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Phenological and morphological characterization of local maize from the municipality of Villaflores- Chiapas, Mexico

Caracterización fenológica y morfológica de maíces locales del municipio de Villaflores-Chiapas, México

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Abstract

Local maize varieties in Mexico play a crucial role in food security, cultural diversity, and agricultural sustainability. These varieties constitute a reservoir of genetic diversity critical for the adaptability of maize to changing climatic conditions. To characterize 12 local maize varieties from the Frailesca Region, Chiapas, an experiment was established under completely randomized field conditions. Evaluated variables included phenological cycle, leaf and root biomass production, plant height, stem diameter, ear shape, and leaf coloration. A Hierarchical Cluster Multivariate Analysis was conducted to group varieties based on their characteristics. A mixed correlation model was used to assess the dynamic proportion of root biomass to total biomass. Two groups were identified based on phenological characteristics: the first type grouped 10 varieties with early traits, and the second type comprised 2 late varieties. Regarding biomass production, three types were found: high biomass production, with 4 varieties; low biomass production, represented by 7 varieties; and one atypically high biomass production variety. Radical biomass increased linearly until 120 days. The variety "Olotillo Amarillo Parral Dos" achieved greater height, while "Macho Totomoxtle Morado" was the smallest. Ear shapes varied between open and semi-open, and the leaf color was an intense green.

Resumen

Los maíces locales en México son cruciales para la seguridad alimentaria, la diversidad cultural y la sostenibilidad agrícola. Estas variedades, constituyen un reservorio de diversidad genética crucial para la adaptabilidad del maíz ante condiciones climáticas cambiantes. Con el objetivo de caracterizar 12 maíces locales de la Región Frailesca, Chiapas, se estableció un experimento en condiciones de campo sobre un diseño completamente aleatorizado. Las variables evaluadas fueron: ciclo fenológico, producción de biomasa foliar y radicular, altura y diámetro del tallo, forma de la espiga y coloración de la hoja. Se realizó un análisis multivariado de Conglomerado Jerárquico, para establecer agrupamientos de variedades según sus características. Se realizó un modelo mixto de correlación para evaluar la dinámica de proporción de biomasa radical con respecto a la biomasa total. Se identificaron dos tipologías de acuerdo con sus características fenológicas; el primer tipo agrupó 10 variedades con características de precocidad y el segundo tipo agrupó 2 variedades tardías. En cuanto a la producción de biomasa, se encontraron tres tipos de variedades, las de alta producción de biomasa donde se conglomeraron 4 variedades, las de Baja producción de biomasa representadas por 7 variedades y una variedad atípica de muy alta producción de biomasa. La biomasa radical, se incrementó con tendencia lineal hasta los 120 días. La variedad Olotillo Amarillo Parral Dos, logró mayor altura, mientras que Macho Totomoxtle Morado, fue la de menor tamaño. Las espigas de los genotipos fueron abiertas y semi-abiertas y el color de las hojas fue de un verde intenso.

Introduction

Maize (*Zea mays* L.) is native to Mexico, where a large number of native varieties have been cultivated since ancient times [1,2]. During the domestication of maize, subsistence farmers developed a selection process based on criteria such as flavor and color, which has resulted in a wide diversity of kernel colors and textures [3]. This diversity has been reflected in the culinary traditions of the Mexican people, where corn is the fundamental raw material in the preparation of dishes such as tortillas, pozol, pinole, tamales, tostadas, tejuino, piznate, atole, marquesote, just to name a few [4,5]. On the other hand, the grains can be used to obtain pigments, sugars and totomoxtle, oils, honeys, ethanol; the plant is used as fodder, silage or stubble, the cob is used for human food or fodder, and the ear is used as fuel [6-8].

For the selection process, other criteria related to the establishment, characteristics and management of the crop have been considered. For example, cultivars have been considered for their ability to adapt to extreme climatic conditions such as drought, resistance to pest and disease attack, capacity to develop in impoverished soils, storage durability and grain weight [1]. These characteristics have contributed to the fact that the selected maize varieties demand less external inputs and can be cultivated in a great diversity of agroecosystems [9,10].

