INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
18F–199/2019/21–4–841–847
DOI: 10.17957/IJAB/15.0964
http://www.fspublishers.org

Full Length Article

Static Magnetic Field Treatments Affect the Light-Induced Germination of Dormant *Paulownia elongata* Seed

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Abstract

Dormancy is a major cause of low germination of freshly harvested *Paulownia elongata* seed. To determine whether magnetic treatments can promote light-induced germination, dormant *P. elongata* seeds were exposed to two magnetic fields (125 and 3 mT) for 0, 10, 30, 60 and 120 min under different light conditions before water uptake, during water uptake and after cold stratification. Exposing seeds to magnetic at different stages resulted in different effects on seed germination: 1) Exposure of dry seeds to 125 mT and 3 mT magnetic fields had negative effects on the germination of *P. elongata*, 2) Exposure of seeds to 125 mT and 3 mT magnetic fields during water uptake had positive effects on the germination only in low light conditions, and 3) especially, exposing seeds to the 125 mT magnetic fields after cold stratification enhanced seed germination and reduced cold stratification time needed to break dormancy. The results suggest that water and cold stratification can affect the responses of seeds to the magnetic fields in *P. elongata* and a 125 mT magnetic field after cold stratification can be used to break *P. elongata* seed dormancy and promote the germination.

Keywords: *Paulownia elongata*; Seeds; Germination; Magnetic field

Introduction

Paulownia has significant economic and ornamental value because of its high growth rate, timber quality, attractive flowers and high nitrogen content, as it serves as both fertilizer and fodder. As reported, *Paulownia tomentosa* and *P. fortunei* exhibit little or no seed dormancy, although light is necessary for the timely germination of fresh seeds (Toda and Isikawa, 1952; Borthwick *et al.*, 1964; Carpenter and Smith, 1981; Grubišic *et al.*, 1985; Zhen, 1999). The germination of *P. elongata* S.Y. Hu seed is also light induced, and the seeds exhibit non-deep physiological dormancy, which can be effectively broken by cold stratification, after-ripening or GA3 (Liu *et al.*, 2017).

Previous work has indicated that the magnetic treatment as a safe, convenient and affordable potential physical treatment to promote seed germination and it can be applied to some crop and forest species production. The effects of magnetic treatments on germination of seeds and growth of plants have been investigated in many studies. The first study (Savostin, 1930) showed increase in the rate of elongation in wheat seedlings under magnetic conditions. Lot of studies tested the interaction of magnetic field and exposure time on seeds of different species and have reported the beneficial effects of magnetic treatments on seeds germination. Stimulating the germination of seeds exposed to magnetic fields had been reported previously by workers dealing with various seeds (Kato, 1998; Aladjadjiyan, 2002; Fischer *et al.*, 2004; Flórez *et al.*, 2007; Vashisth and Nagarajan, 2008, 2010; Gholami and Sharafi, 2010; Yao and Shen, 2015; Vashisth and Joshi, 2017). Negative effects of magnetic treatments on seed germination also were reported (Khonsari *et al.*, 2015). The scientific literature describing the effects of weak magnetic fields on living systems contains a plethora of contradictory reports and few successful independent replication studies (Lacyhulbert *et al.*, 1998; Galland and Pazur, 2005; Pazur *et al.*, 2007; Harris *et al.*, 2009). The mechanism of the effect of magnetic treatment on plant is still not well known, so some influential factors may be ignored.

In some studies, dry seeds were exposed to magnetic treatments to improve germination percentage, speed of germination and seedling vigour in triticale (Alvarez *et al.*, 2012), *Dactylis glomerata* (Bretagnolle *et al.*, 1995), *Brassica oleracea* (Martínez *et al.*, 2014), *Helianthus annuus* (Ananta and Shantha, 2010). And sometimes, magnetic treatments started during seeds water uptake. Exposure of *Zea mays* seeds, which were soaked for 4 h, to stationary magnetic fields resulted in increasing rate of germination and total fresh weight of seedling (Mercedes *et al.*, 2007). Besides, Magnetic Field has been rarely used for improving germination in dormant seed.

To cite this paper: Liu, J., T. Xue, Y. Shen and Z. Wang, 2019. Static magnetic field treatments affect the light-induced germination of dormant *Paulownia elongata* seed. *Intl. J. Agric. Biol.*, 21: 841–847

The objective of this study was to determine whether magnetic treatments can promote the light-induced germination of dormant *P. elongata* seed.

