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Application of Electromagnetic Field in Maize to Improve Productivity under Rain-fed Conditions

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Authors' contributions

This work was carried out in collaboration between all authors. Author MER wrote the protocol, developed the research, conducted the experiment, carried out the statistical analysis and wrote the first draft. Authors CHA and FADP designed, constructed and calibrated the equipment for applying the magnetic field according to the programmed dose. Author ACC helped in the design and conducted the experiment in field, he also interpreted the results. Author JAMC proofread the article in English. All authors read and approved the final manuscript.

Short Research Article

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ABSTRACT

In order to know the feasibility of using physical methods such as pre-sowing treatment and evaluated infield for maize production in agrosystems with moisture and inputs limitations, five varieties were used: "HS-2", "CP-20", "Promesa", "HT-Precoz", "CPV-20", and "Criollo de Mineral de Pozos", Gto. The seeds were treated with 560 mT variable electromagnetic field during 30 minutes before sowing. There were significant statistical differences among treatments for ear weight and for varieties in plant height and ear height and weight. The HS-2 hybrid had the lowest value for emergency velocity and emerged plants percentage, but yielded at 12% humidity 4,950 t ha^{-1} with magnetism and 3,863 t ha^{-1} without magnetism, it out yielded the rest of the varieties; meanwhile the Native variety had 1,864 t ha^{-1} under rain-fed conditions; without treatment it yielded 1,494 t ha^{-1} under rain-fed conditions. It was showed that treatment with the magnetic field tends to increase an

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28.13% and 24.76% in improved and native varieties, respectively. HS-2, CPV-20 and Criollo M. de Pozos varieties had a low grain moisture content when they were harvested suggesting that magnetism could promote an early physiological maturity.

Keywords: Zea mays L; magnetic field; rain-fed conditions.

1. INTRODUCTION

In 2011, the Mexican territory faced drought problems in 40% of its planted area, it had been the most intense since 1941.Furthermore, the country also had to face frosts and floods in wide regions, reducing domestic corn and bean production. Drought in Mexico had caused losses in 6 million hectares of crops in 15 states, mainly in the central and northern part of the country, that are under emergency conditions [1]. Therefore, it is necessary to use various techniques that may contribute to diminish the impact of environmental phenomena on agricultural crops, mainly in corn; techniques that can achieve better yield and grain quality in less time, using less water.

In case of severe drought endangering, local or international production, or due to an increase of demands from different nations, Mexico could be affected, because it is a food importer. In fact, the food imports were supposed to be a transitional activity and they are still being carried out and without paying custom duties. On the other hand, tax burden on grain prices on the international market made corn and other products more expensive. In the Federal District (Mexico D.F.) the ton of grain reached the valueof 5,400 Mexican pesos, a historical maximum, and to 2013, the ton of grain reached the value between 2800 and 3200 mexican pesos. The country imports 10 million tons of yellow maize; thus, the National Confederation of Mexican Maize Producers (CNPMM) stated that South African imports pay 10% higher fees than local producers [2].

Tortilla is a staple food in Mexican diet, the biennial 2009 GRUMA survey indicated that the average tortilla consumption *per capita* in Mexico was 80 kg per year^{-1}; that is, 4.5 tortillas a day on average. Furthermore, there is concern about food shortage supply and its quality, as a consequence of climatic change, abuse of agricultural chemicals, bad agricultural management, few cultivation areas, and lack of investment, and monopolistic practices that promoted the use of transgenic plants. As a consequence, FAO forecasts a capitalist agriculture, risking environment and human life, thus, generating food shortage for the year 2030 and provoking a worldwide collapse [2].

The use of electromagnetic field can be a viable option as seed pre-sowing treatment for the rain-fed zones of our country; it is necessary to increase grain production to guarantee food supply in such zones. The drought that occurred in 2011, food demand by the Asian countries, and grain use for fuel production has given evidence of Mexico´s vulnerability in terms of food security and it is situated among the nations highly dependent on import of basic products like corn, bean and rice [2].

