Article

Electromagnetic field in seedlings, yield and quality of corn in field conditions

Rosalba Zepeda Bautista[1§]
Juan Virgen Vargas[2]
Francisco Suazo-López[3]
F. Arturo Domínguez-Pacheco[1]
Hilda Rodríguez-Rebollar[1]
Claudia Hernández-Aguilar[1]

[1]Higher School of Mechanical and Electrical Engineering-National Polytechnic Institute-Professional Unit 'Adolfo López Mateos'. Col. Lindavista, Mexico City. CP. 07738. (fartur@hotmail.com; hilreb70@hotmail.com; clauhaj@yahoo.com). [2]Valle de México Experimental Field-INIFAP. Highway Los Reyes-Texcoco km 13.5, Coatlinchán, Texcoco, State of Mexico. CP. 56250. (jvirgen-vargas@hotmail.com). [3]Department of Agricultural High School-Chapingo Autonomous University. Mexico-Texcoco Highway km 38.5, Chapingo, State of Mexico. CP. 56230. (suazofl@hotmail.com).

[§]Corresponding author: rzb0509@hotmail.com.

Abstract

To improve productivity and quality of corn grain (*Zea mays* L.) for human consumption, without damaging the environment, the effect of the electromagnetic field (EMF) on physiological quality, yield and health of corn grain was evaluated. The seed was exposed to EMF at an intensity of 3.6 mT. Under field conditions, in 2015 and 2016, varieties were evaluated: H-70, H-61R and V-60 and three times of exposure to EMF (6, 12 and 24 min) more a control (non-irradiated) in a design of random complete blocks. The results showed that the seed exposed for 24 min to EMF increased 10.54% and two days the establishment of seedlings and the average male flowering; likewise, 11.04% the yield ha^{-1} (870 kg ha^{-1}) compared to the non-irradiated control. H-70 and V-60 had higher establishment of seedlings with 24 minutes of exposure to EMF (17.5 and 8.23%) and H-61R with 12 min (9.75%). H-61R and V-60 yielded more (10.85 and 8%) with 12 min of EMF exposure and H-70 increased 27.14% with 6 min compared to the control. The grain was quantified on average 9.22 and 7.72% of *Fusarium* spp. and *Fusarium oxysporum*. With 12 min of EMF exposure, the presence of *Fusarium* spp. in comparison with the control. Electromagnetic field, used as seed pre-sowing treatment of corn varieties, significantly increases the establishment of seedlings, but not the grain yield under field conditions.

Keywords: *Fusarium* spp., *Zea mays* L., hectoliter weight, seed vigor, yield.

Reception date: January 2019
Acceptance date: March 2019

Introduction

Between 2017 and 2026, it is estimated that world corn consumption will grow at an average annual rate of 1.35%. The average consumption will be 1 093.9 million tons, 13.22, 16.48 and 58.68% for human consumption, biofuels and animal feed with an average annual growth rate of 1.99, 1.26 and 1.49% (OECD and FAO, 2017). In 2016, there were 1 060 million tons produced in the world with an average yield of 5.69 t ha^{-1}, 70.61% was produced by EE. UU, China, Brazil, Argentina and Mexico. Mexico produced 28.25 million tons of corn (2.66% of the total) and imported 7.15 million tons.

In 2013, 14.23 million tons of corn were used to produce food with a *per capita* consumption of 318.74 g $person^{-1}$ day^{-1}, which provides the 49.3 and 21.1% of energy and protein required by the human body (FAO, 2018). In developing countries, between 2017 and 2026 consumption will increase 1.45% annually with a difference between production and consumption of 8.58%, equivalent to 48.3 million tons (OECD and FAO, 2017) because productivity is lower, in Mexico it is of 3.71 t ha^{-1}, compared to developed countries, in the USA. UU is 10.96 t ha^{-1}, (FAO, 2018). Therefore, it is necessary to increase the productivity and quality of the corn grain with the efficient use of natural, financial and human resources, without damaging the environment.

In corn, productivity has increased between 50 and 60% due to genetic improvement and between 40 and 50% caused by the management of agronomic practices (Duvick, 2005; Lee and Tollenaar, 2007). In corn hybrids, with the doses 67 and 145 kg N ha^{-1} an average yield of 7.42 and 10.64 t ha^{-1} was obtained, compared to 252 and 202 kg N ha^{-1}, which yielded 36 and 9% more, respectively (Haegele *et al*., 2013; Kovács *et al*., 2014). However, the excessive use of N is causing severe environmental problems due to air, soil and water pollution (Nazir *et al*., 2016; Bouwman *et al*., 2017). An alternative is to use techniques for environmentally friendly production such as the electromagnetic field.

Electromagnetic fields are a combination of invisible electric and magnetic force fields. Alternating magnetic fields reverse their meaning with a regular frequency and are produced by means of devices, such as coils that use alternating current. Because, if an electric field varies with time, a magnetic field is induced (Carbonell *et al*., 2017). The magnetic effects on the plants are explained by the transfer of energy on the matter that contains free radicals that are attracted or repelled according to their charge, which increase their charge and activate.

This gives rise to a biostimulation, whose magnitude depends on the appropriate parameters of the energy that is transferred based on the radical pair model, which has an essential role in the magneto-reception (Galland and Pazur, 2005). The effect of the magnetic field on the germination, growth and yield of the cultivated plants is varied; it depends on the dose of exposure (intensity and time), the species and the cultivar (Pietruszewski and Martínez, 2015; Carbonell *et al*., 2017). Some authors report the positive effect of the magnetic field on several crops, applied to the seed as pre-sowing treatment.