Materials and Methods

Materials

Seeds were collected from *P. elongata* S.Y. Hu trees at The Nanjing Couple Park, Nanjing city, which belongs to subtropics monsoon climate, in eastern China on 12th December 2014, when the fruits had cracked naturally and turned brown. The trees are about 20 years old and planted in alkalescent clay soil.

Immediately after collection, seeds were separated by hand and dried in a dry and well-ventilated room for 48 h. The initial viability was 98% by TZ test. Dried seeds were stored in the dark at room temperature (15–25°C) in brown paper bags for 65 days and 145 days.

Another seed lot with deeper dormancy level was collected in October 25th, 2015, from the same *P. elongata* trees. Seeds were dried in a dry and well-ventilated room for 72 h and used as freshly harvested seeds. The initial viability was 95% by TZ test.

Methods

Magnetic fields treatment: The magnetic fields were generated by square magnets of 50 mm length, 50 mm width and 5 mm height. Two static 125 mT and 3 mT magnetic induction field were provided by a HT20/HT20A digital Gauss meter (Shanghai Huntoon Magnetic Technology Co., Ltd., China) in a central area located about 40 mm × 40 mm from the surface of the magnet to a region 4 mm away, where the seeds were exposed to the magnetic treatment.

Dry Seeds Exposed to Stationary Magnetic Fields

Seeds dry stored for 65 days and 145 days were sown on two layers of dry filter paper in 60 mm-diameter Petri dish and exposed to the two stationary magnetic fields for 0 (control), 10, 30, 60 and 120 min in dark. And then 2 mL of water were added to each Petri dish and the Petri dishes were placed at 25°C for 12 h of imbibition. Petri dishes were wrapped with sheets of aluminium foil to exclude light.

After the magnetic field treatments and imbibition in dark, a group of seed were treated with LED light (approximately 15 μmol m^{-2} s^{-1}) for 0 (dark), 5, 10, 20, 40 h and 30 days (continuous light). The seeds in Petri dishes were then wrapped with aluminium foil, after which the dishes were placed in an incubator at 25°C without light.

After magnetic fields treatment and imbibition in dark, another group of seed were transferred to two layers of filter papers wetted with 2 mL of 1000 mg L^{-1} GA_3 in Petri dishes. Petri dishes were placed at 25°C, in an incubator with continuous light.

Seeds Exposed to Stationary Magnetic Fields after Water Uptake

Seeds dry stored for 65 days and 145 days were sown on two layers of filter paper wetted with 2 mL of water in a 60 mm-diameter Petri dish. After wrapping with sheets of aluminium foil to exclude light, the Petri dishes were placed at 25°C for 10 h of imbibition. After imbibition, seeds were exposed to the two stationary magnetic fields for 0 (control), 10, 30, 60 and 120 min in dark, and then the Petri dishes were placed at 25°C for 120, 110, 90, 60 and 0 min respectively to make the total water uptake time were 12 h before different duration of light.

After the magnetic field treatments (before and after water uptake), the seeds were treated with the same LED light for 0 (dark), 5, 10, 20, 40 h and 30 days (continuous light). The seeds in Petri dishes were then wrapped with aluminium foil, after which the dishes were placed in an incubator at 25°C without light.

Seeds Exposed to Stationary Magnetic Fields after Cold Stratification

Freshly harvested seeds and seeds dry stored for 65 days were sown on two layers of filter paper wetted with 2 mL of water in a 60 mm-diameter Petri dish. After wrapping with sheets of aluminium foil to exclude light, the Petri dishes were placed at 25°C for 12 h of imbibition.

After 12 h of imbibition, the seeds from seeds dry stored for 65 days were placed at 4°C for 48 h. After cold stratification, the seeds were exposed to two stationary magnetic fields for 0 (control), 10, 30, 60 and 120 min in the dark. After the magnetic field treatments, the seeds were treated with the same LED ligh for 0 (dark), 5, 10, 20, 40 h and 30 days (continuous light). The seeds in Petri dishes were then wrapped with aluminium foil, after which the dishes were placed in an incubator at 25°C without light.

