academicJournals

Vol. 13(1), pp. 76-83, 1 January, 2014
DOI: 10.5897/AJB2013.13245
ISSN 1684-5315 ©2014 Academic Journals
http://www.academicjournals.org/AJB

African Journal of Biotechnology

Full Length Research Paper

Electromagnetic field in corn grain production and health

Rosalba Zepeda-Bautista[1]*, Claudia Hernández-Aguilar[2], Francisco Suazo-López[3], Arturo F. Domínguez-Pacheco[2], Juan Virgen-Vargas[1], Cristina Pérez-Reyes[4] and Ignacio Peón-Escalante[2]

[1]National Institute for Forestry, Agriculture and Livestock, Experimental Valley of Mexico, km 13.5 Highway Los Reyes-Texcoco, Coatlinchan, Texcoco, State of Mexico, C. P. 56250, Mexico.
[2]National Polytechnic Institute, SEPI-ESIME, Zacatenco, Professional Unit "Adolfo López Mateos", Col. Lindavista, Mexico, D. F. C. P. 07738, Mexico.
[3]Chapingo Autonomous University, km 38.5 Highway Mexico-Texcoco, Chapingo, Mexico. C. P. 56230, Mexico.
[4]Higher Education Faculty Cuautitlan, National Autonomous University of Mexico, Jorge Jimenez Cantu Av. S/N, Cuautitlan Izcalli, State of Mexico, C. P. 54740. Mexico.

Accepted 17 December, 2013

The effect of electromagnetic field on agricultural characteristics, yield and health conditions of corn hybrids was assessed using biophysical methods, in order to improve production and health of maize grain (*Zea mays* L.) for human consumption. The seed was exposed to electromagnetic field at an intensity of 480 mT. Hybrids San Juan and San Jose and five times of exposure (3, 6, 9, 12 and 15 min) were evaluated, as well as a (non-irradiated) control, in a completely randomized block design. On average, grain yield of 9 tons per ha was obtained. With 12 min exposure to electromagnetic field, plant height increased by 0.56% and stem diameter by 3.19%; likewise, yield per hectare was 6.03%, equivalent to 550 kg per ha, compared to the non-irradiated control. San Jose yielded 8.79% more, with 12 min exposure to electromagnetic field, and San Juan 6.52% more, with 6 min. In grain, an average 23% of *Fusarium* spp. and 19% of *Fusarium moniliforme* were quantified. The presence of *Fusarium* spp. diminished by 33.69 and 13.04% compared to the control, with 3 and 12 min of exposure to electromagnetic field.

Key words: *Zea mays* L., grain yield, *Fusarium* spp., health quality, electromagnetic field.

INTRODUCTION

In 2011, world corn production was 883.5 million tons, 78.5% of which were produced by the USA, China, Brazil, Argentine, Ukraine, India, Mexico, Indonesia, France and Rumania. Mexico produced 17.6 million tons (2% of world production) (FAO, 2012a; SIAP, 2012). In 2009, 113.9 million tons were utilized for the elaboration of food with *per capita* consumption of 17.1 kg; in Mexico, the consumption was higher (120.5 kg person^{-1} per year) with 330 g *per capita* day^{-1}, providing 45.4 and 37.4% of energy and protein required by the human body (FAO, 2012a). In Latin-American countries, the United States, and others, there is significant progress in the consumption of maize products. In 2009, the USA utilized 41.5% of their maize production to produce ethanol (FAO, 2012b), blue corn is used to produce organic cornmeal, fried food (Serna, 2004) and anthocyanins, able to prevent cancer (Cortés-Gómez et al., 2005); yellow corn is utilized to make balanced animal food and fried food,

*Corresponding author. E-mail: rzb0509@hotmail.com. Tel: 015959212738 ext. 193.

and white corn is used in a great variety of foods such as tamales, tortilla chips, atole, nixtamalized cornmeal and tortillas (Muñoz, 2005). In 2009, Mexico used 13.5 million tons for human consumption (FAO, 2012a), especially tortilla made with grain produced in Mexican fields or imported, that on occasions have field or storage fungi, which may cause damage to human health (Anguiano-Ruvalcaba et al., 2005; Méndez and Moreno et al., 2009).

Despite the importance of maize, several studies point out diminution in annual yield mean rates worldwide, as well as in most of the producer countries (FAO, 2012b). Therefore, it is necessary to increase yield and grain quality through efficient use of inputs and natural resources. One alternative may be the use of environmentally-friendly techniques like electromagnetic irradiation, as it is reported that it can improve corn grain quality (Zepeda-Bautista et al., 2011) and wheat yield (Pietruszewski and Kania, 2010). Agricultural techniques have been utilized in order to improve maize kernel production, which on occasion have damaged the environment. In simple parent crossing, hybrids H-47AE, H-50AE, and H-51AE in their androsterile and fertile versions, at applying 150-70-40 kg ha^{-1} of N, P, and K, respectively, increased yield by 18.3% compared to the control (Tadeo-Robledo et al., 2012).

