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Germination and initial growth of triticale seeds under stationary magnetic treatment

Flórez, M. Martínez, E. Carbonell, M.V. Álvarez, J. and Campos, A.
Universidad Politécnica de Madrid. E.T.S. Ingenieros Agrónomos. Dpto. Física y Mecánica de la Ingeniería Agroforestal.
Ciudad Universitaria s/n 28040 Madrid, Spain
mercedes.florez@upm.es
elvira.martinez@upm.es
victoria.carbonell@upm.es
jose.alvarez@alumnos.upm.es
adrian.campos@alumnos.upm.es

ABSTRACT

The main objective of this study is to determine the effects of 125 mT and 250mT magnetic treatment on the germination and initial growth of triticale seeds. This objective has a practical application in agriculture science: early growth of triticale. An increase in the percentage and rate of germination of seeds and a stimulation of growth of seedlings as positive response to magnetic field treatment in rice, wheat, maize and barley seeds have been found in previous studies. Germination tests were carried out under laboratory conditions by exposing triticale seeds to magnetic field for different times. The effect was studied by exposure of seeds prior sowing. The mean germination time were reduced for all the magnetic treatments applied. Most significant differences were obtained for time of exposure of 1 and 24 hours and maximum reductions was 12%. Furthermore, seedlings from magnetically treated seeds grew taller than control. The longest mean total length was obtained from seedlings exposed to 125 and 250 mT for 24 hours. External magnetic fields are assumed to enhance seed vigor by influencing the biochemical processes by stimulating activity of proteins and enzymes. Numerous studies suggested that magnetic field increases ions uptake and consequently improves nutrition value.

Key words: triticale seeds; magnetic field; germination; seedling.

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INTRODUCTION

The effects on living systems of exposure to a magnetic field, particularly on germination of seeds and growth of plants, have been the object of much research. In general, the enhancement of growth due to magnetic field exposure appears to have been confirmed by many scientists. Some have tried to determine effects related with seed germination, such as changes in biochemical activity, curvature, magnetotropism and germination rate. An induction of primary root curvature in radish seedlings in a static magnetic field; the roots responded tropically to magnetic field, with the tropism appearing to be negative was observed; these roots responded significantly to the south pole of the magnet [Yano *et al*., 2001]. The application of magnetic field doses of 4 mT and 7 mT promoted germination ratios of bean and wheat seeds [Cakmak *et al*., 2010]. Magnetic treated pea plants grew higher and heavier than control; the greatest differences were observed for seeds treated with doses of 125 mT and 250 mT, for 24 h or permanent [Carbonell *et al*., 2011]. The positive effects on plants characteristics such as seed germination rate, shoot development, length and weight of plants and yield is reported by numerous authors. The main objective of this study is to determine the effects of magnetic treatment, in addition to the geomagnetic field, on the germination and initial growth of triticale seeds. Magnetopriming of dry seeds of chickpea can be effectively used as a pre-sowing treatment for mitigating adverse effects of salinity at seed germination and early seedling growth [Thomas *et al*., 2013]. A significant effect of non-uniform static magnetic field on tomato seed performance with respect to relative humidity, are observed during seed imbibition rather than during later developmental stages [Poinapen *et al*., 2013]. Magnetic field pre-sowing seed treatment can be used practically to enhance the growth and yield in pea cultivar [Iqbal *et al*., 2013].

MATERIALS AND METHODS

Germination and growth tests of triticale were carried out under laboratory conditions with natural light and the minimum and maximum temperature of 18 ºC and 22 ºC, according to guidelines issued by the International Seed Testing Association [ISTA, 2004] with only slight modifications. Triticale (*X Triticosecale* Wittmack) is a wheat and rye hybrid. Although triticale of grain size, shape and colour resembles that wheat more than rye, still triticale grain is usually larger and longer than wheat grain. Adapted to a wide range of soils and requiring only moderate fertility and moisture, it does not tolerate flooding and is only slightly drought resistant. Seeds were supplied by the Spanish Office of Vegetable Varieties, which guarantees high seed viability and homogeneity and thus significant results with smaller samples.