Several researchers, like [3] have tried to increase yield in agricultural production, it was obtained higher yield in soybean, around 12-13%, when it was used magnetic field, in comparison to the control. In sunflower, photosynthesis rate, root system activity, and nutrient absorption increased [4] as well as amylase activity in crops such as pepper, tomato and cucumber [5]. For maize, [6] reported that grain nutrient content increased, number of kernels per ear, proportion of plants with two ears, and grain yield increased by 2.06% to 9.46%.

The seeds magnetic field treatment increases plant growth. The shoot length, root length, root dry weight, shoot dry weight, dry matter accumulation, fresh root and shoot weight increased significantly [7]. In [8] by applying magnetic field with permanent magnets to seed corn the vigour increased. The influence of a stationary magnetic field with induction of 0,15 T at expositions of 10 min, 20 min 30 min, on maize seeds has been investigated [9], the extinction of the samples treated with a magnetic field has been found to increased by about 20 %. The highest values of the treated sample parameters were obtained after 10-min exposure in the magnetic field. In [10] authors observed, that the root length, radicle length and protein percentage increased by 31.14%, 4.15% and 11.32% respectively. In peas, [11] has been found a significant seed increase having a greater number of sheaths in the treated ones than in untreated plants; this indicated that the efficiency of the applied treatment depends on the variety, the seed exposure dose to the magnetic field and weather conditions.

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Seed irradiation with laser rays provides a positive effect in the seed physiological quality, increases maize seedling emergence, as well as its dry weight and good field establishment [12]; furthermore the laser irradiation significantly diminished the quantity of seeds infected with *Fusarium* spp. fungi up to 61.11% when compared with the control seed (no irradiation) [13].

On the other hand when water is treated with magnetic field, it is obtained a quicker seed germination and higher emergence rate; plants grow more vigorous, the root system develops better, and occasionally it reaches as much twice its length, the flowering cycle is also anticipated and hence the fruit ripens, besides there is a lower evapotranspiration and less water is used [14]. The electromagnetic radiation is a low-cost technique that contributes to the improvement of maize seed physiological quality, resulting in a better emergence rate and field establishment [15].

Because of the above mentioned issues, it is necessary to carry out trials that allow us to know the feasibility of corn seed pre-sowing treatments with variable magnetic field and, evaluate the effects on field under rain-fed conditions, and expect favorable results in the crop establishment and grain production under moisture and agricultural limitations.

2. MATERIALS AND METHODS

2.1 Biological Material

There were used seeds from four improved corn varieties: HS-2, CP-Promesa, HT-Precoz, and CPV-20, provided by the Area of Improvement and Control of Genetic Quality, of the Seed Production Program of the Colegio de Postgraduados, Campus Montecillo, Texcoco, State of Mexico; Criollo from Mineral de Pozos, Gto., was included too. Seeds from all varieties were obtained in the agricultural spring-summer 2011 productive cycle.

2.2 Electromagnetic Field Application

On May 31, 2012, a physical method of magnetic field was applied as pre-sowing seed treatment at the Laboratory of Engineering Systems (ESIME-Zacatenco) of the Instituto Politecnico Nacional. The method consisted to apply 560 mT during 30 minutes of exposure. An irradiator generated an electromagnetic field passing the current flow through an inductor bobbin (coil), and the interruptor was used to select the current intensity until it was obtained the desired level of magnetic induction. Inside the magnetic field and within a homogeneous space in a dielectric container the seeds of five varieties were placed randomly. A Gaussmeter (Gauss/Teslameter, model 5070, F.W. Bell) was used to measure the magnetic field intensity.

