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Agronomic characterization of pigmented native corn populations (*Zea mays* L.)

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ABSTRACT

Objective: To characterize agronomically 52 populations of pigmented native corn (*Zea mays* L.) from Coahuila, Mexico, in order to identify varieties with outstanding agronomic potential and to establish an improvement program with potential for grain yield, with the ability to adapt, and superior nutritional bioactive content.

Design/Methodology: Two experiments were evaluated through an incomplete block design in lattice alpha arrangement, in two localities that are representative of the agricultural area of southeastern Coahuila: a) Yellow populations, mostly of Tuxpeño, Ratón and Tuxpeño Norteño; and b) Anthocyanin populations (blue, red and purple), represented primarily by Cónico Norteño, Elotes Cónicos and Ratón.

Results: There is an environmental effect that contrasts between localities, with differences in grain yield of up to 78%; 25 days of difference in flowering, 53 cm in plant height, and up to seven plants without cobs. The response was product of the agricultural potential in each locality. The outstanding yellow populations due to their superior yield expression in both localities were the landraces Tuxpeño: COAH068, COAH089, COAH177 and COAH215, and Celaya: COAH075. The outstanding anthocyanin populations were Ratón: COAH23 and COAH203; Elotes Cónicos: COAH246 and COAH019; and Elotes Occidentales: COAH021; in addition, the study found populations adapted to a locality.

Conclusion: Among the diversity of the pigmented native corn in Coahuila, there are populations with superior agronomic expression that can be the basis for improving the production, the nutritional quality of the grain, and therefore, of its byproducts.

Keywords: *Zea mays* L., carotenoids, anthocyanins, nutritional quality.

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INTRODUCTION

Corn (*Zea mays* L.) is one of the most important species in Mexico and, due to the large number of races and its broad variation and distribution, it is considered center of origin and diversification of the species (Kato *et al.*, 2009). Among the broad diversity of native corns there is variation in the grain color, and this pigmentation gives them unique phytochemical properties (Serna-Saldivar *et al.*, 2013).

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The main pigments associated with corn are carotenoids and anthocyanins; yellow corn is rich in carotenoids and among them β-carotene is an important antioxidant considered of great relevance in human nutrition (Serna-Saldívar, 2010). Corns with blue, purple, red and black grains have antioxidant activity derived from anthocyanins (Mendoza-Díaz *et al.*, 2012). Corn pigments are innocuous colorings for human consumption and of wide interest for the food, pharmaceutical and cosmetic industry. Presently, given the need to improve the quality of human health, the nutritional bioactive properties of pigmented corns have attracted scientific interest, where a broad variation and wealth has been found.

The state of Coahuila, Mexico, is not an important agriculture and livestock production state, and it has the lowest annual precipitation (332 mm) under which corn can be cultivated. This makes it relevant since it values the adaptation of phytogenetic resources to these conditions. According to SIAP (2019), 30,400 ha of grain corn were planted in the spring-summer 2018 cycle, of which 85% were established under rainfed conditions (25,800 ha), mainly with native populations, concentrated (95%) in five municipalities in the southeastern region of the state: Saltillo, General Cepeda, Arteaga, Parras and Ramos Arizpe.

According to Rincón *et al.* (2015), the diversity of native populations in Coahuila were grouped into eight race groups: Celaya, Cónico Norteño, Elotes Cónicos, Olotillo, Ratón, Tuxpeño Norteño, Elotes Occidentales and Tuxpeño. The native populations were found at an altitude interval between 248 and 2557 masl. Because of the frequency of the populations, the corn races that predominate are Cónico Norteño, Ratón and Tuxpeño Norteño, and the highest yield potential, according to Nájera *et al.* (2010), has been observed in the groups Tuxpeño, Tuxpeño Norteño and Ratón.

According to the catalogue of native corns from Coahuila (Rincón *et al.*, 2010), there are accessions with variants of pigmented corns or with high frequency of pigmented grain. These populations, because of their adaptation to the conditions of regional production, can be the basis of the genetic improvement of varieties for grain production with nutritional bioactive contents appropriate for the elaboration of quality foods, and therefore, the study consisted in defining the accessions of pigmented native corn from Coahuila, and evaluating their agronomic behavior with the objective of selecting the best ones to establish production programs with higher grain quality due to their nutritional bioactive content.

