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PHYSICAL CHARACTERISTICS AND YIELD OF MAIZE GRAIN IN RAINFED CONDITIONS OF HIGH VALLEYS OF MEXICO

María Guadalupe Benítez-Rodríguez[1], Rosalba Zepeda-Bautista[1], Claudia Hernández-Aguilar[1], Juan Virgen-Vargas[2], Israel Rojas-Martínez[3], Arturo Domínguez-Pacheco[1]

[1]National Polytechnic Institute, SEPI-ESIME Zacatenco, Professional Unit 'Adolfo López Mateos', Col. Lindavista, México D.F., C.P. 07738, México
[2]National Institute for Forestry, Agriculture and Livestock, INIFAP, Experimental Valley of Mexico. Km 13.5 Highway Los Reyes-Texcoco, Coatlinchan, Texcoco, State of Mexico. C. P. 56250. Mexico
[3]INIFAP-Tlaxcala Experimental Station, Km. 2.5 Highway Tlaxcala-Santa Ana, Tlaxcala, C.P. 90800, Mexico
e-mail: clauhaj@yahoo.com

Abstract. In the High Valleys of Mexico maize is produced with varied yield and quality which sometimes do not meet the parameters established by maize flour milling and nixtamalization industry for making tortilla. Therefore, an evaluation of the yields and quality of the grain of maize hybrids (*Zea mays* L.) and their relationship with the environment was performed. During the spring-summer cycle 2012, the hybrids HP-1, H-52, H-68, HP-2, H-70, Buho, HP-3, H-57E, H-64, Prospecto-1, H-72 and H-66 were evaluated in Texoloc and Benito Juárez (2240 and 2530 masl), Tlaxcala, Mexico in a design of completely randomised blocks with three replications. Grain yield (GY), thousand grain weight (TGW), hectolitric weight (HW), width (WG), length (LG) and thickness (TG) of grains were measured. The results showed highly significant differences ($p = 0.01$) between locations, hybrids and the interaction locality x hybrids for physical parameters. Among the localities, Texoloc had 86.59% and 24.32% higher GY and TGW compared to Benito Juarez, respectively, while the HW was slightly lower (73.68 kg hL^{-1}). Average yields of the hybrids were 7.7 t ha^{-1}; HP-2, HP-3, H-57E and H-66 hybrids had yields of more than 8 t ha^{-1} and the lowest yield was noted for H-70. The hybrids had an average HW of 74.30 kg hL^{-1}; HP-1, H-68, H-70, Buho, HP-3 and H-72 had values > 74 kg hL^{-1}, complying with the provisions of the quality standard NMX-FF034/1-SCFI-2002 for maize destined for the nixtamalization process. The variation in agroclimatic conditions between the localities affected the yield and physical quality of maize grain.

Keywords: *Zea mays* L., thousand grain weight, grain size, hectolitric weight

INTRODUCTION

Maize (*Zea mays* L.), belonging to the grass family, is cultivated in almost all parts of the world. There is evidence that maize was cultivated in Latin America 7000 years ago, its origins being sought in Central America, especially in Mexico (FAO 2010). Maize is one of the most important agricultural products in Mexico (Castaneda 2011) and it is the base of feeding of the Mexican people (Zepeda *et al.* 2002). In 2011, global maize production was 883.5 million tons, ranking third in world production after wheat and rice. Mexico ranks seventh in global production, with 17.6 million tonnes (2% of world production) (FAO 2012a, SIAP 2012).

Maize has three main applications: food, fodder and raw material for industry. Among these, the highlight is on the use as food, where you can use all the grain, ripe or not, or it can be processed with dry milling techniques to obtain a relatively wide range of intermediate products (FAO 2010). In several cities in Latin America and the United States, there is a constant increase in the consumption of maize products (Zepeda *et al.* 2014); nixtamalized products like maize tortillas, tostadas, tamales, atole, among others, are the most consumed. The maize tortilla has become an important source of energy and protein for Mexicans, providing up to 67% and 37%, respectively, of the amounts required by the human body in agricultural areas of the country (Zepeda *et al.* 2011, Zepeda *et al.* 2009a). Another nutritional contribution of maize products is their being an important source of calcium, useful in combating osteoporosis (Rosado *et al.* 2005), and anthocyanin content related to cancer prevention (Gómez Cortés *et al.* 2005, Castañeda 2011).