2.3 Experimental Trial

On June 4, 2012 (four days after the magnetic field physical treatment was applied), once the agricultural cycle under rain-fed conditions began, the field trial was planted in the C6 experimental plot at *Campus* Montecillo, Colegio de Postgraduados (19º 29' N, 98º 53' W, at 2,250 m above sea level) with semiarid climate BS1, the least arid of the dry climates; rainfalls in summer, annual mean temperature of 14.6ºC, and 558.5 mm of precipitation, with a sandy loam soiland pH of 7.0. The experimental design used was a randomized complete block with 6 replications. Two 5.5m long rows were used and as experimental unit, 44 seeds were sown individually at a distance of approximately 25cm from each other.

2.4 Measured Variables

The physiological quality variables were: Emergence velocity (EV), it was measured by counts starting from the eighth day after sowing; measures were carried out daily at the same hour until a constant number of emerged seedlings was reached. Emergence velocity (EV) was calculated [16]using the following equation:

$$EV = \frac{\text{Number of emerged coleoptiles}}{\text{Days to first count}} + \ldots + \frac{\text{Number of additionally emerged coleoptiles}}{\text{days to final count}}$$

The percentage of establishment (%E) was evaluated on the fourth day after the emergence began, based on the following equation:

$$\%E = \frac{\text{Number of seedlings emerged at the end of the test}}{44} \times 100$$

Where: 44 is the experimental size unit.

Harvest was carried out when grain moisture in the late variety (HS-2) was below 30%. The measured variables were: ear number (EN), number of plants (NP), plant height (PHe), ear height(EH), and ear weight (EW) adjusted to kernel weight at 12% of moisture content, moisture content time and Grain/Ear Relationship (G/ER Variance analysis was made following PROC PRINT SAS 9.3 procedure [17] 2002-2010 by SAS Institute Inc., Cary, NC, USA., it was applied the multiple comparison test Tukey to those variables that had a meaningful effect between treatments (P = .05), it was also used SAS (Statistical Analysis System).

3. RESULTS AND DISCUSSION

Statistically significant differences were observed ($p < 0.01$) (Table 1), for EN, PHe, EH and EW, for varieties, where HS-2 showed the highest values for the four variables EN (50), PHe (285 cm), EH (147.20 cm) and EW (4,652 g), in contrast with the landrace where there were obtained 31 ears and a plant and ear height of 203.5 and 81.75 cm, respectively and 1,771 g of EW.

Table 1. Mean squares and probability value for seed quality of five maize varieties subjected to electromagnetic treatment, grown in field under rain-fed conditions, Montecillo, Texcoco, State of Mexico, 2012

F	DF	EV	%E	EN	PHe	EH	EW
T	1	0.16 (0.5657)	72.35 (0.5095)	60.00 (0.2783)	68.26 (0.6739)	254.20 (0.4705)	4308201.93 (0.0085)
V	4	0.99 (0.1118)	305.44 (0.1315)	604.69 (<.0001)	10897.52 (<.0001)	7160.30 (<.0001)	13767856.27 (<.0001)
V*T	4	0.06 (0.9671)	33.84 (0.9336)	10.70 (0.9292)	334.64 (0.4836)	408.22 (0.5010)	394509.82 (0.6040)
Error	50	0.50	163.91	49.94	380.97	480.80	28690025.00
R^2		0.14	0.14	0.50	0.70	0.55	0.679969
C.V. (%)		15.60	15.28	17.46	7.86	19.45	21.56
Mean		4.53	83.75	40.46	248.20	112.69	3512.01

EV: emergence velocity; %E: percentage of establishment; EN: ear number; PHe: plant height, EH: ear height, EW: ear weight

The results of this study show that by the radiation parameters used (560 mT, 30 minutes), for the variables emergence velocity and percentage of establishment, there are no statistical differences when comparing the varieties with and without electromagnetic field (control). But, It was found, a trend of behavior positive (Promesa, HT-Precoz, CPV-20, Criollo M. Pozos) and negative (HS-2) dependent of variety studied. Perhaps to obtain significant statistical results is required to increase the level of magnetic induction. According to [18] the magnetic effects on plants may be explained by energy transfer to matter containing free radicals, being attracted or repelled according to their load. Energy transfer occurs, when load in these radicals increases and they are activated, which generates biostimulation; together with improvement in germination and growth of the corn seedlings [15,19].

