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Germination of tomato seeds (*Lycopersicon esculentum* L.) under magnetic field

E. Martínez[1], M.V. Carbonell[1], M. Flórez[1], J.M. Amaya[1], and R. Maqueda[2]*

[1]Departament of Physics and Mechanics, College of Agricultural Engineering, Technical University, Ciudad Universitaria s/n, 28040 Madrid, Spain
[2]Environmental, Rural and Marine Ministry, Spanish Office of Vegetable Varieties, Madrid, Spain

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A b s t r a c t. Magnetic field is an inescapable factor for plants on the Earth; however its impact on plants growth is not well understood. Magnetic and electromagnetic treatments are being used in agriculture, as a non invasive technique, to improve the germination of seeds and increase crops and yields. The effects of a stationary magnetic field on the germination and initial stages of growth of tomato seeds (*Lycopersicon esculentum* L.) have been studied. The seeds were exposed to a magnetic field strength (125 or 250 mT) for different time as different treatments (doses D1 to D12). To evaluate germination number of germinated seeds (G), mean germination time (MGT), and the time required for 1 to 90% of the seeds to germinate (T_1, T_{10}, T_{25}, T_{50}, T_{75}, and T_{90}) were determined. Parameter T_{10}, which is closely related to the early germination and latent period of seeds, was reduced when seeds were exposed to a magnetic field. The MGT was also reduced compared to control when seeds were exposed to magnetic field The germination parameters recorded for each treatment were lower than corresponding control values, then germination rate of treated seeds is higher than the control.

K e y w o r d s: magnetic stationary field, *Lycopersicon esculentum* L., germination, seedlings

INTRODUCTION

In general, the living systems are beings influenced by the Earth's magnetism. The processes of life take place in an electromagnetic context result from an interactive conjunction between the vital magnetism and geomagnetic field which is an important global component of the average outside. It is evident that, when an interaction process, take place, any type of modification will repel of some form in the set of vital processes. Magnetic and electromagnetic treatments are being used in agriculture, as a non invasive technique, to improve the germination of seeds and increase crops and yields. References summarize the beneficial effects observed on seedlings magnetically treated under different conditions, which depend on the specific magnetic treatment applied such as time of exposure, magnetic field strength, stationary or alternating, frequency *etc.* These effects include increases of food reserve utilization, better absorption and assimilation of nutrients by plants (Kavi, 1977) and photosynthetic activities (Lebedev *et al*., 1977).

In this study the germination and growth of tomato seeds magnetically treated have been evaluated. In previous studies, the authors have found that magnetic treatment produces a biostimulation on initial growth stages and an early sprouting of several seeds (Amaya *et al*., 1996). Carbonell *et al*. (2000) concluded that a stationary magnetic field acts as a non-invasive external stimulant for germination of rice seeds. Data obtained showed that the exposure to 125 or 250 mT magnetic field generated by magnets for the first 20 min after seeding increases the rate and percentage of germination of rice seeds *vs*. nonexposed seeds. Chronic exposure to the same artificial magnetic field strength also increased the germination over the sprouting stage. The increase in germination when seeds were magnetically treated could be explained by better availability and absorption of nutrients. A stimulatory effect on the first stages of growth of barley plants exposed to 125 mT stationary magnetic field has been found by Martínez *et al*. (2000). Chronic exposure to 125 and 250 mT had a significant stimulatory effect on the initial stages of growth of wheat plants, Martínez *et al*. (2002). Increases on growth of signalgrass seeds were also obtained, (Carbonell *et al*., 2004). Flórez *et al.* (2004) observed a higher germination rate of treated seeds according to a higher length and weight of rice plants exposed to 125 or 250 mT stationary magnetic field for different periods of time

*Corresponding author's e-mail: victoria.carbonell@upm.es

varying from 10 min to chronic exposure. Increases in rate of germination and growth were also obtained for maize seeds; treated plants grew higher and heavier than control, the greatest increased were obtained for plants exposed for 24 h and continuously exposed, Flórez *et al*. (2007). Recently, Carbonell *et al*. (2008) have realized a study about magnetic treatment of grass seeds: *Festuca arundinacea* Scheb and *Lolium perenne* L. They found that the mean germination was significantly reduced by more than 10% related to controls; the time required to the onset of the germination was also reduced. The roots of treated grass seedlings were longer than those of untreated seeds when seeds were permanently exposed.