It is not known exactly when the process of nixtamalization started, however, it has had important implications as a basis for the development of Mesoamerican cultures. The nixtamalization process makes the tortilla have higher nutritional quality compared with crude maize. The tortilla consumed in rural areas is made with maize of the town, which can be white, yellow or coloured (Salinas *et al.* 2010), and the preferences among different types of maize are based on the attributes of colour, flavour, texture, consistency and facility to work the maize dough (Vazquez *et al.* 2010).

The quality of maize grain for alkaline processing is determined by its chemical composition (Jiménez *et al.* 2012) and physical characteristics that determine the quality of the tortilla (Zepeda *et al.* 2007). For processors of maize at industrial level this quality is important, but not for people in rural areas who select maize based on their individual preferences and use amounts of lime in the process of nixtamalization in accordance with their customs and tastes (Rangel-Meza *et al.* 2004). Some other factors that affect the structure and composition of maize grain are the availability of water and nutrients, as well as weather conditions (Zepeda *et al.* 2009b). Maize diversity is mainly in due to rainfed conditions and peasant production systems (Herrera *et al*. 2000), so that farmers have adapted varieties to their environment (Aceves *et al*. 2002). With regard to this area, it is indicated that most of the varieties and hybrids grown in Mexico do not meet all the quality requirements specified in the Mexican Standard for processed corn (NMX-ff-034-2001-SCFI/P-1) (Salinas and Pérez 1997), therefore there is a need to assess the quality of grain suitable for industry or to improve the quality of existing cultivars through agronomic practices (Zepeda *et al*. 2007).

Moreover, our country has experienced a significant increase of various diseases associated with nutrition. Diseases such as myocardial infarction, cancer and diabetes began to increase, becoming main causes of death resulting from a transition in eating patterns and physical activity of the population (Barquera 2005). Some factors that have been documented as major determinants of these problems are: extremely low fruit and vegetable diets, calorie density and lack of physical activity. In recent studies, obesity has been associated positively with hypertension and hypercholesterolemia (DMPH), while uncontrolled blood glucose is associated significantly with abdominal obesity (Campos-Nonato *et al*. 2013). In this transition we are leaving traditional diet rich in grains such as corn tortillas and legumes such as beans, to adopt a new culture of fast food, with high energy but deficient in some essential nutrients. Given the impact that caused an improvement in the quality of life of the people, it is essential to establish preventive rather than corrective measures and to promote the traditional diet correcting the deficiencies rather than to import food patterns of other cultures.

Based on the above, the objective of this study was to evaluate the yield and physical quality of grain of 12 maize hybrids grown at two locations in the State of Tlaxcala, Mexico, to determine if they meet the quality required by cornmeal nixtamalization industry and mill-dyke, and to evaluate the effect of the environment on the yield and physical quality of grain.

MATERIAL AND METHOD

Location. Evaluation tests were established in Benito Juarez, Tlaxcala, located in the Mexican Central Altiplano at 2530 meters above sea level, 19°35'12" North Latitude and 95°25'39" West Longitude, semi-dry mild weather with a mean annual temperature of 13°C, average precipitation of 583 mm and two soil types: cambisoles and fluvisoles. Texoloc is 2240 meters above sea level, 19°16'39" North Latitude and 98°17'02" West Longitude, with mild sub-humid weather, with rainfall in the months of July to September, 16°C mean temperature and 816 mm of annual rainfall. The distribution of temperature and precipitation in 2012 is shown in Figure 1.

