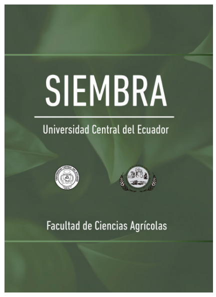
Morphological composition and yields of native maize without the use of agrochemicals in Chiapas, Mexico



Composición morfológica y rendimientos de maíces nativos sin uso de agroquímicos en Chiapas, México

Juan Carlos Caballero Salinas[1], Hugo Adrián. Pizaña Vidal[2], Alma Amalia González Cabañas[3], Erasmo Núñez Ramos[4], Fabian Aguilar Cruz[5], Emmanuel Ovando Salinas[6]

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[1] Universidad Autónoma Agraria Antonio Narro. Centro Académico Regional Chiapas. Prolongación avenida Benito Juárez, Rancho La Concordia. C.P. 30400. Cintalapa, Chiapas, México.
✉ jccs.uaaan@gmail.com
https://orcid.org/0000-0002-3290-2274

[2] Universidad Autónoma de Chiapas. Blvd. Belisario Domínguez Kilómetro 1081, Terán. C. P. 29050. Tuxtla Gutiérrez, Chiapas, México.
✉ hugoadrian_25@hotmail.com
https://orcid.org/0000-0002-9850-1596

[3] Centro de Investigaciones Multidisciplinaria sobre Chiapas y la Frontera Calle María Delina Flores, Barrio Guadalupe. C. P. 29230. San Cristóbal de Las Casas, Chiapas, México.
✉ agonzale@unam.mx
https://orcid.org/0000-0002-5538-2638

[4] Universidad Autónoma Agraria Antonio Narro. Centro Académico Regional Chiapas. Prolongación avenida Benito Juárez, Rancho La Concordia. C.P. 30400. Cintalapa, Chiapas, México.
✉ enramos76@gmail.com
https://orcid.org/0000-0002-7239-1309

[5] Universidad Autónoma Agraria Antonio Narro. Centro Académico Regional Chiapas. Prolongación avenida Benito Juárez, Rancho La Concordia. C.P. 30400. Cintalapa, Chiapas, México.
✉ j.fac@hotmail.com
https://orcid.org/0000-0001-8083-5507

[6] Universidad Autónoma Agraria Antonio Narro. Centro Académico Regional Chiapas. Prolongación avenida Benito Juárez, Rancho La Concordia. C.P. 30400. Cintalapa, Chiapas, México.
✉ jhony2699salinas@gmail.com
https://orcid.org/0000-0001-5099-470X

**Corresponding author:*
hugoadrian_25@hotmail.com

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Abstract

The objective of this study was to characterize the morphological composition of five populations of native maize and estimate their yields using agricultural practices without the use of agrochemicals. The study conducted in 2021, in the municipality of Cintalapa, Chiapas, within the experimental field of the Regional Academic Center of the Antonio Narro Autonomous Agrarian University. The five populations of native maize were provided by farmers from different regions of the state, with prior informed consent. The Agricultural practices consisted of using plant extracts and potassium soap with neem extract (*Azadirachta indica*) to prevent and combat pests. For fertilization, Californian red earthworm (*Eisenia foetida*) leachate and bat guano were applied in their commercial presentation. Morphological characters were evaluated with a descriptive statistical analysis considering days to male and female flowering, plant and ear height ear length and diameter, number of rows per ear and number of kernels per row. Grain yield was estimated by the weight of the ear harvested from a random sample of 20 plants per population. Numerical differences of the studied variables were identified, which demonstrates an existing genetic diversity. The populations with the highest yields were Campeón and Olotillo, with 5.37 and 4.4 ton ha^{-1} (± 1.24), respectively. The data provide information to design native maize conservation strategies through agrochemical-free management.

Keywords: agroecology, bioinputs, genetic diversity, maize conservation.

Resumen

El objetivo de este estudio fue caracterizar morfológicamente cinco poblaciones de maíz nativo y estimar sus rendimientos, empleando prácticas agrícolas sin uso de agroquímicos. El estudio se realizó en el año 2021, en el municipio de Cintalapa, Chiapas, dentro del campo experimental del Centro Académico Regional de la Universidad Autónoma Agraria Antonio Narro. Las cinco poblaciones de maíz nativo fueron proporcionadas por campesinos de diferentes regiones de la entidad, con previo consentimiento informado. Las prácticas agrícolas consistieron en uso de extractos vegetales y jabón potásico con extracto de neem (*Azadirachta indica*) para la prevención y combate de plagas. Para la fertilización se aplicó lixiviado de lombriz roja californiana (*Eisenia foetida*) y guano de murciélago en su presentación comercial. Los caracteres morfológicos se evaluaron con un análisis estadístico descriptivo considerando: días de floración masculina y femenina, alturas de planta y mazorca, longitud y diámetro de la mazorca, y número de hileras por mazorca y número de granos por hilera. El rendimiento de grano se estimó mediante el peso de la mazorca cosechada de una muestra aleatoria de 20 plantas por población. Se identificaron diferencias numéricas de las variables estudiadas, lo que demuestra una diversidad genética existente. Las poblaciones que presentaron mayores rendimientos fueron Campeón y Olotillo, con 5,37 y 4,4 ton ha^{-1} (± 1,24), respectivamente. Los datos aportan información para diseñar estrategias de conservación de maíces nativos con manejo libre de agroquímicos.