Likewise, grain yield increased in corn genotypes with 165 and 300 kg N ha^{-1} in comparison to the control (Boomsma et al., 2009). Mendoza et al. (2006) obtained yield of 10.2 and 8.8 t ha^{-1}, in high-protein quality when applied 200 and 100 kg N ha^{-1}, and 11.8 and 10.9 t ha^{-1} for common maize varieties. During its development, harvest, conditioning, and storage, corn grain is contaminated by pests and fungi. In corn-producing regions in Sonora, Mexico, 76 samples were analyzed, and *Fusarium*, *Aspergillus*, *Penicillium* and *Alternaria* were found to be the fungi of greatest incidence, as well as concentrations of fumonisins, detected in grain, fluctuated between 0.4 and 3.4 μg/g (Gallardo-Reyes et al., 2006).

In Guanajuato, Mexico, *Fusarium* spp., promotes wilt in seedlings and up to adult maize plants, generally causing rot in vegetative organs, *F. verticillioides* and *F. subglutinans* mainly in maize races (Figueroa-Rivera et al., 2010). At Texcoco, Mexico, Rivas-Valencia et al. (2011) observed that hybrids HGVC-2 and Prospecto-4 presented balanced severity of 8.99 and 15.16%, respectively; in Huamantla, hybrid Prospecto-1 had weighted severity of 13%; the detected *Fusarium* species were: *F. subglutinans*, *F. moliniforme*, *F. proliferatum* and *F. oxysporum.*

Likewise, in Valley of Atlacomulco, State of Mexico, 25 corn genotypes were assessed, detecting ear rot of 8% on average; the *Fusarium* species identified were *F. oxysporum*, *F. moliniforme*, *F. graminearum* and *F. poae* (González et al., 2007). Ear rot caused by different *Fusarium* spp. is one of the most harmful foods for human and animal consumption, as well as a real challenge for achieving food innocuousness in maize production; the most important damage is caused by *F. graminearum* and *F. verticillioides*. Currently, most of the endogamic and hybrid lines are susceptible (Mesterhazy et al., 2012); therefore, we need to implement techniques applied to genetic improvement in order to generate resistant genetic materials or other alternatives.

Biophysical methods can be a tool for improving agricultural productivity. French marigold seed exposed to magnetic field at 100 mT during 3 min improved germination and seedling vigor (Afzal et al., 2012). In mushrooms under the same conditions, fresh weight and dry matter increased by 76.42 and 38.26%, and the days to head appearance were reduced by 26.86% (Jamil et al., 2012); in pea, length and dry weight of seedlings increased by 140.5 and 91.3% (Iqbal et al., 2012). Mohammadi et al. (2012) observed that canola seed exposed to laser radiation during 45 min showed significant effect on seed yield per pod and reduction of the impact of salt stress in soil. Higher accumulation of dry matter and sugar content, compared to the non-irradiated plants was observed, when radiating sugar beet seed with laser at pre-sowing (Sacala et al., 2012). Pietruszewski and Kania (2010) indicate 12.5 and 14.5% higher wheat yield than the control, exposing it to magnetic field at a dose of 12.9 and 17.9 k J m^{-3}. In order to increase production and health quality of corn as food for human and animal consumption, by using environmentally-friendly techniques, the effect of electromagnetic field as pre-sowing treatment on agricultural properties, yield and health of maize hybrid grain were evaluated.

The hypotheses were: 1) the application of electromagnetic field as pre-sowing treatment to corn seed would transfer energy, and generate bio-stimulation, which may modify the source of several physiological and biochemical processes, being reflected in plant growth and development, as well as in kernel production and health; and 2) the response of each corn hybrid will be different according to its particular genetic characteristics and to its structural and chemical seed composition.

MATERIALS AND METHODS

During the spring-summer cycle of 2009, an experiment was established in Zumpango, State of Mexico, Mexico (19° 43' 10'' LN, 98° 58' 12'' LW, 2250 m.s.n.m.), presenting sub-humid climate with summer rainfalls [C(w_0)(w)b(i')], annual mean precipitation of 436 mm, annual mean temperature of 15.1°C (García, 1987) and clay loam soil. Twelve treatments were evaluated, product of the combination of two corn hybrids: San Jose and San Juan, and five exposure times to electromagnetic field: 3, 6, 9, 12, and 15 min at intensity of 480 mT and control (non-irradiated), in a completely randomized block design with four replications, the experimental unit was of four 5 m-long and 0.80 m-wide furrows.