In wheat, 12 and 14% more yield was found with magnetic field exposure at a dose of 12.9 and 17.9 kJ m^{-3} s^{-1} compared to the control (Pietruszewski and Kania, 2010). In pea, the length and dry weight of the seedlings increased, and the yield and its components increased (Iqbal *et al*., 2012;

Iqbal *et al*., 2013). In sunflower and French marigold exposed to 30 s and 3 min to electromagnetic field at 30 and 100 mT, an increase of 90% in germination and 400% in emergence of seedlings was observed, respectively (Afzal *et al*., 2012; Matwijczuk *et al*., 2012).

In alfalfa, the emergence and number of plants m^{-2} increased by 36% with 30 s at 30 mT, compared with the control (Ćwintal and Dziwulska-Hunek, 2013). *Vigna radiata* improved seedling germination and length by increasing intensity (0.087-0.226 T) with an exposure of 100 min (Mahajan and Pandey, 2014) and in birch biostimulated seeds aged for 72 h with 5 min at 3.6 mT, 20% more germination was obtained compared to the control (Rico *et al*., 2014). In corn, it has been reported that the electromagnetic field (EMF) improves the physiological quality of the seed, the productivity and the quality of the grain.

Under field conditions, Shine and Guruprasad (2012) found 78 and 40% more leaf area and seedling root length, respectively, with 1 h of EMF exposure at 200 mT compared to the non-irradiated control. In corn grain yield, Zepeda-Bautista *et al*. (2014) report an increase of 6% with 12 min of EMF exposure to 480 mT compared to the control. In physical grain quality, Zepeda *et al*. (2011) observed a decrease of 15.5 and 5% in the rate of flotation and hectoliter weight and 11% in the pericarp retained in the grain after nixtamalization compared to the control.

Corn is commonly colonized by *Fusarium* species and frequently contaminated with mycotoxins that affect the productivity and health of the plant and grain (Cendoya *et al*., 2018). *Fusarium* spp. it causes wilting in seedlings and plants, causes decay in the vegetative organs, ear and grain, mainly *F. verticillioides*, *F. subglutinans*, *F. proliferatum* and *F. oxysporum* (Figueroa-Rivera *et al*., 2010; Leyva-Madrigal *et al*., 2017; Mendoza *et al*., 2017). There is genetic variability between lines and hybrids for resistance to *Fusarium* spp., most are susceptible and the incidence of fungi has increased (Pereira *et al*., 2017).

An alternative is to generate resistant hybrids or use biophysical methods as a magnetic field. Zepeda-Bautista *et al*. (2014) report a decrease of 33, 13 and 10% of *Fusarium* spp. with 3, 12 and 6 min of exposure of the seed to EMF at 480 mT, respectively and Gutiérrez *et al*. (2014) observed 10% less *Fusarium* sp. by exposing the corn seed for 48 h at 4 mT compared to the control.

In developing countries, the productivity of corn is low and the quality of the grain for human and animal consumption and raw material for the industry, sometimes is not satisfactory. The excessive use of N in its production is causing severe problems to the environment. The information on the application of electromagnetic field in corn is focused on germination and growth of the seedling under controlled conditions; while, information on yield and grain quality in field conditions is limited. The objective of the research was to evaluate the effect of the electromagnetic field in the establishment of seedlings, the agronomic characteristics, the yield and the physical and sanitary quality of the grain in corn varieties under field conditions.

Materials and methods

The investigation was carried out in the San Ignacio Experimental Field of the Autonomous University Chapingo, State of Mexico, Mexico 19º 29’ 31.19” North latitude and 98º 52’ 20.86” West longitude and 2 268 masl). The climate is subhumid with summer rains (C (w_o) (w)b (i’)), the average annual temperature of 16.4 ºC, with average annual rainfall of 618.5 mm (SMN, 2018). The soil was free with slightly alkaline pH (7.26), salt-free (electrical conductivity 0.26 dS m^{-1}), organic matter and medium inorganic N (2.15% and 36.5 mg kg^{-1}), very high assimilable P (36.27 mg kg^{-1}) and high K (648 mg kg^{-1}).

During the spring-summer cycle of 2015 and 2016, 3x4 factories were evaluated: three corn varieties (H-61R, H-70 and V-60) and three electromagnetic field exposure times (6, 12 and 24 minutes, intensity 3.6 mT) and a control (without exposure to electromagnetic field) in a randomized complete block design with three repetitions. The experimental unit was four furrows of 5 m length separated at 0.8 m, the two central furrows were used as a useful plot.

Corn seed was exposed to a variable magnetic field by means of a solenoid fed with a sinusoidal signal of 60 Hz, a device that fulfills the hypothesis that the magnetic induction must be uniform throughout the surface of the seed, this was placed in the solenoid The solenoid is an original device designed and built by Domínguez *et al*. (2010), researchers from the School of Mechanical and Electrical Engineering (ESIME) of the National Polytechnic Institute (IPN), Figure 1 shows the distribution of the generated magnetic field. The seed was broadcast on April 30 and May 2 in 2015 and 2016, respectively, and the next day was sowed.