Palabras clave: agroecología, bioinsumos, diversidad genética, conservación de maíces.

1. Introduction

For centuries, Mesoamerican cultures domesticated different maize breeds, adapting them to specific agroecological conditions and using them to produce a great diversity of foods. Different peasant populations adapted these maize to the microclimates of their territories, as well as to their gastronomic or culinary needs (González-Amaro et al., 2017). In addition, maize was considered a fundamental element which is part of the cosmovision of the peoples, "a metaphor of life itself" (Carrillo Trueba, 2009).

In Mexico, maize is the most important crop in cultural, economic and political terms. Almost the entire area cultivated with this plant is planted with native seeds; it is estimated that between 70 and 80%, approximately (Godina-Rodríguez et al., 2020). Hence its importance as a biological and cultural resource that not only represents food, but also safeguards the identities and histories of many rural communities. Generally, these native corns are accompanied by other plants; they are planted in milpas considered as living genetic systems, or biocenotic communities, where different species of social and economic interest such as beans, squash and chili, as well as weed plants that arise spontaneously or as a result of farmers' management (Velázquez-Cárdelas et al., 2018), are interspersed or associated with each other. Their conservation and improvement have largely depended on farmers' local practices and knowledge (Pizaña Vidal and Caballero Salinas, 2020). It has been shown that under some conditions they have advantages over hybrid maize or improved open-pollinated varieties; for example, greater tolerance to drought, resistance to pests and ear rot (Bellon et al., 2006). It is a highly adaptable crop that is well suited to soils with low fertility and adverse climatic conditions (Perales et al., 2003).

Chiapas, a state in southern Mexico, has areas of great maize genetic diversity (Martínez-Sánchez et al., 2017). In 2020, it ranked first nationally in planted area with 690,653 ha, and eighth in production with 1,257,883 ton (Servicio de Información Agroalimentaria y Pesquera [SIAP], 2022). It has been estimated that 75 % of the area is cultivated with native maize and open-pollinated varieties (Coutiño-Estrada et al., 2015) which have been domesticated by farmers. In addition, 20 native races out of the 59 identified in the country have been reported (Perales and Hernández-Casillas, 2005).

For at least forty years, maize in Mexico has been part of erratic policies that have sought to sustain the supply of this food through its importation, thus neglecting national production and those who for generations have been dedicated to cultivating it, especially social sectors that produce on a small and medium scale (Puyana, 2012; Torres Torres, 2018; Yúnez Naude, 2006). When maize has been part of policies to promote production, the emphasis has been placed on the use of modern technologies to increase productivity and economic profitability, which ends up displacing the peasant knowledge pool and puts at risk not only local biotic resources, but also the natural environment, as well as the health of producers and consumers who are exposed to toxic residues contained in agroindustrial inputs (Altieri et al., 2012; Bejarano González, 2017; Consejo Nacional de Ciencia y Tecnología [CONACYT], 2020). Likewise, producers are subject to production systems that depend on agricultural inputs which become more expensive due to market price speculation. Martínez-Reyes et al. (2018) calculated that such dependence is mainly towards fertilizers, which represent between 40 and 50% of total production costs.

Due to the socio-environmental damage generated by the intensive model, various social movements have challenged this form of production, while promoting the revaluation of native corn and the accumulation of traditional knowledge linked to this grain (Hernández-Rodríguez et al., 2020). Native maize breeds and the diverse practices of peasant saving and conservation are being considered as an agroecological alternative that allows the dissemination of traditional knowledge among communities (Pizaña Vidal et al., 2023). Altieri (2003) argues that native maize is fundamental for the development of sustainable forms of agriculture, since it is the axis of practices such as the milpa, a dynamic system of genetic resources of rainfall regime formed by a polyculture in which the "Mesoamerican triad" -maize, beans and squash- is planted together with other species, whose management implies a broader territorial dimension. All these species coexisting in the milpa provide a variety of nutritious foods, vegetable proteins, vegetables and tubers (Pizaña Vidal et al., 2023). In addition, the greater variability characteristic of the milpa, whose base is native corn, contributes to conserving soil fertility, it is independent from agrochemicals, and better tolerates pests and climate change.

It should be noted that agroecology movements advocate the redefinition of the global agrifood system on a sustainable and territorial basis. Agroecology is a scientific, practical and social paradigm (Wezel et al., 2009) where the principles of ecology and agronomy are applied to the understanding and development of agroecosystems, but it also promotes the recovery of peasant production, the reduction or elimination of synthetic inputs and the strengthening of food sovereignty from and for the local level.