The corn seed was exposed to the variable magnetic field by means of a solenoid, device answering the hypothesis that the magnetic induction must be uniform on the entire surface; 200 g were placed in the middle of the solenoid. Figure 1 shows its schematic diagram; the solenoid is an original device, developed and constructed by the research team of ESIME-IPN, and in Figure

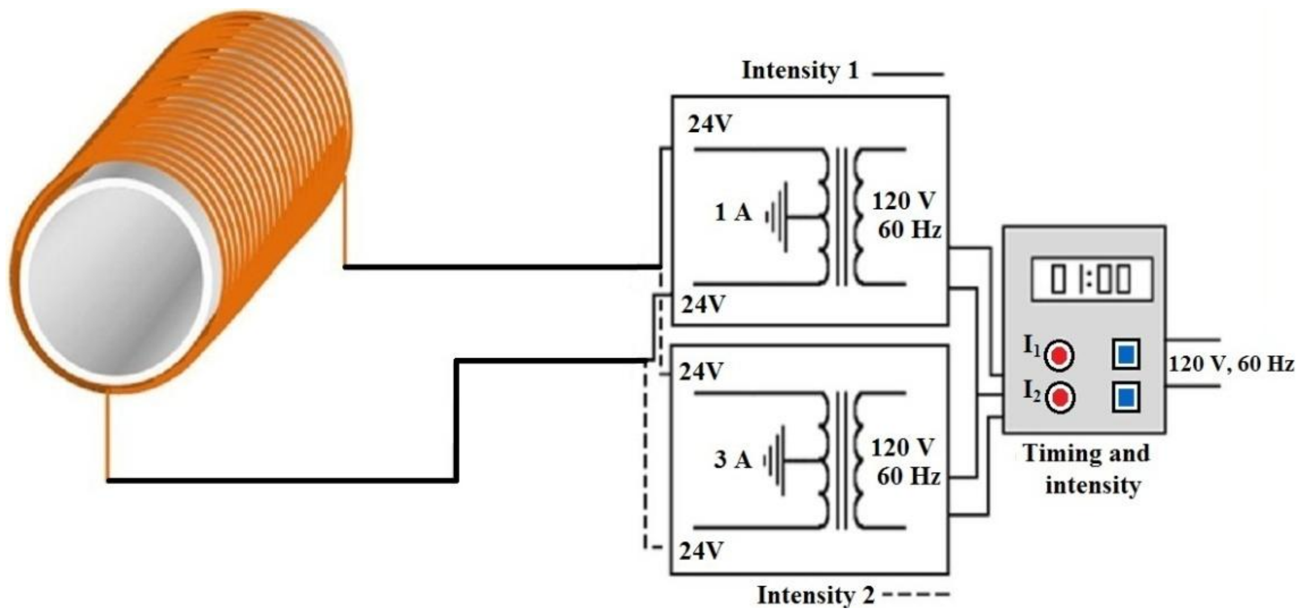

Figure 1. Schematic diagram of the solenoid (Domínguez et al., 2010).

2, the distribution of the generated magnetic field is visualized (Domínguez et al., 2010). The seed was radiated on April 25th 2009 and sown on the next day. Population density was 50,000 plants ha^{-1}, fertilized with 46 N ha^{-1}, using urea as nitrogen source, weeds were controlled with two herbicide applications (Primagram gold, i. a. Atrazine + S-metolaclor).

Three irrigations were carried out: one at sowing (April 29th, 2009) and the following at flowering and grain filling (V0, V18 and R2, respectively) (Ritchie et al., 1993). Harvest was on November 14th, 2009, at physiological maturity, the environment dried up, and kernels were separated from ears by hand, and stored at a temperature of 18°C. Measurements were made: 1) halfway male flowering, days from first irrigation to reaching anthesis in 50% of plants of the experimental plot; 2) plant height, calculating the average of four plants, measured in centimeter from stem base to flag leaf ligule; 3) stem diameter at 30 cm from stem base, using a vernier and considering the average of 4 plants, and 4) grain yield; harvesting the two central rows of the plot and calculating in t ha^{-1} at 14%.

At harvest, 25 ears of each experimental unit were taken randomly and manually shelled when their moisture content was about 12%. Then, for evaluating health condition, the samples of sound kernels with complete structure and full ears were randomly taken and separated. The assessment was carried out in the laboratory of the Grain and Seed Research Unit of Higher Education Faculty Cuautitlan (FESC) in the National Autonomous University of Mexico (UNAM). The mycobiota test was used with agar plate (PDA) (Moreno, 1996), grain was disinfected with sodium hypochlorite at 3%, subsequently, and it was sown in Petri dishes with PDA and placed in a chamber at 25°C for 4 days. A completely randomized block design with three replications was utilized, the experimental unit being 50 kernels. On the fourth day, presence of *Fusarium* spp., *Penicillium* spp., and *Alternaria* spp. was quantified and expressed in percentage. An analysis of variance was conducted by means of PROC GLM procedure of the Statistical Analysis System (SAS, 1989), and the Tukey test (α = 0.05) of multiple comparisons of means was applied to the variables whose mean squares turned out significant. Arc cosine transformation was applied to the variables in percentage.

