Acta Agrophysica, 2011, 18(1), 17-31

PHYSICAL CHARACTERISTICS OF GRAINS OF MAIZE PRE-SOWING TREATED BY ELECTROMAGNETIC FIELDS

Doricela Gutiérrez Cruz[1], *Rosalba Zepeda Bautista*[1],
Claudia Hernández Aguilar[1],
Flavio Arturo Domínguez Pacheco[1], *Alfredo Cruz Orea*[2],
José Luis López Bonilla[1]

[1]Instituto Politécnico Nacional, SEPI-ESIME, Zacatenco, Unidad Profesional "Adolfo López Mateos", Av. Instituto Politécnico Nacional s/n, Unidad Profesional, Colonia Lindavista, Delegación Gustavo A. Madero, México, D.F. C.P. 07738
[2]Departamento de Física, CINVESTAV-IPN, Av. IPN No. 2508, Col. San Pedro Zacatenco, Delegación Gustavo A. Madero, C.P. 07360, México DF
e-mail: gutierrezcruzdo@yahoo.com.mx

Abstract. Electromagnetic fields have many applications in agriculture, but much still remains to be studied to provide scientific evidence of its potential use as an alternative for improvement of food quality from plants whose seed was irradiated, especially in the physical characteristics of the product. In this study we investigated the effects of the electromagnetic fields on the physical quality of maize grain. Twelve treatments were evaluated from a combination of two maize hybrids (San Juan and San Jose) and five times of exposure to electromagnetic field (3, 6, 9, 12 and 15 minutes) plus a control (no electromagnetic treatment) in a design of randomised complete blocks with four replications. Electromagnetic treatment of the hybrid maize seeds (San Juan and San Jose), applied as a pre-sowing treatment, modifies the physical characteristics of maize grains. It was possible to observe that there were significant differences ($p \leq 0.01$) between the experimental treatments and between the hybrids in their grain length (LG), grain width (GW) and 1000-grain weight (TGW). The hectolitric weight (HW) of the hybrids was between 69.05 and 68.98 kg hL^{-1}, respectively. These results could have an impact on the process and quality of the tortilla that is consumed by the population; this is a function of time of exposure to electromagnetic treatment.

Keywords: *Zea mays* L., electromagnetic field, maize grains, physical characteristics

INTRODUCTION

Several problems exist in the world, such as climate change, energy and water supply, poverty, inequality, and the need of food for the population, among others. In general, there is a deficit in the production and quality of food; particularly staple cereals are used in the food industry for the production of various foods for human consumption. In developing countries it is more evident because it causes malnutrition and disease (Hernandez *et al*. 2010), as is the case of obesity which is considered a pandemic affecting most of the Western countries (OECD 2010, WHO 2010). Among the causes associated with this problem are the influences and cultural practices (WHO 2010), such as foods consumed. For example: in Latin America maize is consumed (*Zea mays* L.) (Torres 2000).

Overweight and obesity occur because there exists an imbalance between energy expenditure and food intake deficient in minerals, vitamins, proteins and high in fats, sugars and carbohydrates (FAO 2010). The group of food rich in carbohydrates has been in the sights of nutritionists, due to the excessive consumption that is associated with weight problems (Thomas and Wolever 2003). However, carbohydrates are essential to fill the basic requirements of daily energy. Indeed, starch (complex carbohydrate) is the main source of energy for humans, providing between 58% and 60% of total calories (FAO 2007) required by human body.

Given its importance in consumption and its high content of starch, maize is the crop of higher demand in the world. In 2009 there were 2 489 300 000 t of cereals (rice, oats, sorghum, maize, wheat), of which 817.1 million t belong to the production of maize with a per capita consumption of 16.76 kg per year (FAO 2009). In Mexico, in 2009, there were 20.1 million t (SIAP 2010a) that were used to make tortillas, tamales, gruel, toasts, chips, fried foods, cosmetics, feeds, among others. The 106.3 million Mexicans with age greater than or equal to six years consume about 13 million tons of maize (CONAPO 2009) with per capita consumption of 122.94 kg per year (FAO 2007). In the Federal District the production was 7 000 964 t (SIAP 2010b) to satisfy the demand of approximately 7.2 million people with age greater than or equal to six years (INEGI 2009). Over 50% of the national production is destined for human consumption, which was consumed mainly as tortilla, so it demands, for industrial processing, specific characteristics of the raw material, such as size, colour, texture, grain weight and hectolitric weight (NMX-FF-034/1-SCFI 2002). Therefore, it is necessary to quantify the physical quality of grain to determine whether it satisfies the specifications required by the industry that processes maize flour and mass to make tortilla (Coutiño *et al*. 2008, Salinas and Arellano 1989).