MATERIALS AND METHODS

Biological material

Among the local diversity, 52 native populations of pigmented grain were identified with at least one population in each race group; they derived from four areas of adaptation, defined by the altitude of the collection sites. The populations belong to the collection of the state protected in the Conservation Center for Orthodox Seeds Northern Region. In the study, 27 native populations were used with high frequency of yellow pigmentation grains (carotenoids), 25 anthocyanins (blue and red), and eight control populations (Table 1).

Table 1. Frequency of the pigmented native corn populations from Coahuila, Mexico, in each racial group and their area of adaptation.

Corn races	Populations		Adaptation
	Yellow	Red&Blue	
Conico Norteño	3	12	Highland, Int-Highland, Intermediate
Raton	8	5	Lowland, Intermediate
Tuxpeño	10	0	Lowland, Intermediate
Elotes Conicos	0	5	Highland, Int-Highland, Intermediate
Tuxpeño Norteño	4	1	Intermediate, Lowland
Elotes Occidentales	0	2	Intermediate
Celaya	1	0	Intermediate
Olotillo	1	0	Intermediate
Control	3	5	Highland, Intermediate
Total	30	30	

† Highland (>2000 masl); Intermediate-Highland (1801-2000 masl); Intermediate (1001-1800 masl); Lowland (0-1000 masl).

The agronomic evaluation was carried out in the spring-summer (SS) 2019 cycle, under irrigation conditions, in two environmentally contrasting localities: El Mezquite, municipality of Galeana, Nuevo León, and General Cepeda, Coahuila. For the agronomic characterization, each set (yellow and anthocyanins) was established in an experiment with n=30 populations (Table 1), through an experimental design of incomplete blocks with alpha lattice arrangement (0,1) with two repetitions by locality with fertilization doses of 120-60-60 units of N, P and K, respectively. The agronomic characterization was conducted with mean values by experimental unit of plant height (PTH) (cm), days to male flowering (DMF), number of plants without cobs (PWC), and grain yield (GY) expressed in t ha^{-1} and at 14% moisture.

Information analysis

Given the diversity of the populations studied, associated with the area of adaptation, groups were defined within which the corresponding populations by ecological area were nested (Table 1). The analysis of variance (ANOVA) was conducted according to the experimental design with the GLM procedure of SAS (SAS Institute, 2004), where the effects of localities, adaptation groups, and corresponding interaction were tested, with their respective means comparison through the Tukey test. With ANOVA for populations as fixed effects, the superior ones were identified with a decision value determined by the mean plus once the standard error (μ+SE).

RESULTS AND DISCUSSION

Analysis of variance

The contrast of environmental conditions of production was made evident through the significance between localities ($P \leq 0.01$ and $P \leq 0.05$), which represented the ecological scenario of the southeastern region of the state of Coahuila, under which corn production with native populations takes place. The variation between adaptation groups was also significant and it was associated with the racial and ecological origin of the populations; this condition defined the significance (P≤0.05) of the interaction Localities × Group, where a differentiated response of the groups was observed through the localities of evaluation (Table 2).

Effect of the localities of evaluation

Tables 3 and 4 show the effect between localities; for the case in study, by altitude and climate characteristics, General Cepeda was considered a locality of the intermediate adaptation area and El Mezquite as transition. In the populations of yellow corn, the environmental effect of the site General Cepeda compared to the site El Mezquite produced a decrease of 71.3% in grain yield (GY), 25 d of difference in masculine flowering (DMF), 53.4 cm in plant height (PTH), and a significant increase of non-productive plants (from 0.35 to 5.4 PWC). Correspondingly, in the anthocyanin populations between localities there was an affectation in GY of 78%, 19 d of difference in DMF, 53.8 cm in PTH and presence of the trait of PWC per experimental unit of up to 38%.

