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YIELD AND CHEMICAL COMPOSITION OF FORAGE AND SILAGE OF NATIVE MAIZE UNDER IRRIGATED SEMI-ARID CONDITIONS

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ABSTRACT

The preservation of native maize allows the selection of genotypes with forage potential in specific regions. The objective of the present study was to evaluate the yield and chemical composition of green forage and silage of 10 native and two commercial maize hybrids with forage potential, under semi-arid conditions with irrigation. Genotypes were grouped according to days to male flowering: early (80 days), intermediate (92 days) and late (111 days). Data were analyzed in a randomized complete block design with four replications (Tukey; $\alpha = 0.05$). Intermediate and late maize had the greatest height, total dry matter yield (TDMY) and number of leaves ($p < 0.05$). Late genotypes showed higher values in cob yield and senescent matter ($p < 0.05$). The genotypes Olotillo × Tuxpeño and Tuxpeño II outperformed the hybrids 2038DK and P3966WP (3.50 and 9.24 Mg ha^{-1}, respectively) in TDMY (14.32 Mg ha^{-1}, on average). Olotillo × Tuxpeño and P3966WP presented similar crude protein values in green forage (81 g kg^{-1}; $p > 0.05$). However, when ensiled, the hybrid outperformed native corn by 22 % (92 *vs.* 75 g kg^{-1}; $p < 0.05$). Late-cycle native maize had the highest cob yields (4.59 Mg ha^{-1}) and after ensiling, the ideal pH (< 3.9) and °Brix (8.5) values. The native genotypes Tuxpeño I, Olotillo × Ratón, Olotillo × Tuxpeño and Tuxpeño II could be used in breeding programs to select materials with potential for forage production and conservation.

Keywords: *Zea mays* L., forage conservation, morphological components, °Brix, pH.

INTRODUCTION

In Mexico, the genetic variability of maize (*Zea mays* L.) is a fundamental part of the contribution to future food security. This is due to the variability derived from the selection carried out by farmers, which allows the use of physiological characteristics in genetic improvement programs to obtain the desired objectives (Rivas *et al*., 2020). In the Altiplano Tamaulipeco there are native maize populations that have been selected by producers, mainly for their adaptation to semiarid conditions and grain yield (González-Martínez *et al*., 2018).

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About 65 % of maize production is destined for animal feed, and this has various uses: as silage, grain, post-harvest residue and green consumption (Perales *et al*., 2019). With this crop, green forage yields of up to 55.5 Mg ha^{-1} are obtained (Granados-Niño *et al*., 2022), which increases the animal load and consequently improves the productive efficiency per hectare (Sah *et al*., 2018).

Maize forage should be utilized when a balance is reached between dry matter yield and the highest amount of digestible nutrients, which is when values close to 30 % of dry matter are reached and the grain is ½ and ⅔ in the milk line. Thus, at such stage the highest forage digestibility and amount of soluble carbohydrates are reached (González *et al*., 2006). When considering these criteria, it has been estimated that contents of 88, 270, 229, 431, 225 and 49 g kg^{-1} of crude protein, starch, soluble carbohydrates, neutral detergent fiber, acid detergent fiber and ash, respectively, are obtained (Liu *et al*., 2021). Furthermore, net lactation energy values range from 1.09 to 1.55 Mcal kg^{-1} of dry matter (Robles-Jimenez *et al*., 2021).

Improved seeds are currently used for maize forage production, with which grain and forage yields have increased. However, these available genotypes may not thrive in the future as a result of climate change, since a combination of biotic (higher temperature, water deficiency) and abiotic (pest and pathogen attack) factors would significantly reduce production (Malhi *et al*., 2021). Native maize is a source of germplasm from which genotypes with improved tolerance mechanisms against environmental stressors could be obtained (Robles-Jimenez *et al*., 2021). Those native genotypes are indeed adapted to the specific environmental conditions prevailing where they are grown and of course with a lower investment. Native maize, under conditions of water deficiency stress, has shown higher forage yields and tolerance to pests compared to hybrids or improved varieties (Godina *et al*., 2020). Furthermore, native maize is a viable alternative for use as silage because it increases milk production per hectare and per ton of dry matter compared to hybrid maize (Robles-Jimenez *et al*., 2021). The objective of the present study was to evaluate the yield and chemical composition of green forage and silage of native and hybrid maize with forage potential under semiarid conditions in Tula, Tamaulipas, Mexico.

