
AGRONOMIC CHARACTERIZATION OF TROPICAL MAIZE (*Zea mays* L.) INBRED LINES CONVERTED TO QUALITY PROTEIN CHARACTER

MAURO SIERRA-MACÍAS, PABLO ANDRÉS-MEZA, FLAVIO RODRÍGUEZ-MONTALVO, NOEL GÓMEZ-MONTIEL, ALEJANDRO ESPINOSA-CALDERÓN, ROBERTO VALDIVIA-BERNAL, ARTEMIO PALAFOX-CABALLERO, MARGARITA TADEO-ROBLEDO and OMAR VELÁSQUEZ-GARCÍA

SUMMARY

Maize inbred lines converted to the quality protein character were evaluated for grain yield and agronomic traits. The study was carried out in the Experimental Station Cotaxtla, Veracruz, Mexico, during the autumn/winter 2011/12 and spring/summer 2012 seasons. The experimental design was an alpha lattice 16×8 with 128 treatments and two replications, with one-row plots 2.5m long, 80cm wide and a density of 62500 plants/ha. During crop development, data were recorded about plant and ear height, days to tassel and silking, plant and ear aspect and sanity, ears with bad husk cover, ear rots, grain yield, grain texture and segregation of the opaque character in the grain. Throughout genotypes (G) and environments (E), the majority of traits except for ears with bad husk cover were significant. The analysis of variance combined in two evaluation environments, found statistical significance for G and E, for all traits, except for ears with bad husk cover. For interaction

G×E significant differences for grain yield, days to pollen-shed and silking and lodging were found. The best inbred lines for grain yield and agronomic characteristics were: FAMV537 C-1-1-2, FAMV537C-1-1-1, FAMV537C-2-1-1, (D-539xCML144)F2x-D539RC₂-1-1-4, (D-539xCML144)F2xD539RC₂-1-1-2, (D-539xCML144)F2x D539RC₂-1-1-1, (LT155xCML144) LT155RC₂-1-1-9, (LT155xCML144) LT155RC₂-2-1-1, (LT155xCML144)LT155RC₂-2-2-3, (LT154xCML144)LT154RC₂-5-1-2, (LT154xCML144)LT154RC₂-5-1-1, (CABGxCML144) CABGRC₂-1-1-6, (CABGxCML144) CABGRC₂-1-1-2, (CABGxCML144)CABGRC₂-3-2-5, (VS536xV-537C)VS-536RC₂-1-3-1, (VS-536xV-537C)VS-536RC₂-3-1-7, (VS536xV537C) and VS536RC₂-1-2-7. All had grain yield >4t·ha⁻¹, from 3 to 44% more than the best normal line LT155 (4.1t·ha⁻¹), used as control. Regarding protein quality, synthetics formed with representative lines of each group of converted lines registered 36-55% more lysine and 62-106% more tryptophan than the normal 'Tuxpeño' variety.



Maize (*Zea mays* L.) is the most important crop in Mexico due to

the extended use of corn as food, the economic benefits generated and its social impact. It is currently grown in a

great diversity of ecological niches and under different production systems. The large diversity of landraces that are

KEYWORDS / Endogamy / Quality Protein / Tropical Maize / *Zea mays* /

Received: 05/20/2014. Modified: 07/24/2014. Accepted: 07/25/2014.

Mauro Sierra Macías. Doctor of Sciences in Genetics, Universidad de Colima, Mexico. Researcher, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), Mexico. Address: Campo Experimental (CE) Cotaxtla, Km 34.5 Carretera Federal Veracruz-Cordoba, Medellin De Bravo. C.P. 94270, Veracruz, México. e-mail: sierra.mauro@inifap.gob

Pablo Andrés Meza. Master of Sciences in Tropical Agroecosystems, Colegio de Postgraduados (COLPOS), Veracruz, Mexico. Researcher, CE Cotaxtla, INIFAP, Mexico.

Flavio Rodríguez Montalvo. Agronomical Engineer, Universidad Veracruzana, Mexico. Researcher, CE Cotaxtla, INIFAP, Mexico.

Noel Gómez Montiel. Doctor of Sciences in Genetics, COLPOS, Montecillo, Mexico. Researcher, CE Iguala, INIFAP, Mexico.

Alejandro Espinosa Calderón. Doctor of Sciences in Genetics, COLPOS, Montecillo, Mexico. Researcher, CE Valle de México, INIFAP, Mexico.

Roberto Valdivia Bernal. Ph.D. in Genetics, Iowa State University, USA. Professor, Universidad Autónoma de Nayarit, Mexico.

Artemio Palafox Caballero. Master of Sciences in Rural Development, COLPOS, Montecillo, Mexico. Researcher, CE Cotaxtla, INIFAP, Mexico.

Margarita Tadeo Robledo. Master of Sciences in Genetics, COLPOS, Montecillo, Mexico. Professor, Universidad Nacional Autónoma de México.

