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Conservation of the genetic diversity of local corn (*Zea mays* L.) in the Yucatan Peninsula, Mexico

Introduction

Maize (*Zea mays* L.) is an important cereal member which is historically associated with the original human populations that once populated and till now continues inhabiting the vast and biodiverse continents of the Americas (Serratos-Hernández, 2000). Corn seeds have been reported from several archaeological sites across the Americas dating back as old as 5000 years (Arteaga et al., 2016). Several scholars and researchers consider that the origin of human is inherently associated with the evolution of corn, for example the Ch'ol ethnicity is recognized with the phrase "*men of corn*" (Cross-Cortés, 2000). The genetic diversity of this grass family (Poaceae) member offers a perspective of its relevance as food, and numerous ways in which it is used by the indigenous communities across the Americas, where the crop is reported to have originated (Wellhausen et al., 1951).

Mexico is one of the most important centers of origin for maize and the most diverse representing 64 landraces (59 natives); along with innumerable varieties and "*criollo*" or natives hybrids have been identified. This monumental genetic diversity is the result of the mass selection of the species since it was domesticated from Teosintes or similar to those Mesoamerican Teosintes ancestors (*Ine-Conabio-Sagarpa*, 2008; Arteaga et al., 2016). In the Yucatan peninsula (YP) of Mexico, three maize races (Nal Tel narrower, Dzit Bacal and Xnu'uk Nal or Tuxpeño and two hybrids (Nal Xoy and X'mejen Nal) with restricted distribution have been recorded (Arias et al., 2007). These races and hybrids are disappearing fast as a result of technological displacement imposed by improved varieties and commercial hybrids, produced and distributed by giant multi-national corporations. The genetic erosion due to the subsequent decrease

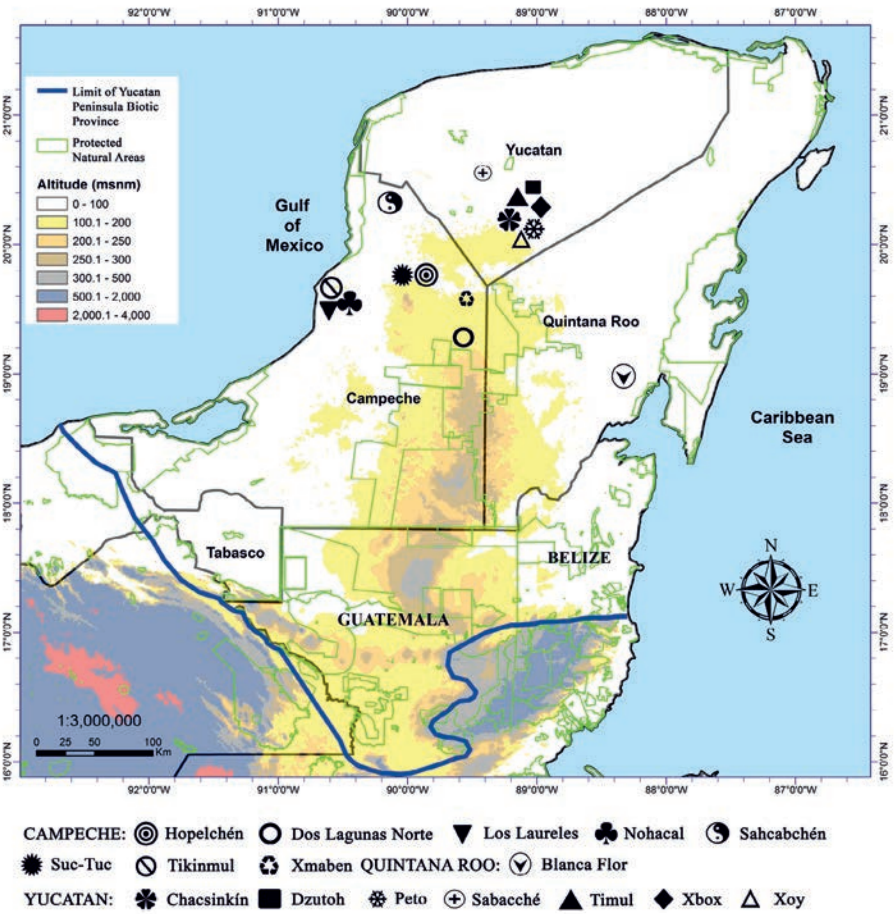

Fig. 1. Localities of cultivation and conservation of native germplasms of corn in the Yucatan Peninsula, Mexico

in seed banks of the local producers and growers, along with incentive policies of replacing native seeds for higher profits and commercial interests further lead to the loss of local genetic diversity of maize landraces and germplasms in the countryside by both rural youth, as well as aging small and medium range producers "*milpero*" (Buenrostro, 2009). Such anthropogenic interferences have been creating a scenario of gradual extinction of the native maize genetic diversity in the YP.