After 12 h of imbibition, freshly harvested seeds were placed at 4°C for 0 day, 8 days, 16 days, 24 days and 32 days. After cold stratification, the seeds were exposed to two stationary magnetic fields for 0 (control), 10, 30, 60 and 120 min in the dark. After the magnetic field treatments, the seeds were treated with the same LED light for 30 days (continuous light) at 25°C in an incubator.

Germination

Samples of 300 seeds sown as three replicates of 100 seeds each were subjected to each treatment. The number of germinated seeds was scored daily over a period of 30 days after the start of incubation, using two minutes of room light for counting each day. Seeds were watered every third day. Visible radicle protrusion from the seed coat was the criterion for germination.

Tetrazolium Tests

Seed viability evaluated by tetrazolium tests (AOSA, 2010). Dry seeds exposed to stationary magnetic fields for 0 (control), 60 min and 120 min and dry stored for 1 day at 25°C followed by tetrazolium tests. Two replicates of 100~105 seeds were used for each treatment.

Statistical Analyses

Statistical analyses of the germination data were performed with SPSS 19.0 for windows software. Data were subjected to ANOVA and means compared using Fishers Least Significant Difference Test.

Results

Germination of Seeds Exposed to Stationary Magnetic Fields before Water uptake

Exposing dry seeds to two stationary magnetic fields had negative effects on the germination of *P. elongata*. For 65 days dry stored seeds, when the dry seeds were exposured to 125 mT magnetic field, the decrease of germination percentage over control was 5~19% in continuous light, 3~14% in 40 h light, 8~17% in 20 h light, 5~9% in 10 h light and 1~8% in 5 h light and when seeds were exposured to 3 mT magnetic field the decrease of germination percentage over control was 3~17% in continuous light, 2~13% in 40 h light, 7~14% in 20 h light, 6~12% in 10 h light and 3~9% in 5 h light (Table 1).

For 145 days dry stored seeds, when the dry seeds were exposured to 125 mT magnetic field, the decrease of germination percentage of over control was 3~11% in continuous light, 3~12% in 40 h light, 3~9% in 20 h light, 3~10% in 10 h light and 0~13% in 5 h light, and when seeds were exposured to 3 mT magnetic field the decrease of germination percentage over control was 2~8% in continuous light, 6~10% in 40 h light, 5~10% in 20 h light, 2~10% in 10 h light and 4~11% in 5 h light (Table 2).

There was significant ($P < 0.05$) difference for two magnetic fields in treated samples when compared to the controls in all the different light for the 145 days and 65 days of dry stored seeds (Table 1 and 2). In some light conditions, only 10 min magnetic treatment can inhibit germination significantly. Magnetic treatment for 30~120 min resulted in significantly lower germination in most light conditions, as compared with the control. In different light conditions, the most effective magnetic treatment in reduction of germination percentage was different.

None of seed germinated in dark regardless of whether magnetic treatments were used (Table 1 and 2). Exposing magnetic treated and untreated seeds to GA_3 solution resulted in high germination percentage and after GA_3 treatment the germination percentage of magnetic treated seeds were not lower significantly than the control (Table 1 and 2).

Tetrazolium Tests

Tetrazolium tests indicated that there is no significant ($P< 0.05$) difference between magnetic treated and untreated seeds before water uptake and seeds viability were more than 95% (Table 3).

Germination of Seeds Exposed to Stationary Magnetic Fields after Water uptake

Exposing seeds to two stationary magnetic fields during water uptake had positive effects on the germination of *P. elongata* seeds in low light conditions. For 65 days of dry stored seeds, when wet seeds were exposured to 125 mT magnetic field, the increase of germination percentage of over control was 0~5% in continuous light, 1~8% in 40 h light, -1~11% in 20 h light, 0~4% in 10 h light and 4~22% in 5 h light and when seeds were exposured to 3 mT magnetic field the increase of germination percentage over control was 0~2% in continuous light, 0~4% in 40 h light, 1~12% in 20 h light, 1~11% in 10 h light and 5-13% in 5 h light. In 5–40 h of light, the two magnetic fields caused significant ($P< 0.05$) improvement, and only in continuous light the magnetic treatment did not result in significantly increase (Table 4).