Omar Velásquez García. Agronomical Engineer, Instituto Tecnológico de Comitancillo, Mexico. Student, CE Cotaxtla INIFAP, Mexico.

coupled to different local applications at tests to its importance. In 2012, 7.37×106ha were planted in Mexico with this crop, with an average yield of 3.19t·ha⁻¹ (SIAP, 2012).

In Mexico, there are 31 million people with malnutrition, out of which 18 million suffer from severe malnutrition; 50% of these are children under 5 years old in rural areas, and 30% live in urban areas (Chavez and Muñoz, 2004; Espinosa *et al.*, 2006). In this framework, maize is essential in the diet of Mexicans, whose apparent consumption per capita is calculated as 209.8kg/year (Morris and López, 2000). Widespread consumption of high quality protein maize could improve the nutritional level in Mexico, especially in children, lactating women and the elderly; However, achieving their extensive use requires the participation of stakeholders at different decision levels, as well as the coordination of various institutions to support such a program (Espinosa *et al.*, 2005).

The high quality protein maize is derived from opaque gene O₂O₂, containing more lysine and tryptophan, component aminoacids of proteins essential for growth and human development (Ortega *et al.*, 1986; Mertz, 1994; Vasal, 2002). The quality of the protein in these maize varieties is similar to that of milk (Bressani, 1994). Vasal and Villegas (2001), using the traditional breeding techniques, incorporated special genes called 'modifier genes', responsible for the texture of the endosperm. These modifying genes confer to the endosperm of grains a harder texture than that of opaque maize, giving to it the appearance of normal maize. Larkins *et al.*, (1994) indicated that maize grains with gene o₂o₂, contain 40-50% more lysine and 35-40% more tryptophan. In tropical maize H-519C, H-553C and V-537C, it was found that the tryptophan content increased in 59, 44 and 74%, respectively, while the lysine content increased in 50, 46 and 47% for each genotype (Sierra *et al.*, 2001).

In a maize breeding program it is important to develop new inbred lines that combine properly in order to produce high yields and a superior agronomic performance (Hallauer and Miranda, 1988). The procedures for developing new varieties of high protein quality maize, as well as the maintenance of parent lines, have been well documented. However, little has been written about the process of conversion of normal maize to the character of high quality protein and its relationship with some traits of economic importance (Trifunovic *et al.*, 2003; Scott *et al.*, 2009).

The conversion of normal maize inbred lines D539, LT-154, CABG, LRB14, LT-155 (parents of the outstanding maize hybrids H-520 and H-512) to quality protein maize (QPM) was started at the Cotaxtla Experimental Station in 2002 (Sierra *et al.*, 1993, 2004), adapted to the tropical area; as well as the synthetic variety VS-536 (Sierra *et al.*, 1992), which is the variety of greatest use in the Mexican Southeast. The inbred lines were crossed with the CML-144 line, and VS-536 was crossed with V-537C as the donor character. After selfing the crosses and selecting the best lines a backcrossing method was used to recover the QPM inbred lines and the VS-536 (Sierra *et al.*, 2001). The objectives of this study were: a) To know grain yield and agronomic characteristics of maize inbred lines converted to the quality protein character and b) Expand the genetic base of high quality protein maize germplasm.

Materials and Methods

Geographic location

The study was carried out in the INIFAP Cotaxtla Experimental Station, municipality of Medellín de Bravo, in central Veracruz state, Mexico, located at 18°56'N and 96°11'W, and 15masl; the climate according to the Köppen classification modified by Garcia (1981), belongs to the climate group Aw1 (w), warm sub-humid, with temperatures average 25°C and annual rainfall of 1400mm distributed from June to November, with a dry season from December to May.

Germplasm

Thirteen inbred lines converted to the character of high quality protein (QPM), derived from the line LT-154, were included in this assessment, as well as 25 lines from LT-155, 19 lines from a composite of broad genetic base (BGBC), 7 lines from D-539, 2 lines from LRB-14, 45 lines from VS-536, 8 recycled lines from V-537C. In order to compare advantages in grain yield and other agronomic traits, the inbred maize lines CML142, CML150, CML159, CML264Q and CML491Q high quality protein were included, as also were included the tropical lines LT-154, LT-155, LT-156 and LT-157 in its normal version, used as checks.

Description of the experiments

During the autumn/winter 2011/12 and spring/summer 2012 seasons, two experiments were planted

with QPM maize inbred lines under a alpha lattice 16×8 design, with 128 treatments and two replications in one-row plots, 2.5m long and 80cm wide with a density of 62500 plants/ha. Weed control was achieved with atrazine in pre-emergence application, fertilization with the formula 161-46-00 was used and pests were also controlled during the development of the crop.

Variables and data logging

During crop development and at harvest time, plant and ear height, days to tassel, lodged plants, appearance and health of the plant and ear, husk cover, rotting ear, grain yield, segregation of the opaque character and grain texture data were recorded.