The grain quality is related to a set of attributes: genetic, sanitary and physical. The physical attributes are associated with the physical constitution that determines the texture and hardness. They are also indicators of commercial quality and stability during their handling and storage (Rooney and Suhendro 1999); the transformation efficiency in processing products in given conditions, and acceptability by the consumer (FAO 2010), plus they are important parameters for the classification of endosperm hardness (Barbosa *et al.* 2005). Regarding any of the physical properties of maize grains, e.g. the 1000-grain weight is directly related to the ratio of pericarp-germ vs. endosperm, which is considered optimum for the production of tortillas if it is greater than 300 g (Rooney and Suhendro 2001). Other authors reported 307 g and 76.5 kg hL^{-1} in their measurements of the 1000-grain weight and the hectolitric weight, respectively (Melesio *et al.* 2008).

To improve grain quality several techniques have been used in order to alter the structural components; e.g. the application of 225 and 300 kg N ha^{-1} in single cross hybrids of maize increased protein content in different proportions and modified the amount of floury and horny endosperm of the grain (Zepeda *et al.* 2009a), while the application of 120 kg N ha^{-1}, in the *Woltario* variety of winter *triticale* resulted in a higher grain yield (Jaśkiewicz 2009). In addition, climatic and soil characteristics of the production site also modify the grain structure. Zepeda et al. (2009b) observed changes in the percentages of endosperm, germ, pericarp and pedicel and hectolitric weight and the characteristics of "nixtamal". In the case of agrochemicals, those are less suitable to be used as they cause degradation of the land and the environment, and therefore the human and animal food (Vasilevski 2003). Thus, it is important to investigate the use of sustainable methods, such as physical methods.

Various physical methods have been used in agriculture for seed treatment and production improvement such as: laser (Soliman and Harith 2010, Perveen *et al.* 2010, Chen *et al*. 2010, Hernandez *et al.* 2009a, 2010), electric field (Moon and Chung 2000, Nechitailo and Gordeev 2004), static magnetic field (Vashisth and Nagarajan 2008, Carkmak *et al*. 2009, Yano *et al*. 2004, Hernandez *et al.* 2007) and electromagnetic field (Galland and Pazur 2005, Hernandez *et al.* 2009b, Dominguez *et al*. 2010, Zepeda *et al*. 2010). In the case of electromagnetic field, it is applied in agriculture for biostimulation processes that – depending on the irradiation parameters - are positive, negative and zero in some variables assessed in different phenological stages. The scientific evidence presented by various authors in the world relates to the possibility of: enhanced leaf growth, chlorophyll, protein; improvement of the germination rate; germination percentage; increase of seed vigour; faster growth; reduced respiration, elevated sugar content; increase of harvest yield; etc. (Galland and Pazur 2005, Ueno 2006, Pietruszewski *et al.* 2007; Nimmi and Madhu 2009, Bujak *et al*. 2009). So that, at the level of crop production, it can enhance the quality of the crops produced.

But it is necessary to run more experiments to determine the potential of electromagnetic field in improving product quality, especially its physical quality. Therefore, the aim of this study was to determine the effect of electromagnetic field treatment applied pre-sowing in maize hybrids seed on the physical characteristics of the grain produced, as well as the response of each genotype to the application of electromagnetic field. The hypotheses were: 1) the application of electromagnetic field in maize hybrids seed, as a pre-sowing treatment, altered the physiological functions of the plant, which is reflected in the physical characteristics of the grain produced; 2) the response of each genotype varies according to their genetic characteristics, especially grain structural components.

MATERIALS AND METHODS

Biological material

The material used in the study was seed of maize hybrids "San Juan" and "San Jose", obtained at the Autonomous University of Chapingo (UACh), located in Chapingo, Mexico State.

Location

The experiment was conducted in Zumpango, State of Mexico, situated at 19° 48' north latitude and 99°06' west longitude at 2 250 meters above sea level (Fig. 1). The climate is temperate sub humid with an average annual temperature of 17° and 436 mm of annual rainfall, with a rainy season between May and September. Frosts occur between October and March, with the temperature dropping to below zero degrees.

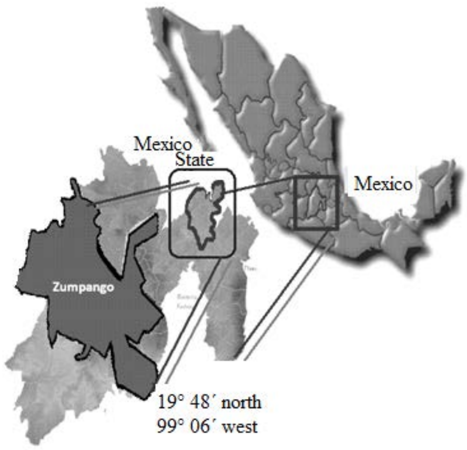
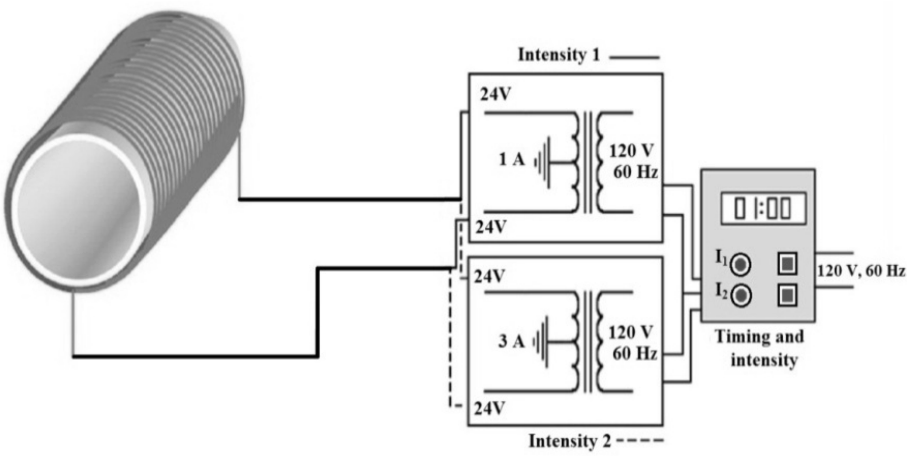


