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THE EFFECTS OF ELECTROMAGNETIC TREATMENTS ON THE GROWTH AND PALMITIC ACID CONTENT OF *Cynara carduncula*s

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ABSTRACT

A field experiment on cardoon seeds (*Cynara cardunculus* L.) was carried out during two successive seasons to study the effect of electromagnetic fields (EMF) on cardoon growth and its palmitic acid content. A 75 mT (*millitesla*) EMF was used as follows: EMF0 (control) not exposed to the magnetic field, three different EMF exposure durations studied as EMF1 (T1): 15 min, EMF2 (T2): 30 min, or EMF3 (T3): 45 min, considered for both non-soaked/dry (D) and soaked seeds (W). The EMF had significant effects on most of the studied parameters. EMF2D and EMF3W exhibited the best growth attributes for dry and soaked seeds, respectively. Additionally, the palmitic acid (C16:0) content in producing seeds was significantly influenced by 15 and 30 min of exposure to the EMF, in the case of dry seeds. The maximum value of palmitic acid content was 11.83% compared to a control value of 9.30%. These findings suggest that EMF treatments of cardoon seeds have the potential to enhance the cardoon plant growth and the palmitic acid content.

Key words:cardoon; *Cynara cardunculus*; electromagnetic field; palmitic acid; seed.

INTRODUCTION

Electro-culture can protect plants from diseases, insects, and frost. This method can also reduce the use of fertilizers or pesticides, and growers can produce higher yields of better quality crops in less time, with less effort, and at a lower cost. Electro-culture can be applied to the seeds, plants, soil, or to the water and nutrients. Noteworthy increases of plant growth and productivity have been claimed in response to electromagnetic fields (EMFs). Latterly in many countries, *C. cardunculus* has been considered a biomass crop for energy and paper pulp production, and as green forage for ruminants in winter seasons (Grewal and Maheshwari, 2011).

An awareness of the bioactive chemical composition of cultivated cardoon is vital to increase its economic value, and subsequently to domesticate its production in the Kingdom of Saudi Arabia (KSA). Palmitic acid (hexadecanoic acid; a saturated fattyacid) is commonly found in animals, plants and microorganisms. Palmitic acid does show antioxidant properties and can help prevent atherosclerosis in rats, but it is not as effective as oleic acid (Cho *et al*., 2010). The salt form of palmitic acid is called palmitate, which is commonly added to low-fat and fat-free milk. Palmitic acid has industrial uses in the production of soaps, cosmetics, and release agents (French *et al*., 2002). In this context, it is important that the oil from cardoon seeds possesses a high palmitic acid content. The aim of this research was to study the effect of EMF treatments at the presowing stage on cardoon plant growth during the vegetative and generative stages, and to evaluate the palmitic acid content of the final seed yield.

MATERIALS AND METHODS

Seedlings and field conditions: Cardoon seeds of uniform size and shape were exposed to a controlled electromagnetic field in collaboration with the Department of Physics, College of Science and Humanities, Prince Sattam bin Abdulaziz University, Alkharj, Saudi Arabia and were sown in the experimental farm station of Sara Alghonaim Research Chair, Alkharj (24° 04′ N, 47° 08′ E), Saudi Arabia. *C. cardunculus* seeds were supplied by Jelitto GmbH, Schwarmstedt, Germany. Monthly temperature values were recorded during the two growing seasons and are presented in Table 1.

Cardoon seeds were sown in trays of 3.2x3.2x4.5 cm cell size in a medium of peat and sand (1:1) in September at the Sara Alghonaim Research Chair, Alkharj, Saudi Arabia. After four weeks, the seedlings were transplanted into pots of 14 cm diameter sprayed with a nutrient solution [1 g^{-1} litre] of (Triplex Amino 20-20-20+MICRO) at age of 5 and 7 weeks. The 8 weeks old cardoon seedlings were transplanted into the field, according to a Complete Randomized Block Design (CRBD) with three replicates. The properties of the soil used for growing cardoon are as presented in Table 2.

The field plot consisted of fifteen plants with a planting density of 10415 plants ha^{-1}, and inter and intrarow distances of 80 and 120 cm, respectively. The transplanting date was the first week of November for two successive seasons. Manual weeding was carried out two times a year over the study period. Minimal fertilization was conducted when the plants exhibited 6-8 true leaves (90 kg ha^{-1} of urea). Manual harvesting of the cardoon heads was undertaken at the end of each of the two growing seasons. All necessary horticultural practices were undertaken for the durationof the two growing seasons.