The Increased of the physiological seed quality is extremely important for rain fed areas where the lack of homogeneity of the soil moisture, seedling emergence is not uniform, and the poor establishment of it results in non- synchronous flowering and ripening, lower soil advantages and in general lower yields; in this respect [19] irradiated maize seed with a solenoid under microtunnel conditions, detected increments of 123.2, 110 and 30.1 % respectively in emergency velocity, emergence percentage and seedling dry weight, in this [20] obtained significant statistical differences for EV in seedbed under microtunnel; also [21] reported that wheat seeds that were treated using 125 and 250 mT germinated in average 3 h less with respect to untreated seeds.

Moreover, several authors have obtained favorable results using magnetic field seedtreatment, in addition to activate the formation of protein and enzyme activity [22], it should be noted that the above observations do not coincide with the results obtained in this study, because it was established under field and uncontrollable weather conditions; in this respect [23] mentioned that both genetic and environmental factors determined the germination rate, germination speed and vigor of seed and seedling. It is noteworthy (Table 2) that the landrace presents very similar performance to the improved varieties, favorable for a proper seedling establishment in field under rain fed conditions.

For the variable EV the obtained values were 4.58 and 4.48 with and without magnetism, respectively, while the following varieties had the following tendency: CPV-20, 4.90; Criollo M. de Pozos, 4.74; HT-Precoz, 4.45; CP-Promesa; HS-2, 4.36 and 4.20. These differences may be due to the increased efficiency of the processes related to cell division [24], enzyme activity and to changes in membrane permeability and sensitivity to transport mechanisms through them [25,26].

In relation to establishment percentage (%E), 84.84% was obtained with magnetic radiation and 82.65% without radiation; whereas the variety factor was 90.34% for CPV-20, 86.93% for Criollo of M. de Pozos, 82.76% for HT-Precoz, 81.44% for Promesa, and 77.27% for HS-2; indicating a differential tendency in plants established in field under rain-fed conditions. [20] mentioned the importance of considering seeds as a complex system, in that way seed specific conditions must be taken into account, as well as the source characteristics of electromagnetic radiation in order to produce bio stimulation effects, this is supported by reports on differences among performance patterns assessed by vigor variables in three different maize genotypes for the 2006 agricultural cycle: CL-4 X CL-1, CL-13 X CL-1, and CL-12 X CL-11; three effects were detected, zero, positive, and negative, with the same irradiation parameters, which indicates that each variety may perform differently at similar levels of irradiation.

Likewise, vegetal species require different radiation levels, as [27] pointed out; they found that the best magnetic treatment for tomato seeds was 0.14 T and exposure time of 1 min, it was obtained better germination, seedling growth rate, and root length; while in onion seed, it grew 12.1 cm with a magnetic intensity of 160 mT and an exposure period of 25 min; root length was 4.35 cm with 20 min time of exposure; the results of this study suggested the convenience of applying better magnetic treatments under field conditions [28]. [29], observed that when it was applied 50 mT, plants were stimulated in their first ontogenetic phase, resulting in greater volume of fresh tissue, increased pigment assimilation and chlorophyll relationship, as well as the average level of nucleic acids, and it was increased seedling length, except for dry matter accumulation. However, at higher magnetic induction (treatments between 100 and 250 mT), there was not any effect for the measured parameters, it was concluded that the treatment with low intensity magnetic field could be the base for agricultural techniques to improve crops in the future. [30] found that when corn seeds were treated using magnetic field (100 mT during 2h and 200 mT for 1h) seedling growth increased, leaf water condition and photosynthesis rate improved, and seedlings antioxidant defense system was reduced belowsoil water stress; thus, pre-sowing seed treatment with static field can be used efficiently to improve plant growth under water stress conditions.