Quality protein

In the conversion of normal inbred lines to QPM the inbred line CML144 was used as donor; for the conversion of VS-536, the V-537C variety was used. The selection of lines, in addition to the agronomic variables, allowed at harvest time a visual qualification of segregation of opaque grains in a scale from 0 to 3, where 0: no presence, 1: few, 2: regular, and 3: a lot of opaque grains, as an indicator of the presence of the character of high quality protein. For determining protein quality, five synthetics were formed with lines that represent the groups of converted lines that determined the lysine and tryptophan content, following the methodologies of AACC (1998) and AOAC (1984).

Statistical methods

Analysis of variance for all variables were done. The variables registered as percentage, such as percentages of lodging, of bad husk cover and of rotten ears, were transformed to degrees bliss for analysis according to the formula $\sqrt{x+1}$, because some plots showed values of zero. For the separation of means the minimum significant difference test was applied at the 0.05 and 0.01 probabilities. A combined analysis for the two evaluation environments was made, as well a comparison of groups of lines, where the t test was applied at 0.05 and 0.01 probabilities (Reyes, 1990).

Results and Discussion

Combined analysis had shown differences in most of the traits, except for percentage of ears with bad husk cover for genotypes and environments

effects (Reyes, 1990). Differences for grain yield, days to tasseling and percentage of lodging in the genotype by environment interaction were also found in the present study. In all instances, the variance due to the environments was greater for all variables, except for percentage of bad husk cover (Table I).

The best lines converted to the high quality protein character ($p \leq 0.01$) for yield and agronomic characteristics across the two environments of evaluation were the four lines derived from LT154 (Table II), with yields of 4.9, 4.4, 3.6 and 3.4t·ha⁻¹, respectively; and 48 to 113% more in relation to the normal line LT154 (Table II). Also, these inbred lines showed good agronomical characteristics; such as good appearance and health on plant and ear, tolerant to lodging, with good husk cover, dent and semi-dent texture; in addition to the advantages that the high quality protein maize represents for consumers (Ortega *et al.*, 1986; Bressani, 1994; Larkins *et al.*, 1994; Mertz, 1994; Vasal, 2002; Chavez and Muñoz, 2004; Espinosa *et al.*, 2005, 2006). These advantages in yield and agronomic traits are important because of their adaptation to the tropical area described by García (1981) and the adoption by the seed industry and farmers (Hallauer and Miranda, 1988).

In reference to the four lines derived from LT155 (Table II), their upper yields (>4.0t·ha⁻¹) had a significantly better performance ($\alpha = 0.05$), 3-10% more than the normal line LT155 control. In addition, these lines were relatively early maturing and had lower plant height; three of them with semi-dented grain texture and the line (LT155×CML144) F2×LT155RC₂₋₁₋₁₋₁₈ had a flint texture.

As to the four inbred lines derived from the CABG shown in Table II, with yields of 4.1 to 5.1t·ha⁻¹, they revealed a better grain yield performance ($\alpha = 0.05$), 8% more than the

normal line LT155, and reached maturity earlier than its normal version LT156. Segregation of the opaque character recorded values of 1 to 2.5, attributes that indicate the presence of the high quality protein character. A similar behavior was observed for lines (CABG×CML144) CABGRC₂₋₁₋₁₋₄, CABGRC₂₋₁₋₁₋₅ (CABG×CML144) and (CABG×CML144) CABGRC₂₋₁₋₁₋₂ (not shown).

The four inbred lines from the D539 (Table II) showed a better grain yield performance ($\alpha = 0.05$), 3-22% more than the best normal check line LT155, with yields up to 4.0t·ha⁻¹. These lines had good aspect of plant and ear, and dent and semi-dent texture.

Five lines derived from VS-536, the variety of greatest use in Southeastern Mexico, constitute a group with outstanding performance (Table II). They showed yields 3-10% higher ($\alpha = 0.05$) than the normal line LT155. These lines have good plant and ear aspect, with dent and semi-dent texture.

The best inbred lines, recycled from V-537C and first high QPM variety ($p \leq 0.05$), were FAMV537C-1-1-2, FAMV537C-1-1-1, FAMV537C-2-1-1 and FAMV537C-2-2-1, with yields well above 4t·ha⁻¹, 20-44% more than the normal line LT155 yield. These lines along with the lines derived from the D-539 line had the highest yields averages and were relatively earlier in maturity than the LT155 line used as check.

In general, the lines converted to QPM with better yield and agronomic traits than the normal were found (Hallauer and Miranda, 1988; Sierra *et al.*, 2001). Availability of QPM maize germplasm is useful for developing better hybrids and synthetics for the Mexican tropics and also for reducing malnutrition (Mertz, 1994; Sierra *et al.*, 2001; Vasal and Villegas 2001; Espinosa *et al.*, 2006).

The lines derived from D539, V-537C, VS-536, LT155, LT154

and CABG had better performance for grain yield and also showed earlier maturity, lower plant height and, with the exception of the lines derived from V-537C, better plant and ear aspect and lower percentage of ears with bad husk cover and ear rot, in relation to the normal lines. Besides, the quality protein maize lines were tolerant to lodging. In relation to the segregation of the opaque character, in all groups a higher frequency between grades 1 and 2 was found, which means that the character of high quality protein is present, without the disadvantage represented by ears with high frequency of opaque grains. Finally, for grain texture, excepting lines derived from LRB and CMLs, which show a flint texture, the rest of the groups had a higher frequency of dent and semi-dent textures.

