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*Original Research*

# Pea (*Pisum sativum*, L.) and Lentil (*Lens culinaris*, Medik) Growth Stimulation Due to Exposure to 125 and 250 mT Stationary Fields

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

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

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### Abstract

Pea and lentil seeds were exposed to 125, 250 mT magnetic field. Total weight, stem weight, total and stem length were measured after 7 and 14 days of exposure. Growth parameters of these seeds were increased; consequently, seedlings from seeds magnetically treated grew taller and heavier than controls. These differences were highly significant for 24 hour (D5, D11) and chronic exposure (D6, D12). An increase in both weight and length of pea and lentil plants was observed with respect to control groups, yielding significant differences in the 14-day group ($p<0.001$) for every parameter. Increased root development was also observed.

**Keywords:** magnetic stationary field, *Pisum sativum*, *Lens culinaris*, seeds, parameters of growth

## Introduction

The electric and magnetic fields produced by electronic devices in everyday use require studies of their effects on living organisms. Magnetic fields (MF) and electromagnetic fields (EMF) have been widely used as pre-sowing seed treatment to increase seedling growth and yield. In previous studies authors have found that magnetic treatment produces biostimulation of the initial growth stages and early sprouting of several seed types [1, 2]. The present study aims to evaluate the effects on the growth of pea and lentil plants from seeds exposed to one of two magnetic field strengths (125 or 250 mT) for different periods of time (1 minute, 10 min, 20 min, 24 h and chronic exposure).

The biological effects of magnetic fields on living systems have been explored by many authors working in several areas, particularly in agricultural science. Most of these studies are focused on the effects of EMFs on seedling growth and yield [3-5], changes in photosynthetic activity under magnetic conditions [6-9] and absorption and assimilation of nutrients [10, 11]. Several authors have found that a stationary magnetic field acts as a non-invasive external germination and growth stimulant. An increase in yield of 6.3% and fiber length of 9.4% in cotton seeds magnetically treated before seeding [12], and a positive effect on the initial growth stages of bean, pea, corn and soya subjected to 0.08 T magnetic field have been found [13].

The number of crops subjected to magnetic fields is increasing steadily. Scientists have tried to determine some magnetic field effects on roots, such as changes in biochemical activity, curvature, and magnetotropism. The induction of primary root curvature in radish seedlings in a static magnetic field was observed; roots responded tropically to the static magnetic field, with the tropism appearing to be negative. These roots responded significantly to the south pole of the magnet [14]. Magnetic field pre-treat-

*e-mail: elvira.martinez@upm.es

ment on cucumber seedlings stimulated seedling growth and development [15]. A significant increase in leaf area and leaf dry weight per tomato plant in the vegetative stage was also observed from seeds exposed to a magnetic field induced by an electromagnet (100 mT for 10 min and 170 mT for 3 min). Also, the leaf, stem and root relative growth rates of plants grown from magnetically treated seeds were greater than those of control plants. At fruit maturity stage, all magnetic treatments significantly increased mean fruit weight, fruit yield per plant, fruit yield per area, and the equatorial diameter of fruit in comparison with controls. Enhancement of growth and yield of tomato crop [16] was found, due to magnetic treatment prior to sowing.

## Material and Methods

The test was performed in the beginning of summer under laboratory conditions. The natural light cycle was 14 h-light/10 h-darkness and the daily temperature 25±2ºC, night temperature 22±2ºC.

### Seeds and Magnetic Treatment

Growth tests were carried out under laboratory conditions to study the effect of the exposure of pea and lentil seeds to stationary magnetic fields. Pea seeds, *Pisum sativum*, L. variety Aravalle, and lentil seeds, *Lens culinaris*, Medik. subsp. culinaris variety Agueda, were supplied by the Spanish Office of Vegetable Varieties, which guarantees high seed viability and homogeneity, and thus the significance of results from a relatively small sample.

The experimental design involved ten replicates (n=10), with 6 seeds in each. Groups of 60 seeds were subject to each magnetic treatment, and analogous groups were used as control. Pea and lentil seedlings were cultured in small plastic pots (6.5 x 6.5 x 5.8 cm) containing 28 g of compacted vegetable substratum; 35 ml of distilled water were added. The vegetable substratum used has the following characteristics: the content in fertilizer is 350 mg/l (N), 300 mg/l ($P_2O_5$) and 400 mg/l ($K_2O$), salt content 1.50 g/l and pH 6.5.

