Article

Stability and adaptation of the yield and quality of tortillas in Tuxpeño corn, High-Valleys

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Abstract

The V-520C variety of corn (*Zea mays* L.) belongs to the Tuxpeño breed, is native to Veracruz (500 meters above sea level) and was adapted to the High Valleys of Mexico (>2 200 masl) with recurrent visual mass selection (SMV) for 19 cycles The objective was to evaluate the stability and adaptation of the original V-520C (C0) and the adapted materials cycle 14 (C14) and cycle 19 (C19) for grain yield and tortilla quality through regression sites (SREG). Between 2013 and 2014, three C0, C14 and C19 genotypes were evaluated in a randomized complete block design with three replications. The evaluations were carried out in the State of Mexico and Veracruz with three experiments per entity. The analysis of variance detected significance ($p \leq 0.01$) between environments, genotypes and the genotype-environment interaction and in the first two Main Components for the six variables. SREG indicates that C19 had better adaptation and stability for grain yield (3.54 t ha^{-1}), tortilla moisture at 24 h (42.72%), cold tortilla yield (1.44 kg kg^{-1} corn) and a reduced force for break the tortilla (193 gf). The SMV produced favorable changes to C19, which presented the best stability and adaptation in the High Valleys of Mexico. Being the Montecillo 2014-S-S environment, the one that discriminated between genotypes and the best mega-environment in the variables studied. All genotypes and environments, with the exception of Tepetates 2014-A-W and Coatlinchan 2014-S-S, met the parameters required by the NMX-034/1 standard for corn destined for the nixtamalization process.

Keywords: *Zea mays* L., GGE biplot, nixtamal quality, regression sites, visual mass selection.

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Introduction

According to the figures of SIAP (2018) in Mexico, a production of about 21 million tons of corn (*Zea mays* L.) was made for grain, of which 12 million are annually destined to the production of tortillas (SE, 2012). Such production had a national average yield of 3.9 t ha^{-1} of grain, 3.8 and 2.2 t ha^{-1} for the State of Mexico and Veracruz, respectively (SIAP, 2018).

The yield and quality of corn tortillas are aspects demanded by farmers and industrialists of tortilla dough (IMT) and nixtamalized flour (IHN), both industries prefer ≤5% of losses of dry matter, IMT a tortilla yield of 1.4-1.6 kg kg^{-1} and a remaining pericarp of ≥30%, while the IHN is ≤30%, such aspects are affected by the conditions of the environments (E), genotypes (G) and interaction Genotype-environment (GE) (Zepeda *et al*., 2009; Vázquez *et al*., 2012).

Molina (1983) suggested visual mass selection (SMV) as a method to adapt corn to other regions, and thus increase local genetic diversity since; through several selection cycles, exotic varieties have similar or superior characteristics to local varieties. SMV has been used to adapt tropical and subtropical materials to temperate climates, such as the High Valleys of Mexico (>2 200 m) (Pérez *et al*., 2000; 2002; 2007).

The Tuxpeño breed, native to the state of Veracruz, is distinguished by its high yield, flexibility of adaptation, some tolerance to drought, resistance to pests and diseases, good quality of the grain and its tortilla (Antuna *et al*., 2008; Wen *et al*., 2012; López-Morales *et al*., 2017). With the purpose of having germplasm with these characteristics, it was decided to adapt the Tuxpeño race to High Valleys, since as it progresses in the SMV the favorable gene frequencies for these attributes are changed (Molina, 1983).

The stability (low GE) and the quality of the tortillas of the breeds have been investigated in a few studies of Mexico together, since there are few breeds adapted to other places where they are original and are rarely used by breeding programs genetic (Castillo, 1993). López-Morales *et al*. (2017) evaluated the Tuxpeño breed adapted to High Valleys, under the AMMI model (main additive effects and multiplicative interactions) and observed that the most advanced selection cycle in SMV had better yields and grain quality with respect to C0, similar results were reported by De Jesús *et al*. (1990); Pérez *et al*. (2000) who studied the cycles: C0 and C2 to C11 and C12 respectively, without the same model and with agronomic variables.