Groups of lines derived from the normal line D-539 and recycled from variety V-537C, had yields with significantly ($\alpha = 0.01$) higher means, with 4.30t·ha⁻¹, 39% more than the normal lines. In other groups statistical difference was not found (Reyes, 1990). The group of lines derived from VS-536 had a mean yield of 3.5t·ha⁻¹, 13% above the normal lines. Lines derived from LT154 and LT155 had mean yields of 3.40t·ha⁻¹, 10% more compared to the normal lines. The groups of lines CABG and CMLs obtained a mean yield of 3.20t·ha⁻¹, 3% more than the normal lines. Finally, a group of two lines derived from the LRB14 had lower average yields, 23% lower than the normal lines. This suggests that lines converted to the character of high quality protein showed good yield and agronomical traits, and are adapted to the tropics, so they can be used as parental germplasm in developing new maize hybrids and synthetics; also indicating that this group of lines broadens the genetic basis for this feature (Table III).

In relation to the quality protein content, synthetics formed with representatives of each group of converted

TABLE I
MEAN SQUARES AND SIGNIFICANCE OF COMBINED ANALYSIS OF VARIANCE
WITH HIGH QUALITY PROTEIN MAIZE LINES. COTAXTLA, VERACRUZ, MEXICO, 2012^a AND 2012^b

Source of variation	DF	GY (t ha ⁻¹)	Days to tassel	Plant height	Plant aspect	Ear aspect	% Lodging	% Cob	% Ear rot	Segr
Genotypes (G)	127	2.73**	16.28**	754.22**	0.40**	0.59**	8.34**	7.50**	3.33**	0.61**
Environments (E)	1	51.19**	1211.5**	144743.9**	3.48**	13.64**	212.14**	1.62 NS	28.43*	7.56**
(G×E) Interaction	127	1.26**	6.22**	220.34 NS	0.23 NS	0.23 NS	4.34**	2.78 NS	2.21 NS	
MSE	254	0.87	4.35	242.65	0.19	0.23	3.08	2.90	2.28	0.38
Average		3.48	61	171	2.34	1.98	11.37	6.66	8.98	1.59
CV (%)		26.83	3.43	9.10	18.58	24.19	66.48	80.25	56.48	38.75

a: autumn-winter season, b: spring-summer season,* Statistical significance at $p \leq 0.05$, ** statistical significance at $p \leq 0.01$, NS: non significant, DF: degrees of freedom, GY: grain yield, % Cob:% of bad husk cover, Segr: segregation of grain opaque character, CV: coefficient of variation, MSE: mean square error.

TABLE II
GRAIN YIELD AND AGRONOMIC TRAITS IN ELITE INBRED LINES OF
QUALITY PROTEIN MAIZE. COTAXTLA, VERACRUZ, MEXICO, 2012^a AND 2012^b