EMF exposure conditions: Presowing electromagnetic field treatments were applied as described by Sharaf-Eldin *et al*. (2015) with slight modifications as shown in Figure 1. The strength of the electromagnetic field (EMF) is being measured by a teslameter in conjunction with a tangential B-probe (Leybold Didactic GmbH, Huerth, Germany).

Cardoon seeds were loaded into a Falcon tube 15 mL, and the Falcon tube was then placed in the ring of the electromagnet. The seeds were exposed to a 75 mT EMF for varying time intervals: EMF1 (T1): 15 min, EMF2 (T2): 30 min and EMF3 (T3): 45 min. EMF0 (control) was not exposed to the electromagnetic field at all. In each case results were considered for both non-soaked/dry (D) and soaked seeds (W), soaked in water for 120 min before the EMF treatments.

Table 1. The meteorological information at the experimental farm station.

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
						Year 2011						
Max *T* (ºC)[1]	41	33	29	21	23	26	30	32	37	39	41	44
Min *T* (ºC)[1]	27	22	10	6	10	13	16	21	27	33	32	32
						Year 2012						
Max *T* (ºC)	37	34	27	34	22	26	29	36	41	42	40	40
Min *T* (ºC)	29	20	14	12	7	12	13	20	32	33	36	29

[1]: mean temperature.

Table 2. Soil properties of the experimental farm station.

Clay (%)	Silt (%)	Sand (%)	$C_{org.}$ (%)	OM[1] (%)	pH	EC (dSm^{-1})	N[2] (ppm)	P[3] (ppm)	K[3] (ppm)
17.2	8.5	74.8	0.36	0.63	7.76	1.47	16.9	14.1	153.17

[1] – organic matter, [2] – total, [3] – available.

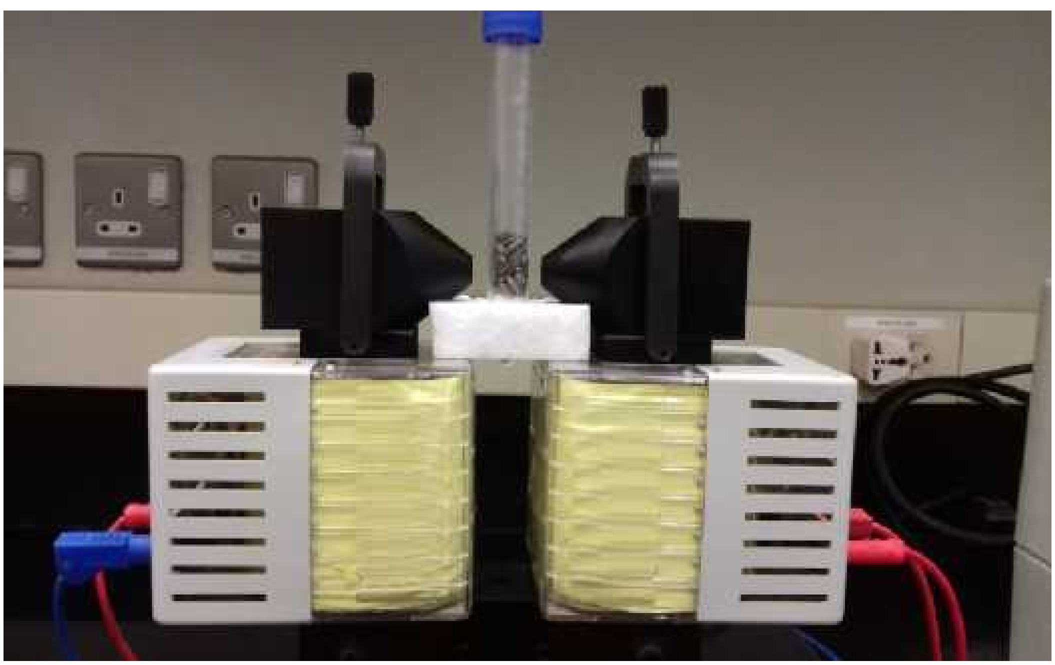

Figure 1. The experimental of electromagnet field setup. A Falcon tube 15 mL is placed in the air gap between the two iron poles to expose the seeds to electromagnetic fields (EMF).

Evaluation of the palmitic acid content in collecting seeds

Sample preparation and extraction procedure: At the end of the two growing seasons, matured cardoon seeds were collected from each treatment. The seeds were processed following the method described by Sharaf-Eldin *et al*. (2015).