The results obtained between localities were contrasting and corresponded to the climate characteristics and the production potential in each locality. Authors such as Espinosa *et al.* (2019) reported a difference in yield of 29.7% in native populations of Coahuila produced in the same localities under evaluation in this study; that is, a detrimental effect 50% lower than the one found in this study; these contrasts were associated to a higher hydric stress and overpopulation of the fall armyworm (*Spodoptera frigiperda*), affecting the cob weight and increasing the number of plants without cob.

Table 2. Mean squares of the analysis of variance for the agronomic characteristics of the native populations of pigmented corn in the state of Coahuila. El Mezquite, Nuevo León and General Cepeda, Coahulia, Mexico (2019).

Source of variation	DF	Yellow accessions				DF	Blue&Red accessions			
		GrYd t ha^{-1}	DtoA d	PHt cm	NPP		GrYd t ha^{-1}	DtoA d	PHt cm	NPP
Environments	1	282.1 **	7183 *	37675 *	357.5 **	1	712.6 **	9652 **	69362 **	1033 **
Repetition	2	4.29 *	75.75 **	1541 *	19.6 **	2	8.81 *	16.14	6204 **	0.9
Block/Repetition × Environments	8	1.05	2.86 *	424.5	5.28	8	1.53	7.38	264.8	5.03
Adaptation groups	3	13.86 **	148 *	2165 **	7.48	2	14.23 **	65.04 *	237.8	153 **
Populations/Groups	26	2.66 *	48.76 **	789.3 **	5.35	27	6.84 **	82.45 **	1372 **	8.55
Environments × Groups	3	0.21 *	69.76 **	1226 **	3.17	2	7.77 *	32.45 **	464	45.2 *
Populations/Group × Environment	26	1.47 *	5.67 *	165.9	5.35	27	5.59 **	13.89 *	370.5	6.53
Error	50	1.1	2.79	199.4	3.54	50	1.13	6.54 *	264.6	5.98
Coefficient of variation (%)		24.11	2.2	7.55	65.07		27.45	3.41	8.05	55.9

**, *=significance at 0.01 and 0.05 levels of probability, respectively; DF=Degrees of freedom; GY=Grain yield; DMF=Days to masculine flowering; PTH=Plant height; PWC=nonproductive plants.

Among experiments, it was observed that the anthocyanin populations were more affected agronomically in the site General Cepeda; the differences were related to the racial origin and altitudinal level of the populations (Table 1), where the populations of yellow grain belonged primarily to the racial groups Ratón and Tuxpeño, with adaptation to Low and Intermediate altitudes, and highlighted by Nájera *et al.* (2010) as those with highest yield potential among the diversity found in Coahuila, while the anthocyanin populations were primarily of the racial group Cónico Norteño, constituted with populations of Elevation and Transition.

Agronomic characteristics of the pigmented populations and interaction with the environment

Table 3 shows the mean values for GY, DMF and PTH of the outstanding yellow populations in at least one locality of evaluation. The values, according to the conditions of each locality, showed the genetic diversity of the native populations evaluated and the

Table 3. Mean values of agronomic characteristics of the outstanding yellow populations in each locality of evaluation.

Corn races	Accession	General Cepeda, Coah.			El Mezquite, N.L.		
		GrYd t ha^{-1}	DtoA d	PHt cm	GrYd t ha^{-1}	DtoA d	PHt cm
Intermediate†							
OL	COAH 040	2.4 *	62.5	155.5	4.1	87	191
TX	COAH 044	2.3 *	63.5	170.5 *	6.4	89	216.5
CE	COAH 075	3 *	70 *	190.5 *	8.8 *	98 *	241 *
CM	POOL33	0.5	69 *	135.5	8.3 *	94 *	193.5
CM	POOL34	2.6 *	65 *	171 *	7.8 *	90	192.5
Lowland†							
RA	COAH 070	2.8 *	62	159.5	6.7	88	227 *
RA	COAH 077	2.4 *	64	145.5	5.6	88	210
RA	COAH 223	1.3	62.5	150	7.4 *	89.5	219.5 *
TX	COAH 068	2.8 *	62.5	161.5	7.6 *	87.5	224.5 *
TX	COAH 078	2	63.5	147	8.2 *	88.5	220.5
TX	COAH 083	2.2	65.5 *	156.5	7.8 *	94.5 *	214
TX	COAH 089	3.3 *	64.5 *	186 *	9.4 *	93 *	246 *
TX	COAH 177	3.8 *	62.5	177 *	7.5 *	89	222 *
TX	COAH 182	3.2 *	64	157.5	6.9	92.5 *	209
TX	COAH 215	2.8 *	64	196 *	7.7 *	92.5 *	225.5 *
TN	COAH 069	1.7	61.5	151.5	8.3 *	88.5	194.5
TN	COAH 178	2.3 *	62	162.5	6.6	90.5 *	226.5 *
Mean (μ)		1.9	63.1	160.2	6.8	88.8	213.7
Standar error (SE)		0.2	0.5	3.1	0.2	1.0	3.6

