Agronomic Performance and Grain Yield of Mexican Purple Corn Populations from Ixtenco, Tlaxcala

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Abstract

Corn is a crop with an enormous potential for the extraction of anthocyanins which, given their bioactive properties and their ability to act as a natural dye, nowadays are a secondary metabolite of wide interest. In Mexico, several variants of corn that accumulate this flavonoid have been found among corn landraces of blue, red, pink, purple or black kernels. Its grain yield potential and agronomic traits have not been widely documented. Since San Juan Ixtenco, Tlaxcala, preserves the "maíces morados" variant (purple corn) and other variants of colored kernels, in this research the grain yield and agronomic performance of 53 corn populations (landraces and some of them at an early stage of breeding) were evaluated at three locations in order to assess quantitatively those traits. Most populations were of pigmented kernels and yielded between 4494 to 882 kg ha^{-1}, they had a late-male flowering period (105 to 90 days to anthesis) and were of intermediate height (plant height from 254 to 176 cm). When purple corn landraces from Ixtenco were produced under environmental conditions different from those of their place of origin, they suffered maladaptation, complications for the establishment and incidence of ear rot, which reduced their grain yield potential. Despite this situation, 10 purple corn landraces from Ixtenco identified as 38, 8, 34, 39, 13, 3, 4, 1, 9 and 18 were outstanding by their grain yield, agronomic traits and their remarkable capacity to accumulate anthocyanins into the kernel and/or the corncob.

Introduction

In Mexico, the genetic diversity of corn is represented and have been kept in 59 to 62 races of corn (Kato et al., 2009). Within this diversity, it has recently been reassessed that corn landraces possess important nutritional and nutraceutical properties; at the same time it has been recognized that its quality is the result of the selection made by Mexican farmers, who have chosen attributes such as color, flavor, aroma and texture (Figueroa et al., 2013).

Since corn landraces have nutritional quality and potential to be used as raw material to obtain usable phytochemicals into the food, pharmaceutical, cosmetology and textile industries, it is considered that these types of corn have a high added value (Gaytán-Martínez et al., 2013). An outstanding landrace is the pigmented corn, which historically has been part of the diet of the indigenous cultures of Mexico and which, due to its bioactive properties, currently is of interest to the scientific community (Ryu et al., 2013). This trend has encouraged some plant breeders, in addition to increase grain yield, to focus on the genetic improvement and development of varieties with differentiated nutritional chemical composition and high concentration of nutraceutical compounds (Serna et al., 2013). An effort has been done to increase carotenoids concentration in the kernels of yellow and red corn, and the amount of anthocyanins in the blue, red, purple or black corn variants.

In spite that blue and red corn have been the kernel colors most explored among pigmented corn (Li et al., 2017), the "maíces morados" of San Juan Ixtenco, Tlaxcala, Mexico, are still a revelation, since there's no scientific precedent about their yield and agronomic traits and also because they have an intense and dark color as the one that Peruvian purple corn exhibits (internationally, it is the most recognized variant of this type of corn). Likewise, they have a similar capacity and even a superior potential to synthesize and accumulate anthocyanins in the kernel than the purple Andean corn (Mendoza-Mendoza et al., 2017), reason why they represent a promising source of anthocyanins that can be used as a natural dye. However, it is required to explore and to characterize this Mexican genetic resource in detail.

Considering that pigmented corn has a demand in the market and there are positive projections about its use at national and international scopes, it was proposed to study the agronomic performance and grain yield of 53 corn populations (landraces and some of them at an early stage of breeding). Most of the germplasm was from San Juan Ixtenco, Tlaxcala and was established at three locations in the High Valleys of Mexico, in order to explore and value them from these points of view. Also, some populations with desirable attributes and with great potential to avail and to keep into the pigmented corn genetic improvement program were identified.