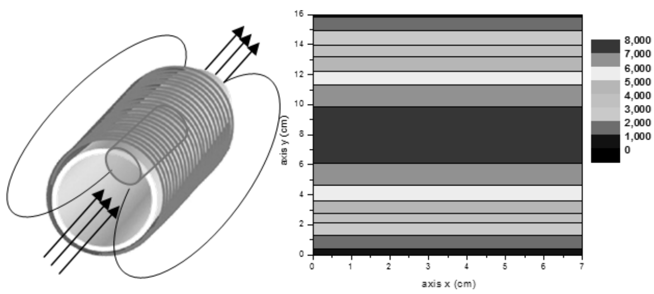
Fig. 1. The location of the research site in Zumpango, Mexico State

Magnetic field Exposure

The experiments were conducted at the Systems Engineering Laboratory at the ESIME-Zacatenco, Mexico. In the physical method of magnetic field treatment applied pre-sowing to maize seeds the flux density was measured in Tesla (T). In the prototype apparatus the electromagnetic field was generated by the passage of current flow through an inductor (coil). A switch was used to select the level of current that feeds the system and thus have the required level of magnetic induction (Fig. 2a). Seed samples (200 g) were placed randomly in a dielectric container and located within the variable magnetic field generated by the inductor. Furthermore, considering that the magnetic field changes from the periphery to the centre, the seed container was placed inside a volume considered homogeneous, the centre of the coil (Fig. 2b).



(a)



(b)

Fig. 2. Prototype irradiating of the electromagnetic field

The value of magnetic induction was B_1 = 480 mT and seeds were subjected to 5 times of exposure plus a control (no radiation) in each genotype. The magnetic induction was measured with a gaussometer (® Lakeshore, Model 410 Westerville, OH, USA). The generated magnetic field distribution along the axes x and y is presented in Figure 3.

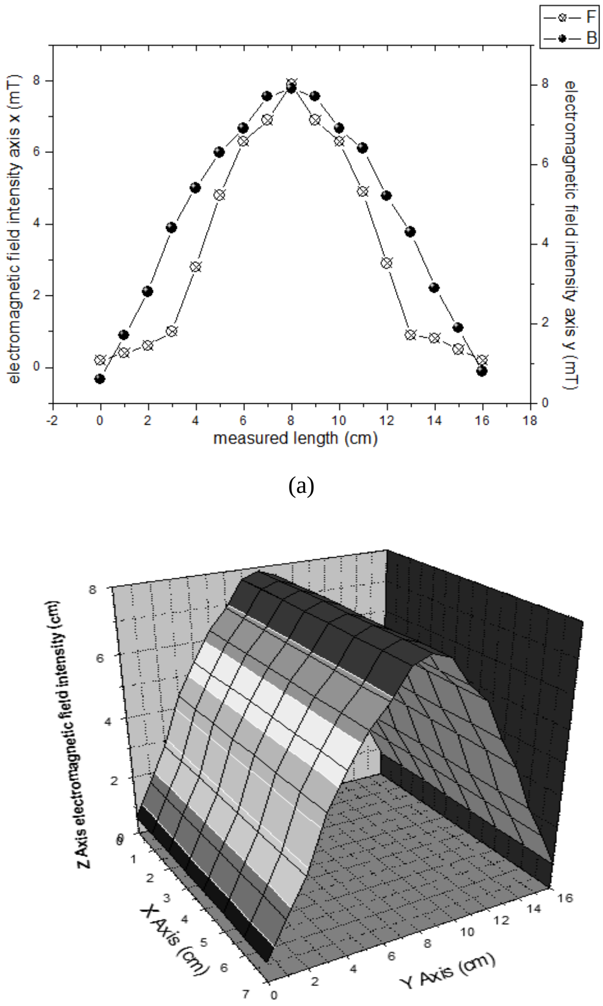


Fig. 3. Electromagnetic field distribution along axes "X" and "Y"

Establishment of sowing

The seeds were treated with electromagnetic field on April 25, 2009, and planted the next day. The sowing was done manually. Twelve treatments were evaluated and the results from a combination of two maize hybrids (San Juan and San Jose) and five times of exposure to electromagnetic field (3, 6, 9, 12 and 15 minutes) plus a control (no electromagnetic radiation) to a intensity of 480 mT, in a design of a randomised complete block with four replications. The experimental unit consisted of four rows of 5 m in length and 0.8 m of width. The population density of 50,000 plants ha^{-1} was used, under irrigation and fertilisation with a dose of 46N-00P-00K using urea as nitrogen source. The crop was maintained free of weeds. The grain harvest was in November 14, 2009, followed by natural drying, threshing and storage at a temperature of 18ºC. Subsequently, the samples were obtained for measurement of physical characteristics for treatment.