RESULTS AND DISCUSSION

Agronomical properties and grain yield

Among corn hybrids, significant differences ($p \leq 0.05$) for halfway male flowering and plant height were observed, on the contrary to stem diameter and grain yield (Table 1), due to their particular genetic characteristics. Similar results were perceived by Avila et al. (2009) in the corn hybrid cultivar at High Valleys of México, Mexico. San Jose hybrid presented one more day for halfway male flowering and 3.75% greater plant height compared to that of San Juan (Table 1). Mean grain yield was > 9 t ha^{-1}, major than average grain production in Mexico (2.22 and 7.51 t ha^{-1}) under rainfed and irrigation conditions, respectively (SIAP, 2012).

There were no significant differences ($p \leq 0.05$) between time of exposure to the electromagnetic field at 480 mT intensity as pre-sowing treatment for agronomical characteristics and grain yield of corn hybrids (Table 1); this is due to the fact that seed bio-stimulation at pre-sowing did not have prolonged significant effect during the maize phenological cycle (155 days after first irrigation). This indicates that it is advantageous to con-duct application of the electromagnetic field during plant growth and development, specifically at the stages of greatest nutrient absorption, such as floral differentiation (V10), flowering (V18) and grain filling (R2) (Ritchie et al.,1993; Mills and Jones, 1996). This can be explicated, based on Galland and Pazur (2005) who mentioned that magnetic effects on plants may be explained by energy transfer to matter containing free radicals, being attracted or repelled according to their load.