Magnetic treatment consisted of different doses (Pi) due to variation in exposure time (t) and the magnetic field induction (B). The static magnetic field was generated by permanent ring magnets, with strengths of 125 mT or 250 mT, external diameter of 7.5 cm, internal diameter of 3 cm, and height of 1 cm for 125 mT magnets and 1.5 cm for 250 mT magnets. Ring analogous to the ring magnets, of the same material but without magnetic induction, were used as blind (Control). Magnetic doses were obtained by exposing the seeds to each magnetic field for different times as shown in Table 1. The experimental design involves four replicates (n=4) with 25 seeds. Thus, groups of 100 seeds were subjected to each magnetic treatment, and an analogous group was used as control. Each replicate was placed in the hollow of a magnet, before coming into contact with water, prior to sowing.

The goal of germination test was to determine the possible influence of magnetic treatment on the time required for germination. Germination was tested by placing 25 treated seeds per Petri dish around a circular line, on filter papers soaked with 12 ml of distilled water. Petri dishes with seeds were labeled and randomly located. Experimental groups P1-P5 (125 mT) and P6-P10 (250 mT), and control C ran simultaneously. For each treatment the number of germinated seeds was counted to determine the time necessary to achieve the final maximum percentage of germinated seeds (G_{max}). Seeds were considered germinated when their radicle measured at least 1 mm. The rate of germination was assessed by determining the mean germination time (MGT) and time required to germinate 1, 10, 25, 50, 75 and 90 percent of seeds (parameters T_1, T_{10}, T_{25}, T_{50}, T_{75} and T_{90}).

The objective of growth test was to evaluate length and weight of triticale plants subjected to magnetic doses described as above during the first stages of development (2^{nd}, 4^{th} and 6^{th} days after seeding). Control C ran simultaneously while treated seeds were exposed to doses P1–P10. The treated seeds with their long axes vertical were glued to filter paper with a non toxic adhesive. Each filter paper with seeds was rolled and placed in a vessel containing distilled water. Rolls carrying 25 seeds were used for each magnetic dose and for control (non-exposed seeds). All vessels containing rolls with seeds were numerically labelled and placed randomly during the test. No other substance was added to the water during the experimental period. Growth was measured as follows: total length (stem + root) and stem length in mm; total fresh weight (stem + root) and fresh stem weight in mg. At 2 and 4 days after seeding, the rolls of filter paper were unrolled and the length of seedlings was measured; the filter papers were then re-rolled and placed again in the vessels in order to evaluate, on the 6^{th} day their length and fresh plant weight of the same group of seedlings.

In germination test, statistical analysis of variance and mean comparisons ($p \leq 0.001$; $0.001 \leq p \leq 0.01$; $0.01 \leq p \leq 0.05$) was performed using the Seedcalculator software developed for seed germination data analysis by Plant Research International; the software provides the germination curves for each treatment, a comparison of the results of all the treatments and a comparison of those results with the result of the control. In growth test, data statistics were analyzed with SPSS 11.0 for Windows software (v.18). Results were subjected to an analysis of variance (ANOVA) to detect differences between the mean of parameters. Normality of data and homogeneity of variance, were checked with the Kolmogorov–Smirnov and Levene tests, respectively. Means were compared using Tukey test (multiple comparisons) and Dunnet test to detect differences between the parameters of treated plants and control.

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RESULTS AND DISCUSSION

Germination test. The percentage of germinated seeds (G_{max}) and the time required for germination (parameters MGT, T_1–T_{90}) were determined for each dose, expressed as the mean of the four replicates and their standard error; the germination parameters obtained from triticale seeds exposed to 125 mT magnetic field (doses P1-P5), and the results obtained for doses of P6-P10 (250 mT) are provided in Table 2 and Table 3 respectively. The number of germinated seeds (G_{max}), from 80 to 99 %, corroborates the high quality of seeds. Fewer than 90% of seeds exposed to a magnetic field for less than 20 minutes germinated earlier than the control seeds; parameters T_{10} – T_{90} and the mean germination time were reduced for all the applied magnetic doses. The mean germination time (MGT) was significantly reduced for doses P3, P4, P5 (18.00±0.24 h), P8, P9 and P10 *vs*. control group. The time required to germinate 1%, parameter T_1, of seeds exposed to a magnetic field was less than control. As T_1 is closely related to the onset of germination, these results indicate that triticale seeds exposed to a magnetic field sprouted earlier. The time required for germination recorded for each treatment was, in general, less than the corresponding control values; thus the rate of germination of treated seeds was higher than that of the untreated seeds (C).

