Colegio de Postgraduados

Morphological and agronomic characterization of pigmented corn races

Hidalgo-Ramos, Dreyli M.[1]; **Rodríguez-Herrera, Sergio A.**[1†]; **Palacios-Rojas, Natalia**[2]; **Lozano-del-Río, Alejandro J.**[3]; **García-Osuna, Hermila Trinidad**[3]; **López-Benítez, Alfonso**[3]; **Mancera-Rico, Arturo**[3*]

[1] Universidad Autónoma Agraria Antonio Narro. Periférico Raúl López Sánchez, Torreón, Coahuila, México. C.P. 27054.
[2] Centro Internacional de Mejoramiento de Maíz y Trigo. km 45 vía México-Veracruz, Texcoco, Estado de México, México. C.P. 56130.
[3] Universidad Autónoma Agraria Antonio Narro, Calzada Antonio Narro 1923, Colonia Buenavista, Saltillo, Coahuila, México. C.P. 25315.
* Correspondence: mncrarico@gmail.com
† All credited authors contributed equally to this research.

ABSTRACT

Objetive: to morphologically characterize accessions of pigmented maize belonging to 25 races for use in genetic improvement programs.

Design/Methodology/Approach: the means of morphological, agronomic and biochemical variables of 275 accessions from 25 maize races were determined. Then, analyses of variance, comparisons of means, and cluster analyses were performed.

Results: there was non-significant variation in plant height, height to the first ear, and number of leaves. The variability was significant in stem diameter, weight of one-thousand grains, grain width, and anthocyanin content. In terms of hardness, 18 of the 25 races fitted the recommended value of flotation index. Four large groups were defined at a Euclidean distance of 5.

Limitations/ Implications of the study: this research was limited exclusively to the study of pigmented accessions, excluding those that lacked this characteristic. This delimitation is justified by the particular objectives of the study. Nevertheless, it is pertinent to consider that the incorporation of non-pigmented accessions in future breeding research could allow the combination of desirable attributes from both (pigmented and non-pigmented) groups. However, genetic variability beyond pigmentation trait is anticipated to be restricted among these groups.

Findings/Conclusions: it was possible to identify the races that comply, in terms of hardness and grain width, with the Mexican standard NMXFF-034/1-SCFI-2020. In addition, the median anthocyanin content was identified, as well as the maximum and minimum value. It was possible to group the races into four groups based on their similarity. The diversity found can be used in genetic improvement programs, as well as in production programs.

Keywords: *Zea mays*, genetic diversity, pigmented maize, native varieties.

Citation: Hidalgo-Ramos, D. M., Rodríguez-Herrera, S. A.†, Palacios-Rojas, N., Lozano-del-Río, A., J., García-Osuna, H. T., López-Benítez, A., & Mancera-Rico, A. (2025). Morphological and agronomic characterization of pigmented corn races. *Agro Productividad*. https://doi.org/10.32854/h38zjr61

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Daniel Alejandro Cadena Zamudio

Received: November 29, 2024.
Accepted: April 16, 2025.
Published on-line: May XX, 2025.

Agro Productividad, 18(4). April. 2025. pp: 199-206.

INTRODUCTION

Mexico is considered the center of origin, domestication, and diversification of maize, since there is a great genetic diversity throughout the national territory, as evidenced by

the 68 native races identified (Kato *et al.*, 2009; Caballero-García *et al.*, 2019; López-Morales *et al.*, 2020). This genetic diversity is composed of complexes of multiple local variants or landraces, which meet the cultural needs of the producers and adapt to the agroecological conditions of each region (Pressoir y Berthaud, 2004). Maize landraces are produced in all agroecological regions of Mexico (Hernandez-Trejo *et al.*, 2023), so those play an important role in the domestic strategies of farmers, because are resistant and predictable options in terms of agronomic behavior, issuing confidence for production (Hellin *et al.*, 2013; Bellon *et al.*, 2011).

Pigmented maize is highly valued by consumers, due to the nice appearance it adds to products that are part of the human diet and economically sustain small producers in rural areas (Hernández *et al.*, 2017). These natural water-soluble pigments of the flavonoid group —anthocyanidin glycosides— which are present in the vacuoles of plant cells, giving red, purple or blue color are known as anthocyanins (Guillén-Sánchez *et al.*, 2014). The content and type of anthocyanins in the maize kernel varies according to the color of the grain and the concentration of the pigment in the different structures (Salinas *et al.*, 2013). The objective of this research was to morphologically characterize accessions of pigmented maize belonging to 25 races for their use in genetic improvement programs.