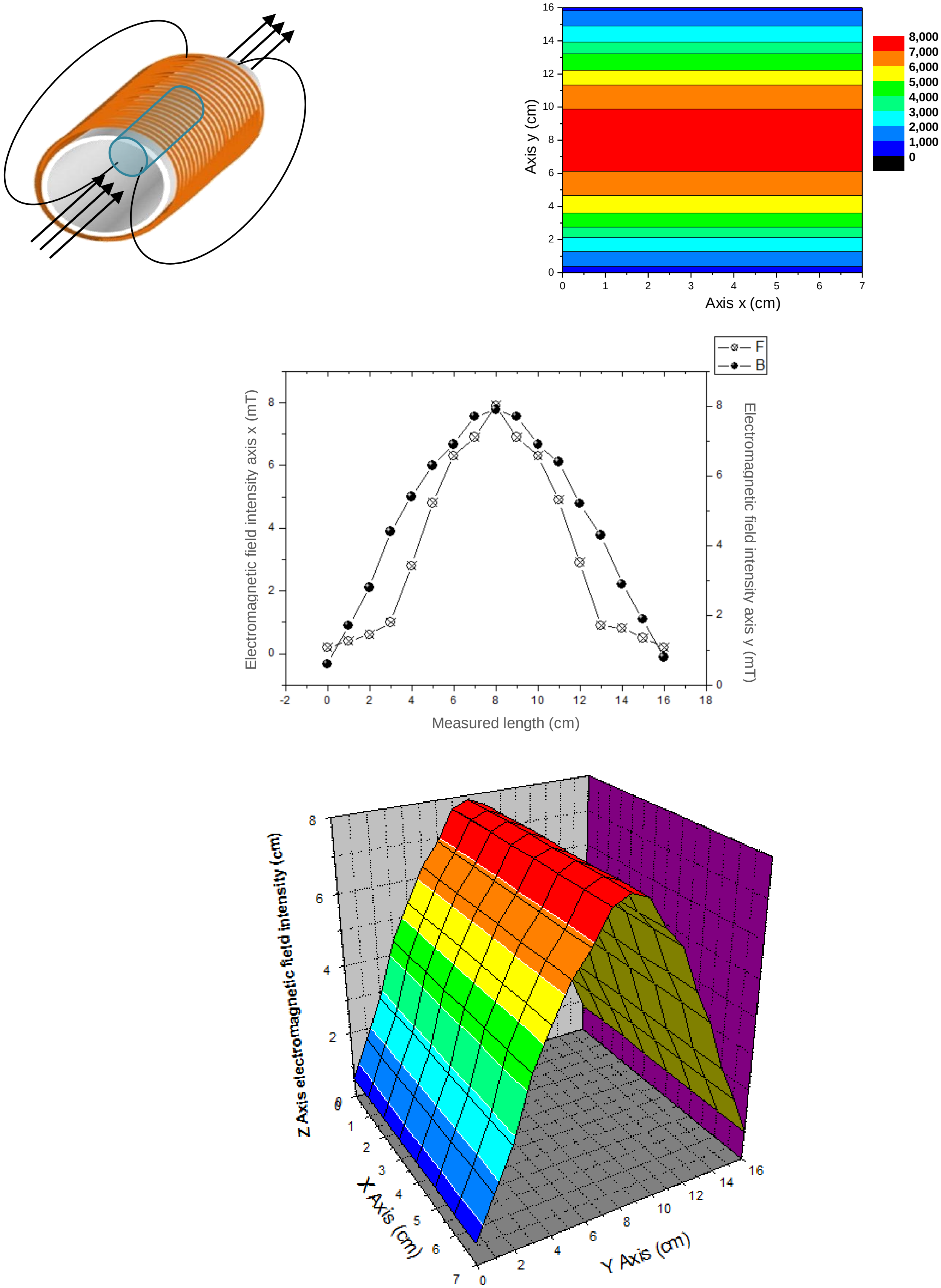

Figure 2. Visualization of the distribution of magnetic field (Domínguez et al., 2010).

Table 1. Comparison of means of agronomical characteristics and grain yield of maize hybrids with different time of exposure to electromagnetic field at pre-sowing.

Hybrid	Halfway male flowering (days)	Plant height (cm)	Stem diameter (cm)	Grain yield (t ha^{-1})
San Jose	92.08[a]	276.93[a]	2.89[a]	9.15[a]
San Juan	90.79[b]	266.97[b]	2.83[a]	9.26[a]
HSD (0.05)	0.67	5.48	0.12	0.53
F-value	0.01	0.01	0.30	0.65
Time of exposure to the electromagnetic field at 480 mT intensity (min)				
Control (non-irradiated)	91.50[ab]	273.51[a]	2.82[a]	9.11[a]
3	91.50[ab]	274.52[a]	2.93[a]	9.16[a]
6	91.50[ab]	269.40[a]	2.83[a]	9.18[a]
9	91.37[ab]	271.47[a]	2.78[a]	8.96[a]
12	90.62[b]	275.05[a]	2.91[a]	9.66[a]
15	92.12[a]	267.77[a]	2.90[a]	9.16[a]
HSD (0.05)	1.16	9.49	0.20	0.92
F-value	0.24	0.56	0.61	0.73
Mean	91.44	271.96	2.87	9.21
C. V. (%)	1.25	3.44	6.91	9.82
SD	1.14	9.35	0.19	0.90

Means with the same letter in each column are statistically equal (Tukey, $p \leq 0.05$). HSD, Honest Significant Difference; C. V., variation coefficient; SD, standard deviation.

Energy transfer occurs, when load in these radicals increases and they are activated, which generates bio-stimulation; together with improvement in germination and growth of the corn seedlings, reported by Hernández et al. (2009) and Domínguez et al. (2010). Nevertheless, with 12 min of seed exposure to irradiation at intensity of 480 mT, an increase in plant height and stem diameter was observed by 0.56 and 3.19%, respectively, as well as 6.03% higher grain yield ha^{-1}, equivalent to 550 kg ha^{-1} with respect to the not exposed control (Table 1).

Interaction of corn hybrids × time of exposure to electromagnetic field

The hybrids showed different response to exposure to electromagnetic field at intensity of 480 mT. Concerning plant height, the hybrids San Juan and San Jose had similar performance with application of 3, 6 and 9 min, whereas with 12 min of exposure to the magnetic field, hybrid San Jose reached the greatest height (1.44% more), compared to the non-irradiated control, and subsequently showed a decrease in plant height by 0.4% (Figure 3). In grain yield, San Jose increased by 8.79 and by 4.39% with exposure of 12 and 15 min, respectively, compared to the yield of the control (Figure 4), which represents 800 and 400 kg ha^{-1} of grain for the producer applying an environmentally-friendly biophysical method. San Juan hybrid presented its maximum yield with an exposure time of 6 min (plus 6.52%), equivalent to an increment of 600 kg ha^{-1} of grain. Hybrid response to electromagnetic irradiation was similar to the one observed in maize seedlings by Hernández et al. (2009); there is, however, little information about the effect of electromagnetic field on maize growth and production; in crops like canola, an increase of seed yield per pod was observed (Mohammadi et al., 2012) and higher yield in wheat, 12.5 and 14.5% (Pietruszewski and Kania, 2010).