In recent years, agroecology has become the main alternative to the industrial model in agriculture; it has gained wide social and political recognition as an alternative capable of addressing the socioecological problems inherited by society from the industrial agricultural system (Holt-Giménez and Altieri, 2013). It is important to note that agroecology, as a technique and as a differentiating factor in the market, is being monopolized by transnational companies that see here a market segment with high growth and economic profitability due to the overpricing of these products. These companies seek to reduce ecological damage through approaches that are "painted green", but which, at bottom, do not question the dependence of producers on agribusiness input supply chains, nor do they question intensive practices (Holt-Giménez and Altieri, 2013; Rosset and Altieri, 2018).

As for the scientific literature, related to native maize, several studies have characterized its morphology (Godina-Rodríguez et al., 2020; Martínez-Sánchez et al., 2017), as well as agronomic, physiological aspects, yield levels and phenotypic traits (Conceição dos Santos et al., 2019; María-Ramírez et al., 2017; Martínez-Sánchez et al., 2018; Tadeo-Robledo et al., 2015). Such experiments have had agronomic management with the use of chemical inputs for weed, pest, disease and fertilization control. However, this type of research disregards the negative effect on both the health of farmers and the ecosystems and consumers of the external resources used.

The objective of this work is to document an evaluation carried out to measure the yields and morphological characteristics of five native corn populations, without the use of agrochemicals: Tuxpeño, Olotillo, As, Campeón and Oaxaqueño. Agrochemicals were replaced by bio-inputs made from plant extracts, potassium soap, bat guano and earthworm leachate. The morphological characterization study provides with information to design conservation and utilization strategies (Martínez-Sánchez et al., 2017) which , together with agronomic management without agrochemicals, constitute a strategy to value the productive potential of the local maize studied. It is argued that the cultivation of native seeds without agrochemicals follows and adheres to the principles of agroecology (Alianza Biodiversidad, 2020). Native seeds themselves are a collective good, that is, a biocultural resource for human life (Gárgano, 2020). This aspect relates seeds to food sovereignty, as maize is the mainstay of many indigenous and peasant communities (García-López, 2020; Pertierra Lazo, 2020), especially of those whose access to external inputs is limited.

2. Materials and Methods

2.1. Study area

The study was carried out in the experimental agricultural field of the Chiapas Regional Academic Center of the Universidad Autónoma Agraria Antonio Narro, located in Cintalapa, a municipality in the state of Chiapas, southern Mexico (Figure 1). Its geographical coordinates are 16° 39' north latitude and 93° 44' west longitude. Cintalapa is located in a relatively low area, at an altitude of 540 m above sea level, which gives it a tropical semi-warm-sub-humid climate and an average annual temperature of around 24.5 °C. Rainfall averages between 800 and 1,200 mm annually. According to NOM-021-SEMARNAT-2000 criteria, the soil texture where the experiment was established is clayey.

2.2. Genetic materials

The native maize seeds were provided by farmers from localities in three municipalities of Chiapas: Cintalapa and Villa Corzo, which are located in the physiographic region of the central valleys, and La Trinitaria, in the