Seeds were placed on the substratum, covered by 31 g of substratum and irrigated with 30 ml of distilled water. To obtain each magnetic dose, pots were placed on the magnet for the established time.

All pots, labeled with numbers, were located randomly in the experiment. Some plants were designated to be measured in the first week and others in the second week.

The exposure time (t) and magnetic field induction (B) of magnetic treatment were varied. The magnetic field was generated by ring magnets (75 mm external diameter, 30 mm internal diameter, 10 mm high, $B_1$ and 15 mm high, $B_2$) with magnetic induction values $B_1$=125 mT and $B_2$=250 mT. Rings analogous to the ring magnets, of the same material but without magnetic induction, were used as blind (Control). The magnetic doses D1-D12 applied were:

- Exposure to 125 mT: D1 (1 minute), D2 (10 minutes), D3 (20 minutes), D4 (1 hour), D5 (24 hours), D6 (continuous exposure).
- Exposure to 250 mT: D7 (1 minute), D8 (10 minutes), D9 (20 minutes), D10 (1 hour), D11 (24 hours), D12 (continuous exposure).

To apply magnetic doses D1-D6, pots were kept on top of 125 mT magnets for the corresponding time; whereas D7 to D12, pots were kept on 250 mT magnets. The distance between any two pots was at least 25 cm, to avoid the influence of each magnet on the neighbouring pots. Pots of control groups (C1 and C2) were placed on blind-rings from the beginning. All doses and controls ran simultaneously. On the 7$^{th}$ and 14$^{th}$ day after seeding, plants were removed from soil, carefully washed and their length and weight were measured. Seedling growth was evaluated in terms of total length (stem+root) and stem length, total fresh weight (stem+root) and stem fresh weight.

### Statistical Analysis

Growth data was statistically analyzed with Windows software SPSS 11.0. The results were variance analyzed (ANOVA) to detect differences between parameter means.

Normality of data and homogeneity of variance were Kolmogorov-Smirnov and Levene-tested, respectively. Means of treated and control plant parameters were compared using Tukey (multiple comparisons) and Dunnet tests.

## Results

### Results of Pea Seeds

Tables 1 and 2 summarize the mean values and standard error of length and weight of pea seedlings cultured in vegetable substratum, measured on the 7$^{th}$ and 14$^{th}$ days after seeding. On the 7$^{th}$ day, stem length and total length between plants subjected to magnetic field (D3, D4, D5, D6, D9, D10, D11 and D12) differed significantly from control lengths ($p<0.001$); increases varied between 17% and 27% relative to control. Fresh stem weight and total weight of pea seedlings subjected to the doses above were significantly different from control. In the same way, on the 14th day, length and weight of plants subjected to doses D5 and D6 were significantly different from control C1, while doses D11 and D12 significantly different from control C2.

### Results of Lentil Seeds

Data obtained for lentil seeds exposed to magnetic field are plotted as bar charts in Fig. 1. From the results we can observe that most parameters of plants subject to magnetic treatment were greater than the controls, measured on the 7$^{th}$ and 14$^{th}$ days after seeding. The most significant increases were achieved for doses D5, D6, D11 and D12; a week after seeding, increases of total length of plants subjected to the above doses were 34.26% (D5), 35.29% (D6), 32.88% (D11) and 62.09% (D12) relative to their controls. On the 7$^{th}$ day, statistical analysis reveals the mean values of stem and total length of plants exposed to dose D2 were significantly greater ($p<0.01$) than the control; doses D3 and D4

Table 1. Growth parameters of pea seedlings exposed to 125 mT stationary magnetic field.