Grain health

In grain of corn hybrids, an average of 28.49% of *Fusarium* spp. was quantified, 19% of which were *Fusarium moniliforme*, and *Fusarium oxysporum*, and to a lesser extent *Fusarium graminearum* to a lesser extent (6 and 2%, respectively) (Table 2). Similar results were observed by Rivas-Valencia et al. (2011) evaluating ear rot severity of corn hybrids in Texcoco and Huamantla, Mexico and Gonzalez et al. (2007) detected 8% of ear rot on average, caused by *Fusarium* spp. in Valle de Atlacomulco, State of Mexico. This indicates that there is *Fusarium* spp. infestation in grain for human consumption causing damage to health (Anguiano-Ruvalcaba et al., 2005; Méndez and Moreno et al., 2009; Mesterhazy et al., 2012).

As for *Fusarium* spp. percentage in maize grain, it was observed that with 3 min of seed exposure to electromagnetic field, the fungus diminished significantly ($p \leq 0.05$) by 33.69% (Table 2), in comparison to the (non-

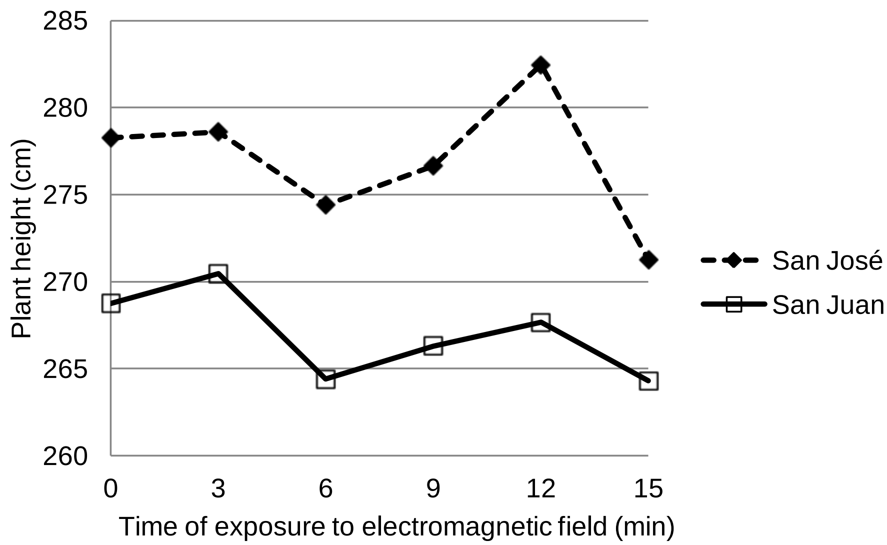

Figure 3. Plant height of maize hybrids with time of exposure to electromagnetic field as pre-sowing treatment.

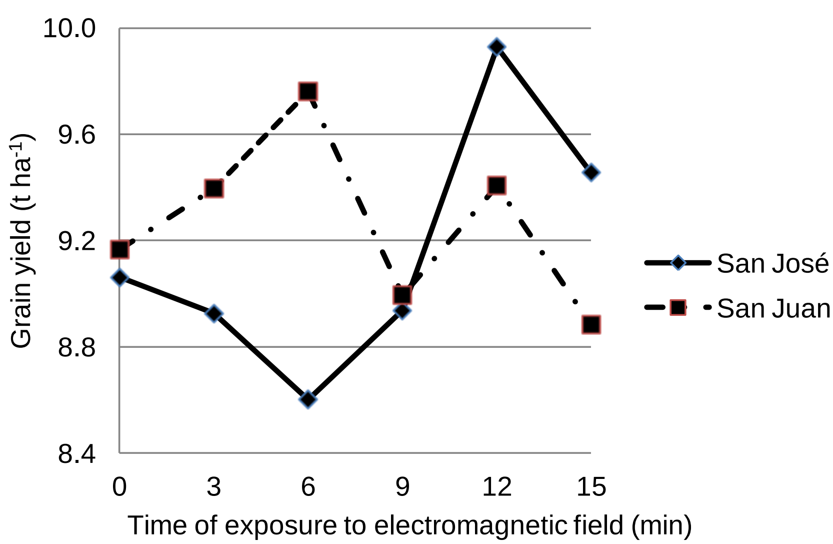

Figure 4. Grain yield of maize hybrids with time of exposure to electromagnetic field as pre-sowing treatment.

irradiated) control, followed by 12 and 6 min with 13.04 and 10.86% less damage. For the control of *F. moliniforme*, we found that with 3, 6, 9, and 12 min of exposure to irradiation, the fungus in grain was reduced to 54, 34, 9 and 15% compared to the control; on the other hand, the exposure to electromagnetic field stimulated the occurrence of *F. graminearum* and *F. oxysporum* (Table 2). Generally, we perceived less presence of *Fusarium* spp., irradiating the corn seed at pre-sowing; hence, applying the treatment to maize seed being produced for human diet could be an alternative method of health control.