Several researchers have studied the domestication process of maize and have identified related characteristics that vary according to the worldview and expectations of those who have developed it in different areas or regions throughout history. This process, largely associated with genetic characteristics and its high capacity for crossbreeding, has served as the basis for studies on terms or concepts that seek to identify and differentiate the varieties and genotypes generalized by large corporations from those maize varieties achieved and preserved by farmers. Among the most notable denominations are hybrid or improved, criollo, acriollados, native and traditional or local maize, as they describe them [11,12].

From the agronomic point of view, the study of maize diversity is an important challenge due to the elements of complexity that condition it, especially when trying to maintain the identity and authenticity of the maize in each locality. For this, it is necessary to have accurate elements of the genetics of these maize varieties, which is the result of the interaction of factors such as management, geographic distance, constant selection and gene flow, which in turn has a marked influence from the anthropogenic point of view [13]. In addition, it is important to consider the morphology and physiology of these maize, with defined indicators that describe their characteristics [13-15].

According to the above, the aim of this work was to carry out the phenological and morphological characterization of a germplasm of 12 local maize varieties from the Frailesca Region-Chiapas, Mexico.

Methods

The study was carried out under field conditions, in the spring-summer 2022 season, at the Centro Universitario de Transferencia de Tecnología San Ramón, Facultad de Ciencias Agronómicas Campus V of the Universidad Autónoma de Chiapas, Mexico, at parallel 16º 15' 13.9" north latitude and meridian 93° 15' 14.2" west longitude, at 610 m.a.s.l. The climate is warm-sub-humid with mean annual temperatures of 22ºC and mean annual rainfall of 1200 mm [16].

The experimental area was 840 m^2 (70 m long by 12 m wide). The 12 genotypes were randomly divided into 50 m^2 plots (10 m long by 5 m wide) spaced 2 m apart. The planting distance was 80 cm between rows and 40 cm between plants, giving a planting density of 156 plants per experimental plot. For each experimental plot, 10 plants were randomly selected to carry out the different phenological and morphological evaluations. The experimental area was considered homogeneous in terms of slope and soil fertility distribution.

Days to emergence (50% of seedlings emerged), days to male flowering (50% of plants were emitting pollen), days to female flowering (50% of plants had receptive stigmas and the beginning of styles), days to physiological maturity (grains with blackish-brown coloration at the tip), were determined.

With the objective of establishing growth dynamics, 10 plants per treatment were randomly selected and identified and the following variables were determined every 30 days until 120 days after planting: plant height from ground level to the node of insertion of the flag leaf (cm); stem diameter (cm), color of the leaf lamina and the shape of the spike. For the determination of fresh and dry leaf and root biomass (g.pl^{-1}), 10 plants were selected and extracted from the field, the leaf and root parts were separated, and the fresh mass was determined with a balance. The samples were dried in an oven at 70°C, until a constant weight was obtained, and the total biomass of the plants was determined.

The phenological data and biomass development obtained were subjected to a multivariate analysis of hierarchical clustering based on Euclidean distance by Ward's method, to establish groupings of varieties according to their characteristics. A non-linear regression analysis was performed using a 3rd degree polynomial model to evaluate the dynamics of aerial biomass production. The dynamics of the ratio of root biomass to total biomass up to 120 days, with the random effect according to the type of variety and its growth pattern, was evaluated by means of a mixed correlation model. The data were processed with the statistical package Statistica for Windows, version 10 [17].

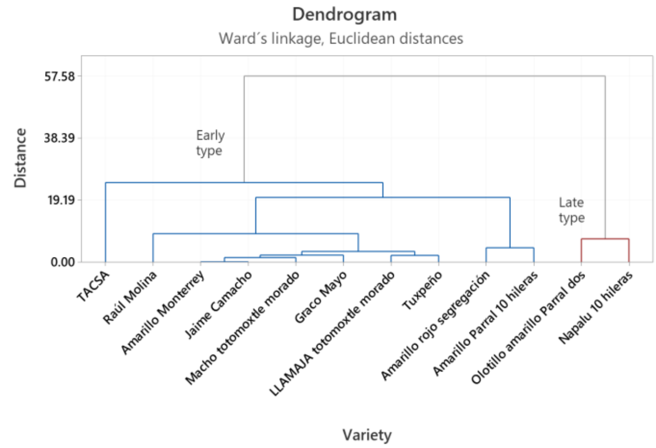
Results

Phenological variables

The 12 maize genotypes evaluated in this experiment showed uniform germination, occurring between 5 and 7 days after planting. This result stands out as a stable and homogeneous manifestation of a process that is susceptible to and could be affected by diverse edaphoclimatic variables. However, in this specific case, a similar behavior was observed in all genotypes, indicating a uniform response in the conditions where the experiment was established.