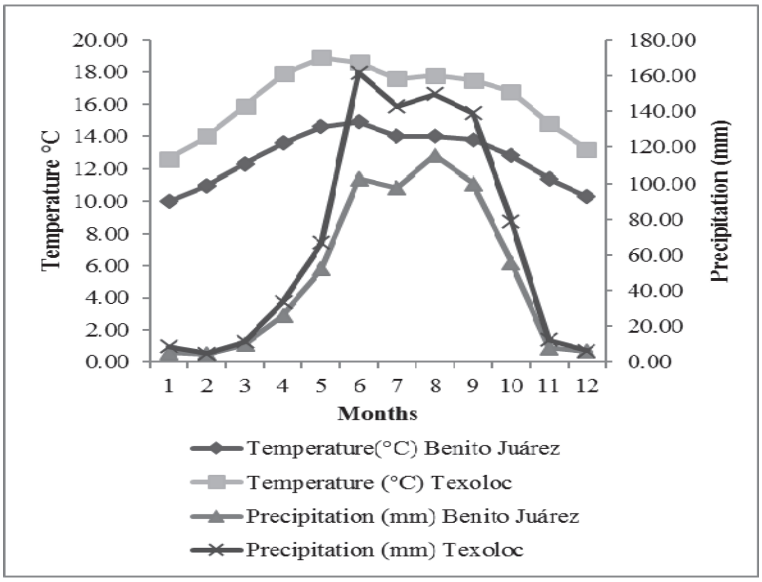

Fig. 1. Temperature and precipitation during 2012 in the municipalities of Benito Juarez and Texoloc, Tlaxcala

The measurement of the physical characteristics of grain of maize hybrids was done in the Laboratory of Systemics in the Department of Systems Section of Graduate Studies and Research, School of Mechanical and Electrical Engineering of the National Polytechnic Institute Unit Zacatenco (ESIME-IPN).

Biological Material. Grain of maize hybrids used for the measurement of the physical characteristics was the product of two experiments aimed at the evaluation of grain quality and productivity of 12 maize hybrids adapted to the High Valleys of Mexico: HP-1, H-52, H-68, HP-2, H-70, Buho, HP-3, H-57E, H-64, Prospecto-1, H-72 and H-66, conducted at the Experimental Station Valley of Mexico, National Institute for Forestry, Agriculture and Livestock (CEVAMEX-INIFAP). Grain from those experiments was used in the experiments conducted in Texoloc and Benito Juarez, State of Tlaxcala, Mexico, using the randomised complete blocks design with three replications, during the spring-summer cycle of 2012.

The experimental unit was 2 furrows of 5 m length spaced at 0.80 m. Agronomic management was done according to the recommendations for the handling of the maize crop in the CEVAMEX. Land preparation was made with machinery (fallow, rastra and furrow), the sowing was done manually, on April 17^{th} and May 17^{th}, 2012 at Benito Juarez and Texoloc, respectively. The population density of 62,500 plants ha^{-1} was used. Fertilisation was made with the formula 120 N-60 P-30 K units per hectare, half of nitrogen and all phosphorus and potassium at sowing and the rest of nitrogen in the second crop. Weed control was done by two applications of herbicides (Primagram gold® at a dose of 2 L ha^{-1} and Marvel® at 1 L ha^{-1}), the first when the weed had a height of 5 cm and the second after the second crop. The experiment was conducted under rainfed conditions. Harvesting was done manually when the formation of the black layer was observed, physiological maturity indicator, followed by natural drying, manual husking and storage at temperature of 18°C. Subsequently, the sample for measuring the physical properties of the grain of the maize hybrids was collected.

Grain yield (GY), in kg ha^{-1} at 14% of humidity, was calculated using the formula: $Y = [PC \times \%DM \times \%G \times CF]/8600$; where PC = field weight of cob in kilograms by useful plot; %DM = dry matter, by difference 100 minus the percentage of humidity obtained from Stenlite® device; %G = Percentage of grain, like average of ratio grain weight and cob weight devoid bracts, five cobs multiplied by 100; CF = correction factor obtained by dividing 10,000 m^2 (1 ha) between the effective surface of plot (8 m^2).

Physical characterisation of grain. The following variables were measured:

1) Thousand grains weight (TGW) – 100 grains were taken randomly and weighed (in 8 replicates). Coefficient of variation was calculated, which was < 4% with the equation:

$$TGW = \overline{X} \times 10 \text{ (ISTA, 1993).}$$

2) Hectolitric weight (HW) was obtained with graduated test tube with capacity of 250 mL PYREX® brand. The test consisted of four replicates of 200 grains for each, deposited by free fall, and the volume was measured. The grain was weighed on an electronic balance brand Velab Model VE-1000, the displaced volume by the grain was recorded immediately and calculated with the equation:

$$Hectolitric\ weight\ (kg\ hL^{-1}) = \left(\frac{displaced\ volume}{weight}\right) \times 100$$

3) Length (LG), width (WG) and thickness (TG) of grain - a sample of 10 grains in 8 replicates was measured with metallic vernier caliper, 5' Pretul® brand; the results were expressed in centimetres.

