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Physical characteristics of maize grain and tortilla exposed to electromagnetic field

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A b s t r a c t. In order to improve the physical characteristics of maize grain and, consequently, those of maize tortilla, a basic food in Latin American countries, using environment-friendly techniques, the effect of electromagnetic irradiation on physical properties of grain, nixtamal, and tortilla of maize varieties was assessed as well as the response of every variety. Grain was exposed to an electromagnetic field of 480 mT intensity induced by a solenoid. There were differences ($p \leq 0.05$) among maize varieties and times of exposure to the electromagnetic field for hectolitre mass, flotation index, mass of 100 kernels, colour of kernel and tortilla (reflectance in %), retained pericarp, loss of solids, and firmness. On average, flotation index of grain, retained pericarp and colour of tortilla diminished by 15.5, 11.0, and 3.1%, respectively, at 15 min of exposure, while firmness and elongation of tortilla increased by 39.4 and 9.3% with respect to the control. Kernel flotation index in HS2 diminished by 39.1% at 15 min, whereas in AS722 and CAZ there was no significant change compared to 0 min. Likewise, in CAZ and HS2 the colour of tortilla decreased by 4.9 and 6.0%, respectively, at 15 min. An increment of 2.6 and 4.5% in AS722 was observed for mass of 100 kernels and colour of grain compared to the control, at 10 min exposure to electromagnetic field. Each variety responded differently to electromagnetic field according to the structure and chemical composition of the grain.

K e y w o r d s: maize, grain, tortilla, electromagnetic field, physical properties

INTRODUCTION

In Latin American countries there is considerable progress in consumption of nixtamalized corn products: tortilla, toasted tortilla chips, tamales, among others. In Mexico maize tortillas are an important source of energy; in 2007, *per capita* consumption was 122.94 kg of maize a year (FAO, 2010). Agricultural zones supply up to 67% of the energy required by Mexicans; besides corn products are the source of calcium which may reduce problems of osteoporosis (Rosado *et al*., 2005) and anthocyanins related to cancer prevention (Cortés-Gómez *et al.,* 2005); likewise, they provide 37 % of the daily protein requirement for the human body (Zepeda-Bautista *et al.,* 2009b). Structural and chemical grain composition directly influences tortilla quality for the consumer; Hernández-Salazar *et al*. (2006) found significant differences between tortillas elaborated with white maize grain and others with blue one, for protein, ashes, lipids, and resistant starch, as well as evaluating grain of corn varieties, they observed that some kinds of corn produce gray masa and tortillas which are not well liked by the consumer (Salinas-Moreno *et al.,* 2007). Zepeda-Bautista *et al*. (2009a, b) also perceived differences among corn varieties for protein, tryptophan, flotation index, hectoliter weight, grain colour, and tortilla colour and yield. On the other hand, Herrera-Corredor *et al.* (2007) at evaluating sensorial quality of 10 tortilla types in Texcoco, Mexico, found that consumers prefer tortillas with agreeable smell and taste that do not break at rolling them up.

Regarding this, techniques have been utilized to improve physical grain quality and, consequently, tortilla, which occasionally have harmed the environment. In corn varieties, fertilization with 300 kg ha^{-1} of N increased protein by 4% and the percentage of solid losses by 2.4% and

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diminished flotation index, retained pericarp, grain colour (% reflectance), and floury endosperm by 10.0, 9.4, 2.2, and 16.9 % respectively, compared to 150 kg ha^{-1} of N (Zepeda *et al.,* 2007; 2009b). In corn varieties with 235 kg ha^{-1} of N, yield, mass and protein content of grain increased, while starch concentration diminished with respect to the control (Uribelarrea *et al.,* 2004). Yield, protein content and grain hectolitre mass significantly increased in corn varieties with 235 kg ha^{-1} of N, but starch and oil content decreased (Miao *et al.,* 2006). Environment, amount and distribution of rainfall, temperature and physicochemical soil characteristics may as well modify the structural composition of corn grain (Zepeda *et al.,* 2009a). Therefore, it is important to assess environment-friendly techniques like electromagnetic irradiation.