The rest of the phenological phases in the 12 genotypes did show important variations, which resulted in groupings of varieties according to the duration of each of the phases. Of the 12 local maize varieties studied, two phenological types were identified. The first type identified, grouping 10 of the 12 varieties, was characterized by greater earliness, and was labeled as "Early Type" varieties. On the other hand, the second group with only 2 varieties was labeled "Late Type" with an average delay of 16 days to physiological maturity (figure 1).

Figure 1. Typology of local maize, based on the behavior of phenological variables



The early varieties in this study exhibited notable differences in their phenological cycles (Table 1). The TACSA variety stood out for its rapid cycle, presenting the formation of female and male flowers at 44 and 48 days, respectively, reaching physiological maturity in only 98 days after sowing. On the other hand, the Amarillo Rojo Segregación variety was one of the latest, requiring 56 and 60 days for male and female flowering, respectively, and reaching physiological maturity in 115 days (table 1).

In contrast, the late varieties presented longer and more differentiated cycles (see table 1). Although the onset of male flowering between the Napalu 10 Hileras and Olotillo Amarillo Parral Dos varieties was only one day apart (62 and 63 days, respectively), the difference between the two varieties is as follows, the latter variety needed 7 additional days for the formation of female flowers, prolonging its physiological maturity to 125 days, making it the late variety. In Napalu 10 Hileras, female flowers appeared only 3 days after male flowers, leading to maturity at 120 days, 5 days earlier than Olotillo Amarillo Parral Dos (table 1).

The phenological stages, such as days to male and female flowering, were manifested differently depending on the genotype. In this sense, the TACSA genotype was the first to initiate female flowering, while the latest was Olotillo amarillo Parral Dos. However, in the rest of the genotypes there were no notable differences in relation to the initiation of the male and female flowering stage (table 1).

Table 1. Phenological behavior of local maize

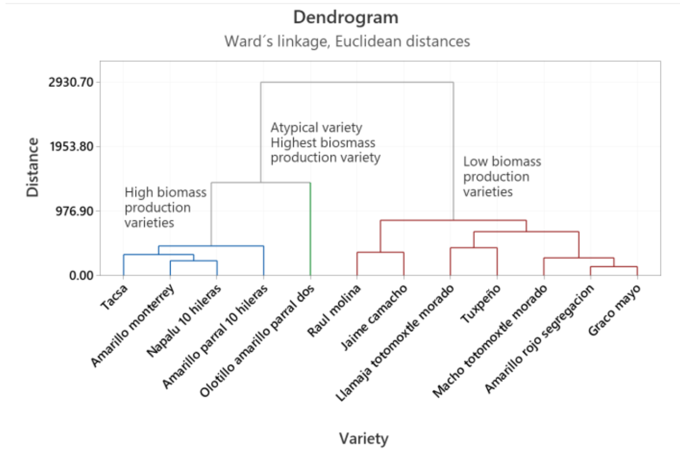
Type	Genotypes	Days to male flowering	Days to female flowering	Days to physiological maturity
Early Type	TACSA	44	48	98
	Raúl Molina	50	53	103
	Amarillo Monterrey	54	56	106
	LLAMAJA Totomoxtle Morado	55	57	107
	Macho Totomoxtle Morado	53	56	106
	Amarillo Rojo Segregación	56	60	115
	Amarillo Parral 10 hileras	55	57	112
	Graco Mayo	53	55	105
	Jaime Camacho	54	56	106
	Mean (Typical Error)	**52.67 (3.67)**	**55.33 (3.32)**	**106.44 (4.88)**
Late Type	Olotillo Amarillo Parral Dos	63	70	125
	Napalu 10 Hileras	62	65	120
	Mean (Typical Error)	**62.5 (0.71)**	**67.5 (3.54)**	**122.5 (3.54)**

In congruence with this behavior, the genotype TACSA was the first to reach physiological maturity, so it is considered early in maturity when compared with the other local maize. On the other hand, the genotype Olotillo amarillo Parral Dos was one of the latest to reach maturity, which did not occur until 125 days (see table 1).