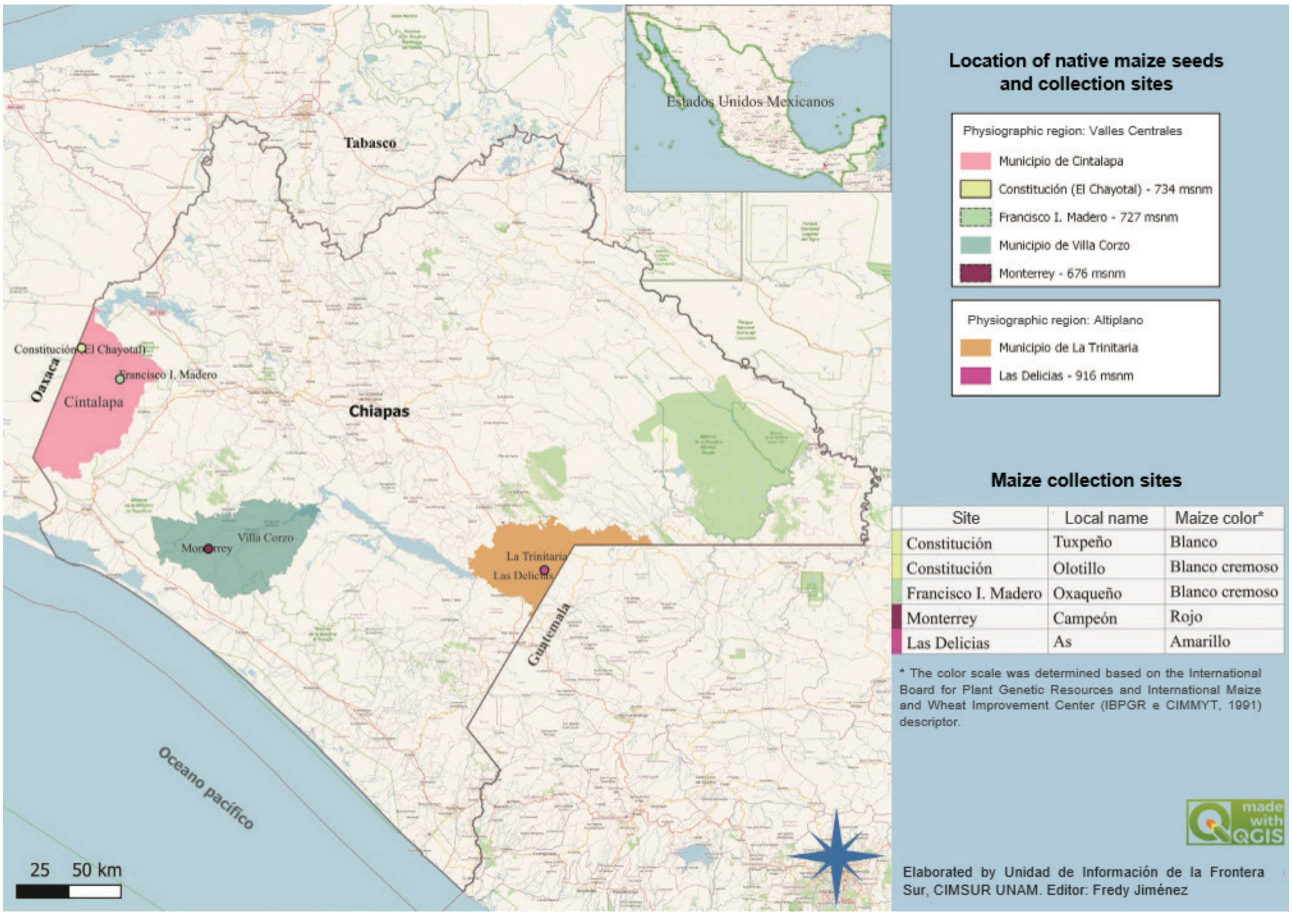

Figure 1. Location of the localities where the maize was collected.

Chiapas highlands (Table 1 and Figure 2). It should be noted that verbal consent of the farmers was requested in order to use the seeds for field evaluation. For more than five years the undersigned authors have conducted ethnographic research in these territories; the collection of these genetic and biocultural resources was carried out through several field trips in these areas of the state of Chiapas.

Table 1. Populations of native maize and collection sites.

Local name	Physiographic region	Location	Municipality	Altitude (m ASL)	Color*
Tuxpeño	Valles centrales	Constitución	Cintalapa	734	White
Olotillo		Constitución	Cintalapa	734	Cream White
Oaxaqueño		Francisco I. Madero	Cintalapa	727	Cream White
Campeón		Monterrey	Villa Corzo	676	Red
As	Altiplano	Las Delicias	Trinitaria	916	Yellow

**The color scale was determined based on the International Board for Plant Genetic Resources and International Maize and Wheat Improvement Center (IBPGR e CIMMYT, 1991) descriptor.*

2.3. Experiment conduct and agronomic management

For the evaluation of the genetic materials, an area of approximately 60 m^2 was available within the experimental field of the Regional Academic Center of the Universidad Autónoma Agraria Antonio Narro. The genetic

Figure 2. Native maize evaluated.

materials were established in five plots, each of which corresponds to two 12 m long furrows, with a distance between furrows of 0.8 m, and of 0.25 m between plants; extrapolated data report a density of 50,000 plants ha^{-1}.

The soil was prepared mechanically; it consisted of a harrow pass with a tractor. For planting, some peasant practices were replicated using the "tapa pie" technique. This technique was used to deposit a corn seed in a small hole, every 25 cm. The hole was opened with the macana (also known as bacana), a traditional tool made with branches of guayabillo (*Psidium sartorianum*), a tree species of the region with solid and durable wood.

The trial was established on February 22, 2021, and maize locally known as Tuxpeño, Olotillo, Oaxaqueño, As and Campeón were grown. The experiment was conducted under drip irrigation conditions. Weed control was carried out on two occasions manually with the use of the coa (hoe). The first at 15 days after sowing [DAF] and the second at 40 DAF. The presence of pests was prevented and controlled with five applications (once a week) of potassium soap and neem extract in commercial presentation; 20 ml of this bio-insecticide were mixed per liter of water. In addition, a bio-preparation was prepared and applied twice to repel insects (aphids, leaf miners, whiteflies and mites) that cause damage to the crop. This was made from a mixture of garlic, habanero bell pepper and pepper. The preparation process was to liquefy 60 g of garlic, 100 g of habanero bell pepper, and 50 g of black pepper, dissolved in a liquid phase of water and 50% alcohol. Subsequently, the mixture was left to stand for 24 hours. The application dose was one liter of bio-preparation in 20 l of water.

On the other hand, fertilization was carried out with locally obtained leachate of red Californian earthworm (*Eisenia foetida*), and the commercial organic product guanafol, formulated with bat guano. Fertilization with leachate was done foliarly at 20 and 30 DAF. Subsequently, two direct applications were made with a mixture of one liter of leachate, 100 ml of guanafol and 20 l of water.

Harvesting was carried out manually in the first week of June, and defined by the physiological maturity of the biological materials evaluated.