†=Adaptation group: Intermediate (1001-1800 m); Lowland (0-1000 m); OL=Olotillo; CE=Celaya; CM=CIMMYT; RA=Raton; TX=Tuxpeño; TN=Tuxpeño Norteño; GrYd=Grain yield; DtoA=Days to anthesis; PHt=Plant height. *=μ+EE; μ=mean; SE=Standar error.

possibility of selecting outstanding germplasm for grain production in each locality. Among the populations, two desired expressions were identified: populations with superior grain yield in both localities, according to the conditions of each one, which were considered stable, and populations with specific adaptation that presented superior yield in at least one locality. Both expressions stood out and these were considered as the outstanding populations to continue in the genetic improvement of the production and the improvement of grain quality.

From the genetic diversity of the populations of yellow grain associated with the racial group and of adaptation, the outstanding populations were from Low to Intermediate, similar to what most of the populations of this coloring represented; the populations of Elevation and Transition, in lower frequency, showed limited expressions.

The populations of the yellow grain considered stable were from the racial group Tuxpeño: COAH068, COAH089, COAH177 and COAH215, with mean yield of 3.1 and 8.0 t ha^{-1} precocious cycle (<65 DMF), and intermediate-late (87.5-93.0 DMF), PTH lower than 2.0 m and higher than 2.2 m, in the sites General Cepeda and El Mezquite, respectively. From the racial group Celaya, the genotype COAH075 stood out with a mean yield between localities of 5.9 t ha^{-1} and the control POOL34 with 5.2 t ha^{-1}.

In addition, six populations showed adaptation to General Cepeda, and they were considered relevant given the climate conditions of the locality and that they showed more than 2.0 t ha^{-1} in it: COAH070, COAH077, of racial origin Ratón; COAH044, COAH182, Tuxpeño; COAH178, Tuxpeño Norteño; and COAH040, Olotillo.

In the site of El Mezquite, with more than 7.0 t ha^{-1}, the ones that stood out were: COAH223, Ratón; COAH078 and COAH083, Tuxpeño; COAH69, Tuxpeño Norteño and the control POOL33. The agronomic expression of the outstanding anthocyanin populations is presented in Table 4, which shows that the variation in yield between these and the yellow populations was similar in the site General Cepeda, but in El Mezquite the variation in the first was higher, although there was a superior expression of yield.

Among the anthocyanin populations, there were also stable populations and with specific adaptation, with the group of Intermediate adaptation standing out: COAH23 and COAH203, Ratón; COAH246, Elotes Cónicos; and COAH019 and COAH021, Elotes Occidentales; these populations showed an interval of variation in yield of 1.4 to 3.0 t ha^{-1} and 7.6 to 11.5 t ha^{-1}, DMF of 61.5 to 71 d and 70 to 90 d; the variation in PTH was from 161 cm to 213 cm and from 212 cm to 269 cm, in General Cepeda and El Mezquite, respectively.

In the specific adaptation a response was observed according to the ecological origin. In the site General Cepeda populations stood out primarily from the Intermediate [COAH025, Ratón; COAH002 and COAH048 (Transition), Elotes Cónicos; COAH031, Tuxpeño Norteño, with mean yield of 2.1 t ha^{-1}], while in El Mezquite for altitude it was COAH011, COAH188, COAH191, COAH311, all of them from the racial group Cónico Norteño, with mean yield of 8.3 t ha^{-1}.