MATERIALS AND METHODS

Location of the experiment

The study was conducted under irrigated conditions, during the spring-summer cycle in 2017, within the facilities of CBTA 117 "Juan Báez Guerra", Ejido Tanque Blanco, municipality of Tula, Tamaulipas, Mexico (22° 54' 28.84" N and 99° 47' 40.22" W, at an altitude of 1086 m). The climate is classified as semi-warm dry (BS_0hw), with an average annual temperature of 19.9 ± 7.8 °C and accumulated annual precipitation between 400 and 450 mm (Vargas *et al*., 2007).

Genetic material

Twelve maize genotypes were evaluated: 10 native and two commercial maize hybrids as controls (Table 1). The native maize was selected from 91 maize populations that González-Martínez *et al.* (2018) collected in the Altiplano Tamaulipeco and classified racially (Table 1). For this study, those genotypes selected had forage characteristics, whose values in plant height, stem thickness, number, length and width of leaves were greater than the average of the 91 populations. Maize genotypes were grouped as early (80 d), intermediate (92 d) and late (111 d) according to the number of days from sowing to male flowering (Muñoz, 2005).

Table 1. Genotype groups and origin of native and hybrid maize (*Zea mays* L.) evaluated in Tula, Tamaulipas, Mexico.

Group	Genotype	Origin (Municipality /Company)
Early (80 DMF)	Tuxpeño Norteño × Celaya	Tula
	Ratón × Olotillo	Jaumave
	Ratón × Tuxpeño	Jaumave
	2038DK	DEKALB®
	Ratón	Tula
	Chalqueño × Tuxpeño	Palmillas
	P3966W	PIONEER®
Intermediate (92 DMF)	Tuxpeño I	Tula
	Olotillo × Ratón	Tula
	Olotillo × Tuxpeño	Jaumave
Late (111 DMF)	Tuxpeño II	Ocampo
	Tuxpeño × Olotillo	Ocampo

DMF: Days to male flowering.

Treatments and experimental design

The 12 maize genotypes were evaluated under a randomized complete block design with four replications per treatment. The experimental plot size was two 5 m long furrows. The row and plant spacing was 0.80 and 0.25 m, respectively.

Crop establishment and management

Land preparation was carried out in accordance with the technological package for corn production in the central and southern zones of the state of Tamaulipas. This consisted of two passes of harrowing and furrowing. Planting was done manually under pre-sowing irrigation conditions (sheet of approximately 0.30 m). Three seeds were deposited per stroke, and at 14 days after sowing (DAS), a thinning was performed leaving one plant to obtain a density of ca. 50,000 plants ha^{-1} according to the recommendations of the technical agenda for southern Tamaulipas in the planting of rainfed corn (INIFAP, 2017). At 35 and 70 DAS, two gravity irrigations were applied (sheet of approximately 0.30 m). Weed control was carried out manually. During the evaluation, the presence of fall armyworm (*Spodoptera frugiperda*) was controlled with an application of Chlorantraniliprole 20 % (80 mL ha^{-1}).

Variables evaluated

After 15 days of female flowering, corn grain was at a stage of maturity between ½ and ⅔ of the milk line and forage was harvested from manually at 20 cm above ground level (Gonzalez *et al*., 2006). Before harvesting the forage, plant height (PHE; m) was measured from ground level to the flag leaf node on two randomly selected plants in each of the plots and the number of leaves (NL) was counted. In each experimental plot, all forage present in two linear meters (20 cm from the ground) was harvested, weighed and a green forage sample was taken from six plants. The sample was separated into morphological components and dried in a forced air oven at 65 °C to constant weight after 72 h. Each component was weighed before and after drying and subsequently the yield (Mg ha^{-1}) of: leaf (LY), stem (SY), ear (EY) and dead matter (DMY) was calculated; the sum of these was expressed as the total dry matter yield (TDMY) (Elizondo and Boschini, 2002; Joaquín *et al*., 2022).