The application of electromagnetic field and radiation may be a good tool for increment in plant growth and yield in agricultural production. Both modify the source of some physiological and biochemical processes of the seed, which increases their nutritional value (Pietruszewski, 2007). In sugar beet roots, sugar content increased as well with presowing seed treatment (Koper *et al.,* 1996); in amaranth seed, treated presowing with electromagnetic field or He-Ne laser light, increment in dry matter, crude protein, and coarse fibre were observed, whereas there was a diminution in oil and carbohydrates (Sujak *et al.,* 2009). In potato plants, magnetic induction of 80 mT caused an increase of 65% in stem and leaf mass after 45 days, with respect to the control (non-irradiated). Presowing stimulation of alfalfa seeds with He-Ne laser light at 3 and 6 mW cm^{-2} significantly increased protein, phosphorus, and molybdenum contents, and diminished crude fibre content in plant dry matter (Ćwintal *et al.,* 2010).

In order to improve physical grain quality and, consequently, that of maize tortilla, using environment-friendly techniques, the effect of electromagnetic irradiation on physical quality of grain, nixtamal, and maize tortilla was assessed, as well as the response of each variety to exposure of electromagnetic field. The following hypotheses were made:
- the exposure to a magnetic field will change some physiological and biochemical processes of corn grain, modifying physical grain quality in structural and chemical composition,
- the response of each maize variety will be different according to their particular genetic characteristics.

MATERIALS AND METHODS

Grain of three corn varieties was used: AS722, HS2, and CAZ, cultivated during the agricultural spring-summer cycle of 2008 at Zumpango, State of Mexico, Mexico, characterized by sub-humid climate with rainfalls in the summer, annual mean precipitation of 625 mm and temperature of 15.1°C (García, 1987). Cultivation was done under seasonal rainfall with irrigation at sowing time; population density was 80 000 plants ha^{-1}; fertilizing with the formula 190N-90P-30K and chemical weed control were carried out. Grain was harvested and conditioned at physiological maturity. In June 2009, grain was treated with automated radiation by computer, controlling time and intensity of the electromagnetic field, induced by solenoid. Twelve treatments were assessed, three varieties: AS722, HS2, and CAZ, and four times of exposure to electromagnetic field: 0, 5, 10, and 15 minutes at intensity of 480 mT, at a randomised complete block design with two replications; the experimental unit was 500 g. The samples were analysed in the Laboratorio de Maíz del Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), at Chapingo, State of Mexico, Mexico.

According to the description by Salinas and Vázquez (2006), the following measures were taken:
- hectolitre mass (kg hl^{-1}),
- flotation index,
- mass of 100 kernels, hundred healthy kernels were counted in duplicate and their mass registered,
- colour of grain and tortilla, measured by means of Agtron equipment and calibrated with mosaics Nos10 and 63; the results were expressed in percentage of reflectance.

In order to make nixtamal and tortilla, 100 g of grain were combined with 0.7% calcium oxide and 200 ml of distilled water, the components were mixed in a 600 ml precipitate glass and heated on a grill until boiling; afterwards they were left standing for 16 h at environmental temperature. Subsequently, the nixtamal was rinsed and ground in a stone mill to obtain the dough. The tortillas were moulded with a tortilla hand press and cooked on a metal hotplate. Remaining pericarp in grain, loss of solids, and firmness and elongation of tortilla were quantified:
- retained pericarp in the nixtamalized grain was obtained from 50 g of grain using 0.35% of calcium oxide and 100 ml distilled water, the pericarp which remained adhered to the grain after rinsing the nixtamal was removed from the ground kernels and quantified on dry base (%);
- loss of solids was measured based on the mixture of nejayote and washing water. Once the volume of nejayote was determined, a 50 ml portion of it was put in a 125 ml precipitate glass and subjected to total evaporation in an oven at 130°C; subsequently, it was weighed and calculated (%);
- tortilla firmness was evaluated determining strength and elongation by means of a TA-X T2i texturometer (Texture Analyzer Stable Microsystems) in freshly made tortillas.

Analysis of variance was applied to the variables through PROC GLM procedure of the Statistical Analysis System (SAS, 1989), and the Tukey test of multiple comparison of means ($\alpha = 0.05$) to the variables whose mean squares turned out to be significant.

RESULTS AND DISCUSSION

Significant differences among the corn varieties were observed for hectolitre mass, flotation index, mass of 100 kernels, and grain colour (reflectance %) (Table 1). There was genetic variability among them. A similar result was observed by Zepeda *et al*. (2007, 2009b). Hybrids AS722 and HS2 showed higher hectolitre mass and mass of 100 kernels than the CAZ variety, since they are corn types with hard grains (flotation index between 13 and 37), whereas CAZ had lower mass because of having softer grain (flotation index between 63 and 87) (Gómez, 1983). Therefore, the harder the corn, the paler the grain colour, due to amylase and amylopectin proportion in grain starch (White, 2001); CAZ had grain with higher reflectance percentage than AS722 and HS2, in other words, lighter (clearer) grain colour.