Statistical Analysis. Data were subjected to analysis of variance, using the PROC GLM procedure of Statistical Analysis System (SAS, 1998), in the randomised complete blocks design with three replications, using the Tukey mean multiple comparison test $\alpha = 0.05$

RESULTS AND DISCUSSION

Analysis of variance showed highly significant differences ($p = 0.01$) between locations and hybrids for yield and physical characteristics of maize grain (Tab. 1). This indicates that between the localities there was a differential effect of the amount and distribution of precipitation and temperature (Fig. 1) that affected the behaviour of the hybrids due to their genetic characteristics. Similar result was observed by Zepeda *et al*. (2009b) and Ramirez *et al*. (2010) in maize hybrids.

Among the localities, Texoloc had 86.59% more grain yield compared to Benito Juarez (Tab. 1) because there was a higher temperature and precipitation during the growing season of maize in the months between May and September (Fig. 1). A similar situation was observed with grain weight and size; 1000 grain weight was 24.32% higher in Texoloc compared to Benito Juarez (282.11 g) and the grain size was larger, while the hectolitric weight was slightly lower in Texoloc (73.68 kg hL^{-1}). This indicates that Texoloc has growing conditions with higher yield potential and grain quality compared to Benito Juarez. Similar results were observed by Arellano *et al*. (2011), Arellano *et al*. (2010) and Avila *et al*. (2009), when evaluating hybrids H-70, H-66 and H-52 in different locations and years of evaluation, under irrigation and rainfed conditions, in states that comprise the High Valleys of Mexico.

Table 1. Yield and physical characteristics of maize grain produced in Benito Juarez and Texoloc, Tlaxcala under rainfed conditions. Spring-Summer 2012

Locality	GY (t ha^{-1})	HW (kg hL^{-1})	TGW (g)	Grain (cm)		
				L	W	T
Benito Juarez	5.37b	74.91a	282.11b	1.22b	0.76b	0.46b
Texoloc	10.02a	73.68b	350.72a	1.35a	0.78a	0.43a
HSD (0.05)	0.58	0.89	2.39	0.01	0.01	0.01
Mean	7.70	74.30	316.41	1.29	0.77	0.45
Significance	**	**	**	**	**	**
C.V (%)	16.06	2.94	2.65	2.79	7.46	11.08
R^2	0.86	0.54	0.97	0.89	0.41	0.36

**Probability is 0.01%; Means with different letters in each column are statistically different ($p = 0.05$); HSD = honestly significant difference; CV = coefficient of variation; R^2= coefficient of determination, GY = grain yield; HW = hectolitric weight; TGW = thousand grain weight; L, W, T = length, width and thickness of grain.

On average, the hybrids yielded 7.7 t ha^{-1}; HP-2, HP-3, H-57E and H-66 hybrids had yields of more than 8 t ha^{-1} and the lowest yield was obtained for hybrid H-70 (Tab. 2). In general, the yields are higher than the national average (2.91 t ha^{-1})

(SIAP, 2012) and acceptable under rainfed conditions. The hybrids showed yields greater than 6 t ha^{-1} due to their genetic adaptation to survive drought and frost in the region and to take advantage of agroclimatic conditions. Virgen *et al*. (2013) and Arellano *et al*. (2011) also observed similar yields of maize hybrids grown under irrigation and rainfed conditions in the states of Mexico and Tlaxcala, Mexico.