For the preparation of the silage, five complete plants were randomly selected in each plot and cut into 1 to 2 cm pieces. Subsequently, the harvested forage was deposited in polyvinyl chloride [PVC (Ø 6” and 40 cm long)] microsilage with a capacity of 7.3 L and a lid at one end (Joaquín *et al*., 2022). The forage was compacted to eliminate the air present inside the microsilage and was sealed with two layers of polyethylene plastic. The microsilage were placed under cover for 65 days. Subsequently, a silage sample was taken and the chemical composition was determined. For the analysis of chemical composition, the six genotypes with the highest TDMY were selected. In both forage and silage, the following were determined: the content (g kg^{-1}) of crude protein (CP), crude fiber (CF) and ash (AOAC, 2019). For silage characteristics, dry matter content (%), pH and soluble carbohydrates (°Brix) were determined (Bravo-Martins *et al*., 2006). To determine the percentage of dry matter of the silage, a sample of about 300 g was taken from each microsilage and dried in a forced air oven at 70 °C, for 72 h. To determine the pH of the silage, a 25 g sample of each microsilage was used and deposited in a 500 mL beaker, then 250 mL of distilled water was added and shaken every 2 min for 10 min and the reading was taken using a potentiometer (HI98130, Hanna Instruments®). For soluble carbohydrate content (°Brix), a silage sample was taken, and a drop of liquid was extracted by pressure and deposited in a refractometer (2806, Spectrum Technologies, Inc.).

Statistical Analysis

Data were analyzed by analysis of variance with the GLM procedure of SAS/STAT® (SAS Institute, Inc., 2002) based on a randomized complete block design with four replications. Comparison of treatment means was performed using Tukey’s test (α = 0.05).

RESULTS AND DISCUSSION

Plant height and forage yield

Late (Tuxpeño II and Tuxpeño × Olotillo) and intermediate (Olotillo × Tuxpeño, Tuxpeño I and Olotillo × Ratón) maize genotypes outperformed native early and commercial hybrids by 27 and 63 % in PHE, respectively ($p < 0.05$; Table 2). Heights similar to that of this study (2.21 m) in native genotypes, and greater in comparison with commercial hybrid genotypes have also been reported (Muñoz-Tlahuiz *et al.*, 2013). These differences can be attributed to the adaptation of these genotypes to the environment where they have developed. Increases in plant height coincide with higher dry matter yield, an important parameter to consider in forage genotypes (Elizondo and Boschini, 2002).

Table 2. Plant height, dry matter yield and morphological components in native and hybrid maize (*Zea mays* L.) genotypes in Tula, Tamaulipas, Mexico.

	Genotype	PHE (m)	NL	TDMY	LY	SY	EY	DMY
				(Mg ha^{-1})				
1	Tux Norteño × Celaya*	1.73 b†	10.3 a	5.28 bc	2.15 cd	2.32 c	0.80 f	0.00 d
2	Ratón × Olotillo*	1.82 b	10.5 a	6.65 bc	2.37 c	2.81 c	1.22 e	0.25 ab
3	Ratón × Tux*	1.77 b	9.5 a	6.59 bc	2.07 cd	2.59 c	1.44 de	0.49 a
4	2038DK*	1.28 c	9.5 a	3.50 c	1.38 e	0.98 d	1.12 e	0.02 c
5	Ratón*	1.61 bc	10.3 a	6.39 bc	2.29 c	2.21 c	1.80 d	0.09 c
6	Chalqueño × Tux*	1.62 bc	9.5 a	5.84 bc	1.95 d	1.54 c	2.32 cd	0.03 c
7	P3966WP*	1.38 c	10.3 a	9.24 abc	2.69 c	2.66 c	3.85 bc	0.04 c
8	Tux I**	2.17 a	12.8 a	12.62 ab	3.74 ab	6.87 b	1.85 d	0.17 b
9	Olotillo × Ratón**	2.13 a	11.8 a	10.62 abc	3.01 bc	4.62 d	3.00 c	0.00 d
10	Olotillo × Tux**	2.23 a	11.5 a	16.49 a	4.26 a	7.73 a	4.33 b	0.17 b
11	Tux II***	2.23 a	11.0 a	15.93 a	3.29 b	6.91 b	5.09 a	0.65 a
12	Tux × Olotillo***	2.11 a	12.0 a	12.71 ab	2.85 bc	5.58 c	4.09 bc	0.19 b