Physical characterisation of grain

In the laboratory, to measure physical characteristics, 300 g samples of grain from each treatment were used. The characterisation of grain was carried out by its shape and size. Previous visual screening was conducted in order to eliminate seeds with mechanical damage, insects, fungi, etc. The variables measured were: 1000-grain weight (TGW), hectolitric weight (HW), grain length (GL), grain width (GW) and thickness of grain (TG).

1) The 1000-grain weight was obtained by counting eight repetitions of 100 seeds of each treatments, which were weighed on a precision balance Ohaus Scout Pro® brand (maximum capacity: 200 to 6000 g, sensitivity: 0.01 to 1.0 g). The Coefficient of Variation (CV%) was calculated, which was 2.0%, and 1000-grain weight was obtained by multiplying per ten the arithmetic mean of the eight repetitions. **2)** to measure the length, width and thickness of grain, samples of 10 grains with 8 repetitions were used, which were measured with metallic Vernier caliper (5', mark Pretul ®), the results were expressed in centimetres. **3)** The hectolitric weight was obtained using a graduated cylinder with a capacity of 250 mL, PYREX®, and the procedure consisted of weighing, in a balance, samples of 100 grains from each treatment, which were deposited into the cylinder with free fall and the volume was measured.

The volume displaced (VD) for the grain in the graduated cylinder was taken as data for the calculation of HW, using equation (1).

$$HW(kg \cdot h \cdot L^{-1}) = \left(\frac{VD}{w}\right) x100 \qquad (1)$$

where: w = sample weight.

Statistical analysis

Analysis was applied to the variables of variance using PROC GLM of Statistical Analysis System (SAS 1989), and for variables whose mean square was found to be significantly different, we used the Tukey test of multiple comparison of means ($\alpha = 0.05$)

RESULTS AND DISCUSSION

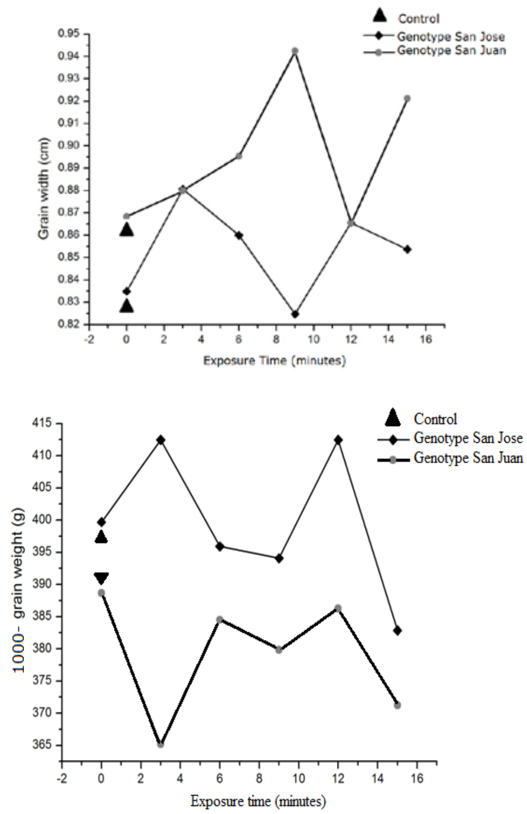
Table 1 shows the analysis of variance, where is possible to observe that there were significant differences ($p \leq 0.01$) between the treatments (combination of genotypes and times of exposure to electromagnetic field) and between the hybrids in the grain length (GL), grain width (GW) and 1000-grain weight (TGW). This indicates that at least one treatment had a difference in grain length, width and 1000-grains weight compared to other treatments due to the pre-sowing application of electromagnetic field to the seeds. This is because the electromagnetic field produces physiological, biochemical and physical changes in cell structures (Pietruszewski *et al*. 2007, Ueno 2006, Hernandez *et al*. 2009b, Dominguez *et al*. 2010), that could be preserved in the plant during growth and reflected finally in the physical characteristics of maize grains (the product of plants from seeds treated pre-sowing with electromagnetic field in this study), because of the electromagnetic field influence both in the activation of ions and the polarization of dipoles in living cells (Galland and Pazur 2005).

Table 1. Mean squares and probability of the physical characteristics of grain of maize hybrids exposed to electromagnetic field pre-sowing

F. V.	DF	GL	GW	TG	TGW	HW
Replications	3	0.007	0.003	0.0005	387.7	0.770
Treatments	11	0.008*	0.004**	0.0004	843.3**	1.965
Genotype (GEN)	1	0.051**	0.023**	0.0005	4946.0**	0.063
Radiation (RAD)	5	0.003	0.002	0.0003	450.5	1.357
GEN*RAD	5	0.005	0.004	0.0004	415.5	2.953
Error	33	0.004	0.002	0.0006	277.9	3.139
R^2		0.48	0.50	0.21	0.53	0.19
C.V. (%)		4.75	4.83	5.25	4.28	2.57
Mean		1.30	0.87	0.47	389.43	69.02

F.V = source of variation; DF = degrees of freedom; GL= grain length; GW= grain width; TG = grain thickness; TGW = thousand grain weight; HW = hectolitric weight; CV = coefficient of variation; R^2 = coefficient of determination.