Table 2. Yield and physical characteristics of grain of maize hybrids grown in Benito Juarez and Texoloc, Tlaxcala under rainfed conditions. Spring-Summer 2012

Locality	GY (t ha^{-1})	HW (kg hL^{-1})	TGW (g)	Grain (cm)		
				L	W	T
HP-1	7.49	75.35a	309.80d	1.30bc	0.76ab	0.43ab
H-52	7.89	72.80ab	293.08ef	1.31b	0.74b	0.46ab
H-68	7.10	75.21a	297.03e	1.26cde	0.75b	0.45ab
HP-2	8.13	74.60ab	285.82f	1.25ed	0.82a	0.43ab
H-70	6.62	75.76a	308.97d	1.25e	0.75b	0.44ab
Buho	7.42	76.44a	337.53bc	1.25e	0.81ab	0.47ab
HP-3	8.44	75.13a	312.18d	1.31b	0.76ab	0.44ab
H-57E	8.88	70.96b	310.60d	1.27bcde	0.77ab	0.45ab
H-64	7.70	73.29ab	366.60a	1.29bcd	0.79ab	0.47ab
Prospecto-1	7.04	73.72ab	333.06c	1.30bc	0.77ab	0.48a
H-72	7.30	74.90a	344.23b	1.38a	0.78ab	0.43ab
H-66	8.37	73.40ab	298.06e	1.29bcde	0.76ab	0.41b
HSD	2.45	3.7	9.86	0.04	0.06	0.05
Significance	0.09	**	**	**	**	**

**Probability 0.01%; Mean values with different letters in each column are statistically different (p = .05); HSD = honest significant difference; CV = coefficient of variation; GY = grain yield; HW = hectolitric weight; TGW = thousand grain weight; L, W, T = length, width and thickness of grain.

The hectolitric weight and grain size are parameters required by the industry of mass and tortilla (Mexican Standard for maize Destined to the Process of Nixtamalization, NMX-FF-034/1-SCFI-PARTE-1, 2002). The hybrids had average hectolitric weight of 74.30 kg hL^{-1}; HP-1, H-68, H-70, Buho, HP-3 and H-72 hybrids had higher values than 74 kg hL^{-1} (Tab. 2), complying with the requirements of the industry. A similar result was observed by Salinas and Perez (1997) and Zepeda *et al*. (2009b) who evaluated the nixtamal-tortilla quality of corn hybrids adapted to the High Valley of Mexico. Also, the thousand grain weight was between 285 and 344 g, and large and medium grain size was observed.

In the interaction "locality of production and hybrids" for grain yield (Fig. 3) a differential response of hybrids in each of the localities was observed due to agroclimatic conditions, mainly the amount and distribution of temperature and precipitation (Fig. 1). Texoloc had higher grain yield of all hybrids compared with Benito Juarez because there was more precipitation (773 mm) in the phenological crop cycle (from April to October) compared to 549 mm in Benito Juarez. H-70, Prospecto-1 and H-68 hybrids had greater variation between localities, on average the yields decreased by 55.64% when they were grown in Benito Juarez. The HP-2 and HP-3 hybrids showed less variation between the localities, with a decrease of 39.74%. In general, yields of hybrids are acceptable because they are higher than the national average (2.91 t ha^{-1}) (SIAP, 2012) under rainfed conditions.

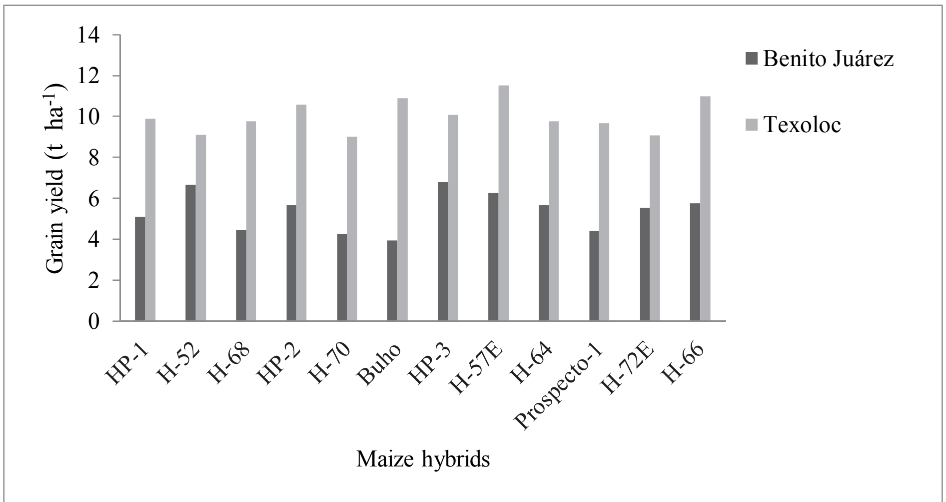

Fig. 2. Locality and hybrid interaction for grain yield of maize grown in Benito Juarez and Texoloc, Tlaxcala during spring-summer 2012