Materials and Methods

Germplasm

Fifty-three corn populations were evaluated at three locations during the spring-summer 2014 cycle: in the Experimental Agricultural Field of Colegio de Postgraduados (CP) at Montecillo, Texcoco, State of Mexico, and at two locations of San Juan Ixtenco, Tlaxcala, Mexico: Cañada and Pueblo. Each population (Pop) was identified by an identification number between 1 and 53; 37 of the populations were of purple kernel color (Pop 1 to 22 and 31 to 45), four of blue kernel (Pop 23 to 25 and 46), seven of white kernel and purple corncob of the Cacahuacintle race (Pop 47 to 53), one of white kernel (Pop 30), one of red kernel (Pop 26), one of pink kernel (Pop 27), one of yellow kernel (Pop 28) and one of trigueño kernel (creamy white kernel color, Pop 29). Most of the populations were native to Ixtenco (41 populations) and 12 were populations at some level of genetic improvement (Pop 19 to 21, 26, 37, 42 to 46 and 52 to 53), named pre-improved populations. Each plant material was represented by 3 kg of seed, supplied by farmers of the community or acquired at the corn fair that annually takes place in the town of Ixtenco. Pre-improved populations were provided by the pigmented corn genetic improvement program.

Experimental design and crop management

Populations were established under randomized complete block experimental design with four replications. The experimental plot size consisted of two rows, each 5 m long while the spacing between rows was 0.8 m. The population density was of 50 000 plants ha^{-1}. At CP, during the production cycle the crop was kept without humidity restrictions and was fertilized with the dose 120-80-00. In contrast, at the locations of Tlaxcala (Cañada and Pueblo) the populations were settled in rainfall conditions and no fertilization was applied.

Agronomic performance and grain yield

To assess the agronomic performance of the populations under study, as well as their grain yield and yield components, ten traits were registered; they were classified into: *a) Phenological:* days to anthesis (DtoA). Consisted on counting the number of days elapsed from sowing until 50 + 1 % of the plants in the plot initiated pollen shed. b) *Agronomic*: plant height (PHt). In each replication, five plants surrounded by neighboring plants (full competence) were measured from the base of the stem to the ligule of the flag leaf, registered in cm; ear health (EHth). In each plot, the EHth of the harvested ears was visually evaluated by assigning a score. It was assumed that because of the symptoms observed, most of the ear rot was caused by fungal diseases; mainly by *Fusarium* spp. and in a lower visual frequency by *Aspergillus* spp. Scores interval were from 1 to 5, depending on the ratio of damage caused by the ear rot. The scoring scale used was the scale modified by De Leon and Pandey (1989), where: 1 = 0 to 20 %; 2 = 21 to 40 %; 3 = 41 to 60 %, 4 = 61 to 80 % and 5 = 81 to 100 % of rotten kernels on the cob (which we considered that could be *F. verticilloides* and/or *F. subglutinans* according to what Morales-Rodríguez *et al*. (2007) described. Also, the number of ears corresponding to each level of the scoring scale was recorded. Subsequently, in each experimental unit, the weighted average of ear health was obtained by the equation used by Briones-Reyes et al. (2015): Weighted average=

$$\frac{[(X_1.Y_1) + (X_2.Y_2) + (X_3.Y_3) + (X_4.Y_4) + (X_5.Y_5)]}{T}$$

where: Xi = Number of ears in each category of the scoring scale; Yi = value of the scoring scale; $T = (X_1 + X_2 + X_3 + X_4 + X_5)$ = total number of ears in each experimental unit. ***c)*** *Yield and yield components*:

Grain yield (GrYd). Grain yield per plot was calculated by the formula:

$$Yd_{Eu} = \frac{([(EWt_{Eu})(SIx)(100\text{-}\%Moist)]\ /100)}{0.86}$$

, where: Yd_{Eu} = Yield per experimental unit; EWt_{Eu} = Ear weight per experimental unit; SIx = Shelling index; % Moist = Percentage of moisture of the grain sample taken at the field and 0.86 = Correction factor to adjust grain moisture to 14 %, GrYd was estimated in kg ha^{-1}; in five primary ears that represented each population the next traits were recorded: **ear length (ELth)**. Taken from the base of the ear to its tip, in cm; **ear width (EWdth)**. It was measured at the central part of the ear, in cm; **ear weight (EWt)**. Determined by averaging the weight of five primary ears that represented the population in each experimental unit, in g; **kernel rows per ear (RwsE)**. In each ear the kernel rows were counted; **kernels per row (KernRw)**. The number of kernels per row of each of the ears was counted. ***d)* Others: shelling index (SIx)**. Obtained by calculating the ratio between kernel weight (KWt, in g) and

$$EWt: SIx = \frac{(Kwt * 100)}{EWt}$$

Statistical analysis

The statistical analysis of the data was computed with the SAS 9.0 Statistics Software (SAS, 2009). A combined variance analysis under the randomized complete block experimental design criteria was performed, as well as the corresponding comparison of means with the Tukey test (P ≤ 0.05).

Population grouping and identification of outstanding populations

In order to avoid an unbiased interpretation of the results due to the diversity of kernel colors and the origin of the populations (landraces and pre-improved populations), after carrying out the statistical analysis the populations were grouped in: purple corn landraces from Ixtenco (PpleCornL = Pop 1 to 18, 22 and 31 to 41), other landraces of Ixtenco (OthrL = Pop 23 to 25, 27 to 30 and 47 to 51) and pre-improved populations (PreImpr = Pop 19 to 21, 26, 37, 42 to 46 and 52 to 53). Moreover, in each group, populations with outstanding traits and with a usable potential to extract anthocyanins (OutPop) were identified. OutPop were characterized by high grain yield (main desirable attribute in the production of corn) and kernel pigmentation (purple, blue, pink or red) and/or colored corncob (purple, pink or red); since a purplish, blueish, reddish and even pinkish coloration is a visual indicator of the ability of the structure to store anthocyanins. It was considered that a population had high grain yield when its grain yield *per se* (population average production) and its grain yield in each location were higher than the average grain yield of the group.

Results and discussion

Variance Analysis

The combined variance analysis showed that there were statistical differences (P ≤ 0.05 and P ≤ 0.01) between populations (Pop) for all the evaluated traits and, in most of the traits among locations (Loc) (Table 1). The interaction PopxLoc was significant, except

Table 1 - Mean squares from the combined analysis of variance for grain yield and yield components, phenological, agronomic and other traits of 53 corn populations evaluated at three locations of the Central High Valleys of Mexico in 2014.

SV	df	GrYd	ELth	EWdth	EWt	RwsE	KernRw	DtoA	PHt	EHth	SIx
Location	2	3.2x107**	68.2**	0.348ns	686.4ns	39.9ns	345.9**	10907.7**	634297**	268.26**	198.7**
Rep (Loc)	9	2.9x106*	2.3ns	0.519**	1078.5ns	9.4**	15.6ns	155.7**	867**	1.87**	15.3**
Population	52	3.7x106**	5.4**	0.491**	2451.1**	11.4**	22.6**	107.2**	1491**	0.76**	21.9**
PopxLoc	104	2.7x106**	2.5*	0.169**	1165.8**	2.0ns	13.0ns	29.2**	643**	0.40**	5.6**
Error	601 π	1.3x106	1.9	0.112	721.8	1.7	9.3	12.8	282	0.2	4
CV (%)	π	39.1	11.6	6.8	23.3	8.8	14.3	3.8	7.4	20	2.2

SV = Source of variation; df = Degrees of freedom; GrYd = grain yield; ELth = ear length; EWdth = ear width; EWt = ear weight; RwsE = kernel rows per ear; KernRw = kernels per row; DtoA = days to anthesis; PHt = plant height; EHth = ear health; SIx= shelling index; ** = P ≤ 0.01; * = P ≤ 0.05; ns = Not significant; π df of the error for PHt and EHth = 665, for DtoA and GrYd = 594 and for SIx = 616

Table 2 - Means by population, by group of populations and by location for grain yield and yield components, phenological, agronomic and other traits evaluated in purple corn landraces from Ixtenco, other landraces from Ixtenco and pre-improved populations.