| Dose | 7th day | | | | 14th day | | | |
|---|---|---|---|---|---|---|---|---|
| | SL (mm) | TL (mm) | SW (mg) | TW (mg) | SL (mm) | TL (mm) | SW (mg) | TW (mg) |
| C1 | 96.97 ± 2.16 | 253.24 ± 5.17 | 385.59 ± 9.92 | 680.71 ± 17.99 | 185.78 ± 3.74 | 331.98 ± 8.42 | 694.64 ± 15.56 | 1,075.93 ± 26.00 |
| D1 | 101.90 ± 2.32$^{ns}$ | 264.48 ± 6.30$^{ns}$ | 398.19 ± 11.22$^{ns}$ | 733.98 ± 20.41$^{ns}$ | 198.73 ± 4.67$^{ns}$ | 346.02 ± 10.88$^{ns}$ | 719.78 ± 21.31$^{ns}$ | 1,115.98 ± 29.43$^{ns}$ |
| D2 | 106.91 ± 1.49$^{c}$ | 292.05 ± 5.78$^{b}$ | 402.95 ± 8.81$^{ns}$ | 747.71 ± 20.76$^{ns}$ | 200.50 ± 3.49$^{c}$ | 345.50 ± 9.14$^{ns}$ | 709.02 ± 16.61$^{ns}$ | 1,100.27 ± 27.82$^{ns}$ |
| D3 | 113.30 ± 1.75$^{a}$ | 301.13 ± 8.96$^{a}$ | 410.84 ± 8.95$^{a}$ | 781.88 ± 19.79$^{a}$ | 206.38 ± 3.93$^{a}$ | 359.91 ± 6.68$^{ns}$ | 787.43 ± 18.50$^{a}$ | 1,216.19 ± 34.47$^{b}$ |
| D4 | 118.56 ± 5.08$^{a}$ | 306.22 ± 8.97$^{a}$ | 415.37 ± 8.84$^{ns}$ | 764.15 ± 18.22$^{b}$ | 210.93 ± 3.09$^{a}$ | 354.57 ± 6.69$^{ns}$ | 774.32 ± 14.90$^{b}$ | 1,255.12 ± 34.11$^{a}$ |
| D5 | 121.25 ± 2.01$^{a}$ | 312.58 ±13.51$^{a}$ | 455.92 ± 10.35$^{a}$ | 796.88 ± 18.22$^{a}$ | 221.36 ± 2.93$^{a}$ | 380.85 ± 7.47$^{a}$ | 800.46 ± 17.73$^{a}$ | 1,268.47 ± 26.01$^{a}$ |
| D6 | 123.39 ± 1.30$^{a}$ | 321.03 ± 5.44$^{a}$ | 472.74 ± 6.14$^{a}$ | 836.67 ± 16.74$^{a}$ | 230.60 ± 3.41$^{a}$ | 393.42 ± 8.16$^{a}$ | 815.19 ± 16.00$^{a}$ | 1,276.07 ± 25.71$^{a}$ |

Time of exposure: 1 minute (D1), 10 minutes (D2), 20 minutes (D3), 60 minutes (D4), 24 hours (D5), chronic exposure (D6) and untreated (C1). SL (stem length), TL (total length), SW (stem weight), TW (total weight). a,b,c indicate significant differences *vs*. control: $^{a}$($p<0.001$); $^{b}$($0.001<p<0.01$); $^{c}$($0.01<p<0.05$); $^{n.s}$ not significant.

Table 2. Growth parameters of pea seedlings exposed to 250 mT stationary magnetic field.

| Dose | 7th day | | | | 14th day | | | |
|---|---|---|---|---|---|---|---|---|
| | SL (mm) | TL (mm) | SW (mg) | TW (mg) | SL (mm) | TL (mm) | SW (mg) | TW (mg) |
| C2 | 93.16 ± 1.29 | 238.71 ± 4.94 | 399.78 ± 8.40 | 752.16 ± 19.44 | 135.00 ± 2.20 | 300.00 ± 6.99 | 582.42 ± 15.27 | 1,044.28 ± 31.77 |
| D7 | 104.17 ± 1.55$^{a}$ | 256.78 ± 4.02$^{ns}$ | 436.05 ±1 0.23$^{c}$ | 835.90 ± 20.59$^{c}$ | 144.91 ± 3.58$^{c}$ | 328.09 ± 6.61$^{c}$ | 640.81 ± 13.42$^{c}$ | 1,102.71 ± 25.67$^{ns}$ |
| D8 | 96.61 ± 1.64$^{ns}$ | 260.08 6.15$^{ns}$ | 466.64 ± 10.76$^{a}$ | 830.39 ± 18.45$^{c}$ | 143.42 ± 1.53$^{ns}$ | 318.92 ± 7.22$^{ns}$ | 666.65 ± 11.75$^{a}$ | 1,136.28 ± 28.01$^{ns}$ |
| D9 | 107.00 ± 1.53$^{a}$ | 288.10 ± 9.58$^{a}$ | 511.57 ± 10.06$^{a}$ | 901.98 ± 19.96$^{a}$ | 148.19 ± 2.28$^{a}$ | 315.73 ± 7.04$^{ns}$ | 666.55 ± 12.89$^{a}$ | 1,148.35 ± 30.89$^{ns}$ |
| D10 | 108.93 ± 2.44$^{a}$ | 285.53 ± 9.89$^{a}$ | 473.53 ± 9.89$^{a}$ | 902.25 ± 23.27$^{a}$ | 149.58 ± 2.90$^{a}$ | 309.42 ± 6.01$^{ns}$ | 660.23 ± 13.98$^{a}$ | 1,133.37 ± 28.76$^{ns}$ |
| D11 | 114.75 ± 1.26$^{a}$ | 285.39 ± 5.31$^{a}$ | 488.78 ± 6.88$^{a}$ | 900.51 ± 17.69$^{a}$ | 153.64 ± 2.81$^{a}$ | 348.88 ± 6.88$^{a}$ | 688.73 ± 15.67$^{a}$ | 1,204.81 ± 31.06$^{a}$ |
| D12 | 119.08 ± 1.05$^{a}$ | 288.31 ± 3.85$^{a}$ | 516.52 ± 8.37$^{a}$ | 912.85 ± 18.84$^{a}$ | 157.77 ± 1.71$^{a}$ | 378.71 ± 7.08$^{a}$ | 711.80 ± 14.52$^{a}$ | 1,219.29 ± 33.42$^{a}$ |