Growth test. The mean total length of triticale seedlings measured on the 2nd day after seeding for all doses, compared with control are shown in figure 1. On the 2nd day, greatest differences in mean total length were observed in doses P10 and P5 compared with control. Results of mean total length measured on the 4th day are shown in figure 2. The greatest length of seedlings was obtained for doses P10 and P9. Figure 3 shows results measured on the 6th day after seeding; plants with all doses were higher than control plants; the greatest increases were obtained for P10 and P8 compared with control. Consequently, all plants exposed to magnetic fields prior sowing grew higher than control.

Although the mechanisms at work in plants and other living systems exposed to a magnetic field are still not well known, several theories have been proposed, including biochemical changes or altered enzyme activities [Phirke *et al*., 1996]. An experimental study on water absorption by lettuce seeds previously exposed to a stationary magnetic field of 1–10mT was carried out; an increase in water uptake due to the applied magnetic field, which could explain of the increase in the germination speed of treated lettuce seeds was reported [García *et al*., 2001]. Exposure to magnetic fields improved parameters like water uptake, leaf photosynthetic efficiency and leaf protein content was found [Shine *et al*., 2011]. Our results are in agreement with the germination data of maize seeds, an increase in germination and shoot development in seeds exposed to 150 mT magnetic field for 10, 15, 20 and 30 minutes was found [Aladjadiyan *et al*., 2002]. Magnetic treatment of 30 mT and 85 mT on two broad bean cultivars affected positively the germination and emergence [Podlesni *et al*., 2004]. Effect of magnetic field on *Asparagus officinalis* and *Ocimum basilicum* seed germination and seedling growth were positive [Soltani *et al*., 2006 a,b]. The leaf, stem and root relative growth rates of tomato plants grown from magnetically treated seeds were greater than those of control plants [Souza *et al*., 2008]. Magnetic field application enhanced chickpea seed germination speed; seedling length and seedling dry weight. Seeds were exposed in batches to static magnetic fields ranging in intervals of 50 mT of from 0 to 250 mT for 1-4 h in steps of 1 hour for all fields. Best results were obtained from exposures of 50 mT for 2 h, 100 mT for 1 h and 150 mT for 2 h [Vashisth *et al*., 2008]. Accelerated germination after magnetic stimulation of wheat seeds was observed working with 30, 45 and 60 mT magnetic field strengths [Pietruszeski *et al*., 2010].

In previous studies author found an increase in the rate of germination of seeds and a stimulation of growth of seedlings. They found a positive growth response to a 125 mT and 250 mT magnetic field in rice, wheat and barley seeds [Flórez *et al*., 2004, Martínez *et al*., 2000, 2002]. The greatest stimulation of growth was observed in seeds chronically exposed to a magnetic field or in seeds treated for 24 hours. An increase of the initial growth stages and an early sprouting of maize seeds exposed to a stationary magnetic field was also observed [Flórez *et al*., 2007], treated plants grew higher and heavier than control. Effect of exposure of grass seeds to 125 mT and 250 mT was studied [Carbonell *et al*., 2008], finding that mean germination time was reduced by 10% compared with control seeds; the time required for germination onset was also reduced and the roots of grass seedlings from chronically exposed seeds grew higher and longer than those of untreated ones. Recently they have also obtained an early germination in *Salvia officinalis* L. and *Calendula officinalis* L, [Flórez *et al*., 2012]. Different theories have been proposed on the biological changes: external magnetic field effects at biochemical level and activating proteins and enzymes can increase the growth potential of seeds; magnetic field can interact with internal electric field of biological systems though its resonating behavior and cold be effective on the diffusion of biological particles in solutions [Liboff *et al*., 1988]. The orientation of ferromagnetic particles and modulation of radical-pair reactions are reported as the mechanism of magnetic field effect [Faten *et al*., 2009]. Living cells possess electric charges exerted by ions or free radicals, which act as endogenous magnets. Treatments with magnetic field are assumed to enhance seed vigor by influencing the biochemical processes that involve free radicals, and by stimulating activity of proteins and enzymes. Numerous studies suggested that magnetic field increases ions uptake and consequently improves nutrition value which could be a good alternative for chemical treatments [Stange *et al*., 2002].