Conclusions

The electromagnetic field used as pre-sowing treatment in seed of corn hybrids can improve plant growth and development, as well as grain yield, according to the hybrid and the time of exposure; however, the effect would be more important, when applying during the stages of higher nutrient absorption (floral differentiation, flowering and grain filling). Exposure of corn seed to electromagnetic field at pre-sowing can be an alternative method for the control of *Fusarium* spp. in maize grains utilized to produce food for human consumption. Every

Table 2. Comparison of means of hybrid maize grain health condition with different time of exposure to electromagnetic field at pre-sowing.

Hybrid	*Fusarium* spp (%)	*Fusarium* (%) *moniliforme*	*graminearum*	*oxysporum*
San Jose	31.22[a]	21.66[a]	2.33[a]	7.22[a]
San Juan	25.77[b]	17.77[b]	1.88[a]	6.11[a]
HSD (0.05)	4.25	3.55	1.21	2.94
F value	0.01	0.04	0.33	0.66
Time of exposure to the electromagnetic field at 480 mT intensity (min)				
Control (non-irradiated)	30.66[ab]	24.00[ab]	0.66[b]	6.00[a]
3	20.33[b]	11.00[c]	1.33[b]	8.00[a]
6	27.33[ab]	15.66[ab]	5.33[a]	6.33[a]
9	33.33[a]	21.66[ab]	2.00[b]	9.66[a]
12	26.66[ab]	20.33[ab]	1.33[b]	5.00[a]
15	32.66[a]	25.66[a]	2.00[b]	5.00[a]
HSD (0.05)	11.02	9.20	3.15	7.62
F-value	0.01	0.01	0.01	0.76
Mean	28.49	19.72	2.11	6.66
SD	6.17	5.15	1.76	4.26

Means with the same letter in each column are statistically equal (Tukey, p≤0.05). HSD, Honest Significant Difference; SD, standard deviation.

corn hybrid and *Fusarium* spp. responded differently to the exposure to magnetic field, according to their structure and composition. Based on the results, it is recommending the San Juan hybrid with 3 min of exposure to the electromagnetic field, as pre-sowing treatment.

ACKNOWLEDGEMENT

The authors thank CONACYT for the support awarded to carry out the present research.

REFERENCES

Afzal I, Mukhtar K, Qasim M, Basra SMA, Shahid M, Haq Z (2012). Magnetic stimulation of marigold seed. Int. Agrophys. 26(1): 335-339.

Anguiano-Ruvalcaba GL, Vargas-Cortina AV, Guzmán De Peña D (2005). Inactivación de aflatoxina B1 y aflatoxicol por nixtamalización tradicional del maíz y su regeneración por acidificación de la masa. Salud Pública de México 47(5): 369-375.

Avila PMA, Arellano VJL, Virgen VJ, Gámez VAJ, María RA (2009). H-52 Híbrido de maíz para Valles Altos de la Mesa Central de México. Agric. Técn. Méx. 35(2): 237-240.

Boomsma CR, Santini JB, Tollenaar M, Vyn TJ (2009). Maize morphophysiological responses to intense crowding and low nitrogen availability: An analysis and review. Agron. J. 111(6): 1426-1452.

Cortés-Gómez A, San Martín-Martínez E, Martínez-Bustos F, Vázquez-Carrillo GM (2005). Tortillas of blue maize (*Zea mays* L.) prepared by a fractionated process of nixtamalization: analysis using response surface methodology. J. Food Eng. 66: 273-281.

Domínguez PA, Hernández AC, Cruz OA, Carballo CA, Zepeda BR, Martínez OE (2010). Influence of the electromagnetic field in maize seed vigor. Rev. Fitotec. Mex. 33(2):183-188.

Figueroa-Rivera MG, Rodríguez-Guerra R, Guerrero-Aguilar BZ, González-Chavira MM, Pons-Hernández JL, Jiménez-Bremont JF, Ramírez-Pimentel JG, Andrio-Enríquez E, Mendoza-Elos M (2010). Characterization of *Fusarium* species associated with rotting of corn root in Guanajuato, Mexico. Rev. Mex. Fitopatol. 28: 124-134.

Food and Agriculture Organization of the United Nations (FAO) (2012a). FAOSTAT (FAO Statistical Databases) Agriculture, Fisheries, Forestry, Nutrition. Rome, Italy. http://faostat.fao.org/default.aspx/. January 2013.

Food and Agriculture Organization of the United Nations (FAO) (2012b). El Estado Mundial de la Agricultura y la Alimentación 2012. Viale delle Terme di Caracalla, 00153 Roma, Italia. 198 p.

Galland P, Pazur A (2005). Magnetoreception in plants. J. Plant Res. 118:371-389.