The regression site model (SREG) has been useful for estimating the stability and GE interaction of yield in corn cultivation, as well as in its tortilla quality characteristics (Vázquez-Carrillo *et al*., 2016), this model it explains the response of genotypes in specific environments and is represented in a GGE biplot graph, where the effects of G and GE interaction are shown, eliminating the effect of locality (Yan *et al*., 2000).

The variety of corn V-520C of the Tuxpeño breed was adapted to High Valleys with SMV, increasing its yield and adaptation repeatedly for cycles 14 (C14) and 19 (C19); however, it is necessary to know their tortilla quality to determine if they meet the quality characteristics demanded by the processing industries. The objective was to determine the stability and adaptation of the yield and quality characteristics of nixtamal and tortilla of the corn variety V-520C (C0), as well as, the materials C14 and C19 evaluated in their original environment (Veracruz) and in the adapted environment (State of Mexico), analyzed using the SREG model. It is expected that the C19 obtain greater stability and adaptation for grain yield and quality characteristics, by having a greater number of cycles adapted with SMV.

Materials and methods

The germplasm evaluated was the corn variety V-520C, called in this study zero cycle (C0), as well as two genotypes adapted to High Valleys by means of the SMV performed repeatedly in the V-520C, called cycle 14 (C14) and cycle 19 (C19). Initially 510 plants were occupied in each cycle, but as progress was made in the SMV, only the best 50 ears in each cycle were visually selected, increasing grain yield and cob characteristics (large, cylindrical, healthy, with rows straight and serrated white grain) typical of the Tuxpeño breed (Molina, 1983).

The SMV for adaptation of C14 and C19 was developed in the Experimental Field of the Graduate College (from 1993 to 2012), located in Montecillo, Texcoco, State of Mexico, at an altitude of 2 250 m, where the subhumid temperate climate predominates (García, 1973).

Location of the experiments

The three genotypes C0, C14 and C19 were evaluated two years in Montecillo (M 2013-S-S and M 2014-S-S) and one in Coatlinchan (C 2014-S-S), municipality of Texcoco, State of Mexico, both belonging to the High Valleys. They were also established, during three agricultural cycles in the town of Tepetates (T 2013-S-S, T 2014-A-W, T 2014-S-S), municipality of Manlio Fabio Altamirano, Veracruz. The experimental design used was randomized complete blocks with three repetitions, where the experimental unit consisted of two 6 m long grooves, 80 cm apart; two seeds were sown every 50 cm, which made a total of 52 plants per plot, with a population density of 50 thousand plants per hectare.

Agronomic management

In the two years of evaluation in Montecillo the fertilization formula was 140-60-00 (kg ha^{-1} of NPK), while in Coatlinchan 140-40-00 was used, prior to a soil analysis to determine the formula of all locations (Table 1), in the locations of the High Valleys, the application of nitrogen was divided into two parts, the first at the time of planting applying all the phosphorus and the second, 35 days after planting. In the three locations an initial irrigation was applied, additionally in Montecillo there were three irrigation risks during the crop cycle.

The dose of fertilization in the three experiments of Tepetates, Veracruz, was 110-46-00, which was divided as follows: 64-18-00 at the time of sowing and the rest, 20 days later. Only to the test of Tepetates autumn-winter (A-W) was applied irrigation every 10 days, since the tests established in spring-summer (S-S) of the years 2013 and 2014 were temporary.

Table 1. Edaphoclimatic characteristics of the six evaluated locations in the state of Mexico and Veracruz (2013-2014).

Location, cycle-year†	State	Altitude (m)	Date Sow/harvest	Fertilization (kg ha^{-1}) of N-P	Soil type with its pH	Precipitation (mm)	T (°C)	
							Max§	Minþ
Montecillo, 2013-S-S	MEX	2 250	21-05/21-11	140-60	Vertisol pH 7.5	1277 a	29	6
Montecillo, 2014- S-S	MEX	2 250	05-06/04-12	140-60	Vertisol pH 7.5	1179 a	29	3
Coatlinchan, 2014- S-S	MEX	2300	09-05/20-11	140-40	Phaeozem pH 6.2	1306 b	30	6
Tepetates, 2013- S-S	VER	20	24-05/23-09	110-46	Vertisol pH 6.3	1227	35.9	21.2
Tepetates, 2014-A-W	VER	20	28-01/16-05	110-46	Vertisol pH 6.3	26 c	42.2	10.6
Tepetates, 2014- S-S	VER	20	27-06/09-10	110-46	Vertisol pH 6.3	1975	34.8	20.2