2.4. Bio-inputs and their influence on production

The use of bio-fertilizers makes it possible to generate alternative resources to promote agricultural systems that do not harm the natural environment and human health. At the same time, it opens the possibility to create productive strategies that maintain or raise corn yields, minimize production costs, and dependence on the market of toxic agrochemicals (Martínez- Reyes et al., 2018). The insect repellent bio-preparation used in the experiment documented here can be made by farmers themselves based on the processing of plant matter that is very easily accessible and inexpensive. The mixture of garlic, chili and pepper contains essential oils to control insects; its potent effects eliminate aphids by inhibiting their respiratory system. Among the advantages of this bio-preparation were found to be:

1. They do not produce hazardous residues that affect the health of the soil, environment and people.
2. They do not affect beneficial fauna (insects and other organisms that naturally control pests and diseases).
3. They do not generate resistance in pests, as it happens with chemical insecticides and fungicides.
4. The extracts are 100% biodegradable (Investigaciones Forestales Agrícolas y Pecuarias [INIFAP], 2021a).

Similarly, organic fertilizer based on earthworm leachate can be produced in small vermicompost modules that do not require high financing[1]. According to Prado García (2021), the leachates from the organic matter worked by the worms include macronutrients such as nitrogen, phosphorus and potassium; the same contained in the humus derived from vermicomposting. The latter is the technique that later allows the production of fertilizers and leachates in the modules. The nutrients obtained naturally here are essential to maintain a fertile soil conducive to plant growth. Among others, some of the advantages of leachates are:

1. Reaches a minimum production of 3,000 l m^{-3} per year.
2. The ingredients are local and economical (bovine manure, dry leaves and soil).
3. Foliar application is simple.
4. It is a favorable input to generate agroecological transition processes towards sustainable, resilient and productive systems.
5. It significantly reduces production costs by eliminating, or minimizing the use of chemical fertilizers.
6. It can be applied at any phenological stage of corn.
7. Avoids the concentration and accumulation of salts in the soil.
8. Promotes the proliferation of beneficial microorganisms: bacteria, fungi, etc. (INIFAP, 2021b).

On the other hand, the guano that was used is a natural fertilizer that comes from bat excrement; according to Hernández Hernández (2017), it is a good source of energy due to its high nitrogen and phosphorus content. It also improves soils and protects plants from pests and diseases.

As for the mixture of potassium soap and neem extract, it has a broad spectrum of action that contributes to integrated pest management (López Díaz and Estrada Ortíz, 2005). The pesticidal compounds of neem, mainly azadirachtin extracted from the seed, have a repellent effect on a multiplicity of insects; more than four hundred species can be controlled with this biopesticide (Morgan, 2004, p. 24). Also, Morgan (2004) explains that azadirachtin is only one compound in the seed. In reality, the important compounds for the insecticidal action of neem seed extract are a group of highly oxidized limonoids. Hence their insecticidal action.

These two bio-inputs, bat guano and the mixture of potassium soap with neem, were available on the market and their costs were accessible: the first was priced at MXN 200 (about US$ 5.3 as of January 31, 2020), and the second at MXN 100 (about US$ 10.6 as of January 31, 2020). It is suggested that bat guano can be replaced by worm humus and the mixture, in due course, can be made by the producers themselves.

2.5 Data registration

Vegetative and agronomic characters were recorded for 20 randomly selected plants from each population (100 in total), based on the IBPGR and CIMMYT (1991) descriptor for maize. These characters are detailed below and the abbreviations used in the results and discussion section are specified.

I. Days of male and female flowering [DMF, DFF]: it was estimated from the day of sowing until 50% of the plants released pollen or emitted stigmas.

[1] Approximately a 3 x 1 m module, enough to provide natural fertilizer to a farming family unit, costs MXN 6,000 (about US$322 as of February 12, 2023).

II. Plant and ear heights [PH, EH]: lengths taken from the soil surface to the base of the ear and knot of the ear insertion were measured.
III. To determine yield, the following were quantified: a) ear length [EL]; b) ear diameter [ED]; c) number of rows per ear [NRE], and d) number of grains per row [NGR]. Subsequently, the ears were dried in the air and shade, until their moisture content (around 14%) allowed manual shelling. This technique is used when a moisture meter is not available (María-Ramírez et al., 2017). Dry grain weight was extrapolated to estimate yield in ton ha^{-1}, based on a density of 50,000 plants and one ear per plant (Sánchez-Hernández et al., 2015).

2.6 Data analysis

Data were analyzed with output tables and descriptive statistics. The variables were entered into the SAS Studio® statistical package to estimate averages, minimum and maximum. The standard deviation, standard error and coefficient of variation were also estimated as evidence of the dispersion behavior of the variables studied; it is considered pertinent to continue the field research with multivariate analysis.

3. Results and discussion

3.1 Days of male and female flowering

The DMF ranged from 62 to 76 days, while the DFF ranged from 64 to 78 days (Table 2). Populations with different production cycles were observed; Oaxaqueño (with 72 DMF and 74 DFF) and As (76 DMF and 78 DFF) obtained values above the mean, exceeding 67.8 DMF and 69.8 DFF. In this sense, they can be considered populations with late flowering stages. The means of both variables studied in this table are very similar arithmetically and their coefficient of variation indicates the stability of each of the studied corns.

Table 2. Averages of DMF and DFF* after sowing, total mean, minimum, maximum and coefficient of variation of native maize evaluated.