Aerial and root biomass

Regarding biomass production, the cluster analysis allowed the formation of three groups that were labeled as "high biomass producing", "atypical very high biomass producing" and "low biomass producing" varieties (figure 2). Among the biomass producing varieties, TACSA, Amarillo Monterrey, Napalu 10 Hileras and Amarillo Parral 10 Hileras were grouped. The second group was represented by a single variety, in this case Olotillo Amarillo Parral Dos, while the third, grouped the genotypes Raúl Molina, Jaime Camacho, Llamaja Totomoxtle Morado, Amarillo Rojo Segregación and Graco Mayo.

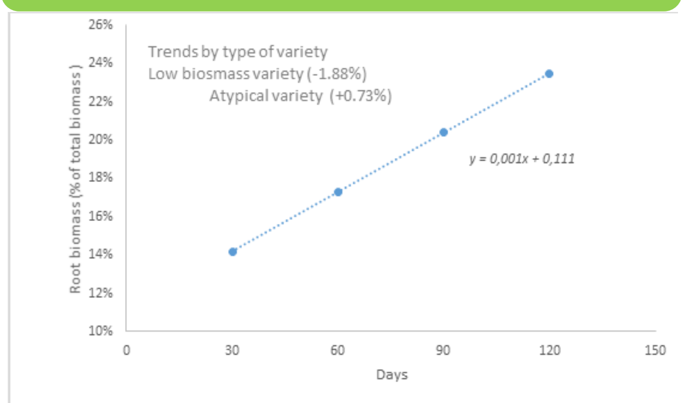
Figure 2. Typology of local maize according to their biomass production



Root biomass proportion

The proportion of plant root biomass increased with a linear trend so that at 120 days it represented 23% of the total biomass, 10% higher than at 30 days (figure 3). This trend was valid for all types of varieties. However, the atypical variety "Olotillo Amarillo Parral Dos" showed a mixed pattern with a trend above the general pattern with a value of 0.77%. On the other hand, in the low biomass producing varieties, the proportion of root biomass tends to be 1.88% lower than the general pattern of genotypes studied (see figure 3).

Figure 3. Percentage ratio of the subterranean part of the plant to the total biomass in local maize



Plant height and stem diameter

The average height of most genotypes is approximately two meters. However, Olotillo Amarillo Parral Dos achieved the greatest height, while Macho Totomoxtle Morado was the smallest (see table 2).

Table 2. Growth indicators of local maize

Type	Genotypes	Plant height (mm)	Stem diameter (mm)
Biomass High Producers	TACSA	2.69	2.5
	Amarillo Monterrey	3.34	2.5
	Napalu 10 Hileras	3.27	3.0
	Amarillo Parral 10 Hileras	3.13	2.9
	Mean (Typical Error)	**3.1 (0.29)**	**2.7 (0.26)**
Biomass Low Producers	Macho Totomoxtle Morado	2.62	2.6
	Amarillo Rojo Segregación	3.41	2.8
	Graco Mayo	3.25	2.7
	Raúl Molina	2.76	2.7
	Jaime Camacho	2.69	2.6
	LLAMAJA Totomoxtle Morado	3.86	2.8
	Tuxpeño	2.99	2.3
	Macho Totomoxtle Morado	2.62	2.6
	Mean (Typical Error)	**3.1 (0.45)**	**2.6 (0.17)**
	Olotillo Amarillo Parral Dos	3.65	2.4

In relation to stem diameter, the Napalu 10 Hileras genotype, was the one that presented the highest values in comparison with Olotillo Amarillo Parral Dos, which showed the lowest thickness, since the plant's growth habit is tall, so the plants tend to have a stem with a relatively smaller diameter.