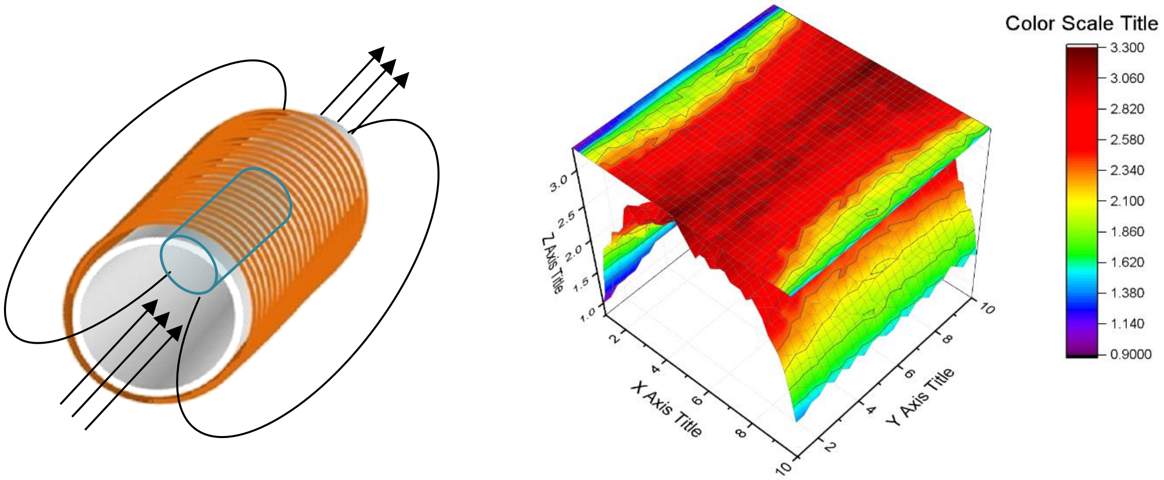

Figure 1. Visualization of the magnetic field distribution in the solenoid (Domínguez *et al*., 2010).

The preparation of the land was fallow, harrowed and furrowed with machinery. Seeding was done manually, in dry soil, at a population density of 70 000 plants ha^{-1}, distance between plants of 17.8 cm and one plant per plant. It was fertilized with 120N-60P-30K in fertigation, the application was weekly from week five after sowing; phosphonitrate, phosphoric acid and potassium nitrate were used as a source of nitrogen, phosphorus and potassium, respectively.

The weed was controlled with the preemergence application of Primagran gold® (ia atrazine + S-metolachlor) at a dose of 1.5 L ha^{-1} and postemergence with Marvel® (ia Dicamba + Atrazine) at a dose of 2 L ha^{-1}, when the weed had a height of 5 cm. On November 15 and 18, 2015 and 2016, harvesting was performed manually when the formation of the black layer at the base of the grain was observed, an indicator of physiological maturity (Virgen-Vargas *et al*., 2016). The drying of the ears was natural in a ventilated place and in the shade, was shelled manually when the moisture content of the grain was around 12% and the grain was stored at a temperature of 18 °C.

The variables evaluated were: 1) establishment of seedlings (EP), was calculated as a percentage with the formula: EP= (number of normal seedlings at 25 days after the first irrigation/112 seeds sown per experimental unit (EU))∗100; 2) average male flowering, it was quantified in the central furrows, the days from the first irrigation until 50% of the plants had the spike releasing pollen; 3) plant height, was measured in five plants taken at random and in cm from the base of the stem to the point of insertion of the spike; and 4) yield, was calculated in t ha^{-1} at 12% humidity with the formula.

Yield= [(PC x %MS x %G x FC)/8800]/1 000; where PC= cob field weight, in kg per useful plot, %MS= percentage of dry matter, by the difference of 100 minus the percentage of moisture content of the seed obtained from the Stenlite® device; %G= percentage of grain, ratio between the weight of grain and the weight of the cob devoid of bracts, average of five ears taken at random, multiplied by 100; FC= correction factor, obtained by dividing 10 000 m^2 (1 ha) between the useful area of the plot (16 m^2); 8 800= factor to adjust the yield to 12% moisture per hectare.

Physical and sanitary quality of the grain

The evaluations were made in the Systemic-Transdisciplinary Laboratory of the Systems Engineering Program at ESIME-IPN, Mexico City, Mexico. A random sample of 1 kg of grain per repetition was used. To determine the physical quality of the grain, we measured: 1) hectoliter weight, was determined on an Ohaus® scale and expressed in kg hL^{-1}; and 2) commercial grain size, the grain was classified with round perforation screens of 8 and 7 mm in diameter, the weight of the grain retained in both screens was added and reported as a percentage.

To determine the sanitary quality of the grain, the drying and freezing paper sanitation test was used (Warham *et al*., 1996), 50 grains per repetition were used. The grains were disinfested with 10% sodium hypochlorite (NaCl) for 3 min and rinsed with distilled water for 1 min, then the grains were placed on moist filter paper in a clear plastic box and sealed with parafilm. For incubation, the boxes were placed at 25 °C for two days (12 h with cold white light and 12 h dark every day).

After the time, they were subjected to freezing at -1 °C for 24 h. Finally, the boxes were placed at 25 °C for 11 days. After 14 days, the number of grains infected with *Fusarium* spp., and *Penicillium* spp. and expressed as a percentage. To detect the presence of mycelial development, each grain was observed with Olympus SZ51® stereoscopic microscope. In the grains, mycelial growth was observed with a variation in white-yellow, salmon pink and gray. For the morphological identification of *Fusarium* species, it was elaborated with the specific keys and descriptions reported by Nelson *et al*. (1983) and for *Penicillium* (Pitt, 1979).

A variance analysis combined with the PROC GLM procedure of the Statistical Analysis System (SAS, 2014) was carried out for the main factors and for the variables whose mean squares showed significant differences, the Tukey ($\alpha = 0.05$) multiple comparison test was used. The percentage variables were transformed with the arcsine function to have them in a normal distribution and to be able to carry out the aforementioned analysis.

Results and discussion

Establishment of corn seedlings in field conditions

In the field of production, the establishment of seedlings is a basic indicator for the productivity of the crop. The exposure of the seed to electromagnetic field, intensity of 3.6 mT (Figure 1), as pre-sowing treatment caused significant differences ($p \leq 0.05$), in the establishment of corn seedlings under field conditions (Table 1).

Table 1. Comparison of means of varieties of corn with different time of exposure of the seed to the electromagnetic field as pre-sowing treatment. 2015-2016.