	Pop	GrYd	ELth	EWdth	EWt	RwsE	KernRw	DtoA	PHt	EHth	SIx
PPleCornL*	38	3737	12.4	4.8	117.9	15.0	23.1	91.8	235.2	2.4	90.54
	34	3646	12.4	5.0	117.1	15.4	23.0	93.4	235.8	2.6	89.27
	39	3572	12.4	5.0	124.2	16.5	22.6	93.4	230.6	2.2	89.74
	8	3330	11.8	5.0	119.0	15.0	21.9	93.3	233.7	2.3	90.08
	13	3242	11.7	5.0	121.7	14.9	21.6	92.7	228.3	2.4	91.38
	3	3181	12.0	5.0	118.3	15.6	21.8	95.2	232.6	2.2	89.76
	4	3033	11.9	4.8	112.3	15.0	21.6	94.8	233.3	2.1	89.72
	1	3021	11.6	4.8	111.9	15.3	21.6	92.3	225.7	2.2	90.46
	9	3117	12.3	4.9	124.4	14.9	22.0	95.5	226.5	2.2	90.09
	18	3025	12.4	5.0	121.8	15.0	23.0	93.9	232.4	2.5	90.68
	MSD	1822	2.2	0.5	42.6	2.1	4.8	5.4	25.5	0.7	3.13
PpleCornL	Average	2939	11.8	4.9	114.5	15.4	21.3	93.7	229.7	2.3	89.93
OthrL	Average	3070	12.3	5.0	126.4	14.5	21.6	96.9	232.2	2.2	90.36
PreImpr	Average	2862	12.1	4.7	104.6	13.9	21.2	96.7	219.1	2.1	87.69
Location	Montecillo	2430	12.7	4.9	113.7	15.0	23.1	86.9	290.8	3.5	88.4
	Cañada	3133	11.6	4.9	115.6	15.4	20.8	98.4	196.6	1.8	90.3
	Pueblo	3092	11.7	4.9	116.4	14.6	20.7	98.3	203.7	1.6	89.8
	Average	2885	12.0	4.9	115.2	15.0	21.5	94.5	230.4	2.3	89.5
	MSD	429	0.4	0.2	8.2	0.8	1.0	3.0	7.0	0.3	0.97

Pop = Population, GrYd = Grain yield in kg ha^{-1}; ELth = Ear lenght in cm; EWdth = Ear width in cm; EWt = Ear weight in g; RwsE = Kernel rows per ear; KernRw = Kernels per row; DtoA = Days to anthesis; PHt = Plant height in cm; EHth = Ear health rated by a scoring scale from 1 to 5 (1 = 0 to 20 %, 2 = 21 to 40 %, 3 = 41 to 60 %, 4 = 61 to 80 %, 5 = 81 to 100 % of rotten kernels on the ear); SIx = Shelling index in percentage; PpleCornL* = Outstanding purple corn landraces from Ixtenco, PpleCornL = Purple corn landraces from Ixtenco; OthrL = Other landraces from Ixtenco; PreImpr = Pre-improved populations. MSD = Minimum Significant Difference (α = 0.05).

for kernel rows per ear (RwsE) and kernels per row (KernRw).