Climate change, another significant challenge for agriculture and agri-production, also needs rapid adaptation options to deal with the production constraints. An important line of work in this regard is to rescue the local maize genetic diversity under a restorative scheme that helps conserving local diversity threatened by several anthropogenic factors and to study their responses to new environmental rigors, determining their ability to continue productivity under the context of highly variable climatic uncertainties.

The main objective of the research has been collecting seeds still used by farmers in their traditional production systems, identifying races and varieties used in YP area and documenting their life cycle and other usage identified by key informants and maize growers and producers.

Material and methods

The study was designed based on the review of specialized literature on native corn (Wellhausen et al., 1951; Serratos-Hernández, 2009; Perales-Rivera, Golicher, 2011). To identify the diversity of races and varieties, specialized literature was reviewed and the fields were located for identifying the possible races and varieties that have been recorded in the YP (Tab. 1 – Appendix); priority areas of cultivation and conservation of native germplasms of corn were visited (Fig. 1). Subsequently, seeds of landraces were purchased in five rural seed fairs (trade shows) in different areas of the YP (Fig. 2). It is important to mention that such traditional rural fairs are significant resource centers where seeds of local landraces and germplasms of maize are sold and exchanged among local farmers and producers. Also in these local events short interviews were successfully conducted with producers, who answered questions about documenting their experiences and sharing traditional knowledge regarding the life cycles of various local maize varieties, the best time of planting and possible partnering with other cultivated species and the source of seeds. In each locality visited (Fig. 1), several corncobs were collected to characterize morphology (number of rows per cobs, number of grains per row and along the cob) (Fig. 3–4) and their performance or yield.

Results

Races, varieties and hybrids

The principal finding with respect to native corn varieties registered in the YP is that these are still in places considered “*Maya centers of resistance*”. However, the quantity and quality of seed available has been reduced, mainly due to severe drought conditions and increased pest pressures. Nevertheless, some native varieties were difficult to find, such as Nal Tel blanco or Sak Nal Tel (Fig. 3A), which is characterized by being precocious corn, high quality, flour, and drought tolerant. The same situation appears true for all varieties to a lesser or greater degree. On the other hand, the presence of two additional races has been recorded in the YP: Palomero Amarillo (Yellow Palomero) (Fig. 3B) and Tabloncillo (Fig. 4). With respect to the conservation