EMF exposure time (min)	Establishment of seedlings	Average male bloom	Plant height	Grain yield	Grain size	Hectoliter weight
	(%)	(days)	(cm)	(t ha^{-1})	(%)	(kg hL^{-1})
Control	82.23 b	83.05 b	249.5 a	7.88 a	93.55 a	75.91 a
6	82.39 b	84.83 ab	257.94 a	8.87 a	94.77 a	76.16 a
12	87.71 ab	84.11 ab	257 a	8.9 a	93.11 a	76.45 a
24	90.9 a	84.94 a	252.33 a	8.75 a	92.88 a	75.62 a
P> F	0.01	0.02	0.08	0.06	0.54	0.41
DMSH	8.34	1.78	9.77	1.14	3.99	1.36
Mean	85.81	84.24	254.19	8.61	93.58	76.04
CV (%)	11.36	2.39	4.35	14.94	6.01	2.02
R^2	0.34	0.77	0.89	0.52	0.51	0.58

Means with the same letter in each column are statistically equal (Tukey, $\alpha = 0.05$). DMSH = honest significant minimum difference. CV= coefficient of variation; EMF= electromagnetic field, intensity 3.6 mT; R^2= coefficient of determination.

This is due to the biostimulation of the seed by the transfer of energy on the matter that contains free radicals that are attracted or repelled according to their charge, which increase their load and are activated (Galland and Pazur, 2005) causing changes in enzymes, chlorophyll and photosynthesis reflected in the growth of the seedling (Javed *et al*., 2011; Shine and Guruprasad, 2012). The improvement in the germination and growth of corn seedlings under controlled conditions was reported by Domínguez *et al*. (2010) and Shabrangi *et al*. (2015) and in field conditions by Shine and Guruprasad (2012).

The corn seed exposed to 24 min to electromagnetic field (EMF) increased 10.54% ($p \leq 0.05$), the establishment of seedlings in field conditions compared to the control not exposed to EMF (Table 1). With 12 min, 6.66% was increased compared to the control, both statistically equal

($p\leq 0.05$). With 24 and 12 min of exposure of the seed to EMF allowed to register values ≥85% of seedlings established in the field; however, only with 24 min, 91% of established seedlings were registered in the corn varieties, value >90% of germination, quantified with the standard germination test, minimum required in the rule for the qualification of corn seed in Mexico (SAGARPA-SNICS, 2016).

The non-irradiated control and 6 min of EMF exposure had a seedling establishment <85%. Under controlled conditions, Domínguez *et al*. (2010) and Zepeda-Bautista *et al*. (2010) reported 90 and 2% increase in the establishment of corn hybrid seedlings with 30 and 15 minutes of EMF exposure at an intensity of 560 and 480 mT compared to the control not exposed to electromagnetic field. Between corn varieties and years of production there were no significant differences ($p\leq 0.05$), for establishment of seedlings in field conditions (Table 2) because the size of the seed was homogeneous (large, round perforation screen of 8 mm in diameter), indirect measurement of the quantity of reserve, used during the germination and establishment of the seedling.

Table 2. Comparison of means of corn varieties. Chapingo, State of Mexico, Mexico. 2015-2016.

Varieties of corn	Establishment of seedlings	Average male bloom	Plant height	Grain yield	Grain size	Hectoliter weight
	(%)	(days)	(cm)	(t ha^{-1})	(%)	(kg hL^{-1})
H-61R	84.53 a	85.83 a	255.62 a	8.02 b	92.33 b	76.41 a
H-70	85.92 a	81.41 b	262.25 a	9.82 a	96.25 a	75.52 a
V-60	86.97 a	85.45 a	244.7 b	7.97 b	92.16 b	76.17 a
P> F	0.75	<0.01	<0.01	<0.01	0.01	0.12
DMSH	6.56	1.4	7.7	0.89	3.14	1.07
Years of production						
2015	87.64a	86.47 a	279.94 a	8.76 a	94.91 a	77.15 a
2016	83.97a	82 b	228.44 b	8.44 a	92.25 b	74.92 b
P> F	0.34	<0.01	<0.01	0.29	0.01	<0.01
DMSH	4.46	0.95	5.23	0.61	2.13	0.73

Means with the same letter in each column are statistically equal (Tukey, α= 0.05). DMSH= honest significant minimum difference.

Likewise, in each sowing soil conditions, drip irrigation (per week 167 m^{3} ha^{-1} at 100% of corn evaporation), average temperature (18.6 °C) and without precipitation were similar (SMN, 2018). In field conditions, similar results have not been reported. Among varieties, 85.81% of seedling establishment (EP) was registered under field conditions. The V-60 variety had the highest establishment of seedlings, 2.44 and 1.05% more than the hybrids H-61R and H-70. In 2015, 3.67% more seedlings were established in the field compared to 2016, statistically equal (α= 0.05).

Agronomic characteristics, yield and physical grain quality

Between time of exposure of the seed to the electromagnetic field as pre-sowing treatment, there were significant differences ($p\leq 0.05$), for male mean flowering (Table 1) because the biostimulation of the seed had an effect on the plant’s growth. The positive effect of the magnetic field in several cultivated plants has been reported by several authors (Pietruszewski and Martínez, 2015).

With 24 min of EMF exposure, two days were increased for male mean flowering compared to the non-irradiated control, which can be useful in a batch of corn seed production, registered and certified categories, to achieve floral synchrony between male and female parents (Virgen-Vargas *et al*., 2016). Zepeda-Bautista *et al*. (2014) reported a one-day increase in male mean flowering with 15 min of seed exposure to EMF at an intensity of 480 mT.