For 145 days of dry stored seeds, when wet seeds were exposured to 125 mT magnetic field, the increase of germination percentage of over control was -1~3% in continuous light, 2~9% in 5 h light and when seeds were exposured to 3mT magnetic field the increase of germination percentage over control was -2~2% in continuous light, and 3–10% in 5 h light. Just in low light (5–10 h light), which were not enough for *P. elongata* seed germination, the two magnetic fields caused significant ($P< 0.05$) increase. In 20 h, 40 h and continuous light, the magnetic treatment did not result in significantly improvement (Table 5). None of seed germinated in dark regardless of whether magnetic treatments were used (Table 4 and 5).

Germination of Seeds Exposed to Stationary Magnetic Fields after Cold Stratification

For 65 days of dry stored *P. elongata* seeds, 48 h cold stratification significantly increased germination percent in different light conditions (Table 6). Exposure of *P. elongata* seeds to 125 mT stationary magnetic fields after cold stratification significantly increased germination percent in different light conditions, compared to the seeds only with cold stratification (Table 6). For germination percentage, the increase in magnetic treatment as compared to the corresponding values of cold stratification treated seeds measured in 125 mT magnetic field treatment were 11–17%

Table 1: The final germination (G) of *P. elongata* seeds dry stored for 65 days exposed to two stationary magnetic fields before water uptake in various light

Treatments	Time (min)	Duration of light treatment (hours)						
		Dark	5	10	20	40	Continuous light	Continuous light+GA_3
		G (%)						
Control	0	0±0	21±1.45a	41±2.60a	50±2.03a	66±1.76a	68±2.03a	91±0.88a
Magnetic field,	10	0±0	20±2.08ab	33±1.45bc	42±1.86ab	63±1.45ab	63±0.58ab	91±1.45a
125 mT	30	0±0	18±1.45ab	34±2.03bc	33±2.89c	55±2.03 cd	57±1.15cd	89±2.03a
	60	0±0	13±0.88c	36±1.15ab	35±2.60bc	52±2.03d	49±3.18 e	88±2.60a
	120	0±0	16±1.73bc	32±2.03bc	40±1.15b	52±2.31d	53±2.03de	90±1.73a
Magnetic field,	10	0±0	16±1.85bc	30±2.60bc	43±4.91ab	64±2.31a	65±2.31a	93±0.33a
3 mT	30	0±0	18±1.73ab	35±2.31 ab	36±1.45bc	58±2.03bc	53±1.45de	90±2.03a
	60	0±0	12±0.33c	31±2.03bc	38±1.45bc	53±2.03cd	59±1.45bc	88±1.45a
	120	0±0	13±0.88c	29±2.31c	42±3.76ab	53±1.45cd	51±0.88e	90±1.73a
LSD		—	4.39	6.26	8.07	5.81	5.45	5.06

The data are means of three replicates ±standard error. The same letter with in a column show no significance at the 0.05% probability level

Table 2: The final germination (G) of *P. elongata* seeds dry stored for 145 days exposed to two stationary magnetic fields before water uptake in various light

Treatments	Time (min)	Duration of light treatment (hours)						
		Dark	5	10	20	40	Continuous light	Continuous light+GA_3
		G (%)						
Control	0	0±0	78±1.76a	86±1.45a	90±1.67a	91±1.20a	91±0.58a	94±1.20a
Magnetic field,	10	0±0	78±1.45a	83±0.88abc	87±1.73ab	88±1.33ab	88±1.73abc	92±1.15ab
125 mT	30	0±0	68±2.02 bcd	78±1.45cd	85±3.18abc	84±2.31bcd	83±1.15de	92±1.76ab
	60	0±0	70±3.17bcd	76±2.03d	81±2.03bc	79±1.73d	80±2.02e	90±2.03ab
	120	0±0	65±2.31 d	79±2.60bcd	82±2.03bc	81±1.15cd	81±1.45de	88±2.40b
Magnetic field,	10	0±0	74±2.03ab	84±0.88ab	85±2.03abc	85±0.88bc	85±0.33bcd	89±2.08ab
3 mT	30	0±0	70±2.89bcd	80±2.02bcd	83±1.45bc	81±2.31cd	89±2.02ab	90±2.60ab
	60	0±0	67±2.03cd	81±2.31abcd	84±2.02abc	85±2.60bc	83±0.33de	93±0.33ab
	120	0±0	72±1.15abc	76±2.60d	80±2.31c	81±2.60cd	84±2.30cde	89±2.03ab
LSD		—	6.47	5.68	6.25	5.65	4.49	5.52