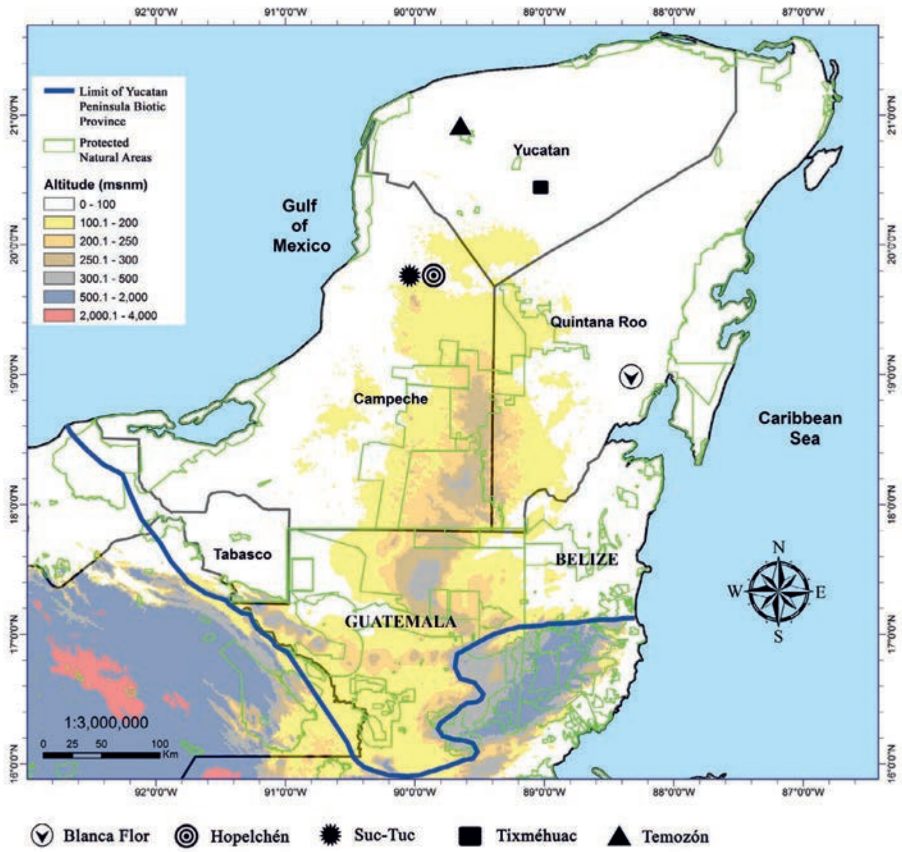

Fig. 2. Localities of rural seed fairs or corn (trade show) in the Yucatan Peninsula, Mexico

of maize germplasm, five varieties: red-white-yellow Nal Tel (Fig. 3C), white-yellow Dzit Bacal (Fig. 3D), white-yellow-red (also known as Chac Chu'ub) Xnu'uk Naal or Tuxpeño, blue Xnu'uk Naal (also known as Eh Hu), Yellow Palomeroand Tabloncil-lo and several hybrids: Xnu'uk Nal (cross between Nal Tel with Tuxpeño), yellow Nal Xoy (possible tri-hybrid between Nal Tel and Xnu'uk Nal) (Fig. 3G), White Nal Xoy (cross between Nal Tel, Tuxpeño and variety), X'mejen Nal (cross between Nal Tel and Dzit Bacal), Chac Xmejen Nal (tri-hybrid between Chac Chu'ub and X'mejen Nal) (Fig. 3H), San Pableño, red Nal Tel (cross between Nal Tel with Chac Ch'ub), Yellow Nal Tel (possible cross between Nal Tel and Nal Xoy) were recovered (Appendix 1 – Tab. 1).

Relevant agroecological characteristics

The varieties registered are characterized by lifecycles, presenting three main classes: precoces (lower lifecycle at 80 days), intermediate (80–110 days) and late (over 110 days). In the germplasm enhancement of maize, the Maya people have made cross