Also, there were differences among the hybrids due to their particular genetic characteristics related to the chemical and structural composition of the grain (Zepeda *et al.* 2009b). On the other hand, no significant differences were found ($p \leq 0.05$) between times of exposure to electromagnetic fields for all variables, but differences were found for the variable probability of 1000-grain weight, indicating that there is a tendency in the effect of electromagnetic field on plant growth and development, which was reflected in the grain. It was observed that at the interaction between genotype x time of exposure to electromagnetic field (GENxRAD) there were differences ($p = 0.09$ and $p = 0.23$) for grain width (GW) and 1000-grains weight (TGW), respectively; i.e. there was a different response of the hybrids at the exposure time to the electromagnetic field. With respect to the width of the grain (Fig. 4a), the San Juan hybrid presented the highest grain width in response to 9, 15 and 6 minutes of pre-sowing exposure of seed to electromagnetic field, with an increase of 8.53%, 6.08% and 3.09%, respectively, compared to the control; also, the lowest value was observed for the control. Whereas, the San Jose hybrid also showed the highest value with 3 minutes of exposure to electromagnetic field and the lowest with 9 minutes, compared with the control, with an increase of 5.47% in the width of grain and a decrease of 1.22%, respectively.



a

b

Fig. 4. Electromagnetic field treatment effects on physical characteristics of maize grain from plants whose seed was treated pre-sowing, a) grain width; b)1000-grain weight

As concerns the variable 1000-grain weight (Fig. 4b), it was observed that the San Jose hybrid presented the highest 1000-grain weight in response to 3 and 12 minutes of exposure to electromagnetic field as pre-sowing seed treatment, with an increase of 3.19% with respect to the control. Whereas, in the San Juan hybrid a decrease was observed in 1000-grains weight with seed exposure to electromagnetic field, when it is compared with the control. The maize hybrids were statistically different (p = 0.05) for GL, GW and TGW (Tab. 3). The hybrids "San Juan" and "San Jose" showed a 1000-grain weight (379.28 and 399.58 g, respectively) greater than the optimal food-grade maize for tortilla production, that parameter being considered to be optimum when its values are greater than 300 g (Rooney and Suhendro 2001).

Table 2. Comparison of means of the physical characteristics of corn hybrids exposed to electromagnetic field pre-sowing.

Genotype	Grain (cm)			Thousand grain weight (g)	Hectolitric weight (kg hL^{-1})
	length	width	thickness		
San Juan	1.27b	0.89a	0.46a	379.3b	69.05a
San Jose	1.33a	0.85b	0.47a	399.6a	68.98a
LSD (0.05)	0.03	0.03	0.01	9.92	1.00

LSD = least significant difference. Values with the same letter in columns are statistically different (p = 0.05).

The hectolitric weight of the hybrids varied between 69.05 and 68.98 kg hL^{-1} respectively (Tab. 2), which is below the requirements provided by the Mexican Norm of quality (74.6 kg hL^{-1}) for maize varieties destined for Nixtamalization (NMX-FF-034/1-SCFI 2002).This is explained because the maize samples with higher grain yield have long and thinner grain, with the length/width ratio greater than 1.5, as is the case with the San Jose genotype used in this study. This correlation is negative with the hectolitric weight, because the spaces between long and thin grains deposited in the container are larger, resulting in lower hectolitric weight. Similar results were obtained by others authors (Vázquez *et al*. 2003, Seifi and Alimardani 2010, Majid *et al*. 2010).

In general, no significant differences (p = 0.05) were noted between the times of exposure to electromagnetic field up to the intensity of 480 mT in terms of their effect on the characteristics of the grains (Tab. 3), however there was found a tendency of the size and weight of the grain of the maize hybrids to increase due to changes produced by the electromagnetic field in the physiological and biochemical processes in early stages of the plant growth (Pietruszewski *et al*. 2007, Sujak *et al*. 2009, Dziwulska-Hunek *et al*. 2009) that modify the characteristics of the product. In this research, a tendency towards the modification of the physical quality of grain was obtained.

These results coincide with those observed by Zepeda *et al*. (2003) who cultivate maize with nitrogen and in a different production environment. Zepeda *et al.* (2010), with 12-minute time of pre-sowing exposure of maize seed to electromagnetic field (CE), obtained the highest 1000-grains weight and hectolitric weight, of 1.32% and 0.94%, respectively, compared with the control.