†= year of sowing and evaluation cycle; S-S= spring-summer; A-W: autumn-winter; MEX= State of Mexico; VER= state of Veracruz; ¶= total precipitation (from sowing/harvesting period); §= maximum temperature; þ= minimum temperature (during the sowing/harvest period); a, b, c= initial watering with 10 cm of leaf + three auxiliary watering with 5 cm of leaf (before and during flowering), initial watering, ten auxiliary watering, respectively, all rolled type.

Variables evaluated

The grain yield (REN) was obtained in t ha^{-1} of grain by the dry weight of the grain with 12% moisture in each plot, extrapolated to the surface of one hectare. Grain cooking times were assigned according to NMX-034/1 (2002): C19 received 40 min (hard), C14, 35 min (intermediate) and C0, 25 min (soft) cooking. In the cooking liquor (nejayote) the loss of dry matter (PMS) was evaluated, and in the nixtamal the retained pericarp (PR), both variables are reported in percentages (Salinas and Vazquez, 2006), in cold tortillas the yield (RTF) expressed as kg of tortillas per kg of grain of processed corn.

Tortilla elaboration was carried out following the traditional method (Vázquez-Carrillo *et al*., 2016). The puncture force to break the tortilla (FP) was evaluated on the Brookfield® CT3 texturometer (Middleboro, MA, USA) and is reported in grams-force (g_f). The FP and humidity of the tortillas (HT24) were evaluated in cold tortillas: 2 and 24 h after processing, respectively. The cold tortillas were packed in ziploc® sealed plastic bags and stored at 4 °C (refrigeration) (Vázquez *et al*., 2015).

Statistical analysis

The grain yield data and quality variables of nixtamal and tortillas were analyzed with the SREG model (Yan *et al*., 2001), using the SAS statistical package for Windows, version 9.0 (SAS, 2002). With this model, a biplot graph was constructed with the first two Main Components (CP1 and CP2) for each variable.

Results and discussion

The analysis of variance detected significance ($p \leq 0.01$) between environments (E), between genotypes (G) and in the genotype-environment interaction (GE) for all six evaluated variables mentioned in Table 2. This means that the SMV effect made important genetic changes in the two selected populations (C14 and C19) with respect to C0, and that at least one genotype was different; likewise, the environments had an effect because they were contrasting, which justified the differences between the means of the variables and environments, where both effects were also reflected in the significance of the GE interaction, which coincides with the data of Vázquez-Carrillo *et al*. (2016); López-Morales *et al.* (2017).

Table 2. Mean squares in grain yield and quality of nixtamal and tortillas of the genotypes investigated in six environments of the state of Mexico and Veracruz (2013-2014).

Source of variation	Degrees of freedom	REN	Nixtamal		Tortilla		
			PMS	PR	HT24	RTF	FP
E	5	11.56**	3.68**	2650.72**	30.79**	0.033**	13014.02**
G	2	17.15**	0.98**	933.88**	37.93**	0.017**	915.9**
GE	10	2.54**	0.3**	83.54**	18.83**	0.004**	807.57**
CP1	6	8.63**	0.44**	418.43**	43.42**	0.011**	1016.69**
CP2	4	1.99*	0.58**	48.15**	0.91	0.002*	951.86**
Error	34	0.75	0.05	3.34	0.91	0.001	48.94
CV (%)	-	34.88	5.09	4.29	2.32	2.293	3.47
R^2	-	0.82	0.92	0.99	0.93	0.875	0.97
$\bar{X}$	-	2.48	4.75	42.54	41.15	1.406	201.25

*= $p \leq 0.05$; **= $p \leq 0.01$; E= environment; G= genotypes; GE= genotype-environment interaction; CP= main component; CV= percentage coefficient of variation; R^2= coefficient of determination; $\bar{X}$= average of the variable; REN= grain yield; PMS= loss of dry matter; PR= retained pericarp; HT24= tortilla moisture at 24 h; RTF= cold tortilla yield; FP= puncture force.