The data are means of three replicates ±standard error. The same letter with in a column show no significance at the 0.05% probability level

Table 3: Viability of two *P. elongata* seed lots exposed to two stationary magnetic fields before water uptake

Treatment	Time (min)	Seed viability (%)	
		Seeds dry stored for 65 days	Seeds dry stored for 145 days
Control	0	97±1.14a	98±0.42a
Magnetic field, 125 mT	60	98±0.40a	96±0.32a
	120	96±0.33a	98±0.75a
Magnetic field, 3 mT	60	97±0.75a	97±1.24a
	120	96±0.41a	97±0.77a
LSD		3.01	3.45

The data are means of three replicates ±standard error. The same letter with in a column show no significance at the 0.05% probability level

Table 4: The final germination (G) of *P. elongata* seeds dry stored for 65 days exposed to two stationary magnetic fields during water uptake in various light

Treatments	Time (min)	Duration of light treatment (hours)					
		Dark	5	10	20	40	Continuous light
		G (%)					
Control	0	0±0	21±1.45e	41±2.60b	50±2.03de	66±1.76c	68±2.03a
Magnetic field, 125 mT	10	0±0	25±1.45de	41±2.60b	49±1.73e	67±1.73c	68±1.15a
	30	0±0	41±2.02a	42±1.45b	59±1.45abc	73±0.58ab	70±2.60a
	60	0±0	44±2.30a	45±2.02b	61±1.15a	73±0.88ab	73±1.15a
	120	0±0	43±1.45a	45±2.31b	60±1.45ab	74±1.45a	72±2.02a
Magnetic field, 3 mT	10	0±0	26±1.86de	40±1.45b	49±2.31e	66±1.73c	69±2.31a
	30	0±0	28±2.33cd	44±0.88b	55±2.03bcd	68±1.45c	68±0.33a
	60	0±0	32±1.45bc	46±2.40b	54±1.73cde	69±1.45bc	70±1.86a
	120	0±0	34±2.02b	52±1.45a	62±0.88a	70±0.88abc	69±2.31a
LSD		—	5.50	5.93	5.04	4.12	5.93

The data are means of three replicates ±standard error. The same letter with in a column show no significance at the 0.05% probability level

Table 5: The final germination (G) of *P. elongata* seeds dry stored for 145 days exposed to two stationary magnetic fields during water uptake in various light

Treatments	Time (min)	Duration of light treatment (hours)					
		Dark	5	10	20	40	Continuous light
		G (%)					
Control	0	0±0	78±1.76d	86±1.45d	90±1.66a	91±1.20abc	91±0.58abc
Magnetic field, 125mT	10	0±0	80±1.45cd	88±0.33bcd	89±1.45a	93±0.33ab	90±1.15bc
	30	0±0	81±1.45bcd	90±0.88abc	90±0.88a	90±0.88bc	94±0.58a
	60	0±0	87±0.88a	92±0.33a	90±0.88a	89±1.73c	91±0.58abc
	120	0±0	84±0.88abc	87±1.15cd	92±0.88a	93±0.88ab	90±1.15bc
Magnetic field, 3mT	10	0±0	81±2.60bcd	86±1.45d	88±1.45a	90±1.45ab	91±0.58abc
	30	0±0	82±1.45bcd	88±0.33bcd	91±0.88a	94±0.33a	89±2.03c
	60	0±0	85±1.45ab	91±1.15ab	90±1.45a	91±1.45abc	93±0.88ab
	120	0±0	88±1.45a	89±1.45abcd	91±1.45a	90±0.33bc	90±1.45abc
LSD	—		4.65	3.15	3.75	3.22	3.29

The data are means of three replicates ±standard error. The same letter with in a column show no significance at the 0.05% probability level

Table 6: The final germination (G) of *P. elongata* seeds dry stored for 65 days exposed to two stationary magnetic fields after cold stratification for 48h in various light