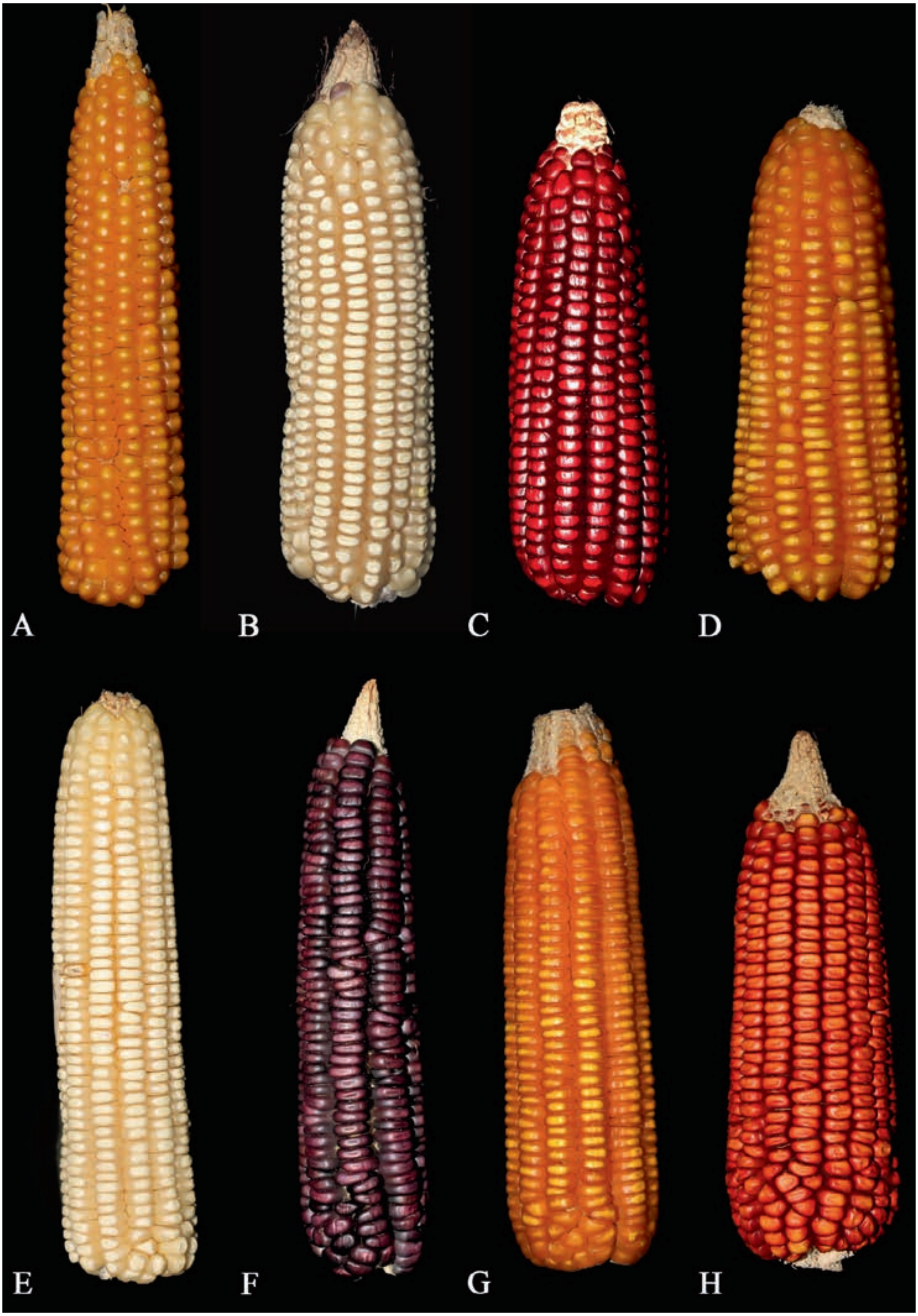

Fig. 3. Races, varieties and hybrids of corn; a – Nal Tel blanco or Sak Nal Tel, B – Palomero Amarillo (Yellow Palomero), C – Red Nal Tel, D – yellow Nal Tel, E – White Dzit Bacal, F – Eh Hu, G – Yellow Nal Xoy, H – Chac Xmejen Nal (Photo. W. Cetzal-Ix)

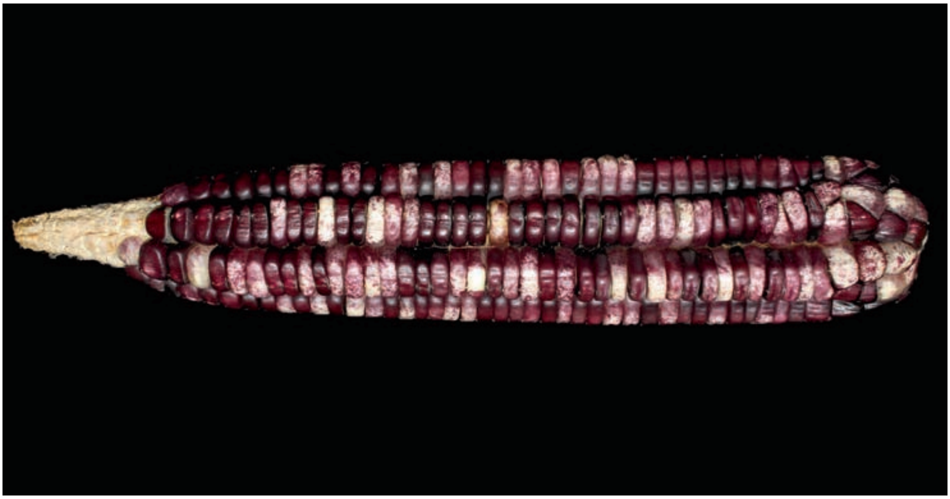

Fig. 4. Tabloncillo race of Corn (Photo. W. Cetzal-Ix)

Tab. 1. Provenances collected between 2015 and 2016 of native varieties of corn in Yucatan and Campeche, Mexico * Number of collections