Spike shape and leaf blade color

The spike shape of the genotypes studied had two manifestations, open and semi-open (table 3). In six of the genotypes the ears were open: Raul Molina, Olotillo Amarillo Parral Dos, Napalu 10 Hileras, Amarillo Parral 10 Hileras, Jaime Camacho and Tuxpeño. Semi-open ears were characteristic of TACSA, Amarillo Monterrey, LLAMAJA Totomoxtle Morado, Macho Totomoxtle Morado, Amarillo Rojo Segregación and Graco Mayo (table 3). All genotypes showed intense green leaf lamina coloration (see table 3).

Discussion

Maize seedling emergence can take 5 to 7 days or more depending on environmental conditions, mainly related to soil temperature and humidity [18,19].

The emergence stage in the life cycle of maize is of crucial importance, marking the moment when the seedling emerges from the soil and begins to grow [18,19]. The early stages of crop development, such as germination and emergence, are susceptible processes. Factors such as seed quality, soil temperature, humidity and planting depth also influence the quality of these processes and determine their uniformity and speed [20].

Table 3. Growth indicators of local maize

Genotypes	Spike Form	Color of the foil sheet
TACSA	Semi-open	Intense green
Raúl Molina	Open	Intense green
Olotillo Amarillo Parral Dos	Open	Intense green
Amarillo Monterrey	Semi-open	Intense green
LLAMAJA Totomoxtle Morado	Semi-open	Intense green
Macho Totomoxtle Morado	Semi-open	Intense green
Amarillo Rojo Segregación	Semi-open	Intense green
Napalu 10 hileras	Open	Intense green
Amarillo Parral 10 Hileras	Open	Intense green
Graco Mayo	Semi-open	Intense green
Jaime Camacho	Open	Intense green
Tuxpeño	Open	Intense green

The emergence process in maize is also influenced by the effect of weed competition and the efficacy of the chemical products used to control them. Slow or uneven emergence can lead to competition with weeds, reducing cotyledon reserves, which is subsequently reflected in subsequent developmental stages and crop yield [20].

In the maturation process, the plants begin to change from green to brown, which is an indicator that the grains have reached their maximum accumulation of dry matter and ensures optimum yield. In this sense, Ron Peñafiel [21], mentions that maize plants have a similar form of development, however, the time between growth stages may vary depending on the type, planting dates, location, altitude at which the maize is located, environmental variables, among other variables.

The phenological development of maize is a multifaceted process influenced by genetic factors inherent to the cultivated variety that can be altered by environmental variables, which have an influence on crop physiology and are generally manifested on growth, development, and yield variables of the crop. For these reasons, the selection work plays an essential role to achieve varieties adapted to specific local conditions and to obtain the maximum expression of the crop depending on the objective pursued.

Factors such as the accumulation of thermal units, day length and light intensity affect the rate of photosynthesis, vegetative growth and the formation of reproductive structures [20].

The relationships described above have been conceptualized as genotype-environment interaction, which translates into how genes and environment interact to influence the development and expression of traits of a given crop, in this case maize [22,23].

As has been demonstrated, the response of plants to this interaction is different and its expression varies among families, species, races and even cultivars. Thus, not all plants have the same capacity to adapt to certain conditions, and at this point, the term phenotypic plasticity is the one that best illustrates these behaviors.
Phenotypic plasticity is the capacity of an organism to produce different phenotypes in response to changes in the environment [24]. In this case, maize is known to have a high phenotypic capacity, which means that it can exhibit a wide variety of physical characteristics and adapt to different environmental conditions [22].

This phenotypic ability is due in part to genetic variability within maize populations. Numerous maize varieties and breeds exist, and farmers have carried out selective breeding and selection over the years to adapt maize to diverse climatic conditions and agricultural requirements [22,24]. The maize plant is highly plastic and can modify its growth and development in response to environmental factors such as light, temperature, humidity, and nutrient availability, among other variables. This ability allows it to thrive in a variety of agricultural environments around the world [22].

For these reasons, understanding the behavior and adaptation of different genotypes to environmental variations have basically been criteria used by producers in their selection process of local maize, although empirically, but with a high success level. Biomass production in maize not only serves as an indicator of crop health, but also plays an essential role in the productivity and efficiency of the agricultural system and the family economy [6]. This process is intrinsically linked to both the quantity and quality of harvested products, including grains. However, its influence is not limited to this, since it is also closely related to the production of fodder, hay or silage [25,26].

