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Agronomic and physiological behavior of maize native to southeastern Mexico

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Abstract

Mexico is the center of origin and domestication of maize (*Zea mays* L.), in some regions there are still creole populations with the potential to generate improved varieties. The objective of this study was to evaluate the agronomic and physiological behavior of twelve maize populations native to southeastern Mexico. The experiment was carried out in Tizimín, Yucatán in 2017. 32 parameters corresponding to vegetative, phenological, agronomic and physiological variables were evaluated. The results showed a difference of 75 cm between the lower plants (Xn-69) and those of higher bearing (CNB), the plants of the population DZ-252 presented greater foliage (19.1 leaves) and greater stem diameter (26 mm), the earliest populations were CM and CCB (65.5 and 65.8 days, respectively). 58% of the populations evaluated exceeded the average yield of the region (4.5 t ha^{-1}). The highest yield was obtained by the CM, Cro, H1 and SP2015 populations (117.7, 105.8, 111.5 and 109.5 g $plant^{-1}$, respectively). The populations CM, DZ2015, Cja and Cro had a higher photosynthetic rate; however, the highest water use efficiency was presented by the DZ-252 and XnQroo populations (8.9 µmol CO_2/mmol H_2O). The CM population stood out for its performance and precocity, the DZ-252 could be used as fodder for the amount of biomass it generated and the XnQroo should be studied under conditions of water restriction for its efficiency of water use, these three populations should be included in breeding programs

Keywords: *Zea mays* L., creole populations, genetic diversity.

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Introduction

Mexico is the center of origin and domestication of maize (*Zea mays* L.) (Matsuoka *et al*., 2002), where a great diversity of native varieties was generated, as a consequence of the selection processes exerted by the main pre-hispanic peoples heirs, custodians and breeders of the native germplasm (Fernández *et al*., 2013). In Mexico, improved maize meets the needs of agribusiness in terms of yield. However, 80% of the maize surface is planted with native varieties, produced under a subsistence or self-consumption system (Sahagún *et al*., 2008).

On the other hand, it is projected that as a result of climate change the temperature will increase and the rainfall patterns will change, this will affect the production of maize in many regions of Mexico (Ruiz *et al*., 2011). Under that scenario, improved maize could be the most affected; while native populations that still retain their ancestral genetic characteristics could be an alternative for medium-term maize production (Hellin *et al*., 2014). For this reason, it is important to identify plant materials with agronomic and physiological characteristics that favor the development of new improved varieties (Ramírez-Días *et al*., 2015).

In this sense, the native maize populations that are sown in particular edafo-climatic conditions of the Mexican southeast have been the basis of the feeding of many peasant families and due to their genetic characteristics that they still conserve could be an alternative to generate new improved varieties (Tuxill *et al*., 2010); however, the research carried out in this region is limited to evaluating the yield and some characteristics of grain (Dzib-Aguilar *et al*., 2011; Cázarez-Sánchez *et al*., 2015; Coutiño *et al*., 2015). Therefore, the objective of this research was to evaluate the agronomic and physiological behavior of 12 maize populations native to southeastern Mexico.

Materials and methods

Twelve maize populations native to southeastern Mexico with agronomic potential were selected, of which nine (Rocame, Cro; Jarocho, Cja; Morales, CM; Napalu, CNB; Chimbo, CCB; San Pableño, H1; San Pableño, SP2015; Dzit bacal, DZ2015; Xmejen nal, XnQroo) were collected directly with producers in the region and three (Xmejen nal, Xn-69; Dzit bacal, DZ-252; Xmejen nal, Xn-159) were obtained from the maize base collection from the germplasm bank of the Science and Technology Park of Yucatan. Five populations come from towns in the center of Chiapas (Cro and Cja, Chiapa de Corzo; CM, Villaflores; CNB and CCB, Suchiapa), three from Campeche (Xn-69, Hopelchen; H1, Becal; SP2015, Vicente Guerrero), two from Yucatán (DZ-252, Valladolid; DZ2015, Peto) and two from Quintana Roo (XnQroo, Nueva Reforma; Xn-159, Felipe Carrillo Puerto).