CONCLUSIONS

Results obtained in this study allow us to conclude that magnetic treatment improves germination rate of triticale seeds. In general, most of the parameters recorded for all the doses applied to triticale seeds were better than control values. Thus, the rate of germination of treated triticale seeds was higher than the untreated seed (C) rate. The greatest reductions in the mean germination time (the most important parameter) were for P10 (24h to 250 mT) and P5 (24h to 125 mT) doses. Furthermore, seedlings from magnetically treated seeds grew taller than control. Seedlings from P10 and P5 obtained the longest mean total length during the 3 days of measurement (days 2, 4 and 6 after sowing).

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Figure 1. Mean total length of triticale plants from seeds exposed to 125 and 250mT, measured on 2nd day, including the 95% confidence intervals. (a) Mean total length for doses 125 mT: P1 (1 min), P2 (10 min), P3 (20 min), P4 (1hour), P5 (24 hours); C (Control). (b) Mean total length for doses 250 mT: P6 (1 min), P7 (10 min), P8 (20 min), P9 (1hour), P10 (24 hours); C (Control).

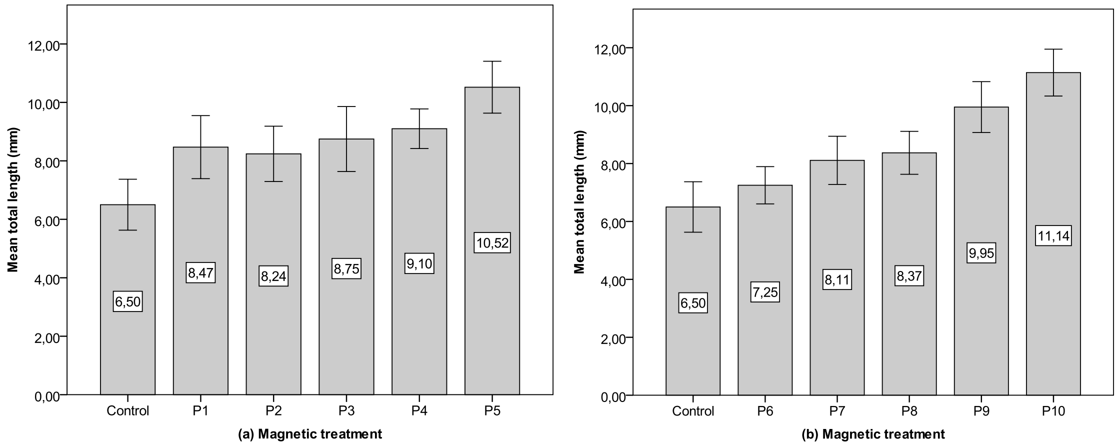

Figure 2. Mean total length of triticale plants from seeds exposed to 125 and 250mT, measured on 4th day, including the 95% confidence intervals. (a) Mean total length for doses 125 mT: P1 (1 min), P2 (10 min), P3 (20 min), P4 (1hour), P5 (24 hours); C (Control). (b) Mean total length for doses 250 mT: P6 (1 min), P7 (10 min), P8 (20min), P9 (1hour), P10 (24 hours); C (Control).