*Early, **Intermediate, ***Late. PHE: plant height, NL: number of leaves per plant, TDMY: total dry matter yield, LY: leaf yield, SY: stem yield, EY: cob yield, DMY: senescent matter yield, Tux: Tuxpeño †Means with different letters in each column indicate significant statistical difference (Tukey, $\alpha = 0.05$).

In our study, the native maize genotypes evaluated showed wide variability in TDMY ($p < 0.05$). The most outstanding genotypes were Olotillo × Tuxpeño, Tuxpeño II, Tuxpeño × Olotillo, Tuxpeño I and Olotillo × Ratón, whose values ranged from 9.24 to 16.49 Mg ha^{-1} (Table 2). In another study in the center of the state of Tamaulipas at an altitude of 193 m, native genotypes presented yields of up to 10.66 Mg ha^{-1} (Joaquín *et al*., 2022), 19 % less than the average obtained in this experiment in the southwest of the state. Such response could be attributed to the fact that the genotypes evaluated in both experiments are from the region known as the Altiplano Tamaulipeco, characterized by altitudes higher than 1000 m, and therefore they showed better adaptation and development in this environment. The commercial hybrid 2038DK showed 75 % less TDMY, which was related to a lower PHE, a characteristic of some improved varieties and hybrids compared to native genotypes (Godina *et al*., 2020; Joaquín *et al*., 2022).

Morphological composition

No statistical difference was found among genotypes evaluated for NL ($p > 0.05$), whose values ranged from 9.5 to 12.8 (Table 2). This characteristic is not determined by external environments, so NL must be genetically defined (Rodriguez *et al*., 2016). The LY was different among the genotypes evaluated ($p < 0.05$), the late corn Olotillo × Tuxpeño and Tuxpeño I presented the highest values of LY ($p > 0.05$); which were 49 and 90 % higher than the commercial hybrids P3966WP and 2038DK, respectively (Table 2). The early-cycle genotypes Ratón× Olotillo, Ratón× Tuxpeño, Tuxpeño Norteño × Celaya, Ratón and Chalqueño × Tuxpeño, presented the lowest SY, with averages of 2.29 Mg ha^{-1}. As plants present late cycles, PHE, LY and SY increase (Sánchez-Hernández *et al*., 2021). The precocity of the populations is established by the microenvironments to which the populations are exposed. Depending on the altitude, temperature and humidity also vary, which in turn influences the duration of the phenological stages, specifically on days to female flowering (Ortega *et al*., 2010). Native maize genotypes display higher yields of leaf and stem components compared to hybrid genotypes that exhibit higher leaf-to-stem ratio (Muñoz-Tlahuiz *et al*., 2013; Godina *et al*., 2020). This leaf-to-stem ratio determines forage quality, since the higher the leaf-to-stem ratio, the higher the crude protein content in the forage (Amador and Boschini, 2000; Joaquín *et al*., 2022).

The genotype Tuxpeño II presented the highest EY ($p < 0.05$), which was 32 % higher than the commercial hybrid P3966WP (Table 2). The Olotillo × Tuxpeño and Tuxpeño × Olotillo genotypes showed a similar EY to P3966WP ($p > 0.05$). These genotypes could be ensiled without the addition of some soluble carbohydrate source, since maize genotypes with forage potential should have around 38 % EY (Zaragoza-Esparza *et al*., 2019). This ensures acetic and lactic acid fermentation, improves neutral detergent fiber dilution and increases forage digestibility (Liu *et al.*, 2021). Tuxpeño II and Ratón × Tuxpeño had the highest DMY; while no senescent leaf material was observed in Olotillo × Ratón and Northern Tuxpeño × Celaya ($p < 0.05$; Table 2). These differences are due to the fact that some genotypes showed a decrease in the leaf:stem ratio due to partial senescence of the basal leaves (Amador and Boschini, 2000). Furthermore, as soon as the leaf senescence process occurs, forage quality begins to decrease. In order to counteract such effect, cutting heights of up to 45 cm are proposed, leaving the less digestible part on the ground (González *et al.*, 2005), which in turn educes the contents of neutral and acid detergent fiber and increases the proportion of cob to TDMY.