Treatments	Time of magnetic treatment (min)	Duration of light treatment (hours)					
		Dark	5	10	20	40	Continuous light
		G (%)					
Control	0	0±0	21±1.45d	41±2.60e	50±2.03d	66±1.76e	68±2.03f
cold stratification	0	0±0	42±2.33bc	64±1.76cd	68±1.76c	73±2.52cd	78±1.15cde
Cold stratification+magnetic field, 125 mT	10	0±0	55±2.52a	70±1.33b	70±2.73abc	76±1.67bc	80±0.33bcd
	30	0±0	53±2.96a	75±1.76a	74±0.67ab	79±1.86ab	82±1.15abc
	60	0±0	59±2.33a	77±1.67a	75±2.03a	79±2.52ab	86±0.88a
	120	0±0	55±2.08a	70±0.58b	74±1.45abc	83±0.88a	83±1.45ab
Cold stratification+magnetic field, 3 mT	10	0±0	41±1.15bc	68±1.73b	68±1.45c	70±1.15de	75±2.33e
	30	0±0	47±2.33b	66±0.33bc	71±2.00abc	73±1.45cd	81±2.08bcd
	60	0±0	40±1.76c	61±1.20d	69±2.19bc	77±0.58bc	77±1.20de
	120	0±0	47±1.00b	62±1.53cd	72±1.53abc	71±1.20d	80±1.53bcd
LSD		—	6.14	4.64	5.48	4.94	4.51

The data are means of three replicates ±standard error. The same letter with in a column show no significance at the 0.05% probability level

Table 7: The final germination (G) of *P. elongata* freshly harvested seeds exposed to two stationary magnetic fields after cold stratification for 8-32 days

Treatments	Time of magnetic treatment (min)	Time of cold stratification / d				
		0	8	16	24	32
		G (%)				
Control	0	0±0	20±2.31de	39±1.86cd	65±2.00cd	82±1.73c
Cold stratification+magnetic field, 125 mT	10	0±0	23±1.45cd	40±1.20cd	67±1.86bcd	81±1.86c
	30	0±0	26±0.58bc	44±2.73bc	69±1.76bc	87±1.45b
	60	0±0	31±1.76a	50±2.91ab	74±2.33a	93±1.00a
	120	0±0	29±2.33ab	54±2.65a	72±1.45ab	90±0.58ab
Cold stratification+magnetic field, 3 mT	10	0±0	20±1.15de	40±2.40cd	62±1.53d	80±0.88c
	30	0±0	19±1.20de	37±1.86d	64±2.60cd	78±1.45c
	60	0±0	21±2.03d	37±2.96d	66±2.03cd	82±1.53c
	120	0±0	18±1.20e	42±1.73cd	64±1.53cd	81±1.45c
LSD		—	4.92	6.92	5.75	4.11

The data are means of three replicates ±standard error. The same letter with in a column show no significance at the 0.05% probability level

in 5 h light, 6–13% in 10 h light, 2–7% in 20 h light, 3–10% in 40 h light and 2–8% in continuous light. Exposure of *P. elongata* seeds to 3 mT stationary magnetic fields after cold stratification did not increase germination percentage significantly, compared to the seeds only with cold stratification (Table 6). None of seed germinated in dark regardless of whether magnetic treatments were used (Table 6). In this test, freshly harvested *P. elongata* seeds possess deepest dormancy level, and none of seed germinated without cold stratification in continuous light regardless of whether magnetic treatments were used. Cold stratification broke seed dormancy and germination percentage increased from 0 to 82% after 32 days of cold stratification. Combination treatments of magnetic treatments and cold stratification also had a significant effect, compared with the control. Exposure of freshly harvested *P. elongata* seeds to 125 mT stationary magnetic fields after cold stratification significantly increased germination percent in continuous light, compared to the seeds only with cold stratification (Table 7). For germination percentage, the improvement in magnetic treatment as compared to the corresponding values of cold stratification treated seeds measured in 125 mT magnetic field treatment were 3–11% after 8 days of cold stratification, 1–15% after 16 days of cold stratification, 2–9% after 24 days of cold stratification, -1–11% after 32 days of cold stratification. Exposure of *P. elongata* seeds to 3 mT stationary magnetic fields after cold stratification did not increase germination significantly, compared to the seeds only with cold stratification (Table 6). Among the various combinations of field strength and duration, 125 mT for 60–120 min exposure gave best results for dormancy release.