MATERIAL AND METHODS

Two kinds of experiments were carried out in order to evaluate the effect of a stationary magnetic field on germination of tomato seeds (*Lycopersicon esculentum*, L.) and growth of seedlings. The study was carried out under laboratory conditions, with natural light and an average room temperature of 182ºC. Magnetic treatment of seeds was realized by exposing them to magnetic field for different time of exposure. Ring magnets with magnetic induction 125 mT (D1-D6) and 250 mT (D7-D12) were used. Their geometric characteristics are 75 mm external diameter, 30 mm internal diameter, 10 mm high or 15 mm high respectively. Magnetic field applied was far higher than 0.042 mT corresponding to the local geomagnetic field in the laboratory measured by an EG and G Geometrics G-866 magnetometer.

Doses applied was obtained as follow: D1 exposure to 125 mT for 1 min, D2 for 10 min, D3 for 20 min, D4 for 1 h, D5 for 24 h and D6 for all period of germination test. Similarly, dose D7 was obtained by the exposure to 250 mT for 1 min, D8 for 10 min, D9 for 20 min, D10 for 1 h, D11 for 24 h and D12 for all period of germination test. Non exposed seeds were used as controls (C).

Seeds were placed on filter paper soaked with 12 ml of distilled water in Petri dishes. Four replicates with 25 seeds in each Petri dish was used in the experimental design, thus groups of 100 seeds were subjected to each magnetic treatment and analogous groups were used as control. To obtain each magnetic dose, Petri dishes were placed on the magnet for the corresponding period of time. Germination tests were performed according to the guidelines issued by the International Seed Testing Association (ISTA, 1999) with slight modifications. Petri dishes with seeds were labeled and randomly located; the distance between any two dishes was at least 25 cm to avoid the influence of each magnet on the other dishes around. All doses and control ran simultaneously, and consequently, under identical light and temperature conditions. Number of germinated seeds was scored four times per day for the time necessary to achieve the final number of germinated seeds (G). Seeds were considered as germinated when their radicle showed at least 2 mm. The rate of germination was assessed by determining the following parameters expressed in days:

- mean germination time (MGT) calculated by integration of the fitted curve and proper normalizationł
- T_1, time required for 1% of the seeds to germinate, it defines the onset of germination;
- T_{10}, time required for 10% of the seeds to germinate, it is closely related to the early germination and latent period of seeds;
- T_{25}, T_{50} and T_{75}: time required for 25, 50 and 75 % of the seeds to germinate.

Germination curves were plotted for each treatment and the statistical analysis was performed using the Seedcalculator software specifically developed for seed germination data analysis by Plant Research International (Wageningen, The Netherlands).

The second experiment was realized to corroborate the observed effect in the first one. Magnetic treatment (D12) was applied with a view to evaluate the percentage of germination, length and weight of tomato plants on the 4, 7, and 10th day after seedling. The seeds were glued to filter paper with non toxic adhesive stick, with their long axes vertical. Each filter paper with seeds was rolled and placed in a vessel containing distilled water. Ten replicates, included 16 seeds, were arranged, each replicate; thus, groups of 160 seeds were subjected to magnetic treatment and analogous groups were used as control. The magnet was placed at the top of the vessel for magnetic treatment (Fig. 1). All the rolls were placed into their magnets simultaneously and vessel were labelled with numbers and randomly located to carry out the experiment. In order to evaluate the initial stages of growth, the length of the same seedlings were measured on the 3rd, 7th, and 10th day. Analogous rings like the ring magnets, manufactured with the same material but without magnetic induction are used as blind (control).