The application of electromagnetic field to the seed did not have a significant effect ($p\leq 0.05$), for plant height and grain yield (Table 1); however, an increase in them was observed in comparison with the control ($p= 0.08$ and $p= 0.06$, respectively). Based on these results and the positive effect of the electromagnetic field on the growth and yield of the cultivated plants reported by several authors (Pietruszewski and Martínez, 2015; Carbonell *et al*., 2017), it is recommended to perform electromagnetic field applications during the phenological cycle of the plant, in the stages of greater nutrimental absorption: floral differentiation (V10), flowering (V18) and grain filling (R2).

The positive effect of magnetic field on wheat yield was reported by Pietruszewski and Kania (2010) and in pea by Iqbal *et al*. (2013). In corn, Zepeda-Bautista *et al*. (2014) reported that with 12 min of seed exposure to EMF (480 mT) in pre-sowing, grain yield was increased by 6%. With 12 min of exposure of the seed to EMF, at an intensity of 3.6 mT, an increase in plant height and grain hectoliter weight of 3 and 0.71% was observed, both statistically equal ($\alpha= 0.05$). With 24 and 12 min to EMF increased 12.94 and 11.04% the grain yield ha^{-1}, equivalent to 1020 and 870 kg ha^{-1}, compared to the control not exposed to EMF.

However, for commercial grain percentage there were no significant differences ($p\leq 0.05$) compared to the control (Table 1). In contrast, corn hybrids showed a 5% decrease in hectoliter weight when the grain was exposed to the electromagnetic field for 15 min at 480 mT Zepeda *et al*. (2011). Between corn varieties and between years of production, significant differences were observed ($p\leq 0.05$), for agronomic characteristics, yield and grain quality (Table 2). In the H-61R hybrid and the V-60 variety four more days were observed for the average male flowering and 2.59 and 7.17% less plant height compared to the hybrid H-70.

The average grain yield was >8.5 t ha^{-1}, higher than the average productivity in Mexico (3.71 t ha^{-1}) (FAO, 2018) and similar to the yields (7.42 and 10.64 t ha^{-1}) reported by Haegele *et al*. (2013) and Kovacs *et al*. (2014) with the application of chemical fertilizers, which sometimes cause severe problems to the environment (Nazir *et al*., 2016). Therefore, the application of electromagnetic field to the seed as pre-sowing treatment is an alternative to improve the yield of corn, without damaging the environment.

The hybrid H-70 yielded 22.44 and 23.21% more and 4% more commercial grain compared to H-61R and V-60. On average, 94% of commercial grain and 76.04 kg hL^{-1} of hectoliter weight were observed, higher values than those required by the dough and tortilla industry (NMX-FF-034/1-SCFI-2002, 2002). Benítez-Rodríguez *et al*. (2014) reported that the hybrid H-70 yielded 48.33% less and similar hectoliter weight of the grain, in rainy season conditions in the High Valleys of Mexico with an annual average precipitation between 583 and 816 mm, compared to the yield and hectoliter weight obtained in fertigation in Chapingo, State of Mexico with an average annual rainfall of 618.5 mm.

In the year of production 2015 four more days were observed for the average male flowering and 22.54% higher plant height, 2.66 and 2.97% more commercial grain and hectoliter weight compared to 2016. This is because the quantity and distribution of the precipitation during the phenological cycle of corn was different, which affected the growth and development of the plant, as reported by Virgen-Vargas *et al*. (2016) in simple corn crosses. Between the months of June to September 2015, the average temperature and precipitation were 10.24 and 5.28% higher than in 2016 (16.6 °C and 408.4 mm). Grain yield was statistically equal (α= 0.05) between years; in 2015, 320 kg ha^{-1} more were produced than in 2016.

Interaction of corn varieties x time of exposure to electromagnetic field

For the established seedling variables and grain yield, the corn varieties showed a statistically equal response (α= 0.05) to the exposure time of the seed to the electromagnetic field (EMF) at an intensity of 3.6 mT. In the hybrid H-70 and the variety V-60 an increase in the established seedlings was observed in the field by increasing the time of exposure of the seed to EMF. In H-70 with exposure of 6, 12 and 24 min increased 3.75, 8.75 and 17.5% and in V-60 0, 1.17 and 8.23% more than the control (not exposed to EMF).

Results contrary to those reported by Zepeda-Bautista *et al*. (2010), that when evaluating the establishment of corn seedlings under controlled conditions they observed an increase, followed by a decrease with increasing the time of exposure of the seed to EMF (3, 6, 9, 12 and 15 min). In the hybrid H-61R with 12 min of exposure had higher establishment of seedlings under field conditions (9.75%) compared to 6 min of exposure to EMF, which showed a decrease of 2.43% (Figure 2).

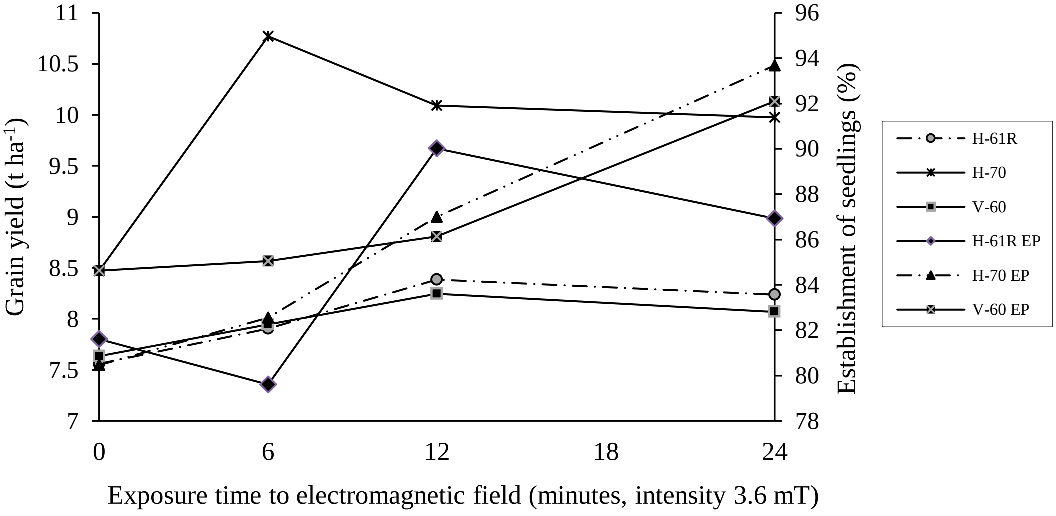

Figure 2. Establishment of seedlings and grain yield of corn varieties with time of exposure of the seed to the electromagnetic field as pre-sowing treatment.