Of the 12 populations evaluated, five are of the Tuxpeño race (Cja, CNB, CCB, H1 and SP2015), two from Vandeño (Cro and CM), three from Nal tel (Xn-69, Xn-159 and XnQro) and two from Dzit bacal (Dz2015 and Dz252).

The experiment was carried out from February to June 2017, an irrigation system from the experimental area of the Technological Institute of Tizimín, Yucatán, Mexico was used. The climate of the site is AW0 (warm subhumid with rains in summer) (Garcia, 2004). The sowing was carried out by punch stroke, with a distance of 80 cm between rows and 20 cm between plants (62 000 plants ha^{-1}), the total area planted was 4 608 m^2.

The formula 120-80-00 (NPK) kg ha^{-1}, was applied, the fertilizer application was divided into two applications: half of the N and all the P was applied one week after the emergence of the seedlings, the rest of the fertilizer was applied four weeks after the first application (growth stage). Weed control was performed manually and Spinetoram was applied only once for pest control.

Variables evaluated

32 variables were evaluated, which were grouped into four groups: I) vegetative variables: plant height, number of leaves below the cob, number of leaves above the cob, total number of leaves, height at the cob, stem diameter, total number of spike branches, length of spike stem, length of branched spike section, length of spike central branch and total length of spike; II) phenological and cob variables: days to male flowering, days to female flowering, number of cobs, cob diameter, cob length, index diameter length of cob, olote diameter and number of rows of grain; III) yield and grain variables: grain weight per plant, weight of 100 grains, grain length, grain width, grain thickness, grain thickness/length index, grain thickness/width index and number of grains per row; and IV) physiological variables: photosynthesis, stomatic conductance, intercellular carbon, perspiration and water use efficiency. The variables of groups I, II and III were measured following the guide of descriptors for maize of IBPGR (1991) and the work of Angeles-Gaspar *et al*. (2010), to calculate the physiological variables (group IV).

Prior to the point measurements, measurements were made throughout the day, where it was determined that at noon (12 h) the plants reached their maximum photosynthetic rate, in addition light saturation curves were performed where it was observed that at a flux density of photons for photosynthesis (DFFF) of 1 500 µmol m^{-2} s^{-1} the maize plants reached their highest photosynthesis values in light saturation (A_{sat}). Considering the above and using an infrared gas analyzer (LICOR, LI-6400xt, Nebraska, USA), when the plants were in fruition (most demanding stage of carbon assimilates), specific measurements were made at noon, with a DFFF of 1 500 µmol m^{-2} s^{-1} and a CO_2 concentration of 400 µmol mol^{-1} (Garruña-Hernández *et al*., 2014). The measurements were made in the central part of the second mature leaf (considering the flag leaf as the first), five plants were evaluated per population, one leaf per plant and three measurements were taken per leaf.

Experimental design and statistical analysis

An experimental design of randomized complete blocks was used, with six repetitions, each block was 24 rows of 40 m long, each population of maize occupied two rows within each block, the experimental unit was 30 plants (i.e. 15 plants of the center in each groove); however, for the physiological variables, five plants were measured per population at the stage of crop development (V8-V10). The data obtained were analyzed with an Andeva and then a comparison of means was made with the Scott-Knott test (α= 0.05). All analyzes were performed with the Infostat 2016 version program.

Results and discussion

In the 32 variables evaluated, the analysis of variance showed significant differences ($p \leq 0.01$) among the populations. This variability could be explained by the high genetic diversity present in the populations studied, in a previous work Santos *et al*. (2017) using molecular markers analyzed the genetic diversity of the same populations studied in this research and concluded that the native maize populations evaluated have high genetic diversity (He= 0.4 and I= 0.54). Other works report that there is great inter and intra racial variability between maize populations native to the Yucatan Peninsula (Burgos *et al*., 2004) and Chiapas (Coutiño *et al*., 2015), this could give an adaptive advantage in case of conditions adverse effects (González *et al*., 2013).