Variety	Campeche*	Yucatan*	Lifecycle
Can Dzit Bacal	2	0	Intermediate
Can Nal Tel	1	1	Precocious
Can Nal Xoy	0	2	Intermediate
Can San Pableño	1	0	Late
Can Xmejen Naal	0	2	Intermediate
Can Xnu'uk Naal	0	1	Late
Chac Chu'ub	1	2	Late
Chac Xmejen Naal	0	3	Intermediate
Chak Nal Tel	1	1	Precocious
Eh Hu	3	2	Late
Mixto	1	0	Late
Yellow Palomero	1	2	Precocious
Pix Cristo	2	0	Late
Sak Dzit Bacal	1	0	Intermediate
Sak Nal Tel	3	0	Precocious
Sak Nal Xoy	0	2	Intermediate
Sak Tux	2	0	Late
Sax Tux (long insertion)	1	0	Late
Sak Xmejen Naal	0	1	Intermediate
Sak Xnu'uk Naal	1	0	Late
Sak San Pableño	3	0	Late
Santa Rosa	1	0	Late
Tabloncillo	0	1	Late
Tuxpeño	1	0	Late

that allows to combine the characteristics of the lifecycle with the organoleptic characteristics of the grains, which has allowed the emergence in the collections of hybrid double and even triple. For example, Chac Xmejen Nal (Fig. 3H) is a reddish corn of intermediate lifecycle (75–80 days), probably from the cross product of Chac Chu'ub of red color with Xmejen Nal (hybrid between Nal Tel and Xnu'uk Nal) or with precocious varieties of Nal Tel of red color (Chu'ub Nal Tel) (Fig. 3C).

Of the 47 samples collected at different sites visited, 10 belong to precocious varieties (Nal Tel and Palomero), 14 to intermediate (Dzit Bacal, Xmejen Naal, Nal Xoy) and 23 correspond to late (Xnu'uk Naal and Tabloncillo) types. The characteristics of cobs of different races, varieties and provenances that facilitate distinguishing them and their values are shown in table 1. Of the total of 25 varieties registered, 18 were reported in Campeche and 13 in Yucatan (Tab. 2). In Quintana Roo, it was not possible to find sources of native maize, except for Xmejen Naal; for which so far no data has been generated. Quintana Roo producers indicate that seeds have been lost due to recurrent drought occurring in the state. The set of late-type corn, the Xnu'uk Naal race, shows the greatest number of records and provenances.

The varieties that were found during expeditions between 2015 and 2016 allowed to determine that native corn germplasm preserved in Campeche and Yucatan belong to the three groups that are subdivided according to their lifecycle and harvest. Materials with long cycles (late) are prevalent in the state of Campeche compared to precocious and intermediate types. The opposite is observed in Yucatan, where corns' intermediate cycles were more common among communities where native corn is

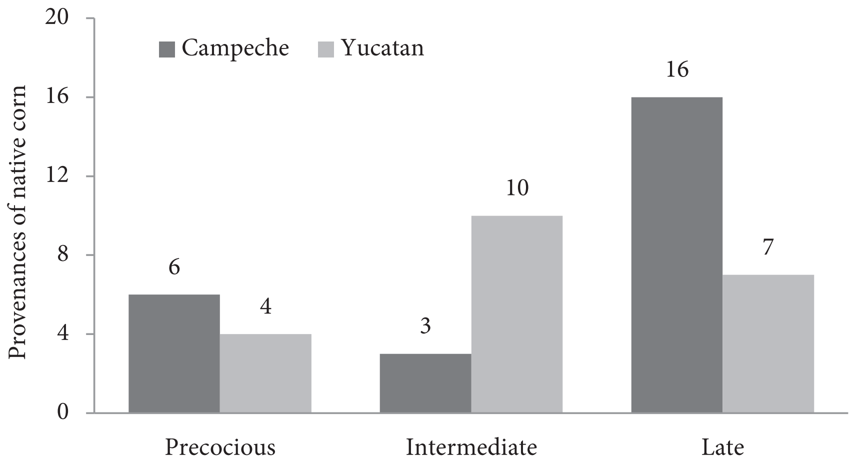

Fig. 5. Number of provenances in which native varieties are reported based on the lifecycle of the varieties collected in the states of Campeche and Yucatan, Mexico

cultivated; although late corns also represent a significant proportion of the diversity of this crop (Fig. 5).

Discussion

The diversity of races and varieties of corn in the Yucatan Peninsula that have been identified in the region include races mentioned by Wellhausen et al. (1951) and Arias et al. (2007) with addition of Tabloncillo and Reventador (Yellow Palomero) races. There is evidence to some gene flow that might have occurred due to the migration of people from rural areas to other parts of Mexico, which have brought seeds that then thrive in their communities. The other alternative is that this evidence may not have been detected in the Peninsula of Yucatan in previous studies. For example, the Tabloncillo (Fig. 4) race has been mentioned to be present in the Gulf of Mexico side. Gene flow has been mentioned by Perales-Rivera and Golicher (2011) as an active process between nine provinces and six biocultural centers of origin and diversity of native maize in Mexico. The Olotillo race, that has been mentioned by Lazos and Cheauvet (2012) to be found in Campeche, is a possible reference to Eh Hu variety, dark purple, often located in different sub-regions of the state and generally in the peninsular region. However, other authors report this as the Eh Hu that is part of the Xnu'uk Naal (Tuxpeño) race.