Table 3. Comparison of means of physical characteristics of grain of the hybrids San Juan and San Jose exposed to electromagnetic field pre-sowing. Zumpango, Mexico, 2009

Exposure time (min)	Grain (cm)			Thousand grain weight (g)	Hectolitric weight (kg hL^{-1})
	Length	Width	Thickness		
			Hybrid "San Juan"		
0	1.26 ab	0.86 a	0.48 a	388.6 a	68.90 a
3	1.25 b	0.88 a	0.46 a	365.2 a	67.68 a
6	1.26 ab	0.89 a	0.48 a	384.5 a	70.35 a
9	1.32 a	0.94 a	0.46 a	379.9 a	69.20 a
12	1.26 ab	0.86 a	0.46 a	386.2 a	69.33 a
15	1.23 b	0.92 a	0.46 a	371.2 a	68.41 a
LSD (0.05)	0.074	0.077	0.035	24.47	2.76
			Hybrid "San Jose"		
0	1.35a	0.83 a	0.46 a	399.7 ab	68.88 a
3	1.33a	0.88 ab	0.48 a	412.5 a	68.98 a
6	1.30a	0.86 a	0.48 a	395.9 ab	68.30 a
9	1.33a	0.82 b	0.46 a	394.1 ab	68.90 a
12	1.28a	0.86 ab	0.48 a	412.5 a	69.73 a
15	1.38a	0.95 ab	0.48 a	382.9 b	69.53 a
LSD (0.05)	0.074	0.047	0.041	26.58	2.65

LSD = least significant difference. Values with the same letter in columns are statistically different ($p = 0.05$).

CONCLUSIONS

1. Irradiation of the hybrid maize seeds (San Juan and San Jose) with electromagnetic field as a pre-sowing treatment modifies the physical characteristics of maize grain, which has an impact on the process and quality of the tortilla that is consumed by the population, this being a function of time of exposure to electromagnetic treatment.

2. Each hybrid showed a different response to the application of the electromagnetic field due to their genetic characteristics, particularly the chemical and structural composition.

ACKNOWLEDGEMENTS

The authors acknowledge the economical supports by Conacyt and Instituto Politecnico Nacional through EDI, PIFI and COFAA scholarships. We also want to thank Ing. E. Ayala for her technical support at the Physics Department of Cinvestav-IPN.

REFERENCES

Barbosa C.G.V., Ortega R.E., Juliano P., Hong Y., 2005. Food powders, Physical properties, processing and functionality. Kluwer Academic/plenum publishers, New York, Boston, Dordrecht, London, Moscow.

Bujak K., Frant M., 2009. Influence of pre-sowing seed stimulation with magnetic Field on spring wheat yielding (in Polish). Acta Agrophysica, 14(1), 19-29.

Cakmak T., Rahmi D., Serkan E., 2010. Acceleration of germination and early growth of wheat and bean seedlings grown under various magnetic field and osmotic conditions. Bioelectromagnetics, 31, 120-129.

Chen Y.P., Jia J.F., Yue M., 2010. Effect of CO_2 Laser Radiation on Physiological Tolerance of Wheat Seedlings Exposed to Chilling Stress. Photochemistry and Photobiology, 86, 600-605.

CONAPO (National Population Council), 2009: November, Available http://www.conapo.gob.mx/.

Coutiño E.B., Vázquez C. G., Torres M. B., Salinas M. Y., 2008. Grain, tortillas and snacks quality of two corn varieties of the comiteco race (in Spanish). Revista Fitotecnia Mexicana, 31, 9-14.

Dominguez P.A., Hernandez A.C., Cruz O.A., Ivanov R., Carballo C.A., Zepeda B.R., Martínez O.E., 2010. Influences of the electromagnetic field in maize seed vigor (in Spanish). Revista Fitotecnia Mexicana, 33, 183-188.

Dziwulska-Hunek A, Kornarzyñski K., Matwijczuk A., Pietruszewski S., Szot B., 2009. Effect of laser and variable magnetic field simulation on amaranth seeds germination. International Agrophysics, 23, 229-235.

FAO (Food and Agriculture Organization of the United Nations), 2009: FAOSTAT (FAO Statistical Databases) Agriculture, Fisheries, Forestry, Nutrition. November, http://faostat.fao.org/ default.aspx/. Rome, Italy

FAO (Food and Agriculture Organization), 2010: The spectrum of malnutrition. November, http://www. fao.org/worldfoodsummit/spanish/fsheets/malnutrition.pdf.

FAO (Food and Agriculture Organization). 2007: FAOSTAT (FAO Statistical Databases) Agriculture, Fisheries, Forestry, Nutrition. November, http://faostat.fao.org/default.aspx/. Rome, Italy.

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

Hernandez A.C., Carballo C.A., Dominguez P.A., 2007. Effect produced by treatment magnetic in maize seeds (in Spanish). Tecnologia Quimica, Special edition, 115-117.

Hernandez A.C., Dominguez P.A., Carballo C.A., Cruz O.A., Ivanov R., López B.J.L., Valcarcel M.J.P., 2009b. Alternating magnetic field irradiation effects on three genotype maize seed field performance. Acta Agrophysica, 170, 7-17.

Hernández A.C., Domínguez P.A., Cruz O.A., Ivanov R., Carballo C. A., Zepeda B.R., 2010. Laser in agriculture. Int. Agrophysics, 24, 407-422.