Adaptation and stability of grain yield

The statistical significance of the GE interaction for the REN indicates that at least one of the genotypes evaluated had better adaptation to a specific environment, in the same way, the two main components (CP1 and CP2) were significant (Table 2), which explained 86.64 % and 13.36% of the variability, respectively (Figure 1A). This could happen by having a small number of both genotypes and environments. The environments to the right in Figure 1A show that genotype C19 was of higher performance in these environments. The length of the environment vector indicates the variability in performance explained by the environments and vice versa (Crossa *et al*., 2015).

In this investigation the components CP1 and CP2 explained 100% of the variability in the six variables studied (Figure 1A-1F), which is attributed to a low GE interaction and a high phenotypic correlation between sites, due to the number of genotypes and of environments included; similar results were observed by Ibañez *et al*. (2006) when evaluating 13 corn hybrids in three locations, which indicates that this study focused on the adaptation and stability of the three genotypes of the Tuxpeño breed with different cycles of SMV, evaluated in six different environments.

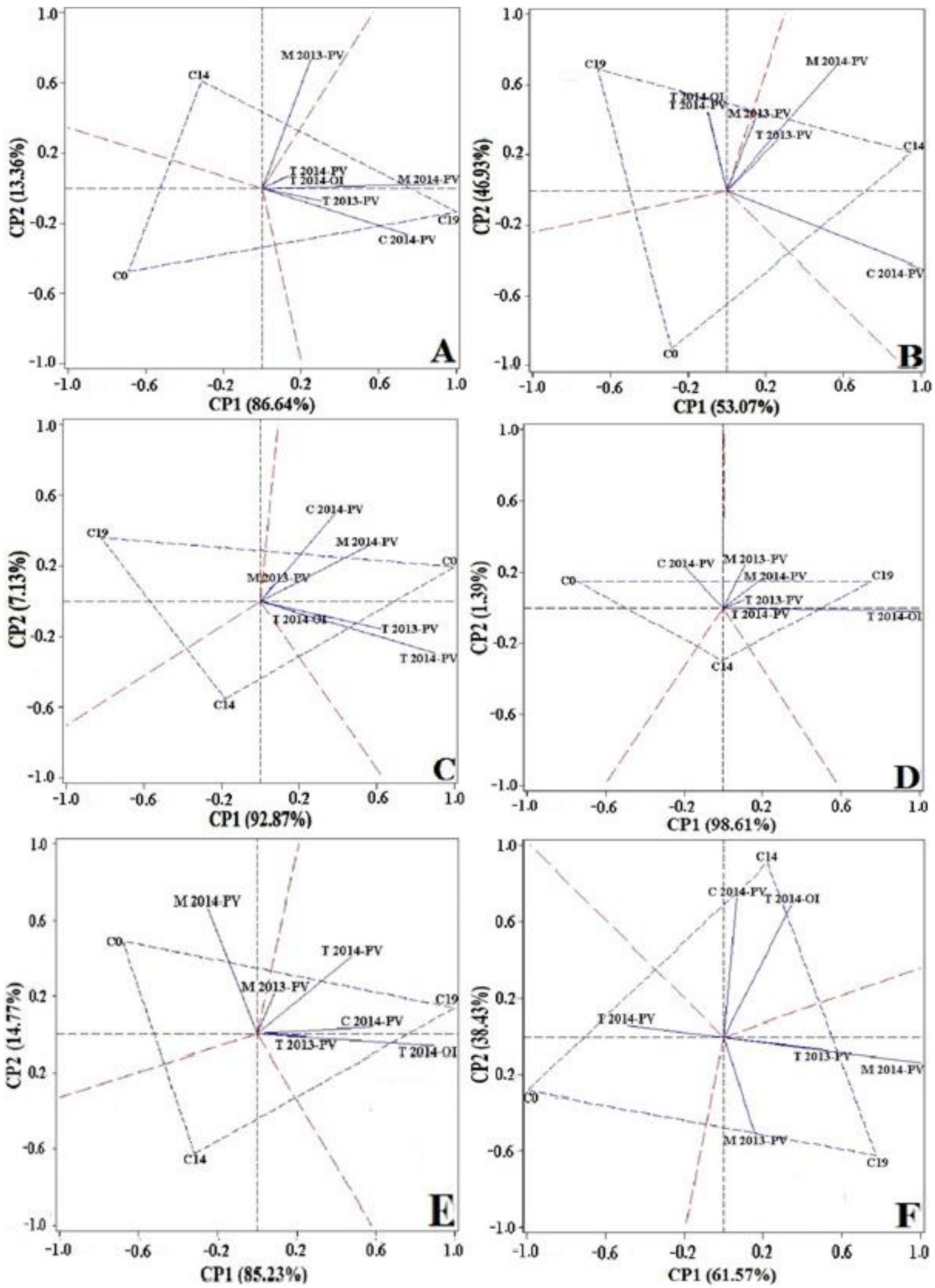

Figure 1. Biplot of the two main components of grain yield. A) loss of dry matter; B) retained pericarp; C) tortilla moisture at 24 h; D) cold tortilla yield; E) puncture force of the tortilla; and F) of the SREG model of the three genotypes.

Thus, genotype C19 was the one with the highest yield (3.54 t ha^{-1}), adaptation and stability in the study environments; while C0 and C14 had an average yield of 1.62 and 2.29 t ha^{-1}, respectively, resulting below the national average of 3.9 t ha^{-1}, according to SIAP (2018) and where its location in the left quadrants and remoteness of CP2= 0, show its instability (Figure 1A).