Genealogy	GY t·ha ⁻¹	Rel %	DT	PH	PA ¹	EA ¹	% Lod	% Cob	% ER	Segr	Text
(LT-154×CML-144)LT-154RC ₂ -5-1-2	4.9*	120	59	180	1.9	1.6	4.2	1.8	4.1	2.0	D
(LT-154×CML-144)LT-154RC ₂ -5-1-1	4.4*	108	62	189	2.0	1.6	0.0	8.3	8.9	1.5	D
(LT-154×CML-144)LT-154RC ₂ -2-1-2	3.6*	88	62	160	2.4	1.6	0.0	0.0	5.8	0.5	SD
(LT-154×CML-144)LT-154 RC ₂ -1-1-2	3.4**	83	63	184	2.6	1.8	2.3	4.5	13.6	1.5	SD
LT-154	2.3	56	66	156	2.6	2.3	0.0	0.0	10.2	1.0	
(LT155×CML144)LT155RC ₂ -1-1-9	4.5*	110	58	176	2.3	1.8	6.0	0.0	4.5	2.0	SD
(LT155×CML144)LT155RC ₂ -2-1-1	4.4*	108	58	171	2.0	1.6	16.7	20.2	4.6	2.0	SD
(LT155×CML144)LT155RC ₂ -2-2-3	4.2*	103	59	180	2.1	1.8	0.0	23.0	11.9	3.0	SD
(LT155×CML144)LT155RC ₂ -1-1-18	4.2*	103	58	175	2.5	2.0	36.0	7.9	9.5	1.5	F
LT-155	4.1	100	61	183	2.4	1.8	21.9	7.9	2.3	1.5	
(CABG×CML144)CABGRC ₂ -1-1-6	5.1*	125	60	203	1.6	1.5	8.6	11.8	6.2	2.5	SD
(CABG×CML144)CABGRC ₂ -1-1-2	4.4*	108	61	194	2.0	1.5	5.6	7.3	2.1	1.0	D
(CABG×CML144)CABGRC ₂ -3-2-5	4.1*	100	61	148	2.8	2.8	0.0	6.7	13.8	1.0	SF
(CABG×CML144)CABGRC ₂ -4-1-2	4.1*	100	60	159	2.4	1.9	3.6	0.0	6.3	2.0	SD
LT-156	2.6	63	63	184	1.8	2.4	0.0	0.0	4.1	1.5	
(D539×CML144)D-539RC ₂ -1-1-4	5.0*	122	61	190	1.9	1.6	22.3	11.8	10.2	1.5	SD
(D539×CML144)D-539RC ₂ -1-1-2	4.7*	115	62	203	2.3	1.4	9.1	10.9	12.3	2.0	D
(D539×CML144)D-539RC ₂ -1-1-1	4.6*	113	61	154	2.0	1.9	1.7	0.0	11.3	3.0	SD
(D539×CML144)D539RC ₂ -1-1-5	4.2*	103	60	161	2.4	1.6	19.4	3.6	5.4	2.0	SF
(LRB14×CML144)LRB14RC ₂ -1-1-2	3.1*	76	60	190	2.3	2.1	3.6	6.6	10.6	1.0	F
(LRB14×CML144)LRB-14RC ₂ -1-1-1	1.6**	39	61	163	3.3	2.8	6.9	5.6	8.7	2.0	F
(VS-536×V-537C)VS-536RC ₂ -1-3-1	4.5*	110	60	166	2.1	2.3	22.1	3.1	8.2	2.0	D
(VS-536×V-537C)VS-536RC ₂ -3-1-7	4.4*	108	59	174	1.8	1.8	0.0	0.0	9.9	1.5	D
(VS-536×V-537C)VS-536RC ₂ -1-2-7	4.3*	105	60	155	2.6	1.6	5.4	13.5	4.8	1.0	F
(VS-536×V-537C)VS-536RC ₂ -2-2-4	4.2*	103	58	169	2.0	1.8	0.0	0.0	6.1	1.5	SD
(VS-536×V-537C)VS-536RC ₂ -2-2-6	4.2*	103	59	175	2.3	1.6	9.2	0.0	4.0	2.0	D
FAM V-537 C-1-1-2	5.9*	144	59	168	1.9	1.0	1.7	8.9	3.3	2.0	SF
FAM V-537 C-1-1-1	5.7*	139	59	184	1.8	1.3	0.0	0.0	5.3	1.5	SD
FAM-V-537 C-2-1-1	5.4*	132	58	161	2.5	1.8	15.0	8.8	6.7	2.5	D
FAM V-537 C-2-2-1	4.9*	120	59	168	2.9	2.5	0.0	34.0	15.6	2.5	SD
CML-142	4.7*	115	62	204	2.3	2.0	0.0	3.6	3.4	1.5	F
CML-159	3.2**	78	60	176	2.5	1.9	10.5	8.8	6.6	1.5	F
CML-491	3.2**	78	64	170	2.4	2.0	7.3	0.0	12.0	1.0	F
Average	3.5		61	171	2.3	2.0	11.4	6.7	9.0	1.6	
MSE	0.87		4.4	242.7	0.2	0.2	3.1	2.9	2.3	0.4	
LSD 0.05	1.3		2.88	21.58	0.61	0.61	2.44	2.36	2.10	1.26	
LSD 0.01	1.71		3.78	28.37	0.81	0.81	3.20	3.10	2.76	1.66	

a: autumn-winter season, b: spring-summer season, * Statistical significance at $p \leq 0.05$, ** statistical significance at $p \leq 0.01$, GY: grain yield, REL%: relative percentage, DT: days to tassel, PH: plant height, PA: plant aspect, EA: ear aspect, % Lod: percentage of lodging, % Cob: percentage of bad husk cover, % ER: percentage of ear rot, Segr: segregation of grain opaque character, CV: coefficient of variation, MSE: mean square error, LSD: least significant difference, Text: grain texture, D: dent, F: flint, SD: semi-dent, SF: semi-flint, ¹: scale of 1 to 5 where, 1 is the best and 5 the worst.

TABLE III
AVERAGE YIELD AND AGRONOMIC CHARACTERISTICS OF GROUPS OF MAIZE INBRED LINES CONVERTED
TO THE OF HIGH QUALITY PROTEIN CHARACTER. COTAXTLA, VERACRUZ, MEXICO, 2012^a AND 2012^b