Hernandez A.C., Domínguez P.A., Cruz-Orea A., Ivanov R., Carballo C.A., Zepeda B.R., Galindo S.L., 2009a. Laser irradiation effects on field performance of maize seed genotypes. Int. Agrophysics, 23, 327-332.

INEGI (National Institute of Statistics, Geography and Informatics), 2009: November, http://www.inegi. gob.mx/inegi/ (in Spanish), Mexico.

Jaśkiewicz B., 2009. Yielding of triticale variety Woltario depending on sowing density and nitrogen application method (in Polish). Acta Agrophysica, 3, 705- 712.

Majid R., Kashani1 A., Zare-Feizabadi A., Koocheki A., Nassiri-Mahallati, 2010. Nitrogen use efficiency of wheat as affected by preceding crop, application rate of nitrogen and crop residues. Australian Journal of Crop Science, 4, 363-368.

Melesio C.J.L., Preciado O.R.E., Terrón I.D.,Vázquez C.M.G., Herrera M.P., Amaya G.C.A, Serna S.S.O., 2008. Production potential and nutritional value physical properties of hybrid high quality protein maize (in Spanish). Agricultura Técnica en México, 34 , 225-233.

Moon J.D., Chung H.S., 2000. Acceleration of germination of tomato seed by applying AC electric and magnetic fields. Journal of Electrostatics, 48, 103-114.

Nechitailo G., Gordeev A., 2004. The use of an electric field in increasing the resistance of plants to the action of unfavorable space flight factors. Advances in Space Research, 34, 1562-1565.

Nimmi V., Madhu G., 2009. Effect of pre-sowing treatment with permanent magnetic field on germination and growth of chilli (Capsicum annum. L.). Int. Agrophysics, 23, 195-198.

NMX-FF-034/1-SCFI, Standard Destined to Mexican Maize Nixtamalization Process, 2002. Non-industrialized food products for human consumption-grain white corn for tortillas alkaline process for corn and corn products nixtamalized . Secretaria de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA) (in Spanish). México, D. F.

OECD (Organization for Economic Cooperation and Development), 2010. Obesity and the economics prevention. November, http://www.oecd.org/dataoecd/49/29 /46077041.pdf.

Perveen R, Ali Q, Ashraf M., Al-Qurainy F., Jamil Y., Ahmad M.R., 2010. Effects of Different Doses of Low Power Continuous Wave He-Ne Laser Radiation on Some Seed Thermodynamic and Germination Parameters, and Potential Enzymes Involved in Seed Germination of Sunflower (Helianthus annuus L.). Photochemistry and Photobiology, 86, 1050-1055.

Pietruszewski S., Muszyński S., Dziwulska A., 2007. Electromagnetic fields and electromagnetic radiation as non-invasive external simulations for seeds (selected methods and responses). Int. Agrophysics, 21, 95-100.

Rooney, L. W., Suhendro E. L., 2001. Food quality of corn. In: Lusas, E. and Rooney, L. W. (eds.) Snack foods processing. Technomic Publishing. Lancaster, PA, USA, 37-72.

Rooney, L. W., Suhendro, E. L., 1999. Perspectives on nixtamalization (alkaline cooking) of maize for tortillas and snacks. Cereal Foods World, 44, 466-470.

Salinas M. Y., Arellano J.L., 1989. Nixtamalera and tortilla quality of maize hybrids with different endosperm type (in Spanish). Rev. Fitotec. Mex, 12, 129-135.

SAS, 2009. Statistical Analysis System for Windows. Release 8.01. SAS Institute Inc., Cary, N. C. USA.

Seifi M.R., Alimardani R., 2010. Comparison of moisture-dependent physical and mechanical properties of two varieties of corn (Sc 704 and Dc 370). Australian Journal of Agricultural Engineering, 1, 170-178.

SIAP (Agrifood and Fishery Information Service), SAGARPA, 2010a: http://www.campomexicano.gob.mx/portal_siap/Integracion/EstadisticaDerivada/ComercioExterior/BalanzaDisponibilidad/Anual/2010/maigrf10.pdf (in Spanish), Mexico.

SIAP (Agrifood and Fishery Information Service), SAGARPA, 2010b. November, http://www.siap.gob.mx/, (in Spanish), Mexico.

Soliman A.S.H., Harith M.A., 2010. Effects of laser biostimulation on germination of acacia farnesiana (L.) Willd. Acta Horticulturae (ISHS), 854,41-50.

Sujak A., Dziwulska-Hunek A., Kornarzyński K., 2009. Compositional and nutritional values of amaranth seeds after pre-sowing He-Ne laser light and alternating magnetic field treatment. Int. Agrophysics, 23, 81-86.

Thomas M.S., Wolever D.M., 2003. Carbohydrate and the regulation of blood glucose and metabolism, Nutrition Review, 61, 40-48.

Torres T. F, 2000. The power of Mexicans at the end of the millennium: from diversity to regional homogeneity . Notes, analysis and information magazine of the National Institute of Statistics, Geography and Informatics (INEGI) (in Spanish), 10, 47-58.