On the other hand, the environments were located in the mega-environment (region where a species of crop is in a fairly homogeneous environment) of the genotype that obtained the highest average yield within each environment. This means that the mega-environment of genotype C19 (Figure 1A) had the highest yields in all the evaluated environments accepted in M 2013-S-S, which could be due to the progress of the SMV cycles that this genotype has, favored by genetic frequencies for performance, such as those found De Jesús *et al*. (1990); Pérez *et al*. (2000) for the Tuxpeño breed in the same variable of genotype V-520C, except in M 2013-S-S which was located in the mega-environment of C14, indicating that for this environment such genotype had the highest average yield of grain. The similarity in the performance of the M 2013-S-S and M 2014-S-S environments (Table 3) is due to the difference between genotypes, as shown in Figure 1A when placed in different mega-environments. The lower yield of the C0 genotype is attributed to its maladjustment to High Valleys (Márquez-Sánchez, 2008).

The arrangement between the environment vectors, with angles less than 90° (Yan *et al*., 2000) allows the organization of genotypes in a very similar way, as happened in the mega-environment of genotype C19 (Figure 1A).

Table 3. Means of grain yield and quality of nixtamal and tortilla of genotypes investigated in six environments of the state of Mexico and Veracruz (2013-2014).

Source	Yield grain (t ha^{-1})	Losses dry material (%)	Pericarp retained (%)	HT24 (%)	Yield tortilla (kg kg^{-1})	Puncture force (g_f)
C0	1.62 b	4.51 c	50.54 a	39.86 c	1.39 b	193.05 b
C14	2.29 b	4.98 a	40.53 b	40.88 b	1.38 b	206 a
C19	3.54 a	4.76 b	36.57 c	42.72 a	1.44 a	204.72 a
DMS	0.7	0.19	1.49	0.78	0.02	5.71
M 2013-S-S	3.56 a	4.5 cd	28.21 d	43.12 a	1.47 a	163.33 d
M 2014- S-S	3.56 a	4.22 de	51.2 b	43.22 a	1.48 a	162.66 d
C 2014- S-S	1.33 b	5.25 b	37.6 c	39.43 c	1.39 b	196.77 c
T 2013- S-S	2.91 a	4.71 c	35.5 c	41.33 b	1.33 c	215.22 b
T 2014-A-W	2.65 a	5.74 a	29.46 d	38.71 c	1.37 bc	204.44 c
T 2014- S-S	0.88 b	4.07 e	73.32 a	41.1 b	1.37 bc	265.11 a
DMS	1.23	0.34	2.6	1.36	0.04	9.95
IMT	-	≤ 5	≥ 30	-	1.4-1.6	-
IHN	-	≤ 5	≤ 30	-	-	-

HT24= tortilla moisture at 24 h; DMS= significant minimum differences; values established by the IMT (dough and tortilla industry) and by the IHN (nixtamalized flour industry). Means with different letters are statistically different (Tukey, 0.05).