Discussion

Exposing *P. elongata* seeds to the stronger magnetic fields after cold stratification enhanced seed germination well and reduced cold stratification time for breaking dormancy (Table 6 and 7). The previous research on *Koelreuteria paniculata* seeds with physical and physiological dormancy showed the germination increased from 56% to 97% by 10 mT magnetic treatment when the magnetic field was applied between scarification and 84 days of cold stratification (Moronek, 1975). Combination treatments of magnetic treatments and cold stratification seemed to be a good method to break physiological dormancy fast. Exposing *P. elongata* seeds to two stationary magnetic fields during water uptake had positive effects on the germination (Table 4 and 5). Few study treated wet seeds by magnetic fields. Exposure of *Zea mays* seeds, which were soaked for 4 h, to stationary magnetic fields resulted in increasing rate of germination and total fresh weight of seedling (Mercedes *et al.*, 2007).

In this test, the positive effects appeared only in low light conditions. Some evidence showed animals and plants also have the ability for magnetic field reception which is light dependent (Möller *et al.*, 2004; Mouritsen *et al.*, 2004; Phillips *et al.*, 2010). A report of magnetic field responses in plants in which two cryptochromes mediate a number of photoresponses, including blue-light growth inhibition and entrainment of the circadian clock (Ahmad *et al.*, 2007). Magnetic field also may affect light reception in *P. elongata* seeds. On the other hand, the positive effects may be subject to seed dormancy releasing. As seeds come out of dormancy, they first enter conditional dormancy, during which they germinate only over a narrow range of conditions. And during the progression of dormancy loss, this range widens (Baskin and Baskin, 2014). The light requirement for *P. elongata* seeds germination reduced as seeds dormancy was broken by dry storage, cold stratification and GA_3 (Liu *et al.*, 2017). Thus exposing *P. elongata* seeds to two stationary magnetic fields during water uptake may have a small effect on breaking seed dormancy.

Exposing dry seeds to two stationary magnetic fields inhibited the germination of *P. elongate* (Table 1 and 2). In most studies about the effect of magnetic treatments on seed germination, dry seeds were exposed to magnetic fields. However, numerous investigations showed that the magnetic treatments on dry seeds can improve germination percentage, speed of germination and seedling vigour in triticale (Flórez *et al.*, 2016), *Dactylis glomerata* (Bretagnolle *et al.*, 1995), *Brassica oleracea* (Martínez *et al.*, 2014), *Helianthus annuus* (Ananta and Shantha, 2010). In spite of the reported beneficial effects in which magnetic fields offer for living organisms, there are some studies showed the negative effects of certain magnetic field intensities on improvement rate and percentage of germination in seeds. For instance magnetic field reduced amount and speed of germination in treated dry seeds of *Myrtus communis* (Khonsari *et al.*, 2015).

Although some study reported negative effects of magnetic treatment, the reason was not shown. Our test provided some evidences that the negative effects of magnetic treatment on *P. elongata* seeds germination were due to the secondary dormancy rather than "magnetic damage", because (1) magnetic treatment did not reduce the seed viability (Table 3) and (2) In continuous light the negative effects on germination were removed by GA_3 (Table 1 and 2) , which was involved in overcoming seed dormancy of a lot of Species (Frankland, 1961; Chen and Chang, 1972; Debeaujon and Koornneef, 2000; Fang *et al.*, 2006; Kimura *et al.*, 2015) and *P. elongata* (Liu *et al.*, 2017).

Exposing seeds to magnetic at different stages resulted in different effects on seed germination. The mechanism of effect of magnetic treatment in plant is still not well known, but the "radical-pair mechanism" mechanisms for magnetoreception is currently receiving major attention (Steiner and Ulrich, 1989; Brocklehurst and Mclauchlan, 1996; Brocklehurst, 2002; Woodward, 2003; Timmel and Henbest, 2004). Upon imbibition, the quiescent dry seed rapidly resumes metabolic activity (Bewley, 1997). Cold stratification also can change the metabolites in seeds. Therefore, imbibition and cold stratification probably cause multiform response to magnetic filed in seeds.

Conclusion

The results show that 1) exposing seeds to 125 mT and 3 mT magnetic fields during water uptake and after cold stratification promote *P. elongata* seed germination under low light conditions, 2) a 125 mT magnetic field after cold stratification can be used to promote the germination of dormant *P. elongata* seeds and 3) water and cold stratification can affect the responses of seeds to the magnetic fields in *P. elongata*.

Acknowledgements

Thanks to the Priority Academic Program Development (PAPD) of Jiangsu Higher Education Institutions for financial assistance.

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(Received 22 September 2018; Accepted 03 November 2018)