The late varieties seem to dominate the current scenario of diversity of native maize germplasm in the Yucatan Peninsula, followed by varieties and hybrids with intermediate lifecycles. This has been mentioned as a preference by Arias et al. (2007). Against the context of possible climate change scenarios, that predicts an increase in the frequency and intensity of the phenomenon of drought; thereby reducing the presence of early varieties that may limit the adaptation options for corn producers in the region. Based on the results obtained, it can be concluded that the genetic diversity of native maize in the Yucatan Peninsula still remains; based on records and collections of germplasm conducted in 2015 and 2016, represented by the same range of races and varieties that have historically been reported for the region (Wellhausen et al., 1951; Arias et al., 2007; Serratos-Hernández, 2009; Arteaga et al., 2016).

Cazares-Sánchez et al. (2015) mentioned that Nal Tel has an average of 22 grains per row, under the results (26 grains per row) in varieties of cobs collected between 2015–2016. Also, for varieties like Xnu'uk Naal, these authors mention an average of 40 grains per row, coinciding with the average obtained in the varieties that are presented in this study. For the state of Campeche, a predominance of maize varieties of late lifecycle is detected and in the Yucatan Peninsula of intermediate lifecycle coinciding with Arias et al. (2007), who mentioned that the region has been demonstrating declining use of precocious varieties and increasing the number of varieties with longer cycles, which may result in a change of production systems to those of temporary irrigation. Varieties with longer periods in their growth and developments tend to produce higher grain yield per unit area. Then the Xnu'uk Naal (Tuxpeño) races are likely to continue to prevail in the region, while precocious Nal Tel race, belonging to the ancient races in Mexico (Wellhausen et al., 1951), appears to decline. Particularly Gallito white (Sak Nal Tel), which was obtained only in small quantities in the Chenes region in Campeche, is quite vulnerable.

A new contribution to the region constitutes the collections of the Yellow Palomero (near Reventador precocious) race and the appearance has strong similarity in their morphometry to Tabloncillo race; which may indicate germplasm movement by exchange of seeds or due to the impact of migrant population in the region. Both materials were documented in the area of Peto, in Yucatan; that also highlights to be the main source of several varieties of native corn for the Yucatan Peninsula in this study.

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Appendix 1

Tab. 1. Races, varieties and characteristics of native corn cob collected between 2015 and 2016 in the Yucatan Peninsula, Mexico. Yucatan Peninsula states: CAM – Campeche, QROO – Quintana Roo, YUC – Yucatan, C – Colonical, Cl – Cylindrical, Co – Cónico, ND – no data collection cobs

Group	Race	Variety (hybrid*)	Provenances	Grain color	Cob long [cm]	Row per cob	Grains per row	Cob shape
Precosious	Nal Tel	Sak Nal Tel	Suc-Tuc [CAM]	white	11	14	30	C
		Sak Nal Tel	Hopelchén [CAM]	white	11	15	18	C
		Sak Nal Tel	Sahcabchén [CAM]	white	14	14	23	C
		Chak Nal Tel	Xoy, Peto [YUC]	red	11	14	25	C
		Chak Nal Tel	Tikinmul [CAM]	red	12	14	27	C
		K'an Nal Tel	Peto [YUC]	yellow	11	14	28	C
		K'an Nal Tel	Suc-Tuc [CAM]	yellow	14	16	28	C
		K'an Nal Tel	Xbox [YUC]	yellow	10	12	24	C
		K'an Nal Tel	Chacsinkín, Peto [YUC]	yellow	13	15	28	C
	Palomero	Yellow Palomero	Peto [YUC]	yellow	12	12	33	Cl
		Yellow Palomero	Timul [YUC]	yellow	9	13	24	Cl
		Yellow Palomero	Tikinmul [CAM]	yellow	10	12	33	Cl
Intermediate	Dzit Bacal	Chac Dzit Bacal	Hopelchén [CAM]	red-dish	ND	ND	ND	ND
		K'an Dzit Bacal	Suc-Tuc [CAM]	yellow	ND	ND	ND	Cl
		K'an Dzit Bacal	Dzutoh, Timul [YUC]	yellow	14	14	33	Cl
		Sak Dzit Bacal	Dos Lagunas Norte, Calakmul [CAM]	white	19	12	43	Cl
		Sak Dzit Bacal	Dzutoh, Timul [YUC]	white	13	12	35	Cl
		Sak Dzit Bacal	Peto [YUC]	white	19	12	47	Cl
	Dzit Bacal por Nal Tel	Sak Xmejen Naal*	Timul [YUC]	white	12-16	12-14	29-35	Cl
		Sak Xmejen Naal*	Blanca Flor, Bacalar (QROO]	white	ND	ND	ND	ND
		Sak Xmejen Naal*	Sabacché [YUC]	white	17	14	39	Cl
		Sak Xmejen Naal*	Dzutoh [YUC]	white	15	14	32	Cl
		K'an Xmejen Naal*	Peto [YUC]	yellow	ND	ND	ND	ND