Even though the obtained results indicated that there is no significant difference for physiological quality on seeds, there is evidence on literature that says that it may be modified through the electromagnetic treatment, which is important if we take into account that the crop establishment will increase vigor and farmers will avoid economical and time losses, especially if we consider that climatic change has threatened our country with drought in wide regions. Seeds treated with electromagnetic field consume up to 75% less water [31], since plant proteins when are stimulated by magnetic radiation are organized in clusters and harden the cell membrane, thus avoiding the evapotranspiration process.

With treated seeds it is possible to avoid heterogeneity at seedling emergency time and achieve good performance, restraining plants with low yield and those with few or without ears [32,33].

For VE and PE variables (Table 2) CPV-20 and Criollo had the highest values both with magnetism and the tested one, in contrast HS-2 obtained the lowest values in both treatments. The Association of Official Seed Analyst (AOSA) [34] defines vigor as “seed properties that determine the potential for a rapid and uniform seedling emergence and development of normal seedlings under a wide range of field conditions”, hence magnetic field radiation is viable in order to increase seed vigor since it increases emergency rate and field establishment, which is critical for crop uniformity.

However, it had greater values for EH, EN, and therefore PHe, EW, in addition HS-2 had the highest EW at 12% moisture content with 5,224 ton/ha^{-1}of ear and 4,079 ton / ha^{-1}, respectively with magnetism and without treatment. In this particular case, there is no correlation of the VE and PE to grain yield (YG), as occurred with the obtained by [35] who detected a positive correlation between emergency speed and grain yield and its components. In the case of HS-2, these differences are expressed due to plants with two ears so yield was increased, otherwise happen with Criollo M. Pozos, that with magnetism the EW was 1,965 and 1,577 ton/ha^{-1} without magnetism. In particular the Criollo M. Pozos and conditions of the place of origin that is a semi- temperate climate with rainfall ranging from 400 to 500 mm annually and the average temperature is 16-18º C, it can be mentioned that it is possible to obtain a yield increase of 25 % when pretreating seed with magnetism is used.

Additionally it is possible to observe that there were significant statistical differences for the variety HT-Precoz in the variables ear height (EH) and ear weight (EW). It was found an increase of 25 and 17% compared with control, having the best outcomes for the samples treated with pre-sowing electromagnetic field.

Table 2. Comparison of the mean of the variables obtained with and without electromagnetic treatment

Variety	EV		%E		EH (cm)		EN		PHe (cm)		EW (t ha^{-1})	
	CM	**SM**	**CM**	**SM**	**CM**	**SM**	**CM**	**SM**	**CM**	**SM**	**CM**	**SM**
HS-2	4.14a	4.25a	76.13a	78.40a	144.91a	149.50a	50.83a	49.16a	293.50a	276.66a	5,224a	4,079a
Promesa	4.46a	4.26a	84.09a	78.79a	113.16a	117.16a	46.16a	43.16a	250.33a	262.66a	4,216a	3,810a
HT-Precoz	4.60a	4.31a	85.60a	79.92a	110.33a	88.33b	39.50a	36.16a	237.00a	238.66a	3,792a	3,246b
CPV-20	4.96a	4.85a	91.28a	89.39a	125.00a	115.00a	37.83a	39.00a	260.00a	256.16a	3,701a	3,506a
Criollo M. Pozos	4.76a	4.72a	87.12a	86.74a	80.33a	83.16a	33.00a	29.83a	205.50a	201.50a	1,965a	1,577a
LSD	0.36		6.63		11.37		3.66		10.12		875.11	

Means with the same letter for each variety with and without electromagnetic treatment are statistically equal (LSD, 0.05). EV: emergence velocity, %E: percentage of field establishment, EH: ear height, EN: ear number, PHe: plant height, EW: ear weight, CM: magnetic treatment, SM: control (untreated), LSD: Least Significant Difference