I Vegetative variables

Regarding the variables height of plant (APL) and height of cob (AMZ), the plants of the CNB population were the highest (270 cm) and with cobs at the highest height of the ground (170.4 cm) statistically surpassing the other populations ($p \leq 0.05$), while the XnQroo and Xn-69 populations were the lowest (197.4 and 195 cm, respectively). Between the lower bearing plants (Xn-69) and the higher bearing plants (CNB) a difference of 75 cm was observed (Table 1). However, it should be noted that the majority of the populations studied were medium in size (between 200 and 240 cm), which gives them tolerance to the acama, the height of the cob in most of these plants was between 100 and 150 cm, highly desirable characteristic for the harvest (Hernández and Esquivel, 2004).

Table 1. Vegetative characteristics of native maize populations in southeastern Mexico (Chiapas, Campeche, Yucatán and Quintana Roo), evaluated under irrigation system in Tizimin, Yucatán, Mexico.

Gen	APT (cm)	AMZ (cm)	NHBM	NHAM	HT	DTA (mm)	NRE	LPE (cm)	LTR (cm)	LRC (cm)	LTE (cm)
CNB	270a	170.4a	10c	6.8b	16.8c	23b	16.5c	4.7b	14.8c	23.5c	38.3b
DZ2015	244.7b	161.5a	9.8c	7.1a	17c	23.6b	21.1b	4.7b	16.1b	22.3c	38.4b
Cja	240.9b	141.6c	9.6c	7.2a	16.8c	24.7a	17.3c	7.1a	15.1c	26.9b	41.9a
DZ-252	240.7b	157.4b	11.9a	7.2a	19.1a	26a	23.8a	4.4b	18a	22.9c	40.9a
Xn-159	239.5b	160.6a	10.4b	7.1a	17.6b	22.6c	21b	3.9b	14c	24.1b	38.1b
Cro	237.3b	133.4c	8.4d	7.3a	15.6d	24b	14.4d	3.6b	15c	25.6b	40.6a
SP2015	226.3b	137.6c	8.5d	7.2a	15.7d	22.3c	15.6c	3.1b	11.3d	29.7a	41a
CM	212.4c	108.9e	7.5e	7a	14.5e	20.3d	12.5d	5.9a	10.6d	28.2a	38.8b
H1	207.4c	95.2f	8.3d	7.3a	15.6d	22c	13d	4.4b	12.1d	28a	40.1a
CCB	205c	96.8f	6.8e	7.1a	13.9e	20.7d	15.7c	5.3a	14.5c	26.9b	41.4a
XnQroo	197.4d	118.8d	7.5e	6.5b	14e	20.6d	17.9c	6.3a	13.6c	25.3b	39b
Xn-69	195d	105.7e	7.1e	7.2a	14.3e	21.9c	19.4b	5.8a	12.2d	21.7c	34c

Gen (genotype); APT (plant height); AMZ (cob height); NHBM (No. of leaves under the cob); NHAM (number of leaves above the cob); HT (total leaf); DTA (stem diameter); NRE (number of spike branches); LPE (peduncle length); LTR (branched section length); LRC (central branch length); LTE (total length of the spike). Means with different literals indicate significant statistical differences (Scott-Knott, $p \leq 0.05$).

The plants of the DZ-252 population statistically had a greater number of total leaves (19.1), greater number of leaves under the cob (11.9) and greater stem diameter (26 mm), in addition they were grouped among the plants with greater number of leaves above the cob (7.2) (Table 1). On the other hand, the plants of the XnQroo population were the least leafy, because in the variables number of leaves under the cob (7.5), number of leaves above the cob (6.5), total leaves (14) and diameter of stem (20.6 mm) were located in the groups with statistically lower values (Table 1).

In this sense, Burgos *et al*. (2004); Angeles-Gaspar *et al*. (2010) mention that both the number of leaves under the cob and the number of leaves above the cob are parameters of great importance to explain the diversity among maize populations. In this regard, we consider them to be highly important variables; however, in this work the diversity between the populations could not be explained considering only these parameters, because in the number of leaves under the cob five statistically different groups are formed, while in the number of leaves above the cob only two heterogeneous groups are formed (one with 10 populations and the other with two).