The interaction "location of production and hybrid" was highly significant ($p \leq 0.01$) for hectolitric weight because at least one hybrid behaved different in each location with different agroclimatic conditions (Fig. 3). 58% of the hybrids had higher hectolitric weight in Benito Juarez compared with Texoloc. Hybrid H-66 was stable, there was no change in hectolitric weight in the two locations (73 kg hL^{-1}), while hybrid HP-3 showed greater variation in hectolitric weight – in Benito Juarez it was 8.36% higher compared to Texoloc, which allows the following conclusion: if you want to produce grain of HP-3 hybrid for mass and tortilla industry it is desirable to produce it in Benito Juarez, because in Texoloc the hectolitric weight is not higher than 74 kg hL^{-1} and the industry would reject it, or accept it subject to a discount for not having the required quality. A similar situation was observed with HP-1, HP-2, H-70 and H-64 hybrids. The hybrids H-52, H-68, Prospecto-1 and H-72 showed less variation between the locations, thus can be produced in both locations yielding grain with similar hectolitric weight.

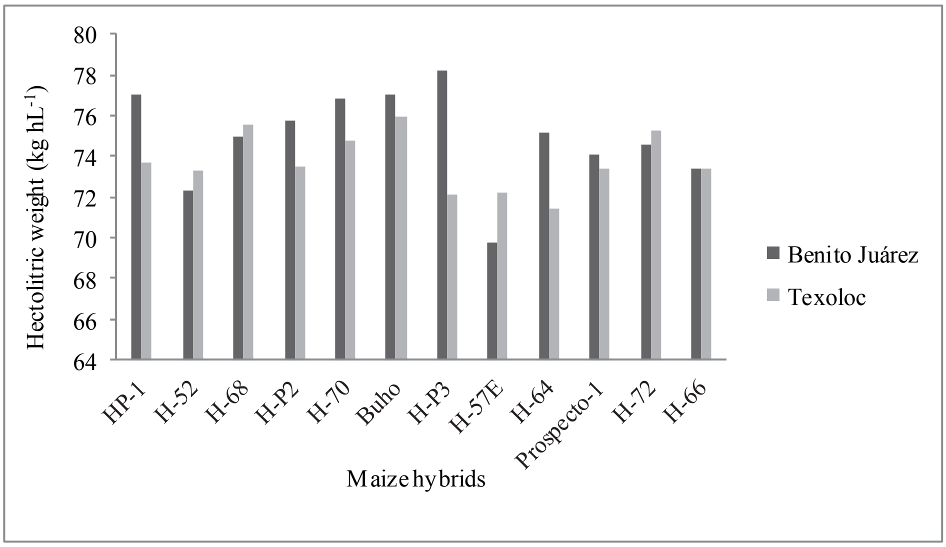

Fig. 3. Interaction locality and hybrids for hectolitric weight of maize grain grown in Benito Juarez and Texoloc, Tlaxcala. Spring-Summer 2012

CONCLUSIONS

1. Based on the results and the prevailing agroclimatic conditions in Benito Juarez and Texoloc, State of Tlaxcala, Mexico, during the crop season spring-summer 2012 the maize hybrids studied yielded on average 7.7 t ha^{-1}, which was significantly higher than the national average (2.91 t ha^{-1}) under rainfed conditions. Therefore, the evaluated hybrids can be grown successfully in both locations, however Texoloc has higher yield potential due to better growing conditions compared with Benito Juarez.

2. The hybrids HP-1, H-68, H-70, BUHO, HP-3 and H-72 had hectolitric weight greater than 74 kg hL^{-1}, complying with the requirements of the industries of dough and tortilla, the thousand grain weight was between 285 and 344 g, and grain size was large and medium. This does not indicate that other hybrids evaluated do not have the attributes to make tortilla of a quality acceptable for human consumption.