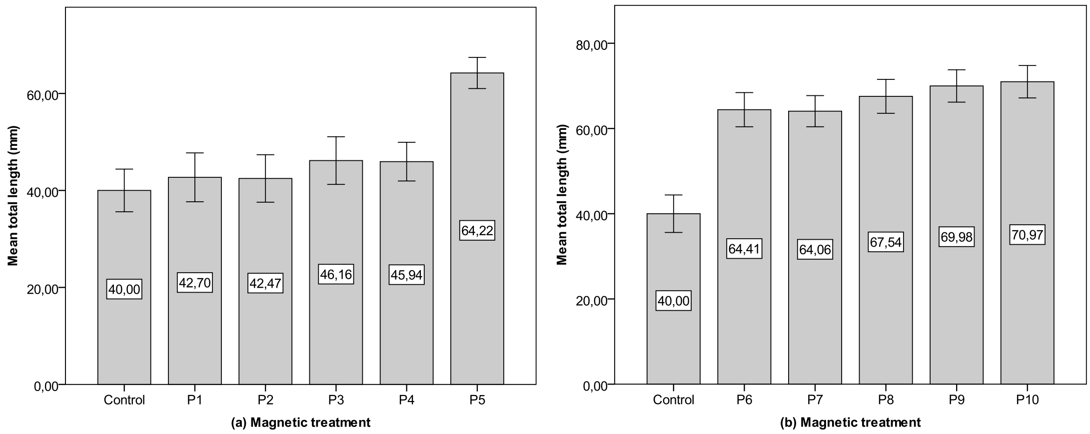

Figure 3. Mean total length of triticale plants from seeds exposed to 125 and 250mT, measured on 6th day, including the 95% confidence intervals. (a) Mean total length for doses 125 mT: P1 (1 min), P2 (10 min), P3 (20 min), P4 (1hour), P5 (24 hours); C (Control). (b) Mean total length for doses 250 mT: P6 (1 min), P7 (10 min), P8 (20 min), P9 (1hour), P10 (24 hours); C (Control).

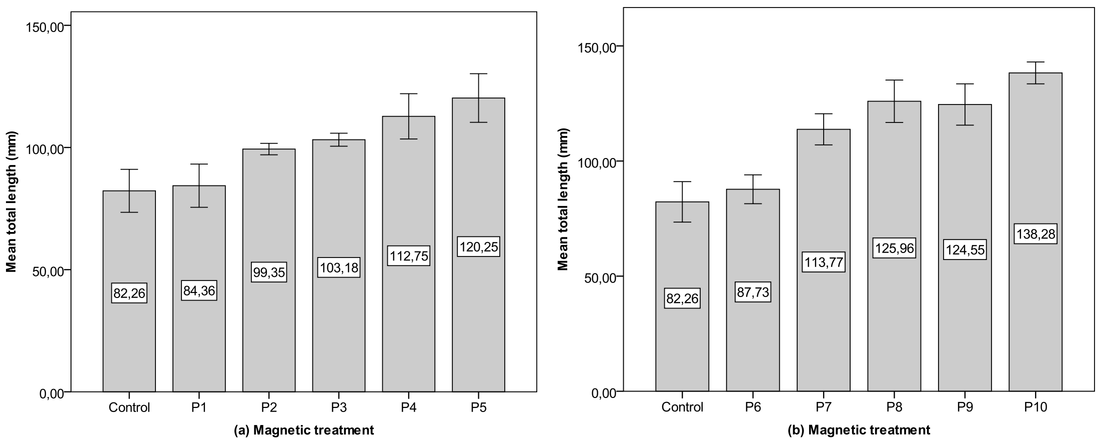

Table 1. Coding of magnetic treatments and exposure time.

Time	125 mT	250 mT
0	C	C
1 min	P1	P6
10 min	P2	P7
20 min	P3	P8
1 h	P4	P9
24 h	P5	P10

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Table 2. Germination parameters determined for triticale seed exposed to 125 mT stationary magnetic fields, expressed as mean value and standard error and as percentage.

G_{max}: number of germinated seeds (%); MGT: Mean germination time; T_1, T_{10}, T_{25}, T_{50}, T_{75}, T_{90}: time needed to obtain 1,

	G_{max}	**T_1**		**T_{10}**		**T_{25}**		**T_{50}**		**T_{75}**		**T_{90}**		**MGT**	
125 mT	**%**	**hours**	**%**	**hours**	**%**	**hours**	**%**	**hours**	**%**	**hours**	**%**	**hours**	**%**	**hours**	**%**
C	80± 1.63	15.12± 0.24	100	16.80± 0.24	100	18.00± 0.24	100	19.20± 0.24	100	20.40± 0.24	100	-	-	19.20± 0.24	100
P1	81± 4.73	14.88± 0.48	98.41± 3.17	16.56± 0.24	98.57± 2.86	17.76± 0.24	98.67± 1.33	19.20± 0.24	100.00± 1.25	20.40± 0.24	100.00± 1.18	-	-	19.20± 0.24	100.00± 1.25
P2	81± 3.79	14.64± 0.72	96.83± 4.76	16.56± 0.48	98.57± 1.43	17.76± 0.24	98.67± 1.33	19.20± 0.24	100.00± 1.25	20.40± 0.24	100.00± 1.18	-	-	19.20± 0.24	100.00± 1.25
P3	93± 1.9 b	13.92± 0.24 a	92.06± 1.59 a	15.84± 0.24 a	94.28± 1.43 a	17.04± 0.24 a	94.66± 1.33 a	18.48± 0.24	96.25± 1.25	19.92± 0.48	97.64± 2.35	22.32± 5.28	-	18.48± 0.24 b	96.25± 1.25 b
P4	95± 1 c	13.68± 0.48 a	90.48± 3.17 a	15.60± 0.24 a	92.86± 1.43 a	16.80± 0.24 b	93.33± 1.33 b	18.00± 0.24 b	93.75± 1.25 b	19.44± 0.24 b	95.29± 1.18 b	20.88± 0.24	-	18.24± 0.24 b	95.00± 1.25 b
P5	96± 1 c	13.44± 0.24 a	88.89± 1.59 a	15.36± 0.24 b	91.43± 1.43 b	16.56± 0.24 b	92.00± 1.33 b	18.00± 0.24 c	93.75± 1.25 c	19.20± 0.24 b	94.12± 1.18 b	20.64± 0.24	-	18.00± 0.24 c	93.75± 1.25 c