Meanwhile, the environments that form an angle close to 90º are not related in the way of ordering all genotypes, as happened between the M 2013-S-S and C 2014-S-S environments. The environments with the longest length of vectors were those of High Valleys (M 2013-S-S, C 2014-S-S and M 2014-S-S) and in turn those that best discriminated the genotypes (Yan *et al*., 2000), due to the process of adaptation of cycles C14 and C19. In both the environments of Tepetates, Ver. (T 2013-S-S, T 2014-A-W and T 2014-S-S) did not discriminate between genotypes (reduced length of the vector), because it was not the selection environment, since these environments recorded higher temperatures (34.8-42.2 °C) and more abundant rainfall (1975 mm) poorly distributed, as López-Morales *et al*. (2017) in the same environments evaluated, as well as lower doses of fertilization, compared to the environments of the High Valleys, according to the soil analysis (Table 1).

The results indicate that SMV is an efficient method to increase the yield and adaptation of the V-520C Tuxpeño corn variety, as the C19 had the best performance in five of the six environments. The results agree with those of Pérez *et al*. (2002; 2007), who used the same variety of the Tuxpeño breed in High Valleys and found that the most advanced cycles in SMV had higher yields than the lower cycles.

Adaptation and stability of nixtamal and tortilla characteristics

The nixtamal and tortilla quality variables showed significance in the first two Main Components (CP), except for HT24 in CP2 (Table 2). In all the quality variables, CP1 and CP2 accumulated 100% of the sum of squares, so that the biplot analysis is viable (Crossa *et al*., 2015), an aspect attributed to the small number of genotypes evaluated in the same population, as observed by Ibañez *et al*. (2006).

In the nixtamalization process the variables that change are: the genotype and the nixtamalization time, the latter is assigned according to the hardness of the grain (NMX-034/1, 2002) and is intended to bring the grain to a degree of similar hydration (Almeida-Domínguez *et al*., 1997).

Genotype C0 (4.51%) was the one with the lowest percentage of dry matter loss (PMS) (Figure 1B), it has a negative interaction coefficient and that is favorable since less GE effect is desired for PMS in the nejayote (Yan *et al*., 2000). Compared to the positive GE interaction coefficient of C14 (the most stable) and C19, which had the highest loss 4.98 and 4.76%, respectively (Table 3).

The three genotypes recorded lower PMS values than those admitted at the maximum (5%) in the NMX-034/1 (2002) standard for corn destined for the nixtamalization process (Table 3). The lower loss of dry matter is associated with a higher yield of dough and tortillas (Vázquez *et al*., 2015); in this sense, it was found that in the T 2014-S-S environment, it was the one with the lowest PMS (4.07%), which was related to hard endosperm grains. The PMS of these genotypes are consistent with that indicated by Salinas-Moreno and Aguilar-Modesto (2010), who indicated that the intermediate endosperm corn had higher PMS compared to those of the hard endosperm.

According to the vectors of Figure 1B, the environments that did not have any relation in the way of ordering the genotypes (close to 90°) were T 2014-A-W, T 2014-S-S and C 2014-S-S, the opposite being observed with the other environments (Yan *et al*., 2000). Lower values of PMS (3%) were reported by Vázquez *et al*. (2010) for the native corn Tuxpeño.

The environments C 2014-S-S and T 2014-A-W exceeded the required value of PMS by the processing industries (≤ 5%), this could happen due to its different edafoclimatic, specifically for the Phaeozem soil type and its ten auxiliary irrigation, respectively (Table 1). The mega-environment of the C14 included four environments (Figure 1B), being the best M 2014-S-S with 4.22% of PMS, since its average was in the range required by the dough and tortilla industry (IMT) and/or of nixtamalized flour (IHN) and was discriminant between genotypes. The C19 was the second best that met the demands of the tortilla dough and nixtamalized flour industries, in addition to having the highest grain yield.