Forage and silage chemical composition

The CP content of the forage at harvest varied among the genotypes evaluated. The maximum values ($p < 0.05$) were presented in P3966W, Tuxpeño I, Olotillo × Ratón and Olotillo × Tuxpeño, whose values ranged between 81 and 85 g kg^{-1} (Table 3). These

Table 3. Crude protein, crude fiber and ash content in forage and silage of native and hybrid maize (*Zea mays* L.) in Tula, Tamaulipas, Mexico.

	Maize genotype	Crude protein	Crude fiber	Ash
			g kg^{-1}	
Forage				
	P3966W*	82 ab†	300 d	85 b
	Tuxpeño I**	81 ab	302 d	87 a
	Olotillo × Ratón*	85 a	328 ab	81 c
	Olotillo × Tuxpeño**	81 ab	312 cd	82 c
	Tuxpeño II***	77 bc	339 a	80 cd
	Tuxpeño × Olotillo***	73 c	322 bc	79 d
Silage				
	P3966W*	92 a	310 a	81 c
	Tuxpeño I**	93 a	284 b	92 a
	Olotillo × Ratón*	92 a	241 d	82 c
	Olotillo × Tuxpeño**	75 c	250 cd	73 d
	Tuxpeño II***	78 bc	254 c	83 bc
	Tuxpeño × Olotillo***	79 b	245 cd	85 b

*Early, **Intermediate, ***Late. †Within columns and by forage and silage, means with different letters indicate statistically significant difference (Tukey; $\alpha = 0.05$).

CP results were higher than those reported by Fuentes *et al.* (2001) at 130 DAS, who reported 75 g kg^{-1}. This difference may be due to the phenological stage of the plant, and the climatic conditions under which the crop was grown. It has been noted that the chemical composition of maize is affected by environmental factors (Loučka *et al*., 2015). The CP values in forage and silage of all genotypes evaluated were greater than 73 g kg^{-1}, so that, when used as feed in ruminants, they could efficiently take advantage of the energy included in cellulose and hemicellulose. For rumen microorganisms to have adequate activity and digest the fiber, it has been reported that the CP content of forage must be >70 g kg^{-1} (Lazzarini *et al*., 2009).

CF consists mainly of structural carbohydrates such as cellulose and hemicellulose, which are metabolized by rumen microorganisms, first degraded to glucose and then to volatile fatty acids (VFAs): acetic, butyric and propionic acids (Church *et al*., 2007). The volatile fatty acids provide about 70 % of the metabolizable energy required by the ruminant (Bergman, 1990). Under our experimental conditions, significant differences were found among genotypes for CF content ($p < 0.05$; Table 3). The genotypes Tuxpeño II and Olotillo × Ratón had the highest values (339 and 328 g kg^{-1}, respectively). In the ensiled materials, the early-cycle hybrid maintained the CF content, while in native maize it decreased (18 %) after the fermentation process. This can be attributed to a higher proportion of cob to total yield, which increases energy content and thus decreases crude fiber and consequently increases *in vitro* digestibility of forage dry matter (Liu *et al*., 2021).