10, 25, 50, 75 and 90 % of seeds to germinate, expressed in hours. Letters indicate differences *vs*. control: c ($p<0.001$); b ($0.001<p<0.01$) ; a($0.01<p<0.05$). Doses 125 mT: P1 (1 min), P2 (10 min), P3 (20 min), P4 (1hour), P5 (24 hours); C (Control).

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Table 3. Germination parameters determined for triticale seeds exposed to 250 mT stationary magnetic fields, expressed as mean value and standard error and as percentage

G_{max}: number of germinated seeds (%); MGT: Mean germination time; T_1, T_{10}, T_{25}, T_{50}, T_{75}, T_{90}: time needed to obtain 1,

	G_{max}	T_1		T_{10}		T_{25}		T_{50}		T_{75}		T_{90}		MGT	
250 mT	**%**	**hours**	**%**	**hours**	**%**	**hours**	**%**	**hours**	**%**	**hours**	**%**	**hours**	**%**	**hours**	**%**
C	80± 1.63	15.12± 0.24	100	16.80± 0.24	100	18.00± 0.24	100	19.20± 0.24	100	20.40± 0.24	100	-	-	19.20± 0.24	100
P6	88± 2.83	14.40± 0.48	95.24± 3.17	16.32± 0.24	97.14± 1.43	17.52± 0.24	97.33± 1.33	18.72± 0.24	97.50± 1.25	20.16± 0.24	98.82± 1.18	-	-	18.96± 0.24	98.75± 1.11
P7	89± 2.5 a	14.16± 0.24	93.65± 1.59	16.08± 0.24	95.71± 1.43	17.28± 0.24	96.00± 1.33	18.72± 0.00	97.50± 0.00	20.16± 0.00	98.82± 0.00	21.6± 0.24	-	18.72± 0.24	97.5± 1.25
P8	94± 1.15 c	13.44± 0.24 b	88.89± 1.59 b	15.60± 0.24 b	92.86± 1.43 b	16.80± 0.24 b	93.33± 1.33 b	18.24± 0.24 a	95.00± 1.25 a	19.92± 0.24	97.65± 1.18	20.88± 0.24	-	18.48± 0.24 a	96.25± 1.11 a
P9	95± 3.79 a	13.20± 0.24 b	87.30± 1.59 b	15.36± 0.24 b	91.43± 1.43 b	16.56± 0.24 b	92.00± 1.33 b	18.00± 0.24 b	93.75± 1.25 b	19.68± 0.24 a	96.47± 1.18 a	20.88± 0.24	-	18.24± 0.24 b	95.00± 1.11 b
P10	99± 1 c	12.72± 0.24 b	84.13± 1.59 b	14.88± 0.24 c	88.57± 1.43 c	16.32± 0.24 c	90.67± 1.33 c	17.76± 0.24 c	92.50± 1.25 c	19.44± 0.24 b	95.29± 1.18 b	20.64± 0.24	-	18.00± 0.24 c	93.75± 1.11 c

10, 25, 50, 75 and 90 % of seeds to germinate, expressed in hours. Letters indicate differences *vs*. control: c ($p<0.001$); b ($0.001<p<0.01$) ; a($0.01<p<0.05$). Doses 250mT: P6 (1 min), P7 (10 min), P8 (20 min), P9 (1hour), P10 (24 hours); C (Control).