In the retained pericarp (PR), C0 was the most stable genotype for this variable and the one with the highest value (50.54%) in the nixtamal (Table 3), the six environments were included in their mega-environment, and four of them discriminated well between genotypes (Figure 1C). All the vectors of the environments were less than 90° between them, which means that they are closely related in the way genotypes are sorted (Yan *et al*., 2000).

In Figure 1C of the PR, a marked difference was observed between the two study areas, according to CP2, which dimensions the GE interaction, the environments of the High Valleys were distributed in the upper right corner and those of the state of Veracruz in the lower right, which indicates, for the PR variables, the genotypes are better adapted to High Valleys, where the locality is located where the SMV was performed (Crossa, 1990).

The significant correlation of PR with REN and PMS ($r= -0.44^{**}$ and $r= -0.6^{**}$, respectively) shows that with increasing REN the PR decreased and genotypes with higher PMS retained less pericarp (PR) (Table 3) Similar results were found by Zepeda *et al*. (2009); Salinas *et al*. (2010) for improved corn. The PR values of genotypes C14 and C19 (Table 3) were approximate to those of Vázquez *et al*. (2010) for the Tuxpeño breed (39.1%), this could happen because these authors made collections between altitudes of 1 900 and 2 900 m, heights similar to High Valleys.

IMT prefers corn with higher PR (≥ 30), because it contributes to the reduction of PMS, increases water retention and improves the texture of the dough and tortilla (Salinas-Moreno and Aguilar-Modesto, 2010); it also provides a greater amount of fiber to the diet (Almeida-Domínguez *et al*., 1997). In this sense all genotypes complied with this industry. While the C19 genotype was the one with the lowest PR (36.57%), so it is attractive to the IHN that requires ≤ 30%, since a greater loss of pericarp favors the production of white flour, the genotypes planted in the T 2014-A-W and M 2013-S-S environments met the standards of this industry (Table 3).

The humidity of cold tortillas after 24 h of storage (HT24) showed the greatest diversity (vector length) among T-genotypes 2014-A-W (Figure 1D); C19 registered the highest value (42.72%) and was similar to that reported by Salinas *et al*. (2010) for tortillas 2 h after processing. This variable has been related to the ability of starches to retain water after the retrogradation occurred during the cooling of the tortillas (Agama-Acevedo *et al*., 2004), also related to the ease of winding the tortilla and less force it has to break (Almeida-Domínguez *et al*., 1997).

Genotype C19 was the one with the highest yield of cold tortilla (RTF) with an average of 1.44 kg kg^{-1}, a value that is in the range (1.4-1.6 kg of tortilla per kg^{-1} of corn) accepted by the industrialists of the Tortilla dough for the corn they process. The C19 showed the greatest stability and adaptation, its mega-environment of this genotype included five of the six test environments (Figure 1E). The correlation of RTF with HT24 ($r= 0.87^{**}$) shows that the processing of corn with a high capacity to absorb water during nixtamalization, ensures a higher yield of tortillas (Salinas-Moreno and Aguilar-Modesto, 2010).

On the other hand, the variable HT24 correlated with REN ($r= 0.33^{*}$) and with PMS ($r= -0.3^{*}$), while the RTF correlated with the variables REN, PMS and HT24 ($r= 0.32^{*}$, -0.3^{*} and 0.57^{**}, respectively); finally, the variable FT also correlated with REN, PR and RTF ($r= -0.42^{**}$, 0.5^{**} and -0.59^{**}, respectively). The asterisk value of the correlation indicates the significance, as well as, the positive or negative relationship that exists between the variables.

Figure 1D corresponding to HT24, shows that in the mega-environment of genotype C0, only the C 2014-S-S environment was discriminated between genotypes, this environment was the only one that was not related to the other vectors of the environments (>90°) (Yan *et al*., 2000). Meanwhile, the other five environments belonged to the mega-environment of C19, where only three environments discriminated between genotypes, of which only M 2013-S-S and M 2014-S-S were located in the extreme right part of the biplot, where the higher averages in genotype and environments (Table 3 and Figure 1D). No environment corresponded to the mega-environment of C14, with T 2014-S-S being the most stable followed by the T 2014-A-W environment.