Ueno S., Shigemitsu T., 2006. Bioengineering and Biophysical Aspects of Electromagnetic Fields. Taylor & Francis Group.

Vashisth Ananta, Nagarajan Shantha, 2008. Exposure of Seeds to Static Magnetic Field Enhances Germination and Early Growth Characteristics in Chickpea (Cicer arietinum L.). Bioelectromagnetics, 29,571-578.

Vasilevsky G., 2003. Perspectives of the application of biophysical methods in sustainable agriculture. Bulgarian J. Plant Physiol., 179-186.

Vázquez C. M., G., L. Guzmán B., J. L. Andrés G., F. Márquez S., y J. Castillo M., 2003. Calidad de grano y tortillas de maíces criollos y sus retrocruzas. Rev. Fitotec. Mex., 26, 231-238.

WHO (World health organization), 2010, Obesity and overweight. December, http://www.who.int/mediacentre/factsheets/fs311/es/index.html.

Yano A., Ohashi Y., Hirasaki T., Fujiwara K., 2004. Effects of a 60 Hz Magnetic Field on Photosynthetic CO_2 uptake and Early Growth of Radish Seedlings. Bioelectromagnetics, 25, 572-581.

Zepeda B. R., Carballo C.A. Muñoz O. A., Mejía C. J.A., Figueroa S.C.B., González C.V., 2007. Nitrogen fertilization and physical characteristics, structural and quality of nixtamal-grain tortilla corn hybrids (in spanish). Agricultura Téc. Méx. 33, 17-24.

Zepeda B.R., Carballo C.A., Hernández A.C., 2009b. Genotype-environment interaction in structure and nixtamal-tortilla quality of kernel in maize hybrids (in Spanish). Agrociencia, 43, 695-706.

Zepeda B.R., Carballo C.A., Muñoz O A., Mejía C.J.A., Figueroa **S C.B**.., González C.V., Hernández A.C., 2009a. Protein, tryphtophan, and structural kernel components in Corn (*Zea mays L.*) Hybrids cultivated under fertirrigation (in Spanish). Agrociencia, 43, 143-152.

Zepeda B.R., Hernández A.C., Domínguez P.A., Cruz O.A., Godina N.J.J., Martínez O.E., 2010. Electromagnetic field and seed vigour of corn hybrids. Int. Agrophys., 24, 329-332.

CECHY FIZYCZNE ZIARNA KUKURYDZY Z ROŚLIN PODDANYCH DZIAŁANIU POLA ELEKTROMAGNETYCZNEGO PRZED SIEWEM

Doricela Gutiérrez Cruz[1], *Rosalba Zepeda Bautista*[1],
Claudia Hernández Aguilar[1],
Flavio Arturo Domínguez Pacheco[1], *Alfredo Cruz Orea*[2],
José Luis López Bonilla[1]

[1]Instituto Politécnico Nacional, SEPI-ESIME, Zacatenco, Unidad Profesional "Adolfo López Mateos", Av. Instituto Politécnico Nacional s/n, Unidad Profesional, Colonia Lindavista, Delegación Gustavo A. Madero, México, D.F. C.P. 07738
[2]Departamento de Física, CINVESTAV-IPN, Av. IPN No. 2508, Col. San Pedro Zacatenco, Delegación Gustavo A. Madero, C.P. 07360, México DF
e-mail: gutierrezcruzdo@yahoo.com.mx

S t r e s z c z e n i e. Pola elektromagnetyczne mają wiele zastosowań w rolnictwie, lecz konieczne są dalsze badania aby uzyskać naukowe dowody na ich potencjalne wykorzystanie jako alternatywnej metody poprawy jakości żywności otrzymywanej z roślin, których nasiona poddano ich wpływowi – szczególnie w odniesieniu do ich cech fizycznych. W prezentowanej pracy badalno wpływ pola elektromagnetycznego na fizyczne cechy ziarna kukurydzy. Badania obejmowały dwanaście kombinacji – dwie hybrydy kukurydzy (San Juan and San Jose) i pięć czasów działania polem elektromagnetycznym (3, 6, 9, 12 i 15 minut) plus kombinacja kontrolna (nasiona bez traktowania polem elektromagne-tycznym). Doświadczenie założono metodą bloków losowych w czterech powtórzeniach. Przedsiewne działanie polem elektromagnetycznym na nasiona hybryd kukurydzy (San Juan and San Jose) modyfikuje cechy fizyczne otrzymanego ziarna. Zaobserwowano istotne różnice ($p \leq 0{,}01$) pomiędzy wariantami doświadczenia oraz pomiędzy hybrydami kukurydzy w takich cechach jak długość ziaren (LG), szerokość (GW) i masa 1000 ziaren (TGW). Masa hektolitrowa (HW) ziarna tych hybryd zawierała się w przedziale od 69,05 do 68,98 kg hL^{-1}. Otrzymane wyniki mogą mieć znaczenie w procesie produkcji oraz jakości tortilli.

S ł o w a k l u c z o w e: *Zea mays* L., pole elektromagnetyczne, ziarno kukurydzy, cechy fizyczne