Grain yield

The grain yield (GrYd) of the 53 populations fluctuated between 4494 and 882 kg ha^{-1} (Pop 53 and 20, respectively). The remarkable difference between the extreme values of GrYd evidenced the existing diversity among populations. The average GrYd of the 29 PpleCornL was of 2939 kg ha^{-1}; in 12 OthrL of 3070 kg ha^{-1} and in 12 PreImpr of 2862 kg ha^{-1}, with a difference of only 208 kg among the upper and lower average GrYd of these groups (Table 2). Based on the average yield of maize in the state of Tlaxcala and the yield at the ejidos of San Juan Ixtenco (2300 kg ha^{-1} and 3000 kg ha^{-1}, respectively) (Hernández, 2014), it was considered that although populations are landraces, most of them had an acceptable GrYd. The statistical differences ($P \leq 0.01$) were associated with the genetic variability of the populations (origin and kernel color), as to the locations and to the interaction PopxLoc.

Among populations, the higher GrYd corresponded to Pop 53 (an intervarietal cross of the Cacahuacintle race), which was statistically similar to GrYd of Pop 26, 29, 30, 42, 46, 48 and 49, which included PreImpr and OthrL with colorations of red, trigueño, white, purple and blue kernel that had a higher yield than 3000 kg ha^{-1}. The 10 PpleCornL of superior yield (statistically equal) yielded between 3737 and 3025 kg ha^{-1} (Pop 38, 34, 39, 8, 13, 3, 36, 9, 4 and 18), while the 3 PpleCornL with the lower yields ranged from 2495 to 2314 kg ha^{-1} (Pop 2, 11 and 15), and were less productive than PreImpr (except for Pop 20), Pop 48 and 49 (Cacahuacintle race) and populations of trigueño, white, yellow and blue kernel color (Pop 29, 30, 28 and 24, respectively).

It was considered that the greater productive capacity showed by PreImpr was due to the accumulation of grain yield favorable alleles, which frequency has been modified by cycles of stratified mass selection or intervarietal crosses (Ali et al., 2007), while a higher yield of some OthrL (Pop 28 to 30 and 48 to 49) compared to PpleCornL, was related to the fact that farmers have shown less interest in the grain production of anthocyanin-colored kernels, and have only taken care of the purple kernel color for the annual sale at the corn fair, compared to the white and yellow corns in which in fact, they have increased their productivity. Also, the difference of GrYd can be associated to the biochemical and structural constitution of the kernel; because depending on the type or race of corn, the kernel may have more or less weight (Figueroa et al., 2013). The fate of the production also influences these differences, since purple corn is only used in the culinary field ("atole agrio") and handicrafts (collars and figures), where grain yield is not a priority but it is the quality and the color brightness of the kernel (Ortiz and Espinoza, 2013).

Among locations, the differences found ($P \leq 0.01$) were caused by the contrasting conditions of moisture, fertility and soil texture that occurred among the locations of the state of Tlaxcala and Montecillo in the state of Mexico. GrYd was superior at Cañada and Pueblo in Tlaxcala and was statistically different from GrYd at Montecillo (Table 2). Although in this location the crop had an appropriate handling of humidity and fertilization, it was observed that the populations studied (most of them were landraces) were highly adapted to the strong environmental pressures of sandy soils, droughts associated to scarce rainfall and bad rainfall distribution, as well as to the presence of frosts; these are the daily conditions of the temporary environments and non fertilized soils of Tlaxcala. The foregoing indicated that corn landraces have a greater specialization to this ecological zone (Boege, 2008).

Interaction Population x Location (PopxLoc)

Regarding the interaction PopxLoc for GrYd, two behaviors were found in PpleCornL: a) populations showed high specificity to the locations of Tlaxcala and b) some populations were capable to adapt to different environmental conditions in comparison to the conditions of their place of origin. In a), it was observed that PpleCornL had adaptation problems to favorable production conditions (in Montecillo the yield of PpleCornL was lower than in Tlaxcala, where they had yields from 4636 to 1976 kg ha^{-1}); Pop 36 exemplified the most drastic case of maladaptation, since it showed high specificity to the locations of Tlaxcala (GrYd greater than 3000 kg ha^{-1}) and in Montecillo it only produced 318 kg ha^{-1}. In b), there were populations with adaptability, as these were able to have an outstanding production at all locations evaluated; Pop 34, 39 and 38 yielded the most at Cañada and Pueblo while at Montecillo they produced more than 2000 kg ha^{-1}.