For grain yield, the hybrid H-61R and the variety V-60 yielded more (10.85 and 8%) with 12 min of exposure to EMF, while, the hybrid H-70 increased its yield 27.14% with 6 min of exposure in comparison with the control not exposed to EMF (Figure 2). This represented an increase of 800, 600 and 2 300 kg ha^{-1} of grain for the producer with the application of a biophysical method friendly to the environment.

Each variety of corn had a different response to the time of exposure to the EMF, behavior similar to that observed by Zepeda-Bautista *et al.* (2014) when evaluating the performance of corn hybrids with EMF exposure of the seed as pre-sowing treatment. However, there is little information on the effect of the electromagnetic field in the establishment of seedlings, growth and production of corn in field conditions (Pietruszewski and Martínez, 2015).

In other crops such as wheat, 12 and 14% more yield was observed with exposure to magnetic field at a dose of 12.9 and 17.9 kJ m^{-3} s^{-1} compared to the control (Pietruszewski and Kania, 2010) and in pea, was observed the highest production of green pods per plant and per hectare with the exposure of 5 min at an intensity of 180 mT (Iqbal *et al*., 2013).

Corn grain health

Between years of production there were no significant differences ($p \leq 0.05$) in the percentage of grains infected by *Fusarium* spp. and by *F. oxysporum* probably because the physical and chemical characteristics of the soil and the agronomic management were similar; in addition, between June and September the temperature and precipitation in 2015 were slightly higher (18.3 °C and 430 mm) compared to 2016 (16.6 °C and 408.4 mm), which did not affect the percentage of grains infected by *Fusarium*; however, there was a higher percentage of grains infected by *F. graminearum* (Table 3).

Table 3. Comparison of means of sanitary quality of the grain of corn varieties with different exposure time of the seed to the electromagnetic field as pre-sowing treatment. Chapingo, State of Mexico. 2015-2016.

Years of production	*Fusarium* spp. (%)	*Fusarium Graminearum* (%)	*Fusarium Oxysporum* (%)	*Penicillium* spp. (%)
2015	8.55 a	0.55 b	8 a	3.77 a
2016	9.88 a	2.44 a	7.44 a	2.55 a
P> F	0.27	0.01	0.92	0.38
DMSH	3.67	1.5	3.23	1.99
Varieties of corn				
H-61R	10.33 a	2.33 a	8 a	3.5 a
H-70	10.66 a	1.16 a	9.5 a	2.33 a
V-60	6.66 a	1.00 a	5.66 a	3.66 a
P > F	0.08	0.35	0.1	0.76
DMSH	5.41	2.21	4.76	2.94
Exposure time of the seed to electromagnetic field, intensity 3.6 mT (min)				
Control	8.22 a	1.77 a	6.44 a	2.44 a
6	10 a	1.55 a	8.44 a	3.77 a
12	7.33a	1.55 a	5.77 a	4.44 a
24	11.33 a	1.11 a	10.22 a	2 a
P> F	0.29	0.91	0.1	0.53
DMSH	6.87	2.81	6.04	3.73
Mean	9.22	1.5	7.72	3.16

Means with the same letter in each column are statistically equal (Tukey, α= 0.05). DMSH= honest significant minimum difference.

In 2016, the percentage of grains infected by *F. graminearum* was higher (2.44%) compared to 2015 (0.55%). Similar values (between 1.88 and 2.33%) were recorded by Zepeda-Bautista *et al*. (2014) in corn hybrids in the State of Mexico.

In the grain of corn varieties, 9.22% of grains infected by *Fusarium* spp., 7.72% by *Fusarium oxysporum* and 1.5% by *Fusarium graminearum* were quantified (Table 3). Cendoya *et al*. (2018) reported between 13 and 16% severity of ear rot of corn hybrids in Texcoco and Huamantla, Mexico associated with the presence of *Fusarium verticilloides*, *F. subglutinans*, *F. proliferatum* and *F. oxysporum*. This indicates that the grain of corn was colonized by *Fusarium* species that affects the grain health as reported by Cendoya *et al*. (2018).

Among corn varieties there were no significant differences ($p\leq 0.05$) for the percentage of grains infected by *Fusarium* spp.; that is, the *Fusarium*-infected grains were similar among genotypes. Contrary results were observed by Pereira *et al*. (2017) when evaluating hybrids and corn lines. The hybrids H-61R and H-70 had on average 10% of grains infected by *Fusarium* spp. and between 8 and 9.5% by *F. oxysporum*; while, the variety V-60 had the lowest values (6.66 and 5.66%).

The percentage of grains infected by *Fusarium* spp. was lower than reported by Zepeda-Bautista *et al*. (2014) in corn hybrids (28.49%). Between years of production and varieties of corn there were no significant differences ($p\leq 0.05$) for percentage of grains infected by *Penicillium* spp., on average it was 3.16% (Table 3), it was always observed in grain separated from *Fusarium* spp. In 2015 and in the hybrid H-61R, the percentage of grains infected by *Penicillium* spp. They were 47.84 and 50.21% higher compared to 2016 and the H-70 hybrid.