Gallardo-Reyes ED, Ibarra-Moreno GM, Sánchez-Mariñez RI, Cuamea-Cruz G, Molina-Gil G, Parra-Vergara NV, Rosas-Burgos EC, Cortez-Rocha MO (2006). Micobiota de maíz (*Zea mays* L.) recién cosechado y producción de fumonisina B1 por cepas de *Fusarium verticillioides* (Sacc.) Nirenb. Rev. Mex. Fitopatol. 24(1): 27-34.

García ME (1987). Modificaciones al Sistema de Clasificación Climática de Köppen. UNAM. México. D. F. p. 217.

González HA, Vázquez GLM, Sahagún CJ, Rodríguez PJE, Pérez LDJ (2007). Rendimiento de maíz de temporal y su relación con la pudrición de mazorca. Agric. Técn. Méx. 33(1): 33-42.

Hernández AC, Domínguez PFA, Carballo CA, Cruz OA, Ivanov R, López BJL, Pastor VMA (2009). Alternating magnetic field irradiation effects on three genotype maize seed field performance. Acta Agrophys. 14: 7-17.

Iqbal M, Haq ZU, Jamil Y, Ahmad MR (2012). Effect of presowing magnetic treatment on properties of pea. Int. Agrophys. 26(1): 25-31.

Jamil Y, Haq Z, Iqbal M, Perveen T, Amin N (2012). Enhancement in growth and yield of mushroom using magnetic field treatment. Int. Agrophys. 26(1): 375-380.

Méndez AA, Moreno ME (2009). Las micotoxinas, contaminantes naturales de los alimentos. Revista Ciencia 61: 1-7.

Mendoza EM, Mosqueda VC, Rangel LJA, López BA, Rodríguez HSA, Latourniere ML, Moreno ME (2006). Densidad de población y fertilización nitrogenada en la clorofila, materia seca y rendimiento de maíz normal y QMP. Agric. Técn. Méx. 32(1): 89-99.

Mesterhazy A, Lemmens M, Reid LM (2012). Breeding for resistance to ear rots caused by *Fusarium* spp. in maize-a review. Plant Breed. 131: 1-19.

Mills HA, Jones JB Jr. (1996). Plant Analysis Handbook II: A Practical Sampling, Preparation, Analysis, and Interpretation Guide. Micromacro Publishing, USA. pp.112-191.

Mohammadi SK, Shekari F, Fotovat R, Darudi A (2012). Effect of laser priming on canola yield and its components under salt stress. Int. Agrophys. 26(1): 45-51.

Moreno ME (1996). Análisis Físico y Biológico de Semillas Agrícolas. Tercera ed. Universidad Nacional Autónoma de México. México, D. F. p. 393.

Muñoz OA (2005). Centli-maíz: prehistoria e historia, diversidad, potencial, origen genético y geográfico. 2da. Edición. Ed. Colegio de Postgraduados, Texcoco, México. p. 210.

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

Ritchie WS, Benson GO, Lupkes SJ, Salvador RJ (1993). How a corn plant develops. Cooperative Extension Service Ames, Iowa. Iowa State University of Science and Technology. http://www.ag.iastate.edu/departments/agronomy/corngrows.html. May 2002.

Rivas-Valencia P, Virgen-Vargas J, Rojas-Martínez I, Cano-Salgado V, Ayala-Escobar V (2011). Evaluation of ear rot in hybrid maize in High Valleys. Rev. Mex. Cienc. Agríc. 2(6): 845-854.

Sacala E, Demczuk A, Grzys E, Prosba-Bialczyk U, Szajsne H (2012). Impact of presowing laser irradiation of seeds on sugar beet properties. Int. Agrophys. 26(1): 295-300.

Serna SSO (2004). Foods from maize. In: Encyclopedia of Grain Science. Wrigley C. and Walter C. (ed.). Elsevier.

Servicio de Información y Estadística Agroalimentaria y Pesquera (SIAP) (2012). Producción agrícola ciclo primavera-verano 2011. Maíz grano. http://www.siap.gob.mx/. January 2013.

Statistical Analysis System (SAS) Institute Inc. (1989). SAS/SAT User's Guide. Version 6. Fourth Edition. Volumen l. Cary, NC: SAS Institute Inc., p. 943.

Tadeo-Robledo M, Espinosa-Calderon A, Chimal N, Arteaga-Escamilla I, Trejo-Pastor V, Canales-Islas E, Sierra-Macías M, Valdivia-Bernal R, Gómez-Montiel NO, Palafox-Caballero A, Zamudio-González B (2012). Plant density and fertilization in hybrid maize androesterile and fertile versions. Terra Latinoamericana 30(2): 157-164.

Zepeda BR, Hernández AC, Suazo LF, Domínguez PA, Cruz OA, Martínez OE, Hernández SLM (2011). Physical characteristics of maize grain and tortilla exposed to electromagnetic field. Int. Agrophys. 25(4): 389-393.