Differences in grain yield in HS-2, CPV-20 and Criollo due to magnetic treatment effect may be because seeds increase the α-amylase activity, generating an increase in the production of the vegetal gibberellin hormoneand activity of hydrolytic phosphataseenzyme [36]. With magnetism, soil water has less superficial tension**,** higher electric conductivity, and solubility; it is lighter, purer, and more fluid, compared to water in its normalstate; plants raise photosynthesis level and seed production [37]. Another effect of magnetic field on maize applied to seedlings during 30h, induced stimulation rate by 30% in root length, compared to the control, and acropetal as well as basipetal cellular expansion, [38]. Besides [15] found significant differences for PE in corn with a value of 90.5%, under microtunnel conditions and among treatments of electromagnetic radiation, and for emergence rate and dry weight of the aerial part.

Table 3 shows the average behavior of % of grain at harvest, Grain/Ear Relationship (GER) and grain yield per hectare with and without electromagnetic treatment. It is possible observe thatHS-2, CPV-20, and Criollo of M. de Pozos had less grain moisture content at the harvesting moment (Table 3); it may be possibly because the magnetism favored ear rapid physiological maturity, possibly due to the magnetism improves the integrity of the cell membrane to prevent loss and electrical conductivity and thereby facilitate the shortening of the cycle to physiological maturity [39] Promesa and HT-Precoz, however, show an inverse performance, that is, they had higher moisture content when the seed is treated with electromagnetic field. In RGM there is a differential response, it is favorable for HS-2 (84.40), Promesa (80.00) and Criollo M. de Pozos (89.90) varieties, where it could be assumed that the magnetic field applied to the seed allowed a higher efficiency in grain filling, whereas the opposite occurred with HT-Precoz and CPV-20, which have the highest RGM from untreated seed samples.

Grain yield at 12% moisture is favorable to treat seed prior to planting with magnetic field, which increases up to 28% in HS-2, 25% Mineral Wells Criollo, 15% CPV-20, 11% Promesa while in the Trilinear Early hybrid there was a reduction of 7.5%. Each variety responds in a different way to magnetic field intensity and to the time period it was exposed [11]. Then, future research will therefore have to be carried out on much wider germplasm, irradiation parameters and several weather conditions.

Table 3. Grain% Moisture, Grain/Ear Relationship (GER) and grain yield per hectare with and without treatment with electromagnetism

Variety	Treatment	% of grain at harvest	GER	Grain yield (t ha^{-1}) at 12% of humedity
HS-2	CM	18.9	84.40	4,950
	SM	28.1	80.86	3,863
Promesa	CM	27.3	80.00	3,993
	SM	25.9	79.10	3,612
HT-Precoz	CM	21.4	79.76	3,037
	SM	15.5	86.66	3,264
CPV-20	CM	20.9	81.63	3,480
	SM	24.7	82.22	3,034
sCriollo M. Pozos	CM	17.7	89.90	1,864
	SM	19.3	89.74	1,494

ger: grain/ear relationship

In this regard, yield increase can be explained by [18], who pointed out that the magnetic effect on plants is given by the energy transfer to the material containing free radicals, being attracted or repelled according its load, thus producing energy transfer when the load is increased and these radicals are activated, generating the bio-stimulation [19].

4. CONCLUSION

1. In the present research project it has been found that the effects of alternating magnetic field treatments, in maize seeds, depend on the seed variety. Then, it was found, positive biostimulation effects for the variety HT-Precoz in the variables ear height (EH) and ear weight (EW), it was observed a significantly increment of 25 and 17% compared with control (untreated). For the varieties HS-2 and Promesa, HT-Precoz, CPV-20 and Criollo M. Pozos there were a trend of negative and positive biostimulation effects, respectively.
2. The use of magnetism could be an economical viable technique that increases productivity and it would be accepted in regions with low humidity and limited use of agricultural supplies.
3. It is advisable to develop further research in relation to the dose and timing of the magnetic field, there should be run tests in the laboratory and in field, considering that there are differential responses among varieties in their different phenological stages.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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