On the other hand, García and Watson (2003) mention a positive correlation between stem diameter and resistance to maize in maize plants. When considering the above, the plants of the Cja (Chiapas) and DZ-252 (Yucatán) populations would have an advantage over the others in relation to the acame, as a coincidence the two populations are of medium size (240.9 and 240.7 cm, respectively). In the male inflorescence, the plants of the DZ-252 population had the highest number of spike branches (23.8) and the largest length of the branched section (18 cm), while the CM (12.5) and H1 (13) had the least amount of branches in the spike and together with the SP2015 plants the shortest branched sections (10.6, 12.1 and 11.3 cm, respectively) (Table 1).

In the length of the peduncle the populations formed two statistical groups, with the exception of the Cja population (7.1 cm), the plants with the longest peduncle (CM: 5.9, CCB: 5.3, XnQroo: 6.3 and Xn-69: 5.8 cm) were those of lower height (Table 1). The plants of the SP2015 (29.7 cm), CM (28.2 cm) and H1 (28 cm) populations presented the longest central branch and it was the same populations that statistically had the shortest branched section (Table 1).

In the total length of the spike, statistical differences were found between populations, there was 7.9 cm difference between the longest and the shortest spike, the plants of the populations Cja (41.9 cm), CCB (41.4 cm), SP2015 (41 cm), DZ-252 (40.9), Cro (40.6 cm) and H1 (40.1 cm) presented the longest spike, while those of the population Xn-69 (34 cm) had the shortest spike (Table 1). All spike variables resulted in a high variation coefficient, higher than the one reported by Camacho and Chávez (2004). In this sense, the characters of the spike are the most important to characterize varieties and describe the genetic diversity of the region (Burgos *et al*., 2004).

II Phenological and cob variables

The earliest populations were CM (65.5 and 68.5 days at male and female flowering, respectively) and CCB (65.8 and 68.2 days at male and female flowering, respectively). In the earliest the difference between male and female flowering was 3 and 2.4 days (CM and CCB, respectively). The latest populations were DZ-252 (86.3 and 97 days at male and female flowering, respectively) and Xn-159 (85.3 and 93.8 days at male and female flowering, respectively) with lapses between an event and another 10.7 days (DZ -252) and 8.5 days (Xn-159).

The cobs of the earliest populations had the largest diameter (CM: 4.4 cm and CCB: 4.5 cm) and the later populations the cobs with smaller diameter (DZ-252: 3.8 cm and Xn-159: 3.9 cm) (Table 2). The precocity is a very important factor, which denotes the adaptation of the populations to the environmental conditions, allows the farmer to choose what material to sow according to their needs and the time of the year (Angeles-Gaspar *et al*., 2010). The plants of the DZ-252 population were the only ones with two cobs per plant, statistically surpassing the other populations that presented one cob per plant (Table 2).

Table 2. Phenological and cob characteristics of native maize populations in southeastern Mexico (Chiapas, Campeche, Yucatán and Quintana Roo), evaluated under the irrigation system in Tizimin, Yucatan, Mexico.

Gen	DFM (days)	DFF (days)	NMZ	DMZ (cm)	LMZ (cm)	DMZ/LMZ	DOL (cm)	NHG
CNB	74.3c	89.2b	1.2c	3.9c	17a	0.23d	2.5b	10.7d
DZ2015	82.5b	91b	1.3b	3.3d	14.6b	0.24d	1.9d	10.5d
Cja	72.2d	82c	1.3b	4.2b	17.9a	0.24d	2.5b	12.4b
DZ-252	86.3a	97a	1.7a	3.8c	14.7b	0.27c	2.3c	12.3b
Xn-159	85.3a	93.8a	1.5b	3.9c	12.9c	0.31b	2.2c	11.1d
Cro	70.8d	77d	1.2c	4.3b	17a	0.26c	2.5b	13.4b
SP2015	71d	77.3d	1.1c	4.2b	16.9a	0.25c	2.4b	13b
CM	65.5f	68.5f	1c	4.4a	16.3a	0.27c	2.4b	12.9b
H1	74.8c	82.2c	1.4b	4.1b	17.3a	0.24d	2d	13b
CCB	65.8f	68.2f	1c	4.5a	14b	0.33a	2.7a	12c
XnQroo	68.2e	73.2e	1.5b	3.5d	13.2c	0.27c	1.9d	12.7b
Xn-69	67.8e	73e	1.4b	4.2b	14.5b	0.29b	2.5b	15.3a

Gen (genotype); DFM (days to male flowering); DFF (days to female flowering); NMZ (No. cobs); DMZ (cob diameter); LMZ (cob length); DOL (olote diameter); NHG (No. of rows of grains). Means with different literals indicate significant statistical differences (Scott-Knott, $p \leq 0.05$).