In addition, the biomass remaining after the grain harvest is used in various ways, either as direct animal feed for grazing or by incorporating it into the soil. These practices not only ensure the feeding of livestock in producer families, which usually combine maize production with livestock, but also contribute significantly to soil improvement or conservation, especially in cases where there are soil erosion problems [6, 27].

The development of a vigorous root system allows efficient exploration of the soil in search of essential nutrients. The absorption of elements such as nitrogen, phosphorus and potassium is fundamental for plant growth. A healthy root system contributes directly to the aerial development of the plant. The balance between the root mass and the aerial part is essential for the proper functioning of processes such as photosynthesis, nutrient translocation, and the formation of storage structures. Agrotechnics can influence this relationship through practices that favor an adequate balance between root and aerial development [20].

It is important to note that some varieties, having a tall growth habit, faced problems related to lodging. Height is a crucial physiological characteristic that is closely related to plant development and is indicative of its growth rate. However, the taller the plants are, the more susceptible they are to prostration due to their weight when adverse weather conditions or strong wind events occur [20,28]. Height is also influenced by the interaction of factors such as light, humidity and nutrient availability [21,29]. All of these are related to genetic characteristics unique to the genotypes and crop management.

Once all the leaves have finished appearing, the panicle begins to grow, and later the formation of pollen grains begins. After full emergence of the panicle, pollen grains are released, starting in the lower part of the upper middle third of the main axis of the panicle and continuing towards both ends. These clusters host many spikelets or other clusters containing flowers with long filamentous stamens, where pollen or male gametes originate [20].

The terms "open" and "semi-open", when applied to the ears of maize plants, refer to the arrangement of flowers along the ear. These characteristics are of particular importance in relation to pollination and, consequently, grain production [30]. When spikelets are open, there is more space between each female flower as we move up or down the spike. This arrangement facilitates pollen entry and pollination by reducing obstructions between flowers. Open spikes are often associated with greater pollination efficiency and, in some cases, greater resistance to lodging. On the other hand, in semi-open spikes, the female flowers are closer together, creating less space compared to a fully open spike. This type of arrangement falls somewhere in between a fully open and a more closed spike, which may have implications for pollination efficiency and competition between flowers for available resources.

The study of the characteristics of corn ears and leaf coloration is fundamental since they directly influence the development and yield of the crop. The ears, which house the kernels, are essential for seed production and, therefore, for harvesting. The arrangement, length and shape of the spikelets are determining factors in pollination efficiency and grain formation [21].

On the other hand, leaf coloration is a crucial indicator of plant health and its ability to photosynthesize. An intense green color suggests a good level of chlorophyll and photosynthetic activity, which contributes to good plant development. Changes in leaf coloration can reveal nutritional deficiencies or health problems, allowing early interventions to maintain maize vitality and yield [20]. Overall, understanding and managing these traits is essential to optimize the growth, productivity, and quality of the maize crop.

The results obtained in this article highlight the need to acquire in-depth knowledge about the characteristics of local maize varieties cultivated and preserved by farmers in the Frailesca Region. The safeguarding of these varieties not only implies an important biological responsibility due to the genetic richness they treasure, but also forms an integral part of the sociocultural, economic, and productive life of numerous families in this region.

Given the wide diversity of agroecosystems and types of farming families present in the Frailesca Region, it is essential to expand studies related to this topic to other communities, municipalities and shared lands with different demographic, cultural and geographic characteristics. This broader approach will allow for a more complete and contextualized understanding of the importance of local maize varieties in diverse agricultural environments.

Conclusion

Within the set of maize varieties examined, a remarkable diversity in their phenological characteristics and biomass production capacity was highlighted. In terms of phenological development, early and late varieties were distinguished. In terms of biomass production, two different groups were defined: high-yielding and low-yielding varieties. It was observed that low biomass yielding varieties, exhibited a tendency to reach production peaks earlier compared to high yielding varieties. These findings underline the intrinsic variability in the phenological, and productive cycle of the local maize varieties evaluated.

Consent for publication

The authors read and approved the final manuscript.

Competing interest

The authors declare no conflict of interest. This document only reflects their point of view and not that of the institution to which they belong.

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