Num lines	Genealogy	GY (t ha ⁻¹)	TC	Rel %	Days to tassel	Plant height	Plant aspect ¹	Ear aspect ¹	% Lodging	% Cob	% ER	Segr	Text
6	D-539	4.30	3.80**	139	61	173	2.2	1.8	11.1	4.8	9.7	2.2	SD
8	V537C	4.30	4.00**	139	59	162	2.5	1.9	5.4	14.0	10.7	2.0	SD
45	VS-536	3.50	1.52 NS	113	61	170	2.3	1.9	14.3	4.0	8.6	1.5	SD
7	LT154	3.40	0.95 NS	110	61	171	2.3	1.9	8.2	2.9	9.4	1.0	SD
33	LT-155	3.40	1.14 NS	110	61	170	2.4	2.1	13.2	8.4	10.0	1.5	SD
18	CABG	3.20	0.36 NS	103	61	175	2.3	2.0	7.5	5.8	6.8	1.5	SD
5	CMLS	3.20	0.31 NS	103	61	181	2.4	2.2	7.2	18.3	12.2	1.6	F
2	LRB-14	2.40	1.70 NS	77	61	176	2.8	2.4	5.3	6.1	9.7	1.5	F
4	LTs normal	3.10		100	63	178	2.3	2.2	7.0	6.9	5.3		SD
128	Average	3.50			61	171	2.3	2.0	11.4	6.7	9.0		

a: autumn-winter season, b: spring-summer season, **: Statistical significance at $p \leq 0.01$, NS: non significant, GY: grain yield, TC: calculated T, Rel%: relative percentage, %Cob: percentage of bad husk cover, %ER: percentage of ear rot, Segr: segregation of grain opaque character, Text: grain texture, ¹: scale of 1 to 5 where, 1 is the best and 5 the worst, SD: semi-dent, F: flint.

lines, had 36-55% more lysine and 62-106% more tryptophan in relation to the normal 'Tuxpeno' maize (Table IV), which represents a significant added value for the nutrition of consumers (Ortega *et al.*, 1986; Bressani, 1994; Larkins *et al.*, 1994; Mertz, 1994; Sierra *et al.*, 2001; Vasal, 2002; Chavez and Muñoz, 2004; Espinosa *et al.*, 2005, 2006). Therefore, promissory lines of different origins converted to the character of high quality protein, with good yield and agronomical traits, that can form new synthetics and hybrids adapted to the Mexican tropic were found.

Conclusions

The majority of groups of inbred lines converted to quality protein character showed better grain yield and agronomical traits than the normal original lines; with the exception of the LRB lines. In relation with the high quality protein maize, the germplasm base was broadened, as new lines from different origins were obtained, with good agronomical behavior, that can form better combinations for developing new hybrids and varieties for the Mexican tropics. The best inbred lines, for yield and agronomics traits, were derived from D-539 and recycled from V-537C. In relation to the quality protein character, synthetics formed with representatives of each group of converted lines, these had 36-55% more lysine and 62-106% more tryptophan in relation to the normal 'Tuxpeno' maize, which is a significant added value for the nutrition of consumers.

REFERENCES

AACC (1998) *Approved Methods of the American Association of Cereal Chemists*. 10th ed. American Association of Cereal Chemists. St. Paul, MN, USA. 120 pp.

AOAC (1984) *Official Methods of Analysis*. 13th ed. Association of Official Analytical Chemists. Rockville, MD, USA. pp. 132-133.

Bressani R (1994) Opaque 2 corn in human nutrition and utilization. In *Quality protein maize. 1964-1994. Proc. Int. Symp. on Quality Protein Maize*. EMBRAPA/CNPMS. Sete Lagoas, MG, Brazil. pp. 41-63.

Chávez VA, Muñoz CM (2004) *La Tortilla de Alto Valor Nutritivo*. Mc Graw Hill. Mexico, 110 pp.

Espinosa CA, Gómez MN, Sierra MM, Caballero HF, Coutiño EB, Palafox CA, Rodríguez MFA, García B, Betanzos ME (2005) Los maíces de calidad proteínica y

TABLE IV
CONTENT OF LYSINE AND TRYPTOPHAN IN SYNTHETICS WITH MAIZE LINES CONVERTED TO THE CHARACTER OF HIGH QUALITY PROTEIN. COTAXTLA, VERACRUZ, MEXICO, 2011

Genotype	% Lysine	Relative %	Genotype	% Tryptophan	Relative %
Synthetic 1	0.390	155	Synthetic 5	0.113	206
Synthetic 5	0.375	149	Synthetic 1	0.095	173
Synthetic 2	0.359	142	Synthetic 4	0.093	169
Synthetic 4	0.342	136	Synthetic 2	0.089	162
General mean	0.367			0.098	
Tuxpeno (normal)*	0.252	100		0.055	100

* de Vidal *et al.* (2008).

la producción de semillas en México. *Ciencia y Desarrollo*: 1-10.

Espinosa CA, Gómez MN, Sierra MM, Betanzos ME, Caballero HF (2006) Variedades e híbridos de maíz de calidad proteínica en México. *Ciencia* 57: 28-34.

García E (1981) *Modificaciones al Sistema de Clasificación Climática de Köppen*. 3^a ed. Instituto de Geografía. Universidad Nacional Autónoma de México. México. 252 pp.

Hallauer AR, Miranda BJ (1988) *Quantitative Genetics in Maize Breeding*. 2nd ed. Iowa State University Press. Ames, IO, USA. 664 pp.