Variable	Tuxpeño	Olotillo	Oaxaqueño	Campeón	As	Total average	Minimum	Maximum	Variation coefficient
DMF	62	64	72	65	76	67,8	62	76	7,86
DFF	64	66	74	67	78	69,8	64	78	7,64

* DMF = Days to male flowering; DFF = days to female flowering.

Table 2 shows that Tuxpeño had the earliest flowering stages, with 62 DMF and 64 DFF. This earliness is typical of this maize, and the data presented here are similar to those of Martínez-Sánchez et al. (2017), who, for the same race, recorded lower intervals of 60 DMF to 61 DFF[2] . The fact that its cycle is short allows it to complete its vegetative development with a smaller amount of water (Ramírez, 2013), which is why it is also used in regions with low levels of rainfall, or where rainfall periods are shorter. It is predominantly planted in tropical lowland rainfed areas during the spring-summer period1.

It should be noted that farmers cultivate native maize of different vegetative cycles on their plots, adjusting planting dates according to rainfall behavior (Martínez-Sánchez et al., 2017). In localities of the municipalities of Cintalapa, Villaflores and Villa Corzo, whose territories cover a good part of the central valleys of Chiapas (also known as central depression), it was observed that farmers plant up to five different maize populations, using different designs and arrangements of agricultural systems, depending on the length of their productive cycle and climatic conditions (Caballero Salinas et al., 2023; Pizaña Vidal and Caballero Salinas, 2020). It seems worth mentioning an anecdote by Hernández-Xolocotzi (1971, p. 6), which reflects the extensive knowledge

[2] Variation in DFM and DFF is likely due to the environmental strata of each agroecological niche (Ángeles-Gaspar et al., 2010).

that farmers have about native maize, its vegetative cycle and its link with nature (rain); it also expresses the wise local management of weather and the risks of climate variability that today are identified as climate change.

Cuenta que durante la recolección de maíz en Tlaxcala encontró a un agricultor viejo y su familia durante la siembra de su parcela. Les solicitó ver la semilla que usaban y al sacar una muestra encontró una mezcla de maíz amarillo, maíz morado, maíz blanco y una revoltura de frijol. He aquí el diálogo entre el investigador y el campesino:

"¿Cuál de estos maíces es más breve? –pregunté.

Dijo el viejo, canoso, de piel arrugada y curtida: –El amarillo es de cinco meses, el morado de seis y el blanco de siete.

–¿Y cuál rinde más?

–El amarillo poco, el morado un poco más y el blanco es mejor.

–¡Ah! ¿Y por qué no siembra puro blanco en lugar de esa revoltura?

El viejo sonrió mostrando unos dientes cristalinos y pequeños como los granos del maíz reventador.

–Eso es lo que dijo mi hijo. Pero dígame, señor, ¿cómo van a venir las lluvias este año?

–Óigame, yo soy agrónomo, no adivino.

Ya ve. Solo Tata Dios sabe. Pero sembrando así, si llueve poco, levanto amarillo; si llueve más levanto más, y si llueve bien, pues levanto un poco más de las tres clases".

He says that while harvesting corn in Tlaxcala he met an old farmer and his family during the planting of their plot. He asked them to show him the seed they were using, and when he took a sample he found a mixture of yellow corn, purple corn, white corn and a mixture of beans. Here is the dialogue between the researcher and the farmer:

"Which of these corns is the shortest? -I asked.

Said the old, gray-haired man with wrinkled and tanned skin: "The yellow one is five months, the purple one six months, and the white one seven months.

-And which one yields more?

-The yellow one a little, the purple one a little more, and the white one is better.

-Ah! And why don't you plant pure white instead of that mess?

The old man smiled, showing crystalline teeth as small as the kernels of the popping corn.

-That's what my son said. But tell me, sir, how are the rains going to come this year?

-Listen, I'm an agronomist, not a fortune teller.

You see. Only Tata Dios knows. But planting like this, if it rains a little, I raise yellow; if it rains more I raise more, and if it rains well, I raise a little more of the three kinds.".

3.2. Plant and ear height

Table 3 shows the numerical differences in PH and EH of the five corn populations studied. It can be seen that the average PH ranged between 105.6 and 156.4 cm and the average EH between 209.7 and 263.3 cm. The highest PH values were found for Oaxaqueño (263.3 cm) and Olotillo (260.6 cm), above the total mean (234 cm). The tall growth habit of native maize is an undesirable agronomic characteristic for some commercial systems, due to the probability of lodging (Ramírez-Díaz et al., 2015); this problem was not observed in the populations evaluated. In contrast, the tall bearing of these same varieties has a high forage potential -good palatability characteristics- because they provide abundant foliage that can be used for livestock feeding (Sánchez-Hernández et al., 2015) or for the preparation of composts and plot covers. Of the five populations, Tuxpeño recorded the lowest growth habit (209 cm). It is also observed that, in Oaxaqueño, Olotillo and As, cobs were inserted above the average stem height (133.9 cm). This reduces wildlife damage and flooding risks when grown in low-lying areas (Ramírez-Gómez et al., 2020). In addition, the EH was on average between 105.6 and 156.4 cm, a desirable characteristic for harvesting according to the farmers' experience. The coefficients of variation for these variables in the Champion show a smaller difference (PH: 8.88) showing less variability in PH.