Among times of exposure to electromagnetic field at intensity of 480 mT, there were also significant differences for grain characteristics (Table 1), whenever the electromagnetic field modifies the source of physiological and biochemical grain processes changes its nutritional value (Ćwintal *et al.,* 2010; Pietruszewski, 2007; Sujak *et al.,* 2009). With 15 min exposure to the electromagnetic field, on average, flotation index and grain colour diminished by 15.5 and 2.7%, respectively, compared to the control (without electromagnetic irradiation); similar results were observed with nitrogen application by Miao *et al*. (2006), Oikeh *et al.* (1998) and Zepeda *et al.* (2007).

Among the varieties there were differences in the response to exposure to electromagnetic field at 480 mT intensity. In AS722 an increase by 2.6 and 4.5% of 100 kernels mass and grain colour was noted at exposure of 10 min, with respect to the grain not exposed to electromagnetic field; a contrary situation was observed in HS2, which diminished mass of 100 kernels at increasing time of exposure, and there was diminution in colour of grain at 5 and 10 min of exposure to electromagnetic field. In the CAZ variety, having soft grain, a diminution of 9.02% in colour of grain was found, with 10 min of electromagnetic field, and a corresponding increment in mass of 100 kernels. With respect to grain flotation index, decrease by 39.1% was observed in hybrid HS2 at exposure to electromagnetic field for 15 min (Fig. 1), whereas in hybrids AS722 and CAZ there was no considerable change compared to the control.

Among the variables measured during processing of nixtamal and tortilla elaboration, significant differences ($p \leq 0.05$) were noted among corn varieties and exposure time to the electromagnetic field at intensity of 480 mT for retained pericarp, loss of solids, colour (reflectance %) and

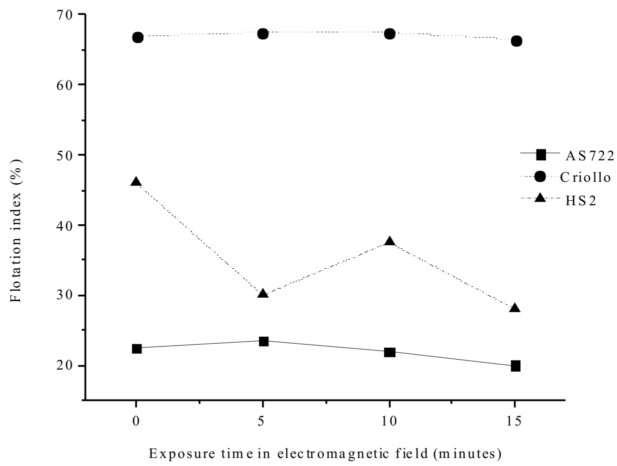

Fig. 1. Grain flotation index of corn varieties with time of exposure to electromagnetic field.

T a b l e 1. Comparison of means of grain characteristics of corn varieties with different time of exposure to electromagnetic field

Varieties	Hectolier mass (kg hl^{-1})	Flotation index (%)	Mass of 100 kernels (g)	Grain colour* (% R)
AS722	79.00a	22.00c	38.15b	56.50c
HS2	75.25b	35.37b	41.65a	60.00b
CAZ	72.40c	67.12a	34.80c	62.87a
DMS	0.27	1.96	0.08	0.74
	Time of exposure to electromagnetic field (intensity 480 mT)			
Testigo	75.66a	45.16a	38.41b	61.16a
5 min	75.73a	40.33bc	37.49c	59.50b
10 min	75.53ab	42.33b	38.54a	59.00b
15 min	75.26b	38.16c	38.35b	59.50b
DMS	0.31	2.27	0.09	0.85

Means with the same letter in each column are statistically equal (Tukey α=0.05), *percentage of reflectance (% R), DMS – minimum significant difference.

tortilla firmness (Table 2). Hybrid HS2 had 4.46 and 3.94% more retained pericarp than AS722 and CAZ, respectively, and consequently lesser solid loss than both varieties, parameters influencing the colour of nixtamalized corn meal and tortilla, besides favouring viscosity and adhesiveness of masa and tortilla (Martínez *et al*., 2001). In variety CAZ and hybrid AS722, whiter tortillas were obtained than in HS2, due to the nixtamalisation process, and structural and chemical grain components (Salinas *et al.,* 2007). As for tortilla firmness measured through strength and elongation, tortilla elaborated with HS2 required greater force for being broken, therefore, the tortillas were harder than those made with AS722, and the softest tortillas were elaborated with CAZ grain; a similar situation was observed with tortilla elongation, due to the resistance before being broken (Table 2).