Larkins BA, Dannehoff DF, Bostwick EO, Moro GA, Lopez MA (1994) Opaque 2 modifiers, what they are and how they work. In *Quality protein maize. 1964-1994. Proc. Int. Symp. on Quality Protein Maize*. EMBRAPA/CNPMS. Sete Lagoas, MG, Brazil. pp. 133-148.

Mertz E (1994) Thirty years of opaque 2 maize. In *Quality protein maize. 1964-1994. Proc. Int. Symp. on Quality Protein Maize*. EMBRAPA/CNPMS. Sete Lagoas, MG, Brazil. pp. 1-10.

Morris ML, López P MA (2000) *Impactos del Mejoramiento de Maíz en América Latina 1966-1997*. CIMMYT. Mexico. 45 pp.

Ortega CA, Villegas E, Vasal SK (1986) A comparative study of protein changes in normal and Quality Protein Maize during tortilla making. *Cereal Chem*. 63: 446-451.

Reyes CP (1990) *Diseño de Experimentos Aplicados*. 3^a ed. Trillas. Mexico, 348 pp.

SIAP (2012) *Anuario Estadístico de la Producción Agrícola de los Estados Unidos Mexicanos*. Servicio de Información Agroalimentaria y Pesquera www.siap.sagarpa.gov.mx (Cons. 11/2014).

Scott MM, Peterson JM, Hallauer AR (2009) Evaluation of combining ability of quality protein maize derived from US public inbred lines. *Maydica* 54: 449-456.

Sierra MM, Rodríguez MFA, Castillo GR, Preciado ORE, Márquez SF (1992) *V/S-536 Variedad sintética de maíz para el trópico de Veracruz y Regiones similares*. Folleto Técnico N° 2. Campo Experimental Cotaxtla. SARH. INIFAP CIRGOC. Veracruz, México. 11 pp.

Sierra MM, Rodríguez MFA, Preciado ORE, Castillo GR, Ortiz CJ, Márquez SF, Tosquy VOH (1993) *H-512, Híbrido de Maíz de Cruza Doble para el Trópico Húmedo de México*. Folleto Técnico N° 3. Campo Experimental Cotaxtla. SARH. INIFAP CIRGOC. Veracruz, México. 13 pp.

Sierra MM, Palafox CA, Cano RO, Rodríguez MFA, Espinosa CA, Turrent FA, Gómez MN, Córdova OH, Vergara AN, Aveldaño SR, Sandoval RJ, Barrón FS, Romero MJ, Caballero HF, González CM, Betanzos ME (2001) *Descripción Varietal de H-519C, H-553C y V-537C, Maíces con Alta Calidad de Proteína para el Trópico Húmedo de México*. Folleto Técnico N° 30. Campo Experimental Cotaxtla. SARH. INIFAP CIRGOC. Veracruz, México. 21 pp.

Sierra MM, Palafox CA, Rodríguez MFA, Espinosa CA, Gómez MN, Caballero HF, Barrón FS, Zambada MA (2004) *H-518 y H-520, Híbridos Trilineales de Maíz para el Trópico Húmedo de México*. Folleto Técnico N° 38. Campo Experimental Cotaxtla. SARH. INIFAP CIRGOC. Veracruz, México. 16 pp.

Trifunovic S, Cordova H, Crossa J, Pandey S (2003) Head to head and stability analysis of maize (*Zea mays* L.) inbred lines. *Maydica* 48: 263-269.

Vasal SK (2002) High quality protein corn. In Hallauer AR (ed.) *Specialty Corns*. 2^a ed. CRC. Boca Raton, FL, EEUU. pp. 85-129.

Vasal SK, Villegas E (2001) *The Quality Protein Maize Revolution. Improved Nutrition and Livelihoods for the Poor*. CIMMYT. Mex. 7 pp.

Vidal VA, Vazquez CMG, Coutiño EB, Ortega CA, Ramírez DJL, Valdivia BR, Guerrero HMJ, Caro VFJ, Cota AO (2008) Calidad proteínica en colectas de maíces criollos de la sierra de Nayarit, México. *Rev. Fitotecn. Mex.* 31: 15-21.

CARACTERIZACIÓN AGRONÓMICA DE LINEAS TROPICALES DE MAIZ (*Zea mays* L.) CONVERTIDAS AL CARÁCTER DE CALIDAD DE PROTEÍNA

Mauro Sierra-Macías, Pablo Andrés-Meza, Flavio Rodríguez-Montalvo, Noel Gómez-Montiel, Alejandro Espinosa-Calderón, Roberto Valdivia-Bernal, Artemio Palafox-Caballero, Margarita Tadeo-Robledo and Omar Velásquez-García