In the length of the cob there is a 5 cm difference between the populations with the longest cob (Cja: 17.9 cm) and the shortest one (Xn-159: 12.9 cm) (Table 2). The statistical group with the longest cob length was formed by the populations Cja (17.9 cm), H1 (17.3 cm), Cro (17 cm), CNB (17 cm), SP2015 (16.9 cm) and CM (16.3 cm), while that the populations XnQroo (13.2 cm) and Xn-159 (12.9 cm) form the group with shorter cobs (Table 2). The results of diameter and length of cob in this work are inferior to those reported by Coutiño *et al*. (2015) in maize populations in central Chiapas, but similar to those reported by Camacho and Chávez (2004) in populations in the Yucatan Peninsula.

On the other hand, the diameter diameter/length of the cob is an indicator of the morphometry of the cob, a high value indicates a more conical or robust cob in the wide-long ratio. In this sense, the cobs of the CCB population with an index of 0.33 statistically exceeded those of the other populations, it is likely that the thickness of the pot has an influence on this characteristic because the cobs of CCB also had a larger diameter of the olote (2.7 cm) statistically surpassing the rest of the populations (Table 2), the common name that this population receives is ‘Chimbo’, whose meaning refers to the ovoid shape of the cob.

On the other hand, in the variable rows of grain, the cobs of the Xn-69 population had more rows per cob (15.3 rows), statistically surpassing the other populations, while the populations Xn-159 (11.1 rows), CNB (10.7 rows) and DZ2015 (10.5 rows) formed the statistical group with fewer rows (Table 2).

III Performance and grain variables

The lowest yield (g plant^{-1}) was presented by the two populations of Yucatan (DZ2015 and DZ-252 with 45.1 and 55.2 g plant^{-1}, respectively) and one of Quintana Roo (Xn-159 with 56 g plant^{-1}), statistically the largest grain yield per plant was obtained by two populations from Chiapas (CM and Cro with 117.7 and 105.8 g plant^{-1}, respectively) and two from Campeche (H1 and SP2015 with 111.5 and 109.5 g plant^{-1}, respectively) (Table 3).

Table 3. Yield and grain characteristics of native maize populations in southeastern Mexico (Chiapas, Campeche, Yucatán and Quintana Roo), evaluated under the irrigation system in Tizimin, Yucatán, Mexico.

Gen	RG (g/plant)	P100s (g)	LG (mm)	AG (mm)	GG (mm)	GG/LG	GG/AG	GH
CNB	68.2c	31.3b	9.5c	9.8a	4.3a	0.5a	0.5a	25.7c
DZ2015	45.1d	22.7f	9.7c	8.7c	3.3d	0.4c	0.4b	24.5c
Cja	86.7b	29.4c	10.4b	9.3b	3.9b	0.5b	0.4a	31b
DZ-252	55.2d	23.6e	9.9c	9c	3.8b	0.4b	0.4a	23.5c
Xn-159	56d	23.9e	9.8c	9c	3.5c	0.4c	0.4b	24.1c
Cro	105.8a	30.7b	10.4b	8.9c	3.8b	0.4c	0.4a	32.9a
SP2015	109.5a	28.4d	10.9b	8.8c	3.8b	0.4c	0.4a	32.3a
CM	117.7a	29.5c	11.6a	9.4b	3.7b	0.3d	0.4b	33.5a
H1	111.5a	30c	11.3a	8.5d	3.8b	0.3d	0.4a	34.7a
CCB	95.1b	33a	10.4b	10.1a	3.4b	0.5b	0.4b	26c
XnQroo	82.7b	18.9g	9.6c	7.5e	3.2d	0.3d	0.4a	29.6b
Xn-69	66.5c	23.2f	9.9c	8.3d	3.8b	0.5b	0.5a	26.8c

Gen (genotype); RG (grain yield); P100s (weight of 100 seeds); LG (grain length); AG (grain width); GG (grain thickness); GH (No. grains per row). Means with different literals indicate significant statistical differences (Scott-Knott, $p \leq 0.05$).