Statistical analysis was conducted using SPSS for Windows (version 11.0). After testing the normality of the data distribution, the variance analysis (ANOVA) was used to test the main effects of magnetic field (MF) treatment and their interaction. Kolmogorov-Smirnov and Levene tests were carried out to check normality of data and homogeneity

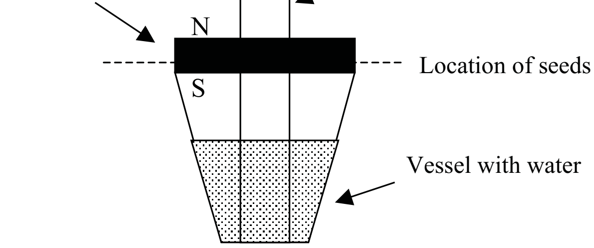

Fig. 1. Vessel containing distilled water, roll of filter paper with seeds inside the hollow cylindrical magnet.

of variance respectively. Means were compared using Tukey test (multiple comparison) and Dunnet test to detect differences between results from treated plants *vs*. control.

RESULTS AND DISCUSSION

The germination parameters determined for each treatment, expressed as mean of the four replicates and their standard error are provided in Table 1. Data were compared by the Seedcalculator software in order to establish the significant differences between each treatment and the control. The results indicate that germination was affected by the magnetic treatment. In general, the germination parameters (T_1-T_{90} and MGT) recorded for each treatment were lower than corresponding control values (C), consequently the germination rate of treated seeds was higher than the untreated seeds.

The MGT was significantly reduced compared to control when seeds were exposed to magnetic field except doses D1 and D7. The most significant differences were found for D12 (107.76 h), D11 (108.48 h), D10 (113.29 h), D6 (110.40 h), D5 (111.36 h) and for D3 (109.92 h) *vs.* control (117.60 h). The time taken for 50% of seeds to germinate (T_{50}) is close to MGT and a reduction of this parameter for all doses applied *vs.* control was also observed. Statistical analysis

T a b l e 1. Germination parameters determined for tomato seeds exposed to 125 and 250 mT stationary magnetic field, expressed as mean and standard error

Dose	Exposure times	Number of germinated seeds (%)	Time (hour) error standar						
			T_1	T_{10}	T_{25}	T_{50}	T_{75}	T_{90}	MGT
Exposed to 125 mT stationary magnetic field									
C	non exposed	90.00 ±1.00	86.88 ±1.68	97.92 ±0.72	105.12 ±1.44	115.20 ±2.40	129.36 ±3.36		117.60 ±1.44
D1	1 min	91.00 ±2.52	88.32 ±1.20	96.96 ±0.96	102.96 ±0.72^{c}	111.12 ±0.72^{c}	124.32 ±4.08		114.00 ±1.20^{b}
D2	10 min	89.00 ±1.00^{b}	89.76 ±0.48^{c}	98.16 ±0.72	103.92 ±0.96	111.60 ±1.20^{c}	124.08 ±2.64		113.04 ±1.44^{b}
D3	20 min	90.00 ±4.16	84.96 ±1.20	94.56 ±0.96^{b}	101.40 ±1.68^{b}	109.44 ±2.16^{c}	121.68 ±3.60^{c}		109.92 ±1.68^{a}
D4	1 h	90.00 ±3.46	84.96 ±0.96	94.80 ±0.96^{b}	101.52 ±1.20^{b}	111.12 ±2.16^{c}	126.96 ±5.28		114.00 ±2.16^{c}
D5	24 h	92.00 ±1.00	82.80 ±2.16	92.64 ±0.48^{a}	99.36 ±1.20^{a}	108.48 ±2.16^{b}	122.64 ±2.16^{c}		111.36 ±0.96^{a}
D6	chronic exposure	91.00 ±1.91	88.32 ±0.96	94.80 ±0.72^{b}	99.60 ±0.72^{a}	106.32 ±0.72^{a}	118.32 ±1.20^{a}		110.40 ±1.20^{a}
Exposed to 250 mT stationary magnetic field									
C	non exposed	90.00 ±1.00	86.88 ±1.68	97.92 ±0.72	105.12 ±1.44	115.20 ±2.40	129.36 ±3.36	162.24 ±5.76	117.60 ±1.44
D7	1 min	91.00 ±1.91	83.04 ±1.44^{c}	94.56 ±0.48^{a}	102.72 ±0.96^{c}	114.00 ±2.40	132.48 ±5.52	–	117.60 ±2.40
D8	10 min	92.00 ±3.65	86.40 ±1.44	94.80 ±1.20^{b}	100.56 ±1.20^{b}	108.48 ±1.92^{b}	120.72 ±4.80^{c}	169.44 ±37.20	111.36 ±1.92^{b}
D9	20 min	95.00 ±3.00	85.68 ±1.92	94.56 ±0.48^{a}	100.56 ±1.20^{b}	108.72 ±2.16^{b}	120.44 ±3.84^{c}	143.52 ±34.00	111.84 ±0.96^{a}
D10	1 h	94.00 ±2.00	87.36 ±0.72	95.76 ±0.96^{c}	101.52 ±1.20^{b}	109.44 ±1.68^{b}	121.44 ±1.68^{b}	153.84 ±37.92	113.28 ±0.48^{b}
D11	24 h	90.00 ±2.58	84.72 ±2.40	92.40 ±1.20^{a}	97.92 ±1.20^{a}	105.6 ±1.44^{a}	118.56 ±2.40^{b}	–	108.48 ±2.64^{a}
D12	chronic exposure	95.00 ±1.00^{c}	87.60 ±0.96	93.84 ±0.72^{a}	98.16 ±0.48^{a}	103.92 ±0.72^{a}	112.80 ±1.92^{a}	135.12 ±19.68	107.76 ±1.68^{a}