RESUMEN

Líneas de maíz convertidas al carácter de calidad de proteína fueron evaluadas para conocer su rendimiento y características agronómicas. La evaluación se realizó en el Campo Experimental Cotaxtla, Veracruz, México, durante los ciclos otoño-invierno 2011/12 y primavera-verano 2012. Se utilizó un diseño alpha látice 16×8 con 128 tratamientos y dos repeticiones, en parcelas de un surco de 2.5m de largo, separados 80cm y con densidad de 62500 plantas/ha. Durante el desarrollo del cultivo se registraron las variables: altura de planta y de mazorca, días a floración, aspecto y sanidad de planta y mazorca, mazorcas con mala cobertura, mazorcas podridas, rendimiento de grano y segregación del carácter opaco en el grano. Del análisis de varianza combinado en los dos ambientes de evaluación se encontró significación estadística para genotipos (G) y ambientes (A) en todas las variables, excepto para mazorcas con mala cobertura; para la interacción GxA se encontró

significancia para rendimiento de grano, días a floración y % de acame. Las líneas sobresalientes en cuanto a rendimiento y características agronómicas fueron entre otras: FAMV537C-1-1-2, FAMV537C-1-1-1, FAMV537C-2-1-1, (D-539xCML144)F2xD539 RC₂-1-1-4, (D-539xCML144)F2xD539RC₂-1-1-2, (D-539xCM-L144)F2xD539RC₂-1-1-1, (LT155xCML144)LT155RC₂-1-1-9, (LT155x-CML144)LT155RC₂-2-1-1, (LT155xCML144)LT155RC₂-2-2-3, (LT154x-CML144)LT154RC₂-5-1-2, (LT154xCML144)LT154RC₂-5-1-1, (CABGxCML144)CABGRC₂-1-1-6, (CABGxCML144)CABGRC₂-1-1-2, (CABGxCML144)CABGRC₂-3-2-5, (VS-536xV-537C)VS-536RC₂-1-3-1, (VS-536xV-537C)VS-536RC₂-3-1-7, (VS-536xV-537C)VS-536RC₂-1-2-7, con rendimientos >4t·ha⁻¹, de 3 a 44% más que la mejor línea normal LT155 (4,1t·ha⁻¹), utilizada como testigo. En relación con calidad de proteína en sintéticos formados con líneas representativas de cada grupo de líneas convertidas, estos registraron 36-55% más lisina y 62-106% más triptófano con relación al maíz 'Tuxpeño' normal.

CARACTERIZAÇÃO AGRONÔMICA DE FILEIRAS TROPICAIS DE MILHO (*Zea mays* L.) CONVERTIDAS AO CARÁCTER DE QUALIDADE DE PROTEÍNA

Mauro Sierra-Macías, Pablo Andrés-Meza, Flavio Rodríguez-Montalvo, Noel Gómez-Montiel, Alejandro Espinosa-Calderón, Roberto Valdivia-Bernal, Artemio Palafox-Caballero, Margarita Tadeo-Robledo e Omar Velásquez-García

RESUMO

Fileiras de milho convertidas ao caráter qualidade de proteína foram avaliadas para conhecer seu rendimento e características agronômicas. A avaliação foi realizada no Campo Experimental Cotaxtla, Veracruz, México, durante os ciclos outono-inverno 2011/12 e primavera-verão 2012. Utilizou-se um delineamento alpha látice 16×8 com 128 tratamentos e duas repetições, em trechos de um sulco de 2.5m de largura, separados 80cm e com densidade de 62500 plantas/ha. Durante o desenvolvimento do cultivo se registraram as variáveis: altura de planta e de espiga, dias para floração, aspecto e sanidade de planta e espiga, espigas com má cobertura, espigas podres, rendimento de grão e segregação do caráter opaco no grão. Da análise de variação combinada nos dois ambientes de avaliação se encontrou significação estatística para genótipos (G) e ambientes (A) em todas as variáveis, exceto para espigas com má cobertura; para a interação GxA se encontrou significância para rendimento de grão, dias para floração e % de acama-

mento. As fileiras sobressalentes quanto a rendimento e características agronômicas foram entre outras: FAMV537C-1-1-2, FAMV537C-1-1-1, FAMV537C-2-1-1, (D-539xCML144)F2xD539 RC₂-1-1-4, (D-539xCML144)F2xD539RC₂-1-1-2, (D-539xCML144)F2xD539RC₂-1-1-1, (LT155xCML144)LT155RC₂-1-1-9, (LT155x-CML144)LT155RC₂-2-1-1, (LT155xCML144)LT155RC₂-2-2-3, (LT154xCML144)LT154RC₂-5-1-2, (LT154xCML144)LT154RC₂-5-1-1, (CABGxCML144)CABGRC₂-1-1-6, (CABGxCML144)CABGRC₂-1-1-2, (CABGxCML144)CABGRC₂-3-2-5, (VS-536xV-537C)VS-536RC₂-1-3-1, (VS-536xV-537C)VS-536RC₂-3-1-7, (VS-536xV-537C)VS-536RC₂-1-2-7, com rendimentos >4t·ha⁻¹, de 3 a 44% a mais do que a melhor fileira normal, LT155 (4,1t·ha⁻¹), utilizada como testemunha. Em relação à qualidade de proteína em sintéticos formados com fileiras representativas de cada grupo de fileiras convertidas, estes registraram 36-55% mais lisina e 62-106% mais triptófano em relação ao milho 'Tuxpeño' normal.