GC-MS analysis: The gas chromatography-mass spectrometry analysis (GC-MS) is an advanced technique to isolate, identify and quantify the main components in a sample substance. Three different analytical methods were used to identify the compounds: 1) Kovats indices (KI), 2) GC-MS retention indices (authentic chemicals), and 3) mass spectra (authentic chemicals and the NIST05 spectral library collection). Identification was considered to be tentative when it was based only on mass spectral data (Sharaf-Eldin *et al*., 2015).

Statistical analysis: All the experimental data were statistically analysed using CoStat Version 3.03, an interactive statistics program for computers. F-test and the least significant difference (LSD) used for the comparison between treatment means at the 5% probability level, according to Snedecor and Cochran (1982).

RESULTS AND DISCUSSION

The growth parameters of *C. cardunculus* plants were compared with control plants 105 days after transplanting. It was found that EMF treatment in the presowing stage significantly enhanced the growth characteristics of plant height, number of leaves and number of offshoots per plant, fifth leaf width and length, and longest leaf length. The palmitic acid content in the collected yield of seeds was also found to have significantly increased at the 95% confidence interval of the mean. Figure 2 represents the mean values of plant height and shows the 95% confidence interval of the mean. Significant differences between both electromagnetically treated and untreated seeds were observed for all the applied exposure durations, compared to the control group, but the strongest effects were evident for EMF2D followed by the EMF3W treatments.