3.3. Characteristics of the ear

Numerical differences were also found for the variables that define the characteristics of the ears (EL, ED, NRE, NGR) (Table 4). A difference of 5.84 cm was observed between the Olotillo race with the highest EL (15.9 cm) and the Tuxpeño with the shortest EL (10.1 cm). The populations that presented values below or equal to the total mean were the Tuxpeño and Oaxaqueño, with 10.1 cm and 13.9 cm, respectively. This result may be associated with early maize having a short duration of the vegetative phase and, therefore, small ears (Ramírez, 2013). However, Tuxpeño together with Campeón showed the highest ED, both with 4.5 cm. The coefficient of variation of Tuxpeño for ED was the lowest, and it was also the genotype with the least PH, which could refer to the long

Table 3. Means and descriptive statistics of AP and AM of native maize populations.

Populations	Variable*	Mean (cm)	Standard deviation	Minimum	Maximum	Standard error	Coefficient of variation
Tuxpeño	PH	209,7	34,5	105	270	7,72	16,47
	EH	105,6	16,8	60	134	3,77	15,99
Olotillo	PH	260,6	52,4	168	332	11,72	20,12
	EH	155,0	34,0	89	212	7,60	21,94
Oaxaqueño	PH	263,3	36,6	209	338	8,19	13,91
	EH	156,4	25,3	102	209	5,65	16,17
Campeón	PH	217,7	19,3	185	255	4,32	8,88
	EH	117,0	18,9	90	158	4,23	16,19
As	PH	218,8	31,5	160	270	7,05	14,40
	EH	135,4	26,2	87	176	5,86	19,37
Totales	PH	234,0	42,5	105	338	4,25	18,19
	EH	133,9	31,83	60	212	3,18	23,77

**PH= plant height; EH= ear height.*

Table 4. Means and descriptive statistics of EL, ED, NRE and NGR of native maize populations.

Poblaciones	Variable*	Media (cm)	Desviación están-dar	Mínimo	Máximo	Error estándar	Coeficiente de variación
Tuxpeño	EL	10,1	2,9	3,5	15,5	0,68	28,86
	ED	4,5	0,4	3,6	5,3	0,11	10,38
	NRE	12,9	2,2	10	19	0,52	17,06
	NGR	19,8	8,6	6	36	2,03	43,43
Olotillo	EL	15,9	4,5	8	22	1,01	28,45
	ED	3,8	0,6	2,5	4,5	0,14	16,53
	NRE	9,4	2,3	5	14	0,52	24,87
	NGR	30,7	17,5	8	54	3,91	56,91
Oaxaqueño	EL	13,9	3,2	8	22	0,72	23,47
	ED	4,1	0,8	2,4	5,6	0,18	20,14
	NRE	10,9	1,6	6	14,0	0,37	15,43
	NGR	24,5	4,8	10,7	29,8	1,08	19,76
Campeón	EL	14,4	2,7	10	19	0,60	18,78
	ED	4,5	0,5	2,8	5,2	0,11	11,48
	NRE	12,8	1,9	8	16	0,43	15,20
	NGR	28,1	6,9	6,3	38	1,55	24,68
As	EL	14,8	1,8	10	18	0,44	12,74
	ED	4,2	0,67	2,8	5,4	0,16	15,89
	NRE	10,3	2,4	5	14	0,57	23,70
	NGR	21,6	10,2	5	39	2,40	47,12
Totales	EL	13,9	3,7	3,5	22	0,37	26,63
	ED	4,2	0,6	2,4	5,6	0,07	16,23
	NRE	11,2	2,5	5	19	0,25	22,30
	NGR	25,1	11,1	5	54	1,13	44,19

*EL = ear length; ED = ear diameter; NRE = number of rows per ear; NGR = number of kernels per row.

process of directed genetic selection both in the experimental field where the variety was originally generated, as well as by the subsequent selection of farmers in the field. In numerical order, they were followed by As, Oaxaqueño and Olotillo. The variety with the highest EL was Olotillo with 15.9 cm. This variety presented a reduced DM; that is, an inverse relationship between the variables EL-ED is expressed: the higher the EL, the lower the DM.

Plant and ear heights [PH, EH], ear length [EL]; b) ear diameter [ED]; c) number of rows per ear [NRE], and d) number of grains per row [NGR].

The highest NRE were found in the populations with the highest ED, i.e., Tuxpeño (12.9 NRE) and Campeón (12.8 NRE), whose values exceeded the mean of the five maize varieties evaluated (11.2 NRE). The corn that showed the highest NGR were also those with high EL values. Here Olotillo stands out, which obtained 30.7 NGR and reached the highest EL. Campeón also achieved important estimates with 28.1 NGR and 14.4 EL. The data obtained here for Olotillo are consistent with those of Martínez-Sánchez et al. (2017) in research conducted in Chiapas.