Time of exposure: 1 minute (D7), 10 minutes (D8), 20 minutes (D9), 60 minutes (D10), 24 hours (D11), chronic exposure (D12) and untreated (C2). SL (stem length), TL (total length), SW (stem weight), TW (total weight). a,b,c indicate significant differences *vs*. control: $^{a}$($p<0.001$); $^{b}$($0.001<p<0.01$); $^{c}$($0.01<p<0.05$); $^{n.s}$ not significant.

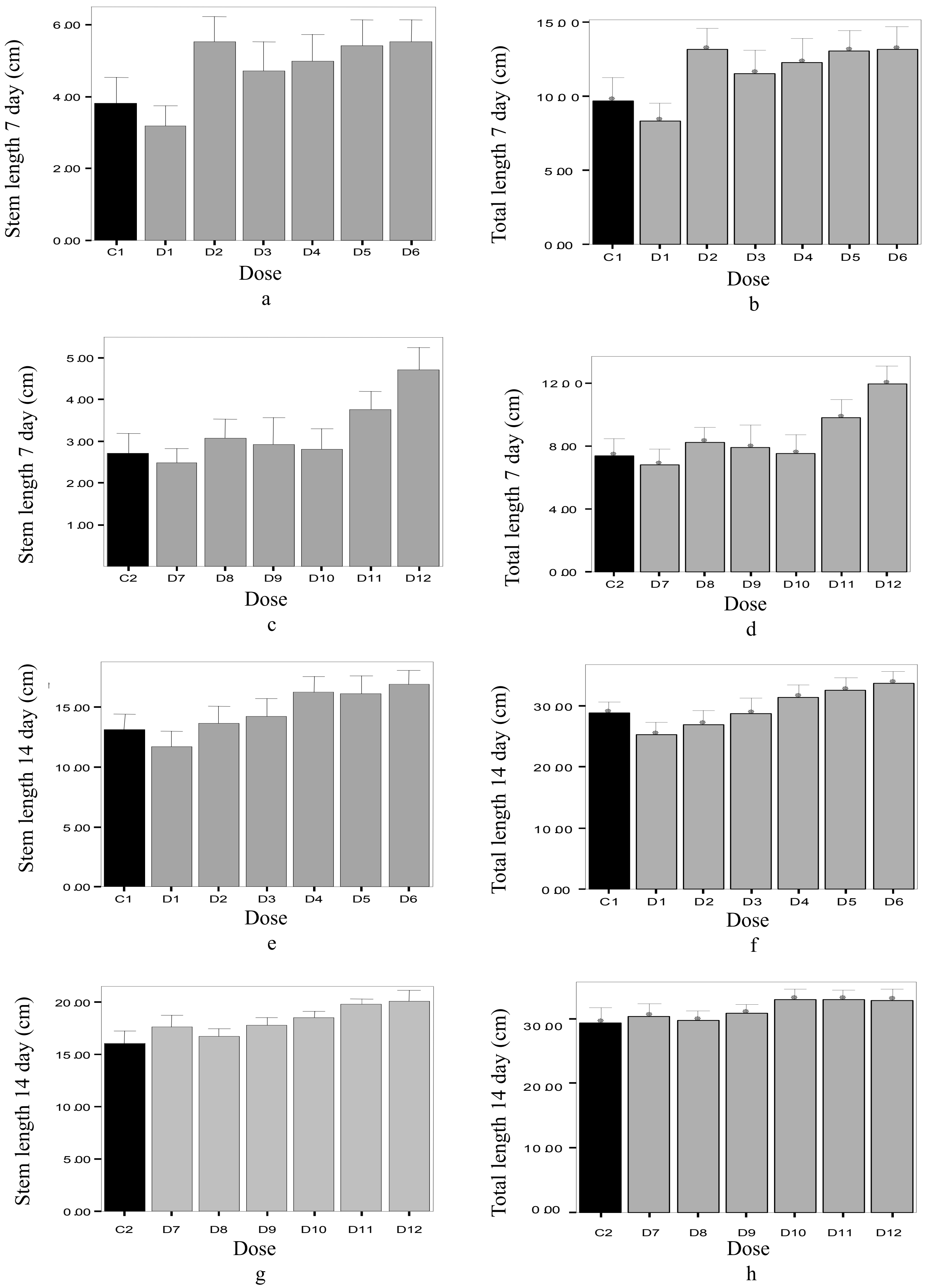


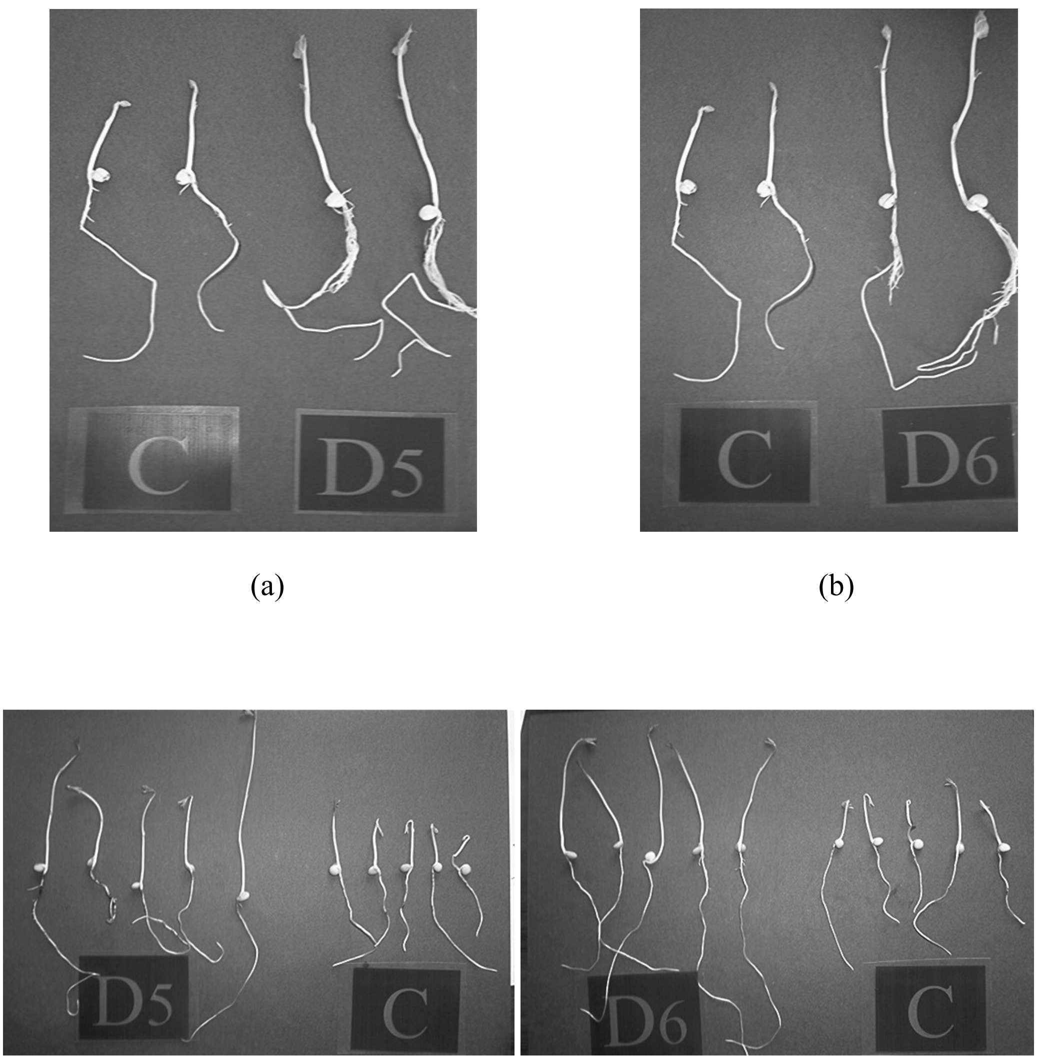

Fig. 1. Growth parameters of lentil seeds; (a, b) stem and total length on the 7th day, doses D1-D6 and C1; (c, d) stem and total length on the 7th day, doses D7-D12 and C2; (e, f) stem and total length on the 14th day, doses D1-D6 and C1; (g, h) stem and total length on the 14th day, doses D7-D12 and C2.

provided significant differences ($p<0.05$) relative to control. Similar increases were obtained for the stem and total weight of plants. On the 14th day, statistical analysis revealed that doses D11 and D12 provide the greatest increases of most parameters and leads to the conclusion that magnetic treatment of lentil seeds has a positive effect on growth.

From joint analysis of the results obtained for both species of seeds, it is apparent that exposure of seeds to both magnetic field strengths for all doses increases length and weight. In addition, we observed that roots of plants exposed to a magnetic field were more highly developed, as shown in Fig. 2. This indicates that the magnetic field has a positive effect on the growth of roots and stems.