Native maize Tuxpeño I presented the highest ash content, both in fresh forage and silage, with 87 and 92 g kg^{-1} ($p > 0.05$; Table 3). These results were superior to those reported by Jiménez-Leyva *et al*. (2016) in evaluating a commercial maize hybrid, who found variations in ash content from 71 to 58 g kg^{-1} between 103 and 135 DAS. In native maize, it has been determined that ash concentration decreases after 80 DAS (Amador and Boschini, 2000). High ash contents are indicators of high concentrations of minerals present in the soil, which can affect plant development and decrease as plant growth occurs (Ruiz and Armienta, 2012). Trace minerals such as Ca, Fe, P, Se, Zn, Mn, Cu and Co can be found in ashes, which are necessary to form cellular proteins, coenzymes and enzymes involved in ruminal processes (Durand and Komisarczuk, 1988). Therefore, their deficiency affects VFAs production, fiber digestibility and feed digestion (Church *et al*., 2007).

Silage characteristics

Among the genotypes and groups evaluated, no significant statistical difference was found for pH ($p > 0.05$; Table 4). The average value was 3.8, which indicates that the ensiling process was adequate. Lactic acid producing bacteria, such as *Lactobacillus* spp., *Pediococcus* spp., *Enterococcus* spp., *Lactococcus* spp., and *Streptococcus* spp., develop better at pH values of 4.0 to 5.0 (Garcés *et al*., 2004; Church *et al*., 2007).

These pH levels are obtained when the silage contains between 30 and 35 % dry matter and by maintaining this percentage, pH levels are maintained over time, remaining also, the chemical composition and fermentation of the forage (Loučka *et al*., 2015). For soluble carbohydrate content (°Brix), the intermediate genotype Olotillo × Tuxpeño had the highest value ($p < 0.05$), followed by Olotillo × Ratón, Tuxpeño II and Tuxpeño × Olotillo (Table 4). These results are different and superior to those obtained by

Table 4. Silage characteristics of native and hybrid maize (*Zea mays* L.) genotypes in Tula, Tamaulipas, Mexico.

	Maize genotype	pH		°Brix		Dry matter (%)	
1	Tuxpeño Norteño x Celaya*	3.8	a†	7.5	c	19.4	bc
2	Ratón × Olotillo*	3.9	a	6.0	d	20.4	b
3	Ratón × Tuxpeño*	3.8	a	7.5	c	23.8	ab
4	Hybrid 2038DK*	3.8	a	6.5	d	17.4	c
5	Ratón*	3.9	a	6.5	d	20.4	b
6	Chalqueño × Tuxpeño*	4.0	a	7.5	c	21.4	ab
7	Hybrid P3966W*	3.9	a	6.5	d	20.0	bc
8	Tuxpeño I**	3.8	a	7.0	cd	20.9	b
9	Olotillo × Ratón**	3.7	a	8.5	b	27.7	a
10	Olotillo × Tuxpeño**	3.8	a	9.5	a	26.0	a
11	Tuxpeño II***	3.7	a	8.5	b	27.8	a
12	Tuxpeño × Olotillo***	3.8	a	8.5	b	23.2	ab

*Early, **Intermediate, ***Late. †Means with different letters within columns indicate significant statistical difference (Tukey; $\alpha = 0.05$).

Do *et al.* (2012), who when evaluating the silage of maize hybrids in the milky and doughy state, reported values of 4.3 and 4.9 °Brix, respectively. In sugarcane silage with values of 21 °Brix, it has been reported that adequate microbial fermentation activity occurs (Bravo-Martins *et al.*, 2006). However, it has been mentioned that for wet forages a minimum of 6 °Brix is required, therefore, the values of °Brix found in the maize genotypes in the present study are appropriate to achieve an adequate lactic fermentation (Garcés *et al*., 2004). The dry matter content of the silage showed an increase as time to harvest increased, with contents up to 27.8 % for late cycle Tuxpeño II (Table 4). In this regard, different cutting dates have been evaluated and dry matter showed an increase, with optimum values between 26 and 37 % for adequate silage between 123 and 131 DAS (Jiménez-Leyva *et al*., 2016).

CONCLUSIONS

Native maize can be an option for forage production in the semiarid region of Mexico. According to total dry matter yields and crude protein content, the genotypes Tuxpeño I, Olotillo × Ratón, Olotillo × Tuxpeño and Tuxpeño II could be used in breeding programs to select materials with potential for forage production and conservation.

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