The HT24 variable is correlated with REN (positive) and with PMS (negative). It has been reported that tortilla moisture two hours after processing correlates with HT24; the latter showed significance between genotypes and between environments (Table 2), both results were similar to those reported by Zepeda *et al*. (2007) and Salinas *et al*. (2010). The HT24 of C19 (Table 3) was similar to that of the Tuxpeño breed (42%), reported by Vázquez *et al*. (2010), which confirms the affinity between the adapted material (C19) with the native version planted in High Valleys.

Figure 1E, corresponding to the performance of cold tortilla (RTF), shows that genotype C0 and C14 were located in quadrants CP1< 0, which means that they are less adapted, adding the M 2014-S-S environment that discriminated between genotypes, being the highest average with 1.48 kg kg^{-1} located in the mega-environment of C0 (Table 3). Meanwhile, the remaining five environments were located in quadrants CP1> 0, which have a close relationship between them (<90°), as well as the mega-environment of C19 (the most stable), where T 2014-S-S and T 2014-A-W were discriminant, while for C14 no environment corresponded, indicating its poor result in all test environments. The RTF correlated positively with the HT24 variable, which indicates that the higher the yield of tortillas increased.

The environmental effect in High Valleys evaluated in this work coincides with the results of Zepeda *et al*. (2007) and those of Vázquez *et al*. (2015) for RTF values, this is because these authors used the same environments to evaluate, in addition to being the place of adaptation of the materials; likewise, its results had averages greater than those observed here (Table 3). RTF is a variable that is very sensitive to the effects of nitrogen fertilization and moisture (irrigation)

(Table 1), as noted by Zepeda *et al*. (2007) and Salazar-Martínez *et al*. (2015). Both the averages of the C19 genotype, as well as the two Montecillo environments, complied with the RTF values demanded by the IMT, so they are the most recommended for this industry.

The softer tortillas (<strength) were produced with the original genotype (C0), while the C14 and C19 cycles required more strength and this was statistically the same in these two cycles of improvement (Table 3), however, the C19 tortillas required a puncture force (FP) equal to that of tension (204 gf) reported by Antuna *et al*. (2008) for the Tuxpeño breed, concluding that Tuxpeño creole corn tortillas were the best textured. Similarly, with the corn produced in Montecillo (both cycles), the softest tortillas were produced (Table 3), which indicates that the good quality of the original creole tortillas was maintained in the adaptation environment.

The inclusion of C19 in the mega-environment that includes the Montecillo localities, shows its adaptation, in addition in this locality the highest discrimination between genotypes was presented (Figure 1F). Meanwhile, the mega-environment of genotype C14 included environments C 2014-S-S and T 2014-A-W, the latter discriminated between genotypes. Genotypes C19 and C14, as well as their environments, showed greater adaptation (CP1> 0) than C0 and T 2014-S-S (CP1< 0). Each mega-environment ordered the environments in a similar manner (<90°). The significance of FP in this study is consistent with that reported by Vázquez-Carrillo *et al*. (2016) in the three sources of variation (Table 2). In addition, genotype C19, in the M 2014-S-S environment recorded the highest grain yield and a high percentage (43.22%) of HT24 (Table 3), as indicated by the correlation analysis.

Conclusions

The visual mass selection (SMV) produced favorable changes in the variety of corn V-520C of the Tuxpeño breed with 19 cycles of selection (C19). This genotype presented the best stability and adaptation under the regression sites (SREG) model for the High Valleys of Mexico and the state of Veracruz with respect to cycles 0 (C0) and 14 (C14), and increased grain yield to 45.7 % and tortilla up to 0.05 kg kg^{-1}, being softer and more humid with respect to C0. SREG revealed that the environment of Montecillo 2014-S-S was the one that best discriminated between genotypes, exceeding 75.2% in grain yield, 10.4% in humidity of tortillas at 24 h, 10.1% in tortilla yield and decreasing to 38.6% in puncture force, this with respect to the lower environments of each variable. The genotypes and environments complied with the NMX-034/1 standard for corn intended for nixtamalization.

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