On the other hand, the exposure of the seed during 6 and 24 min to EMF increased the presence of *Fusarium* spp. in 21.65 and 37.83% and *F. oxysporium* 31.05 and 58.69% in comparison with the non-irradiated control. For *Penicillium* spp. in grain of corn, an increase of 54.51 and 81.96% was observed with the exposure of 6 and 12 min of the seed to EMF as pre-sowing treatment (Table 3). In general, a lower presence of *Fusarium* spp. with the application of the electromagnetic field to the seed in pre-sowing, so it could be an alternative method for controlling the fungus in corn grains to produce food for human consumption.

Conclusions

The electromagnetic field used as pre-sowing treatment in seed of corn varieties significantly increased the establishment of seedlings and the average male flowering in field conditions. For grain yield there was no significant effect ($p\leq 0.05$)); however, an increase was observed ($p= 0.06$). The corn varieties had a response statistically equal to the time of exposure of the seed to the electromagnetic field for establishment of seedlings and grain yield in field conditions according to the structural composition of the seed.

Cited literature

Afzal, I.; Mukhtar, K.; Qasim, M.; Basra, S. M. A.; Shahid, M. and Haq, Z. 2012. Magnetic stimulation of marigold seed. Int. Agrophys. 26(1):335-339. https://doi.org/10.2478/v10247-012-0047-1.

Benítez, R. M. G.; Zepeda, B. R.; Hernández, Aguilar, C.; Virgen, V. J.; Rojas, Martínez I. and Domínguez, P. A. 2014. Physical characteristics and yield of maize grain in rainfed conditions of High Valleys of Mexico. Acta Agrophysica. 21(4):403-414.

Bouwman, A. F.; Beusen, A. H. W.; Lassaletta, L.; van Apeldoorn, D. F.; van Grinsven H. J. M.; Zhang, J. and van Ittersum, M. K. 2017. Lessons from temporal and spatial patterns in global use of N and P fertilizer on cropland. Sci. Rep. 7:40366. https://doi.org/10.1038/srep40366.

Carbonell, M. V.; Flórez, M.; Martínez, E. y Álvarez, J. 2017. Aportaciones sobre el campo magnético: Historia e influencia en sistemas biológicos. Rev. Intropica. 12(2) http://dx.doi.org/ 10.21676/23897864.2282.

Cendoya, E.; Chiotta, M. L.; Zachetti, V.; Chulze, S. N. and Ramirez, M. L. 2018. Fumonisins and fumonisin-producing *Fusarium* occurrence in wheat and wheat by products: A review. J. Cereal Sci. 80:158-166. https://doi.org/10.1016/j.jcs.2018.02.010.

Ćwintal, M. and Dziwulska-Hunek, A. 2013. Effect of electromagnetic stimulation of alfalfa seeds. Int. Agrophys. 27:391-401. https://doi.org/10.2478/intag-2013-0009.

Duvick, D. N. 2005. Genetic progress in yield of United States maize (*Zea mays* L.). Maydica. 50(3):193-202.

FAO. 2018. Food and Agriculture Organization of the United Nations. FAOSTAT-FAO Statistical Databases) Agriculture, Fisheries, Forestry, Nutrition. Rome, Italy. http://www.fao.org/faostat/en/.

Figueroa, R. M. G.; Rodríguez, G. R.; Guerrero, Aguilar, B. Z.; González, C. M. M.; Pons, H., J. L.; Jiménez, B. J. F.; Ramírez, P. J. G.; Andrio, E. E. y Mendoza, E. M. 2010. Caracterización de especies de *Fusarium* asociadas a la pudrición de raíz de maíz en Guanajuato, México. Rev. Mex. Fitopatol. 28(2):124-134.

Galland, P. and Pazur, A. 2005. Magnetoreception in plants. J. Plant Res. 118:371-389. https://doi.org/10.1007/s10265-005-0246-y.

Gutiérrez, A. M.; Torres, G. C. and Díaz, E. J. 2014. Effect of magnetic fields in germination, growth, and microbial florishing in seedlings of *Brachiaria humidicola*, *Panicum maximum*, and *Zea maiz* (Poaceae). Rev. Cienc. 18(1):9-17.

Haegele, J. W.; Cook, K. A.; Nichols, D. M. and Below, F. E. 2013. Changes in nitrogen use traits associated with genetic improvement for grain yield of maize hybrids released in different decades. Crop Sci. 53:1256-1268. https://doi.org/10.2135/cropsci2012.07.0429.

Iqbal, M.; Ahmad, I.; Hussain, S. M.; Kheral, R. A.; Bokhari, T. H. and Shehzad, M. A. 2013. Optimization of pre-sowing magnetic field doses through RSM in pea. Int. Agrophys. 27(3):265-274.

Iqbal, M.; Haq, Z. U.; Jamil, Y. and Ahmad, M. R. 2012. Effect of presowing magnetic treatment on properties of pea. Int. Agrophys. 26(1):25-31. https://doi.org/10.2478/v10247-012-0004-z.

Kovács, P.; Van Scoyoc, G. E.; Doerge, T. A.; Camberato, J. J. and Vyn, T. J. 2014. Pre-plant anhydrous ammonia placement consequences on no-till *versus* conventional-till maize growth and nitrogen responses. Agron. J. 106(2):634-644. https://doi.org/10.2134/agronj2013.0356.

Lee, E. A. and Tollenaar, M. 2007. Physiological basis of successful breeding strategies for maize grain yield. Crop Sci. 47(S3):S202-S215. https://doi.org/10.2135/cropsci 2007.04.0010IPBS.