Among the pigmented populations studied, the presence of the racial groups Ratón, Tuxpeño and Tuxpeño Norteño was frequent in the yellow ones, and of Cónico Norteño and Elotes Cónicos in the anthocyanins; this frequency agreed partially with the diversity

Table 4. Mean values of agronomic characteristics of the outstanding anthocyanin populations in each locality of evaluation.

Corn races	Accession	General Cepeda, Coah.			El Mezquite, N. L.		
		GrYd t ha^{-1}	DtoA d	PHt cm	GrYd t ha^{-1}	DtoA d	PHt cm
Higland†							
CN	COAH188	0.6	63	151	9.2 *	80.5	243 *
CN	COAH191	0.3	68 *	156	9 *	80.5	220
CN	COAH198	0.3	67 *	157.5	6	79.5	216.5
CN	COAH311	1.2	70.5 *	183 *	7.8 *	91.5 *	290 *
PE	PERU2	2.4 *	71 *	203.5 *	7.6 *	90 *	230.5
Intermediate-Highland †							
CN	COAH017	0.7	60	150	8.1 *	74	210
Intermediate†							
EC	COAH048	3.2 *	66.5	207.5 *	5.4	87 *	212
RA	COAH023	2.1 *	68 *	189 *	10.5 *	86	243.5 *
RA	COAH025	1.8 *	70 *	163	3.2	97 *	215
RA	COAH203	1.7 *	64	176.5	9.2 *	80.5	219.5
RA	COAH227	1.3	69.5 *	191 *	8 *	95 *	243 *
EC	COAH002	1.5 *	60.5	177	6.9	82.5	218
EC	COAH246	1.4 *	61.5	161	8.5 *	78	212
EC	COAH1019	0.9	60	172.5	8 *	78	229.5
EO	COAH019	3 *	64.5	202.5 *	7.7 *	90 *	247 *
EO	COAH021	1.8 *	67.5 *	213.5 *	11.5 *	87.5 *	269.5 *
TN	COAH031	2.2 *	63.5	187 *	2.7	92.5 *	206.5
Mean (μ)		1.1	65.4	175	6.6	84.4	228.8
Standar Error (SE)		0.15	0.75	3.66	0.45	1.15	4.01

†=Groups of adaptation: Elevation (>2000 m); Transition (1801-200); Intermediate (1001-1800 m); POP=Population; CN=Cónico Norteño; OL=Olotillo; TX=Tuxpeño; EC=Elotes Cónicos; BO=Bolita; CM=; RA=Ratón; TN=Tuxpeño Norteño; EO: Elotes occidentales; GY=Grain yield; DMF=Days to male flowering; PTH=Plant height; *: μ+SE; SE=Standard Error.

of the predominant racial groups reported by Nájera *et al.* (2010), since the Tuxpeño race stood out in the yellow and Cónico Norteño in the anthocyanins, according to the component of pigmentation.

Among the populations, a general agronomic behavior was found according to the racial origin and their adaptation conditions; that is, Ratón, Tuxpeño and Tuxpeño Norteño with adaptation to Low and Intermediate altitudes, associated with similar conditions to General Cepeda and Cónico Norteño to areas of Transition and Elevation similar to El Mezquite; this behavior was also reported by Nájera *et al.* (2010).

Among the yellow populations, the racial groups Tuxpeño and Celaya stood out for their stability, while with specific adaptation the races that stood out were Ratón, Tuxpeño, Tuxpeño Norteño and Olotillo; in the anthocyanins, the stable ones were Ratón, Elotes Cónicos and Elotes Occidentales, while for adaptation the ones that stood out were Ratón, Elotes Cónicos, Tuxpeño Norteño and Cónico Norteño. Based on this, it was defined that although there was a predominance of racial groups among the diversity of the state, the smaller groups are also important in the component of diversity and particularly in the production of pigmented grain.

CONCLUSIONS

Among the diversity of native populations characterized for having a high frequency of pigmented grain, there are populations with outstanding agronomic expression that can be the basis for the improvement in production and the increase in the nutritional-functional bioactive content in the grain destined to the elaboration of foods of better quality.

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