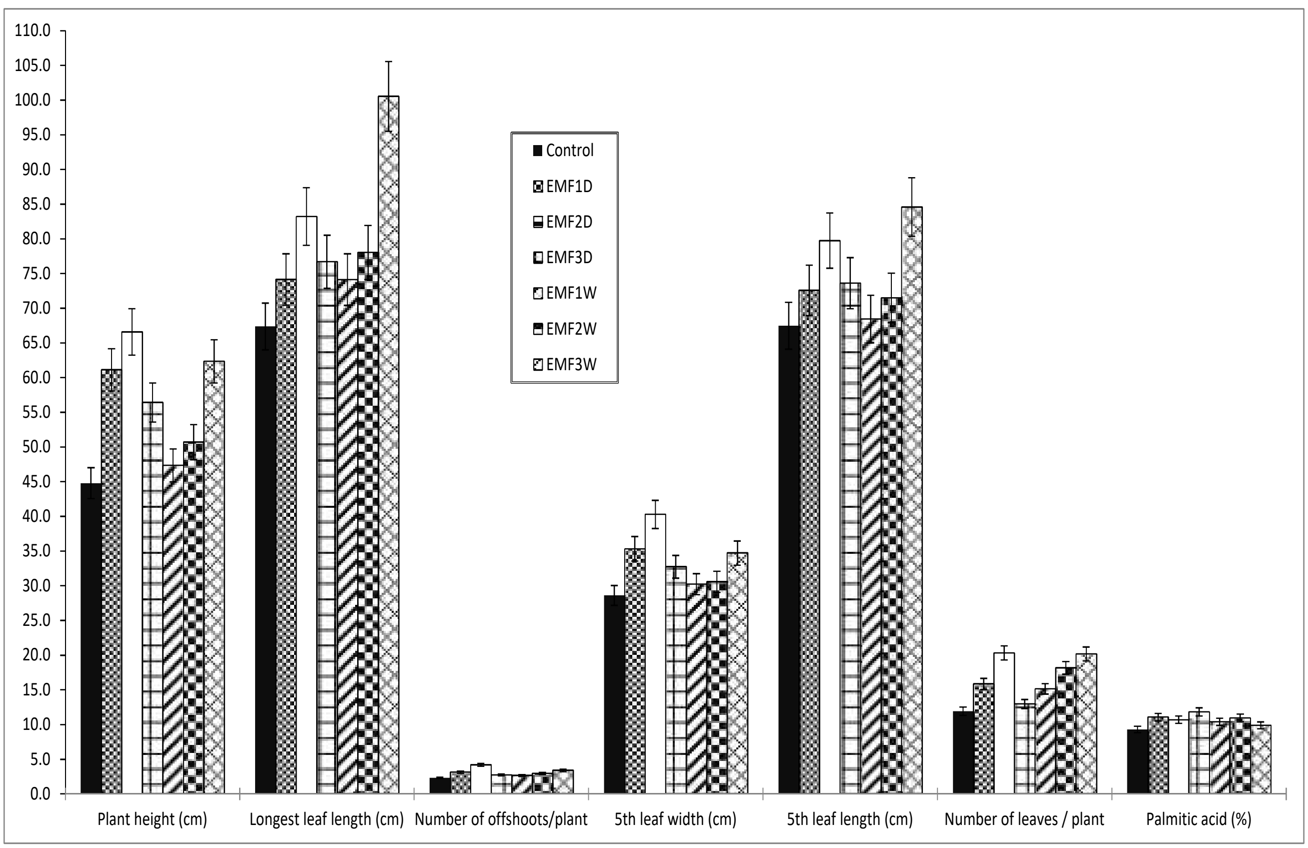

Figure 2. The effect of electromagnetic field (EMF) on *C. cardunculus* growth and palmitic acid content during the first season. Control: not exposed to the EMF, three different EMF exposure durations as EMF1 (T1): 15 min, EMF2 (T2): 30 min, or EMF3 (T3): 45 min, D: non-soaked/dry seeds, W: soaked seeds. The legend for Y-axis is [cm, pure number and percentage] in correlation exactly as presented in X-axis.

The mean number of leaves per plant of treated sample was 20.32 for EMF2D followed by EMF3W (20.17), while that of control was just 11.92. The number of offshoots per plant was also found to be remarkably less significantly affected ($P<0.05$), with pre-treatment, increasing the number of offshoots per plant compared with untreated samples. The maximum value of offshoot numbers per plant was 4.20 compared to a control value of 2.33 (Figure 2). This suggests that lateral growth was greatly increased after pre-treatment with EMF. Figure 2 sets out the mean values of cardoon plant fifth leaf width and length, showing the 95% confidence interval of the mean. The greatest differences between treated and untreated samples were obtained for the exposure durations of EMF2D and EMF3W, respectively. Significant differences compared to the control were also obtained, however, for all other applied exposure durations.

Figure 2 demonstrates the mean values of longest leaf length, showing the 95% confidence interval of the mean. Here, the greatest differences between treated and untreated samples were obtained for exposure durations of EMF3W and EMF2D. Significant differences compared to the control were also obtained, however, for all other applied exposure durations. Finally, in respect to the palmitic acid content of the collected yield of seeds, EMF pre-treatment enhanced the palmitic acid content compared to the untreated samples. The maximum value of palmitic acid content was 11.83% compared to a control value of 9.30% (Figure 2). The same trends for all parameters shown in Figure 2 were observed in the second season, but with slight differences in values as shown in Figure 3.

It is significant to note that the growth parameters of cardoon plants treated with EMF were found to be significantly better than those of the control plants: the EMF treatments improved plant height, number of leaves and offshoots per plant, fifth leaf width and length, longest leaf length, and palmitic acid contents of the collected yield of seeds. Our findings are in agreement with those of other researchers across a range of different crops. Flórez *et al*. (2007) and Vashisth and Nagarajan (2008) noted improvements in the growth of maize, chickpea and sunflower seeds when treated magnetically (Vashisth and Nagarajan, 2010). Likewise, Fischer *et al*. (2004) observed improved growth of sunflower plants compared to the growth exhibited by untreated seed samples. Marks and Szecówka (2010), meanwhile, reported that the surface parts of the potato plant exhibited more vigorous growth when subjected to variable presowing EMF stimulation, and Flórez *et al*. (2004) reported improvements in rice germination when exposed to 125/250 mT EMF for specific time intervals.

The literature clearly shows that the most beneficial effects occur when there is an appropriate combination of optimal exposure doses and optimal exposure durations. This study shows that appropriate EMF treatment for specific exposure durations can accelerate the growth and enhance the palmitic acid content of the collected seeds significantly in the cardoon plant. Our results in respect to the growth parameters of cardoon plants are in agreement with (Yinan *et al*. (2005) for cucumber and Podleśny *et al*. (2004) for magnetically treated wheat, barley and many bean cultivar seeds.

The fact that our results show that the improvement in cardoon plant growth parameters is correlated with the palmitic acid content suggests that these improvements might be attributed to higher α-amylase, dehydrogenase, and protease activities (Vashisth and Nagarajan, 2010). α-Amylase, in particular, is responsible for depleting the nutrient reserves of the seedling during germination, therefore a more active α-amylase may be a factor in the increased growth in magnetically treated seeds compared with the unexposed control.

One model that has been suggested to explain how EMF interact with biological systems is the radical pair mechanism. In this model electromagnetic fields are seen as modulating the single/triplet inter-conversion rates of a radical pair. The EMF increases the average concentration of free radicals by prolonging their lifetime and thus increasing the probability of a radical reaction with cellular components. When the exposure duration of EMF is increased, the effects of that field on growth parameters change because of the increased peroxide activity (Atak *et al*., 2003).