3. The variation between agroclimatic conditions of the locality of production affected the yield and physical grain quality of maize hybrids due to their particular genetic characteristics.

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WŁASCIWOŚCI FIZYCZNE I PLONY ZIARNA KUKURYDZY W WARUNKACH DESZCZOWEGO ZASILANIA W WODĘ W WYSOKICH DOLINACH MEKSYKU

María Guadalupe Benítez-Rodríguez[1], *Rosalba Zepeda-Bautista*[1], *Claudia Hernández-Aguilar*[1], *Juan Virgen-Vargas*[2], *Israel Rojas-Martínez*[3], *Arturo Domínguez-Pacheco*[1]

[1]Narodowy Instytut Politechniczny, SEPI-ESIME Zacatenco, Zakład Specjalistyczny im. 'Adolfo López Mateos', Col. Lindavista, México D.F., C.P. 07738, Meksyk
[2]Narodowy Instytut Leśnictwa, Rolnictwa i Hodowli Zwierzęcej, INIFAP, Meksykańska Dolina Doświadczalna. Km 13.5 Highway Los Reyes-Texcoco, Coatlinchan, Texcoco, State of Mexico. C. P. 56250. Meksyk
[3]INIFAP-Stacja Doświadczalna Tlaxcala, Km. 2.5 Highway Tlaxcala-Santa Ana, Tlaxcala, C.P. 90800, Meksyk
e-mail: clauhaj@yahoo.com

Streszczenie. W Wysokich Dolinach Meksyku produkowana jest kukurydza o zróżnicowanej jakości i poziomie plonowania, która nie zawsze spełnia wymagania przemysłu młynarskiego i nixtamalizacji mąki kukurydzianej do produkcji tortilli. Z tego powodu przeprowadzono badania, mające na celu ocenę plonowania i jakości ziarna hybryd kukurydzy (*Zea mays* L.) oraz ich zależności od warunków środowiskowych. W sezonie wiosenno-letnim roku 2012 przeprowadzono badania na hybrydach HP-1, H-52, H-68, HP-2, H-70, Buho, HP-3, H-57E, H-64, Prospecto-1, H-72 oraz H-66 w Texoloc i Benito Juárez (2240 i 2530 m n.p.m.), Tlaxcala w Meksyku. Badania przeprowadzono w systemie bloków losowych, w trzech powtórzeniach, dokonując pomiarów plonu ziarna, masy tysiąca ziaren, masy hektolitra ziarna oraz szerokości, długości i grubości ziarna. Stwierdzono istotne różnice ($p = 0,01$) pomiędzy lokalizacjami, hybrydami oraz interakcjami lokalizacja-hybryda w zakresie parametrów fizycznych ziarna. Wartości plonu i masy 1000 ziaren w Texoloc były wyższe odpowiednio o 86,59% i 24,32% w porównaniu do wartości otrzymanych w Benito Juarez, podczas gdy wartość masa hektolitra była nieznaczenie niższa (73,68 $kg \cdot hL^{-1}$). Średni plon ziarna hybryd wyniósł 7,7 $t \cdot ha^{-1}$; plony hybryd HP-2, HP-3, H-57E i H-66 były powyżej 8 $t \cdot ha^{-1}$, a najniższy plon uzyskano dla hybrydy H-70. Średnia wartość masy hektolitra dla hybryd kukurydzy wyniosła 74,30 $kg \cdot hL^{-1}$; dla hybryd HP-1, H-68, H-70, Buho, HP-3 i H-72 były > 74 $kg \cdot hL^{-1}$, spełniając wymagania jakościowe normy NMX-FF034/1-SCFI-2002 dla kukurydzy przeznaczonej do procesu nixtamalizacji. Zróżnicowanie warunków agroklimatycznych pomiędzy badanymi lokalizacjami miało wpływ na plonowanie i charakterystyki fizyczne ziarna kukurydzy.

Słowa kluczowe: *Zea mays* L., masa tysiąca ziaren, wielkość ziarniaka, masa hektorlitra ziarna