It was observed that OthrL and PreImpr yielded the most at Pueblo and Montecillo, respectively, so it was considered that each group of populations was adapted to the environmental conditions in which they were crafted or built up. However, despite this specificity, there were some blue-kernel OthrL (Pop 24 and 25) that had the capacity to adapt to optimal production conditions, as they yielded more at Montecillo than in the other two locations (GrYd fluctuated between 3596 and 2683 kg ha^{-1}); in contrast, Pop 20 (PreImpr of purple kernel) had reduced adaptability, because under scarce rainfall, sandy soils and sowed at a greater depth in Tlaxcala, its production was of 126 and 242 kg ha^{-1} in Pueblo and Cañada, respectively, while in Montecillo its GrYd was of 2277 kg ha^{-1}. Also, it was noted that Pop 42 and Pop 44, built up from PpleCornL and improved by stratified mass selection, had a similar GrYd at the three locations under study (3873 to 2109 kg ha^{-1}), which showed that the genetic improvement, in addition to increase the yield of corn landraces, can improve the capacity of the populations to adapt to diverse environmental and management factors.

Yield components

As to yield components, on average, the 53 corn populations had an ear length (ELth) between 13.6 and 10.6 cm, ear width (EWdth) of 5.2 to 4.2 cm, ear weight (EWt) from 156.3 to 75.6 g, kernel rows per ear (RwsE) between 16.6 and 11.3 kernel rows, and kernels per row (KernRw) from 26.0 to 18.3 kernels. Only ELth and KernRw revealed statistical differences between locations and were superior at Montecillo (Table 2). On average, PpleCornL had 11.8 cm of ELth, 4.9 cm of EWdth, 114.5 g of EWt, 15.4 RwsE and 21.3 KernRw, while the ears of OthrL were longer (12.3 cm), slightly wider (5.0 cm), heavier (126.4 g), with lower RwsE (14.5 kernel rows) and similar KernRw (21.6 kernels); in PreImpr the average values of ELth, EWdth, EWt, RwsE and KernRw were: 12.1 cm, 4.7 cm, 104.6 g, 13.9 kernel rows and 21.2 kernels, respectively (Table 2).

The significant interaction PopxLoc for ELth showed that the ears of PpleCornL were longer at Montecillo and only in this location statistical differences were detected; ELth fluctuated from 14.6 cm (Pop 32) to 9.0 cm (Pop 36). It was observed that in spite of the lack of adaptation of PpleCornL to Montecillo, the favorable production conditions had a positive effect on this trait. In the locations of Tlaxcala, there were no differences between populations, probably due to the fact that production took place under seasonal rains conditions. Tadeo et al. (2012) point out that the limited humidity during the production cycle favors similar expressions between varieties.

Among populations, it was observed that the upper EWdth was found in Pop 10, 29 and 46 (5.2 cm) and the lower EWdth in Pop 20 and 21 (4.2 cm). Among locations, EWdth was statistically similar (Table 2), since it is a trait not easily affected by environmental effects (Herrera et al., 2000); though the interaction PopxLoc ($P \leq 0.01$) showed that the populations had higher EWdth at Montecillo; the EWdth of Pop 32, 22, 15, 48, 51, 44 and 53 were statistically similar but with thicker ears (EWdth between 5.5 and 5.3 cm).

The highest EWt (156.3 g) corresponded to the Pop 29 (trigueño) and the lowest EWt to the Pop 21 (PreImpr of purple kernel) with 75.6 g; this variation was associated to the biochemical and structural constitution of the kernel (Figueroa et al., 2013) since often the blue and purple kernels of corn have a more floury endosperm than the white or trigueño corn and therefore are less heavy. Based on the interaction PopxLoc ($P \leq 0.01$), it was considered that PpleCornL, OthrL and PreImpr had an adequate weight as their average EWt was higher than 100 g; this EWt was interrelated to the ear type and size (medium) of the landraces where the characteristics of the Conico race prevail; PpleCornL showed higher EWt at Cañada, while OthrL weighed more at Pueblo and PreImpr at Montecillo; that is, EWt showed a direct association to its adaptation area.