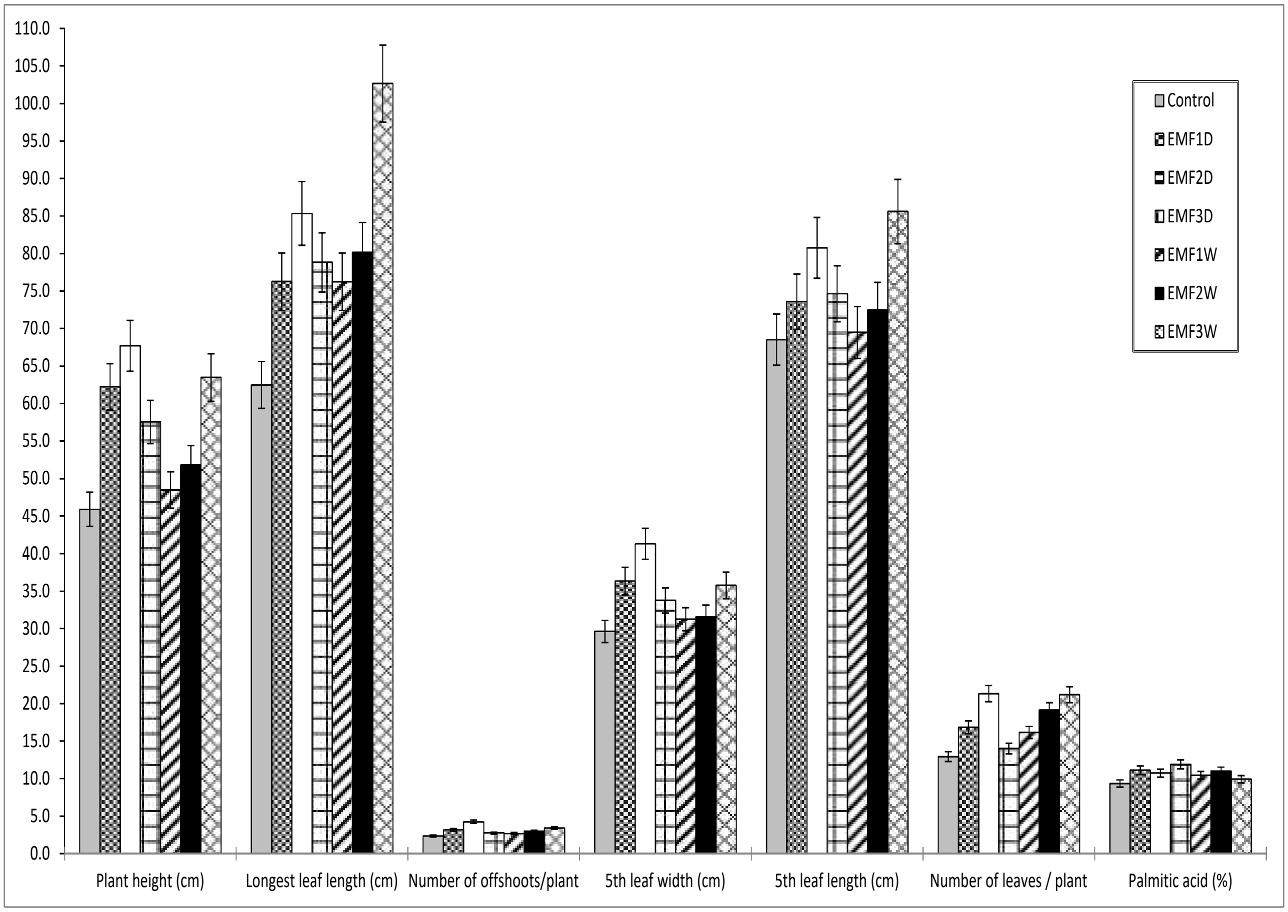

Figure 3. The effect of electromagnetic field (EMF) on *C. cardunculus* growth and palmitic acid content during the second season. Control: not exposed to the EMF, three different EMF exposure durations as EMF1 (T1): 15 min, EMF2 (T2): 30 min, or EMF3 (T3): 45 min, D: non-soaked/dry seeds, W: soaked seeds. The legend for Y-axis is [cm, pure number and percentage] in correlation exactly as presented in X-axis.

Conclusions: This study has shown that the electromagnetic field (EMF) treatments significantly enhanced cardoon (*Cynara cardunculus* L.) plant growth parameters in comparison with a control sample. In addition, EMF treatments have a significant positive effect on the palmitic acid content of cardoon seeds. Together, these results indicate that magnetically treated seeds can be used to improve growth rates in agricultural settings, leading to enhanced biomass and palmitic acid content. These findings suggest that EMF treatments of cardoon seeds have the potential to enhance the plant growth and the palmitic acid content.

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