Upper letters indicate differences *vs*. control: a – $p < 0.001$, b – $p < 0.01$, c – $p < 0.05$.

showed significant differences $p<0.001$ for D6, D11 and D12; $p<0.01$ for D5, D8, D9 and D10, and $p<0.05$ for D1, D2, D3 and D4. Parameter T_{10}, which is closely related to the early germination and latent period of seeds, was reduced when seeds were exposed to a magnetic field. The T_{10} value for treatments D3 to D12, varying from 94.56 h (D3) to 92.40 h (D11) was significantly lower than 97.92 h needed for the control seeds; this reduction implies an earlier onset of germination process. The time taken for 75% of treated seeds to germinate (T_{75}) was reduced for all doses except D7. Parameter T_{75} of control seeds was 129.36 h while the T_{75} of D12 was 112.80 h, this value involves the 87.19% of time required for control seeds. Number of germinated seeds (G) oscillated from 90 to 95 %, which corroborates the high quality of seeds. Results indicate that magnetic treatment improves germination of tomato seeds; parameters $T_{10}-T_{90}$ and the mean germination time, were reduced for all the magnetic doses applied. Then, germination rate of treated seeds is higher than the control.

Figure 2a shows germination curves for the treatments D3, D5, D6 and C; Fig. 2b shows the germination curves for doses D9, D11 and D12 and control. Curves located left of control, indicate earlier sprouting, then seeds magnetically treated, plotted in Figs 2a and b, showed that the germination rate of treated seeds was higher than the untreated seeds (C).

Figure 3 shows the total length for tomato plants chronically exposed to 250 mT stationary magnetic field (D12) and control (C) measured the 4, 7, and 10th day. Significant differences ($p<0.001$) on total length between plants subjected to magnetic field and control ones were obtained; We can observe that magnetic treatment produces an increase in the first stages of growth of tomato plants.

References about the biological effects of magnetic field have demonstrated that magnetic field can cause or alter a wide range of phenomena, but the wide diversity of the reported effects remains the greatest problem for this research. Basic hypotheses concerning magneto-sensing and consequent signal transduction, specially that involving calcium, are considered (Belyavskaya, 2004). Studies carried out by Aksyonov *et al*., 2001 showed that 15 min treatment of wheat seeds by 30 mT magnetic field followed by 17 h imbibitions, when they initiated root growth, increased the root formation by nearly 25%; the length of 6 day seedlings displayed a 40% increase.