Phenological, agronomic and other traits

The days to anthesis (DtoA) were statistically different between locations, among populations and for the interaction PopxLoc (Table 1). On average, PpleCornL had 93.7 DtoA and pollen shed occurred approximately three days before in comparison to OthrL and PreImpr groups (Table 2). Pop 21 was the earliest and Pop 37 the latest. The average of DtoA by locations was of 94.5 days, that is, populations exhibited a late male-flowering period.

It was observed that in comparison to the DtoA between locations, at Montecillo the populations had an earlier pollen shed with 86.9 DtoA (Table 2); this was attributed to the production system implemented at the community of San Juan Ixtenco, since sowing is carried out in deep furrows with the intention to find the residual moisture preserved in the soil from the winter rains (Hernández, 2014); this agricultural practice delays the germination, establishment and development of the crop. In contrast, at Montecillo the sowing is done at a lower depth and immediate irrigation is applied which, induces seeds germination as well as their rapid establishment. The interaction PopxLoc corroborated that at Montecillo male flowering occurred before than at the other two locations. This meant that in general terms, the populations modified their male-flowering period to adapt to the conditions of the different locations evaluated; according to Buckler et al. (2009), the plant adapts to its environment through the modification of its phases of vegetative and reproductive growth, responding to the local effects of the weather. For example, some PreImpr became of late-flowering period under the adverse environmental conditions of Tlaxcala.

Among populations, plant height (PHt) was similar for OthrL (232.2 cm) and PpleCornL (229.7 cm), while PreImpr had plants with lower height (219.1 cm) (Table 2); Pop 20 and 21 (purple kernel) were the only ones that had a height lower than 2 meters; on the other hand, Pop 30 (white kernel) had the highest plant height (254.0 cm). The statistical differences found for PHt between locations (Table 2) as well as the interaction PopxLoc revealed that, in the face of better production conditions, populations tended to increase PHt. At Montecillo, the plant height of Pop 10, 33, 36 and 38 of PpleCornL, Pop 30 and 51 of OthrL and Pop 19, 37 and 53 of PreImpr was higher than 3 meters; while at the locations of Tlaxcala, the populations mentioned had a lower height, the populations of PpleCornL reduced their height approximately by 1 m, the populations of OthrL between 0.5 and 1 m, and the populations of PreImpr did not reach 2 m of height. The above, in addition to being the result of the genetic constitution of the populations (Peiffer et al., 2014), was largely associated to the availability of moisture and nutrients in the soil that influenced PHt, so when the production of corn occurred in rainfall season, PHt was lower because the rainfall incidence was restricted and therefore, the growth of corn was limited (Pandey et al., 2000), and when moisture was provided at the adequate development stages, the plants had higher PHt, as observed at Montecillo (Table 2). Likewise, it is possible that in Tlaxcala, the low availability of nitrogen in the soil (the soil is not fertilized, only the crop residues are incorporated into de soil) could have restricted the growth of the plant; since a reduced supply of nitrogen has negative effects on plant height (Novoa and Loomis, 1981).