## Discussion

These results are in agreement with those reported by several authors from different seeds and magnetic field strengths. Magnetic-treated seeds germinated better than control seeds, with a notable increase in height of lentils and tomato plants subjected to 250 mT stationary magnetic field [17]. Epicotyls of pea seedlings incubated under low magnetic field (LMF) were elongated. Cell elongation and increased osmotic pressure of cell sap were found in the epidermal cells exposed to LMF [18]. A stationary magnetic field acts as a non-invasive external stimulant for germination of rice seeds; data obtained showed that exposure to an artificial magnetic field generated by magnets for the first 20 min after seeding increases the rate and percentage of germination of rice seeds vs. non-exposed seeds [19]. Chronic exposure to the same magnetic field strength significantly stimulated the initial stages of growth of wheat plants [20]. Increased germination and shoot development in wheat seeds exposed to 150 mT magnetic field for 10, 15, 20 and 30 minutes were found with similar results for tobacco seeds [21, 22]. Other authors obtained similar results, depending on magnetic field strength, seed studied and other conditions. The positive effect of magnetic treatment on the germination and emergence of bean cultivars was confirmed; plant emergence from magnetized seeds




(a) (b) (c) (d)

Fig. 2. Comparison of seedlings exposed to 125 mT magnetic field with control; (a) pea seedlings, D5 and control C1; (b) pea seedlings, D6 and control C1. (c) lentil seedlings, D5 and control C2; (d) lentil seedlings, D6 and control C2.

was 2-3 days earlier than control; yield was increased due to the larger number of pods per plant [20]. Complementary studies revealed other effects of magnetic fields on plants, such as an increase of aminoacid uptake and ion movement across the plasma membrane [24] and the stimulation, by chronic exposure, of biosynthesis of chlorophyll and carotenes, with an increase of up to 21% [25]. Germination and the initial stages of growth of rice plants exposed to 125 mT or 250 mT stationary magnetic field for periods of time varying from 10 minutes to chronic exposure were studied. Increases in rate of germination and growth were also obtained for maize seeds; treated plants grew higher and heavier than control. The greatest increases were obtained for plants exposed for 24 h and continuously exposed [26, 27]. All samples of young plants of maize exposed to a magnetic field varying from 50 to 250 mT were longer [28].

## Conclusion

Results obtained for pea and lentil seeds allow us to conclude that magnetic treatment improves the first stages of growth of plants. The magnetic doses applied to these seeds were accompanied by an increase in the parameters of growth; consequently, the seedling from magnetically treated seeds grew taller and heavier than their controls. These differences were significant for 24 hours (D5, D11) and chronic exposure (D6, D12).

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