Leyva, M. K. Y.; Sandoval, C. E.; Calderón, V. C. L.; Larralde, C. C. P. and Maldonado M. I. E. 2017. Pathogenic and genetic variability of *Fusarium verticillioides* from maize in northern Mexico. Can. J. Plant Pathol. 39(4):486-496.

Mahajan, T. S. and Pandey, O. P. 2014. Magnetic-time model at off-season germination. Int. Agrophys. 28(1):57-62. https://doi.org/10.2478/intag-2013-0027.

Matwijczuk, A.; Kornarzyñski, K. and Pietruszewski, S. 2012. Effect of magnetic field on seed germination and seedling growth of sunflower. Int. Agrophys. 2683):271-278.

Mendoza, J. R.; Kok, C. R.; Stratton, J.; Bianchini, A. and Hallen-Adams, H. E. 2017. Understanding the mycobiota of maize from the highlands of Guatemala, and implications for maize quality and safety. Crop Prot. 101:5-11. https://doi.org/10.1016 /j.cropro.2017.07.009.

Nazir, M.; Pandey, R.; Siddiqi, T. O.; Ibrahim, M. M.; Qureshi, M. I.; Abraham, G.; Vengavasi, K. and Ahmad, A. 2016. Nitrogen-deficiency stress induces protein expression differentially in low-N tolerant and low-N sensitive maize genotypes. Front. Plant Sci. 7:1-16.

Nelson, P. E.; Toussoun T. A. and Marasas, W. F. O. 1983. *Fusarium* Species: An Illustrated Manual for Identification. Pennsylvania State University Press, University Park, Pennsylvania, USA. 193 p.

NMX-FF-034/1-SCFI-2002. Norma mexicana para maíces destinados al proceso de nixtamalización (0022). Productos alimenticios no industrializados para consumo humano-cereales-Parte I: maíz blanco para proceso alcalino para tortillas de maíz y productos de maíz nixtamalizado-Especificaciones y Métodos de prueba. Secretaría de Economía (SE). México, DF.

OECD-FAO. 2017. Organization for Economic Co-operation and Development and Food and Agriculture Organization of the United Nations OECD-FAO Agricultural Outlook 2017-2026. OECD Publishing, Paris. http://dx.doi.org/10.1787/agr_outlook-2017-en.

Pereira, G. S.; Pinho, R. G. V.; Pinho, E. V. R. V.; Pires, L. P. M.; Junior, L. A. Y. B.; Pereira, J. L. A. and Melo, M. P. 2017. Selection of maize inbred lines and gene expression for resistance to ear rot. Genet. Mol. Res. 16(3):1-21. http://dx.doi.org/10.4238/gmr16039415.

Pietruszewski, S. and Kania, K. 2010. Effect of magnetic field on germination and yield of wheat. Int. Agrophys. 24(3):297-302.

Pietruszewski, S. and Martínez, E. 2015. Magnetic field as a method of improving the quality of sowing material: a review. Int. Agrophys. 29(3):377-389. https://doi.org/10.1515/intag-2015-0044.

Pitt, J. I. 1979. The genus *Penicillium*, and its teleomorphic states: Eupenicillium, and Talaromyces. Academic Press. New York, USA. 641 p.

Rico, M. F.; Domínguez, P. A.; Hernández, A. C.; Paniagua, P. G. and Martínez, O. E. 2014. Effects of magnetic field irradiation on broccoli seed with accelerated aging. Acta Agroph. 21(1):63-73.

Ritchie, S. W.; J. J. Hanway, J. J. and Thompson, H. E. 1996. How a corn plant develops. Spec. Rep. 48. Coop. Ext. Serv. Iowa State Univ. of Sci. and Technol. Ames, IA. 25 p.

SAGARPA-SNICS. 2016. Regla para la calificación de semilla de maíz (*Zea mays* L.). https://www.gob.mx/cms /uploads/attachment/file/172412/Maiz.pdf.

SAS. 2014. Statistical Analysis System (SAS/STAT 9.3 user's guide. SAS Institute Inc., Cary, NC, USA.

Shine, M. B. and Guruprasad, K. N. 2012. Impact of pre-sowing magnetic field exposure of seeds to stationary magnetic field on growth, reactive oxygen species and photosynthesis of maize under field conditions. Acta Physiol. Plant. 34(1):255-265. https://doi.org/10.1007/s11738-011-0824-7.

SMN. 2018. Servicio Meteorológico Nacional. Normales climatológicas por estación. Estado de México. http://smn.cna.gob.mx/es/informacion-climatologica-ver-estado?estado=mex.

Virgen V. J.; Zepeda B. R.; Ávila P. M. A.; Rojas M. I.; Espinosa C. A. y Gámez V. A. J. 2016. Desespigamiento en cruzas simples progenitoras de híbridos de maíz (*Zea mays* L.) para Valles Altos de México. Agrociencia. 50(1):43-59.

Warham, E. J.; Butler, L. D. and Sutton, B. C. 1996. Seed testing of maize and wheat: a laboratory guide. Centro Internacional de Maíz y Trigo (CIMMYT). El Batán, Estado de México, DF. 84 p.

Zepeda, B. R.; Hernández, A. C.; Suazo, L. F.; Domínguez, P. A.; Cruz, O. A.; Martínez, O. E. and Hernández, S. L. M. 2011. Physical characteristics of maize grain and tortilla exposed to electromagnetic field. Int. Agrophys. 25(4):389-393.

Zepeda, B. R.; Hernández, A. C.; Suazo, L. F.; Domínguez, P. F. A.; Virgen, V. J.; Pérez, R. C. and Peón, E. I. 2014. Electromagnetic field in corn grain production and health. African J. Biotechnol. 13(1):76-83. https://doi.org/10.5897/AJB2013.13245.