About ear health (EHth), in the 53 corn populations it was observed an incidence of fungal diseases that caused ear rot. According to Munkvold and White (2016) and the symptoms observed in the harvested set of ears, we assumed that the main causal agent of the disease was *Fusarium* spp., because during harvest, ear rot appeared as individual rotten kernels or as randomly scattered groups of rotten kernels. Even further studies are required, probably *Fusarium* species that caused the damage of the kernel could be *F. verticilloides* and *F. subglutinans*, since they are the only species that have been reported previously in Mexico as causal agents of ear rot (Morales-Rodriguez et al., 2007). Results showed that more than 21 % of the ears harvested of PpleCornL, OthrL and PreImpr were affected (Table 2). At Montecillo the EHth score was the highest (EHth = 3.5, Table 2); that is to say, that more than 41 % and less than 60 % of the ears harvested were rotten. It was considered that the incidence of ear rot was an effect triggered by the change of the environmental conditions of production caused by displacing the populations from their place of origin and adaptation. In both Cañada and Pueblo (with statistical similarity) the EHth score was low, ear rot did not exceed 20 % of damage (Table 2).

The interaction PopxLoc showed that PpleCornL had serious ear health problems at Montecillo (EHth = 3.6) where Pop 18, 33, 34 and 41 were the most susceptible to ear rot, with more than 61 % of rotten harvested ears; Pop 48 and Pop 51 (Cacahuacintle race) of the OthrL group displayed the same trend to ear rot. EHth was contrasting within PreImpr, the Pop 45 derived from PpleCornL was the most affected (EHth = 4.5) and the Pop 19 and Pop 26 (purple and red kernel from different origin) were the least affected, they were more adapted to the environmental conditions of Montecillo and had less than 20 % of rotten ears. It was observed that at Cañada and Pueblo the ear health improved remarkably and there were no statistical differences; the damage was less than 20 % with a score interval of 1.1 to 1.8 (Table 2).

As for the shelling index (SIx), results indicated that between populations the lower SIx was 85.5 % (Pop 37) and the maximum was 91.4 % (Pop 13); the OthrL group had the highest SIx (Table 2). Among locations, Montecillo was statistically different from the locations of Tlaxcala, with a lower SIx (88.4%). Taking into consideration the SIx average per group, in the interaction PopxLoc it was found that both PpleCornL and OthrL had a SIx greater than 90 % at Cañada and Pueblo; and in the case of PreImpr, in any location SIx was higher than 90 %; however, in comparison with the SIx value reported by Pecina et al. (2011) for corn landraces of Tamaulipas (SIx = 72.2 and 85.5 %, was considered as a high shelling index), the SIx of all the populations was high. This is a desirable trait in corn, which is quite common in corn landraces and is highly appreciated by farmers.

Outstanding populations (OutPop)

The 10 PpleCornL with outstanding traits and usable potential for the extraction of anthocyanins were Pop 38, 8, 34, 39, 13, 3, 4, 1, 9 and 18 (Table 2). Of the OthrL group, the outstanding blue kernel genotypes were Pop 23 and Pop 24, Pop 27 of pink kernel, and Pop 48 and Pop 49 of Cacahuacintle race of white kernel with purple corncob. From the PreImpr group, Pop 37, 42, 19 and 44 (purple kernel), Pop 26 (red kernel) and Pop 46 (blue kernel) were considered of interest.

Conclusions

On average, the purple corn landraces of Ixtenco (PpleCornL) produce 2939 kg ha^{-1}, have a late mate-flowering period (94 DofA), intermediate height (229.7 cm); corn ears measure 11.8 cm in length and 4.9 cm in width, weigh 114.5 g, have 15.4 kernel rows with 21.3 kernels each, and 90 % of the ear is constituted by kernels. These populations are susceptible to the incidence of ear diseases, approximately between 20 and 40 % of the ears harvested can be affected by ear rot. The ear health problems increase notably in the PPleCornL when they are produced under environmental conditions different from those of their place of origin; usually they suffer maladaptation and establishment complications. Even though PPleCornL are adapted to Ixtenco environmental conditions, some of them are able to be productive under optimal and restrictive environments, therefore, they compete agronomically with corn of other kernel colors. The populations 38, 8, 34, 39, 13, 3, 4, 1, 9 and 18 of the PpleCornL group were outstanding and of wide interest for the purposes of a pigmented corn genetic improvement program.

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