Intermediate	Chac Chu'ub por X'mejen Nal	K'an Xmejen Naal*	Dzutoh, Timul [YUC]	yellow	14	14	32	Cl
		Chac Xmejen Naal*	Peto [YUC]	red	16	15	32	C
		Chac Xmejen Naal*	Box [YUC]	dark red	14	13	32	Co
		Chac Xmejen Naal*	Dzutoh, Timul [YUC]	red	19	13	39	Co
	Xnu'uk Naal por Nal Tel	Sak Nal Xoy*	Xoy, Peto [YUC]	white	19	12	46	Co
		Sak Nal Xoy*	Dzutoh, Timul [YUC]	white	16	16	27	Co
		K'an Nal Xoy*	Xoy, Peto [YUC]	yellow	19	16	36	Co
	Xnu'uk Naal x Nal Tel	K'an Nal Xoy	Dzutoh, Timul [YUC]	yellow	17	12	38	Co
Late	Xn'´uk Naal	Chac Chu'ub	Dos Lagunas Norte, Calakmul, [CAM]	red	17	13	27	Cl
		Chac Chu'ub	Timul [YUC]	red	16	13	36	Cl
		Chac Chu'ub	Xoy, Peto [YUC]	red	17	16	42	Cl
		Pix Cristo	Dos Lagunas Norte, Calakmul [CAM]	white with red	20	12	33	Cl
		Pix Cristo	Suc-Tuc [CAM]	white with red	21	8	50	Cl
		K'an Xnu'uk Naal	Peto [YUC]	yellow	ND	ND	ND	ND
		Sak Xnu'uk Naal	Sahcabchén [CAM]	white	18	14	42	Cl
		Sak Xnu'uk Naal	Sabacché [YUC]	white	18	10	45	Cl
		Sak Xnu'uk Naal	Suc-Tuc [CAM]	white	15	12	32	Cl
		Sak Xnu'uk Naal	Peto [YUC]	white	18	14	26	Cl
		Eh Hu	Xoy, Peto [YUC]	purple	18	12	44	Cl
		Eh Hu	Dzutoh, Timul [YUC]	purple	16	12	39	Cl
		Eh Hu	Xmabén, Calakmul [CAM]	purple	ND	ND	ND	ND
		Eh Hu	Suc-Tuc [CAM]	purple	18	12	44	Cl
		Eh Hu	Los Laureles [CAM]	purple	ND	ND	ND	ND
		Sak Tux	Suc-Tuc [CAM]	white	ND	ND	ND	Cl
		Sak Tux	Xmabén, Calakmul [CAM]	white	ND	ND	ND	ND

		Sax Tux (long insertion)	Dos Lagunas Norte, Calakmul [CAM]	white	16	14	34	Cl
		Santa Rosa	Xmabén, Calakmul [CAM]	yellow	ND	ND	ND	ND
		Mixed uxpeño	Nohacal [CAM]	white	17	16	4.3	Cl
			Los Laureles [CAM]	yellow y rojizo	ND	ND	ND	ND
Late		Sak San Pableño	Sahcabchén [CAM]	white	17	14	41	Cl
		Sak San Pableño	Sahcabchén [CAM]	white	15	13	22	Cl
		Can San Pableño	Sahcabchén [CAM]	yellow	16	16	27	Cl
		Sak Xnu'uk Naal	Hopelchén [CAM]	white	ND	12	37	Cl
	Tabloncillo	Tabloncillo	Peto [YUC]	purple and white	ND	8-12	47	Cl