However, none of these four populations with higher yields stood out in the variable ‘weight of 100 seeds’, where the population that statistically exceeded the others was the CCB (33 g), also from Chiapas (Table 3). This indicates that the populations with the highest yield did not have the heaviest or largest grains, because although the CM and H1 grains were the longest (11.6 and 11.3 mm, respectively), the grains of the four populations with the highest performance did not stand out in width and thickness, in these variables the CNB population stood out (with 9.8 and 4.3 mm, respectively); therefore, the CNB population statistically exceeded all others in the grain thickness/length index (0.5).

It should be noted that the four populations with the highest yield were those with the highest number of grains per row (H1: 34.7, CM: 33.5, Cro: 32.9 and SP2015: 32.3 grains/row), while the cobs of the CCB population that they had obtained the heaviest grains (based on the weight of 100 seeds) statistically placed in the group with less grains per row (Xn-69: 26.8, CCB: 26, CNB: 25.7, DZ2015: 24.5, Xn-159: 24.1, DZ-252: 23.5 grains/row) (Table 3). These results show that populations from other sites in southeastern Mexico can outperform the populations that farmers in the region have used for years, which can be a planting alternative due to the potential they have to become improved varieties.

If the yield of irrigation maize in the Mexican southeast is considered to be 4.5 t ha^{-1} (SIAP, 2016), 58% of the populations evaluated exceed the average yield suggested for the region, highlighting 7.3 t ha^{-1} of the CM population of Chiapas, equivalent to the hybrid (H-520), one of the most recommended for the region (Sierra-Macías *et al*., 2008).

In addition, in this study the number of cobs per plant did not influence the final production yield, since the only population that presented two cobs per plant (DZ-252) was the least productive. In this way, it is demonstrated that the potential that some native populations of southeastern Mexico have can contribute to genetic improvement in the region of the Mexican tropics (Arellano *et al*., 2010).

IV Physiological variables

In general, plants of all populations had high values of net assimilation (photosynthesis) and low rates of intercellular carbon (Table 4), the fact of having C4 metabolism gives them this quality. However, in the net assimilation rate (photosynthesis) the populations CM (39.8 µmol m^{-2} s^{-1}), DZ2015 (37.8 µmol m^{-2} s^{-1}), Cja (37.3 µmol m^{-2} s^{-1}) and Cro (37.2 µmol m^{-2} s^{-1}) statistically outperformed the others (Table 4). Cong-feng *et al*. (2015) mention that photosynthetic capacity is related to grain yield and biomass production.

Table 4. Physiological characteristics of native maize populations in southeastern Mexico (Chiapas, Campeche, Yucatán and Quintana Roo), evaluated under the irrigation system in Tizimin, Yucatán, Mexico.

Gen	A_N (µmol m^{-2} s^{-1})	g_s (µmol m^{-2} s^{-1})	C_i (µmol mol^{-1})	E (mmol m^{-2} s^{-1})	EUA (µmol CO_2/mmol H_2O)
CNB	35.3b	0.29b	133a	5.2b	6.8e
DZ2015	37.8a	0.28b	109.2c	4.4c	8.6b
Cja	37.3a	0.27b	94.4d	5.9a	6.4f
DZ-252	34.5b	0.27b	123.9b	3.9c	8.9a
Xn-159	34.5b	0.24c	92.9d	5.2b	6.7e
Cro	37.2a	0.28b	106.6c	4.3c	8.7b
SP2015	36.2b	0.25c	98.3d	5.1b	7.1d
CM	39.8a	0.34[a]	137.8a	5.7a	6.9d