Our results are in agreement with those reported by Pittman (1963) who observed an increase on rate of germination of cereal seeds exposed to magnetic field. Alexander and Doijode (1995) noted that the application of an external magnetic field as a pregermination treatment improved the germination and seedling vigour of low viability rice and onion seeds. Similar results were obtained by Murphy (1994) and Phirke *et al.* (1996). Further, Pietruszewski (1996) reported greater albumin, gluten and starch contents in wheat seeds exposed to a magnetic field. The mechanisms at work when plants and other living systems are exposed to a magnetic field are not as well known yet, but several theories have been proposed, including biochemical changes or altered enzyme activities. Boe *et al.* (1963, 1968) proposed a possible mechanism associated with magnetism to accelerate tomato ripening. Dayal and Singh (1968) exposed tomato seeds to different magnetic fields varying from 15 to 155 mT

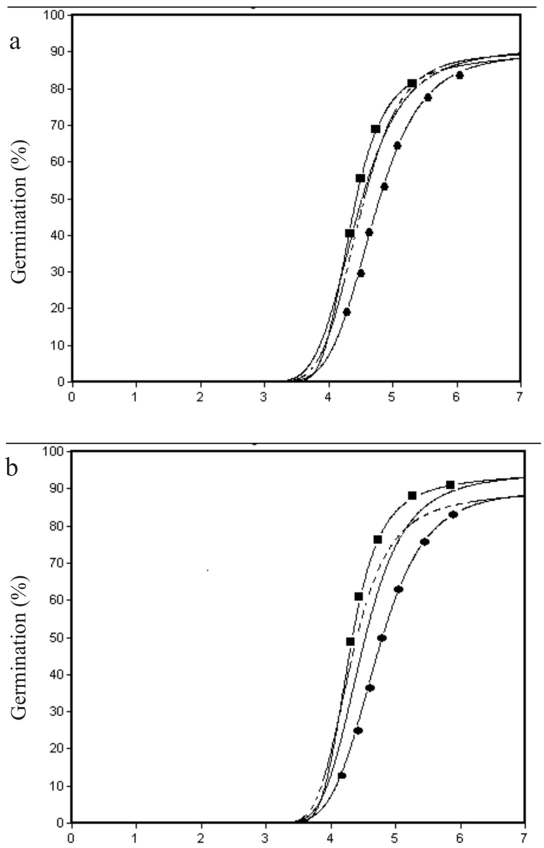

Fig. 2. Germination curves of tomato seeds: a – seeds exposed to 125 mT for 20 min (D3), 24 h (D5), chronic exposure (D6) and control; b – seeds exposed to 250 mT for 20 min (D9), 24 h (D11), chronic exposure (D12) and control.

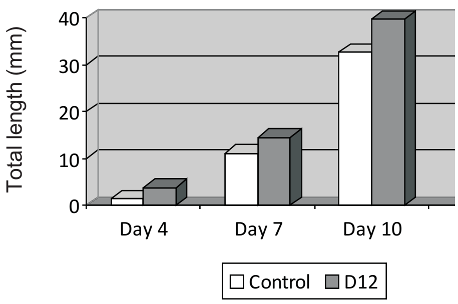

Fig. 3. Total length for tomato plants chronically exposed to 250 mT stationary magnetic field (D12) and control (C) measured the 4, 7 and 10th day.

for different exposure time and they observed an increase in height and number of primary branches in treated plants. Garcia *et al.* (2001) observed that lettuce seeds previously treated in a stationary magnetic field of 1-10 mT germinated earlier than the untreated, which could be due to an increase in water uptake rate. Podleśny *et al*. (2004) published the positive effect of magnetic treatment on the germination and emergence of two broad bean cultivars. Similar effects were observed on cucumber seedlings by Yinan *et al.* (2005). Soltani *et al*. (2006 a, b) have published the positive effect of magnetic field on *Asparagus officinalis* and *Ocimun basilicum* seed germination and seedling growth.

CONCLUSIONS

1. Germination parameters (T_1-T_{90}), recorded for each treatment, were lower than corresponding control values (C), consequently the germination rate of treated seeds was higher than the untreated seeds.

2. The mean germination time (MGT) was significantly reduced compared to control when tomato seeds were exposed to magnetic field.

3. Magnetic treatment increases the first stages of growth of tomato plants.

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