Abstract

The production of native corn at regional level is greatly limited by the seasonality of rainfall, availability of adequate lands, poor fertility status of the soil, high input costs and constraints of resources of the local corn growers and/or producers. The challenges of reduced cultivable area give very little opportunity for increasing production area in a sustainable manner; it is important to note that the soil recover its fertility status through crop rotation and prolonged rest period (>25 years) known as sequential agroforestry system or "*milpa*". During 2015, corn collections were performed in the Yucatan Peninsula, Mexico that included five races from the Yucatan (in localities of Nohacal and Peto) and Campeche (Calakmul, Suc-Tuc, Sakabchen, I Chek) states. The races identified were: 1) Nal-Tel (gallito), 2) Dzit Bacal, 3) Xnu'uk Naal (Tuxpeño), 4) Palomero and 5) Tabloncillo. The local varieties, Pix Cristo (Knees of Christ), Eh Hu (Purple maize) and Chac Chu'ub (Chac's Blood or Red maize), are included within the Tuxpeño (Xnu'uk Naal) race. The land race of corn that is in imminent danger of extinction is Nal-Tel, characterized by its precocity and ability to escape periods of low rainfall; it is important to rescue it for adoption to the practices of local and regional production. The adaptation of this race as a germplasm is important due to its resilience to climate change itself. Palomero, Tabloncillo, Pix Cristo, Chac Chu'ub and Eh Hu can thus be used in traditional food industry, to preserve the traditional knowledge and to provide opportunities for additional income for the local, rural communities. Yellow Palomero and Tabloncillo races are new records of germplasm for the region; and hence it is essential to exchange their seeds among local producers and growers.

Key words: Campeche, conservation, corn, cultivation, genetic diversity, Mexico, Yucatán

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Zachowanie różnorodności genetycznej rodzimej kukurydzy (*Zea mays* L.) na Jukatanie w Meksyku

Streszczenie

Produkcja rodzimej kukurydzy na poziomie regionalnym jest znacznie ograniczona przez sezonowość opadów, dostępność odpowiednich gruntów, zły stan żyzności gleby, wysokie koszty produkcji i ograniczenia zasobów lokalnych plantatorów lub producentów kukurydzy. Apele o zmniejszenie powierzchni uprawnej dają bardzo małą szansę na zwiększenie powierzchni produkcyjnej w sposób zrównoważony; ważne jest, aby pamiętać, że gleba może odzyskać swój status płodności dzięki płodozmianowi oraz dłuższym okresom spoczynku (>25 lat), zwanym sekwencyjnym systemem agroleśnym lub „*milpa*". W 2015 roku na Jukatanie w Meksyku przeprowadzono zbiory kukurydzy, które obejmowały 5 lokalnych odmian z regionu Jukatan (w miejscowościach Nohacal i Peto) i Campeche (Calakmul, Suc-Tuc, Sakabchen, I Chek). Zidentyfikowano następujące odmiany: 1) Nal-Tel (gallito), 2) Dzit Bacal 3) Xnu'uk Naal (Tuxpeño), 4) Palomero i 5) Tabloncillo. Lokalne odmiany Pix Cristo (Kolana Chrystusa), Eh Hu (kukurydza purpurowa) i Chac Chu'ub (kukurydza czerwona) obejmowały również odmianę Tuxpeño (Xnu'uk Naal). Nal-Tel jest odmianą kukurydzy, która jest narażona bezpośrednio na niebezpieczeństwo wymarcia. Charakteryzuje się wczesnym rozwojem i zdolnością przetrwania w okresach niskich opadów, co jest ważne dla jej ratowania w celu praktycznego zastosowania w lokalnej i regionalnej produkcji. Przystosowania tej odmiany, jako plazmy zarodkowej, są ważne ze względu na jej odporność na zmiany klimatyczne. Palomero, Tabloncillo, Pix Cristo, Chac Chu'ub i Eh Hu mogą być stosowane w tradycyjnej produkcji spożywczej, w celu zachowania wiedzy oraz zapewnienia możliwości dodatkowego dochodu dla lokalnych społeczności wiejskich. Żółte odmiany Palomero i Tabloncillo są nowymi archiwami plazmy zarodkowej dla regionu i dlatego niezbędna jest wymiana ich nasion wśród lokalnych producentów oraz plantatorów.

Słowa kluczowe: Campeche, ochrona, kukurydza, uprawa, różnorodność genetyczna, Meksyk, Jukatan

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