With 15 min of exposing the corn kernels to the electromagnetic field, on average, a diminution of the retained pericarp by 11.02% was observed, compared to the control, due to change in the chemical structure of the pericarp by irradiation, which improves quality of nixtamalized corn meal utilized to produce food in Latin American countries (tortillas, toasted tortillas, cereal, and snacks among others); likewise, loss of solids increased by 5.01% and tortilla colour diminished by 3.14% with respect to the control (non-irradiated). Zepeda *et al.* (2007) also found changes in pericarp and tortilla colour of 10 corn hybrids at applying nitrogenous fertilization. On the other hand, 15 min of exposure to electromagnetic field increased strength by 39.36% and elongation by 9.30%; that is, tortilla resistance grew, parameter related to tortilla rollability, able to be rolled up without breaking, determinant in the sensorial quality for the consumer (Herrera *et al.,* 2007).

The corn varieties had different response to exposure to the electromagnetic field (intensity 480 mT). In AS722 and HS2, the retained pericarp increased by 12.4 and 18.9% at 5 min exposure, while in CAZ the highest increment (6.2%) was observed for 10 minutes of electromagnetic field compared to the control. With respect to tortilla firmness, in hybrid AS722 there was no significant effect of grain exposure to electromagnetic field before initiating the process of tortilla elaboration, but there was, when increasing strength and elongation with 5 and 15 min, compared to non-irradiated grain; the opposite situation was perceived in HS2, with 5 and 15 min strength increased by 62.8 and 36.33%, whereas in the CAZ variety an increment of 172.1% was noted with 10 min time of exposure to electromagnetic field, compared to the control. This contributes to making tortilla of better sensorial quality for the consumer; because it is desirable that tortilla should not be very hard, nor too soft, but of intermediate texture for chewing (between 300 and 400 g of strength). For tortilla colour in variety CAZ and hybrid HS2, a diminution by 4.9% and 6.0%, respectively, was observed with 15 min. of exposure to electromagnetic field (Fig. 2).

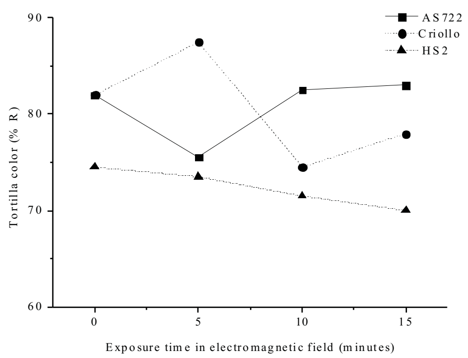

Fig. 2. Tortilla colour of corn varieties with different time of exposure to electromagnetic field.

T a b l e 2. Comparison of means of nixtamal and tortilla characteristics of maize varieties with different time of exposure to electromagnetic field

Parameters	Retained pericarp (%)	Loss of solids (%)	Tortilla colour* (% R)	Strength (g)	Elongation (mm)
			Varieties		
AS722	34.85b	3.83a	80.75a	263.48b	7.67ab
HS2	39.31a	3.30b	72.37b	301.30a	8.20a
CAZ	35.37b	3.88a	80.50a	212.94c	7.29b
DMS	2.47	0.05	0.74	23.59	0.60
		Time of exposure to electromagnetic field (intensity 480 mT)			
Testigo	36.48a	3.59b	79.50a	195.77b	7.20b
5 min	38.57a	3.72a	78.83a	287.22a	8.11a
10 min	38.52a	3.61b	76.16b	281.13a	7.71ab
15 min	32.46b	3.77a	77.00b	272.83a	7.87ab
DMS	2.85	0.06	0.85	27.24	0.69

*Explanations as in Table 1.

CONCLUSIONS

1. Electromagnetic irradiation is an environment-friendly technique which can modify physical grain quality and, consequently, maize tortilla quality according to the combination of intensity and irradiation time.

2. Each corn variety responded differently to the application of electromagnetic field according to structure and chemical composition of grain.

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