Additionally, the germination percentage of soybean increased by 12% when seed was treated with a time-varying magnetic field of 1.5 μT at 10 Hz for 20 days and daily for 5 h [16].

Funding: This work was supported by the UCCS center of the BioFrontiers Institute.

Acknowledgments: The author would like to thank the Colorado Department of Agriculture for providing industrial hemp seed for this study. During the time of this study, the University of Colorado, Colorado Springs (UCCS) campus had an active industrial hemp registration which was issued by the Colorado Department of Agriculture.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Going into Its Fourth Harvest, Industrial Hemp Industry Still Facing Growing Pains. Available online: https://www.denverpost.com/2017/09/10/colorado-culvitars-hemp-farm-harvest/ (accessed on 29 December 2017).
2. Soil Moisture and Temperatures. Available online: http://frontrangeweather.net/wxsoil.php (accessed on 29 December 2017).
3. Quin, C.; Wang, F.; We, D.; Qin, W. Effect of different temperatures on the germination of fire hemp seeds. *Med. Plant* **2014**, *5*, 70–72.
4. Hemp Feasibility Study. Available online: https://hemptoday.net/wp-content/uploads/2017/08/hemp-feasibility-study.pdf (accessed on 2 January 2018).
5. Rochalska, M.; Orzeszko-Rywka, A. Magnetic field treatment improves seed performance. *Seed Sci. Technol.* **2005**, *33*, 669–674. [CrossRef]
6. Araújo, S.S.; Paparella, S.; Dondi, D.; Bentivoglio, A.; Carbonera, D.; Balestrazzi, A. Physical Methods for Seed Invigoration: Advantages and Challenges in Seed Technology. *Front. Plant Sci.* **2016**, 7. [CrossRef] [PubMed]
7. Maffei, M.E. Magnetic field effects on plant growth, development, and evolution. *Front. Plant Sci.* **2014**, *5*, 445. [CrossRef] [PubMed]
8. Da Silva, J.A.; Dobránszki, J. Magnetic fields: How is plant growth and development impacted? *Protoplasma* **2016**, *253*, 231–248. [CrossRef] [PubMed]
9. Alexander, M.P.; Doijode, S.D. Electromagnetic field: A novel tool to increase germination and seedling vigor of conserved onion (*Allium cepa* L.) and rice (*Oryza sativa* L.) seeds with low viability. *Plant Genet. Resour. Newslett.* **1995**, *104*, 1–5.
10. Carbonell, M.V.; Martinez, E.; Amaya, J.M. Stimulation of germination in rice (*Oryza Sativa* L.) by a static magnetic field. *Electromagn. Biol. Med.* **2000**, *19*, 121–128. [CrossRef]
11. Martinez, E.; Padrino, M.V.C.; Garcia, M.F.; de la Escosura, J.M.A.G. *Effect of Static Magnetic Field Exposure of Salvia Seeds on Germination Characteristics (Salvia officinalis, L.)*; E.T.S.I. Agrónomos (UPM): Raudondvaris, Lituania, 2008.
12. Vashisth, A.; Nagarajan, S. Effect on germination and early growth characteristics in sunflower (Helianthus annuus) seeds exposed to static magnetic field. *J. Plant Physiol.* **2010**, *167*, 149–156. [CrossRef] [PubMed]
13. Aladjadjiyan, A. Study of the influence of magnetic field on some biological characteristics of Zea mais. *J. Cent. Eur. Agric.* **2002**, *3*, 89–94.
14. Labouriau, L.G.; Osborn, J.H. Temperature dependence of the germination of tomato seeds. *J. Therm. Biol.* **1984**, *9*, 285–294. [CrossRef]
15. Moon, J.; Chung, H. Acceleration of germination of tomato seed by applying AC electric and magnetic fields. *J. Electrostat.* **2000**, *48*, 103–114. [CrossRef]
16. Radhakrishnan, R.; Ranjitha Kumari, B.D. Pulsed magnetic field: A contemporary approach offers to enhance plant growth and yield of soybean. *Plant Physiol. Biochem.* **2012**, *51*, 139–144. [CrossRef] [PubMed]