Gen	A_N (µmol m^{-2} s^{-1})	g_s (µmol m^{-2} s^{-1})	C_i (µmol mol^{-1})	E (mmol m^{-2} s^{-1})	EUA (µmol CO_2/mmol H_2O)
H1	35.8b	0.24c	92.8d	4.9b	7.4c
CCB	35.3b	0.23c	83.2d	5b	7.1d
XnQroo	35.5b	0.26c	111.1c	4c	8.9a
Xn-69	35.7b	0.24c	92.5d	4.1c	8.7b

Gen (genotype); A_N (photosynthesis); g_s (stomatal conductance); C_i (intercellular carbon); E (perspiration), USA (water use efficiency). Means with different literals indicate significant statistical differences (Scott-Knott, $p \leq 0.05$).

In this sense, the plants of the DZ2015 and Cja populations were among the highest. The four populations with the highest photosynthetic rate (CM, DZ2015, Cja and Cro) were among those with the most leaves accumulated below the cob, and Cja, Cro and CM were those with the longest cobs, this suggests that the largest amount of the carbon assimilates, they were derived to biomass production, specifically to increase plant height and basal area, as well as cob size.

Likewise, of the four outstanding populations in yield, the plants of the CM and Cro populations stood out, it is worth mentioning that the populations with high yields were medium in size (207 to 237 cm), which suggests that a large part of their photoassimilates they were destined to increase the number of grains per row and thus increase their yield. In addition to be the plants with the highest photosynthesis rate, CM plants also had the highest stomatal conductance (0.34 µmol m^{-2} s^{-1}).

The (Table 4) had the greatest gas exchange (CO_2 and H_2O) between the interior of the leaves and the surrounding atmosphere, this caused its perspiration rate (5.7 mmol m^{-2} s^{-1}) to be one of the highest (Table 4) and the loss of water through the stomata during gas exchange influenced the efficiency of water use in CM plants to be the lowest (6.9 µmol CO_2/mmol H_2O) (Table 4). Based on the aforementioned, CM was the population with the best yield, to ensure its excellent productivity (grain yield) it is recommended to sow under irrigation and not temporary conditions.

As mentioned earlier, the plants of the DZ-252 population were the most leafy (largest number of thickest leaves and stems), despite having the lowest photosynthesis rate (34.5 µmol m^{-2} s^{-1}) they also had the lower perspiration rate, this indicates that they fix less carbon than other populations but at the same time lose less water during gas exchange, which together with the XnQroo population had the best water use efficiency (8.9 µmol CO_2/mmol H_2O), in addition, biologically employ an interesting reproduction and survival mechanism because they produce two cobs instead of one.

It is worth mentioning that this population (DZ-252) comes from the same region where the study was carried out and both agronomic and physiological results demonstrated the adaptation that exists to the environmental conditions of the place. Yang *et al*. (2012) mention that high values in the efficiency of water use is characteristic of plants adapted to drought conditions. DZ-252 plants do not have a good grain yield compared to other populations evaluated in this study, but they have excellent performance in biomass accumulation and better water use efficiency, it could be recommended as fodder or as grain production in temporary, the latter waiting for low yields, but with the possibility that physiologically can withstand intraestival drought events.

In addition, it could be included in genetic improvement programs to seek drought resistance along with populations with good yield.

Conclusions

The four groups of variables helped highlight the genetic diversity that exists between populations. At morphological level both in plant and on the cob, there was a high variability. Maize populations from other regions may develop the same or better than those commonly grown in the region. The highest grain yield was obtained by two populations from Chiapas (CM and Cro) and two from Campeche (H1 and SP2015).

The lowest yield was obtained by two populations from Yucatán (DZ2015 and DZ-252) and one from Quintana Roo (Xn-159). The CM population from Chiapas stood out for its performance and precocity, it is an excellent material that could be used in the generation of improved varieties; however, it is recommended to sow in irrigation conditions, due to the high loss of water (perspiration) that it has during gas exchange (photosynthesis).

Due to the efficiency of water use (photosynthesis/perspiration), the DZ-252 population could be used as fodder, due to the high biomass production it presents and the XnQroo population as temporary grain production, both materials could withstand events of Intra festival drought and guarantee the livelihood of farmers who do not have an irrigation system.

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