The numerical differences found in the populations evaluated demonstrate the existence of genetic diversity. Some authors, such as Ángeles-Gaspar et al. (2010) and Delgado-Ruiz et al. (2018) attribute this diversity to empirical selection by farmers according to their uses and ecological niches. The results confirm that native maize constitutes a dynamic agricultural system that, through its open pollination (gene movement) and the constant exchange of seeds by producers, make variability possible with a high number of combinations that allow the creation of new varieties with desirable agronomic characteristics and attributes (Cabrera-Toledo et al., 2019).

3.4. Yields of evaluated populations

Table 5 shows the estimated yields based on the extrapolation of 50,000 plants ha^{-1}. It was observed that Campeón, Olotillo and Oaxaqueño maize showed yields above the total average (3.72 ton ha^{-1}). Campeón and Olotillo stand out with respective yields of 5.37 ton ha^{-1} and 4.40 ton ha^{-1}, which are values above or equal to the average yield of maize under irrigation in the state of Chiapas for the 2021 agricultural cycle (SIAP, 2022).

Table 5. Grain yield of native maize populations.

Populations	Ear weight* (kg)	Kernel weight (kg)	100 kernel weight (kg)	Percentage of ear (%)	Yield (kg ha^{-1})**
Tuxpeño	1,3	0,99	0,038	23,85	2.470
Olotillo	2,1	1,76	0,032	16,19	4.400
Oaxaqueño	2	1,53	0,040	23,4	3.820
Campeón	2,7	2,15	0,036	20,22	5.370
As	1,6	1,02	0,044	36,5	2.550
Media	1,94	1,49	0,038	24,032	3.720
Desviación. estándar	0,53	0,50	0,004	7,61	1.240
Mínimo	1,3	0,99	0,032	16,19	2.470
Máximo	2,7	2,15	0,044	36,5	5.370

**Weight of ears harvested in the 20 randomly sampled plants.*
***Extrapolation to 50,000 plants per hectare according to the planting density established in the plots.*

Tuxpeño maize, behind Oaxaqueño and As, was the third population with the highest 100 kernel weight value (0.038 kg). However, it showed the lowest yield per hectare (2.47 ton ha^{-1}), which can be attributed to the fact that it was the variety with the lowest values of EL and NGR (Table 4), which is reflected in the ear weight, as it obtained the lowest record (1.3 kg). Probably, one explanation for the low yield of Tuxpeño (2.47 ton ha^{-1}) is due to the fact that it is an experimental field-improved maize with management dependent on the use of agrochemicals. As, on the other hand, it offered the highest value in 100 kernel weight; however, its yield was below the total average, due to the fact that it had the highest percentage of ear (36.50 %).

Olotillo, which showed the second lowest 100-grain weight (0.032 kg), but the second highest yield per hectare, stands out. This can be attributed to the EL and the smallest percentage of the ear (16.19%), from which it derives its name, due to the thickness of the ear. Regarding the extrapolated grain yield per hectare, it is important to highlight that some populations studied in this research are similar to that of Martínez-Sánchez et al. (2018) whom used chemical inputs in their agronomic management, for example, Tuxpeño 2.8 ton ha^{-1}. Therefore, the results show that the use of bio-fertilizers favors maize yield by the effect of beneficial microorganisms (Martínez-Reyes et al., 2018).

4. Conclusions

The morphological differences identified in the native maize populations helped to demonstrate the genetic diversity that exists in Chiapas, both in the morphology of the plant and in the corncob. This diversity is not the result of an isolated biological process, but of the interaction and cultural adaptation of peasant societies with their natural environment. Although this process was not described in this research, because it is beyond the purposes of this research, other works have shown that the practices of domestication and selection of maize define the morphological characteristics of the plants and cobs according to a multiplicity of criteria that the farmers themselves value as relevant: height, size, color, yield, flavor, among others (Delgado-Ruiz et al., 2018).

This work demonstrated that native maizes grown without agrochemicals are resources that provide average yields such as those officially recorded for the state (4.40 tons, according to SIAP estimates). Olotillo, for example, reached 4.40 tons ha^{-1} and Campeón exceeded 5 tons ha^{-1}.

This is significant considering that the experiment used bio-fertilizers and plant extracts instead of synthetic fertilizers and other agrochemicals that cause significant damage to ecosystems and human health.

Thus, it highlights the importance of agrochemical-free agricultural practices and the need to decrease dependence on agribusiness supply chains. In fact, the production of leachate and extracts can be a process led by local producers. They can produce the bio-fertilizers themselves and, thus, reduce the impact of rising agricultural input prices.

Contributor Roles

- Juan Carlos Caballero Salinas: conceptualization, formal analysis, investigation, methodology, supervision, visualization, writing – original draft.
- Hugo Adrián Pizaña Vidal: conceptualization, formal analysis, visualization, writing – review & editing.
- Alma Amalia González Cabañas: conceptualization, formal analysis, writing – original draft.
- Erasmo Núñez Ramos: formal analysis, investigation, methodology.
- Fabian Aguilar Cruz: investigation, methodology.
- Emmanuel Ovando Salinas: investigation, methodology.

Ethical Issues

Ethics approval Not applicable.

Conflict of Interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

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