MATERIALS AND METHODS

Genetic material

A total of 275 pigmented maize accessions corresponding to 25 maize races were evaluated; these were provided by the gene bank of the International Maize and Wheat Improvement Center (CIMMYT, Mexico). These accessions come from tropical and subtropical regions of the Mexican Republic. The races are (English transliterated) Ancho, Arrocillo, Arrocillo Amarillo, Azul, Bofo, Bolita, Cacahuacintle, Celaya, Chalqueno, Conico, Conico Norteno, Cristalino de Chihuahua, Elotes Conicos, Elotes de Sinaloa, Elotes Occidentales, Maiz Dulce, Mushito, Nal-Tel, Olotillo, Oloton, Pepitilla, Reventador, Tabloncillo, Tepecintle and Tuxpeno.

Experimental site

The evaluation of the genetic materials was done in the experimental lands of the Universidad Autónoma Agraria Antonio Narro in Saltillo, Coahuila, Mexico, at coordinates 25° 20’ 37” N and 101° 01’ 53” W and 1820 m altitude; With an average annual rainfall of 400 mm and an average annual temperature of 20 °C.

Crop management

The sowing was made in June 2019, manually with a population density of 62 500 plants per hectare, in rows separated 0.80 m, and 0.20 m between plants. The experimental units located in 4 m long furrows per accession. The technical management of the crop was based on the recommendations of (SAGARPA, 2015). In the soil, the fertilization dose of 300 kg ha^{-1} of nitrogen in the form of urea, and 100 kg ha^{-1} of phosphorus was applied. Weeds were controlled manually and mechanically at pre-planting and 30 days after planting.

Variables evaluated

Plant height. The measurement of this variable was done in the reproductive stage of the crop (R1, or presence of '*jilote*', the tassel), excluding the size of tassel and silks. Four plants under full competition were taken as the experimental unit by accession, reporting the plant height value in meters (m).

Height to the first ear. Sampling was done in the reproductive stage of the crop (R5, or physiological maturity by milky kernels line), measuring from the base of the stem to the beginning of the first ear. Four plants under full competition by accession were taken as the experimental unit.

Stem diameter. This variable was measured at a height of 10 cm from the base of the stem. The sample was evaluated at the end of the vegetative stage of the crop (VT, or presence of tassel), taking as the experimental unit a total of 4 plants under full competition by accession.

Number of leaves per plant. This variable was measured at the end of the vegetative stage of the crop (VT), taking as an experimental unit a total of 4 plants under full competition by accession.

Weight of one-thousand grains. For each accession, the average weight of 100 grains was recorded in triplicate, then that value was extrapolated, according to ISTA (2018) procedure.

Grain width. The average width of 10 grains per accession was determined, according to the methodology described by SNICS (2014), with the use of a digital Vernier (Truper, Model 14388, Mexico).

Total anthocyanin content. Twenty grains of each accession were ground and anthocyanin extraction was performed by weighing 20 mg of flour inside 1.5 mL Eppendorf tubes and adding 1.3 mL of trifluoroacetic acid (TFA). The absorbance of the samples was read at 520 nm in a Quant BioTek microplate reader (Palacios, 2018). The results were recorded in micrograms per gram ($\mu g\ g^{-1}$).

Grain hardness. To determine this variable, the flotation index was obtained by performing the procedure as described in the NMXFF-034/1-SCFI-2020 standard (Secretaría de Economía-México, 2020). This consists of placing 100 grains in a sodium nitrate solution at a 1.25g mL^{-1} density ($\pm$0.001 g mL^{-1}), at a temperature of 22 °C to 23 °C; then quantifying the number of grains risen to the surface. Very hard grains are considered when the number of grains rising to the surface goes from 0 to 12; hard grains account from 13 to 37 rising to the surface; in grains with intermediate hardness 38 to 62 rise to the surface; soft grains if the number of grains rising to the surface ranges from 63 to 87; and very soft grains if rising grains are accounted from 88 to 100 grains (the total of grains in the sample).

Statistical analyses

To compare the agronomic, morphological, and biochemical variables of 25 pigmented maize races, an analysis of variance and a comparison of means using Tukey's test ($p \leq 0.05$) were performed. The coefficient of variation of the flotation index for each race was obtained through the accessions. Based on the variables, total anthocyanin content, flotation index, weight of one-thousand grains, grain width, plant height, stem diameter, height to the first ear, and number of leaves per plant; a cluster analysis was performed to generate a dendrogram, calculating the Euclidean distance with data standardized to mean zero and variance one. These analyses were performed in the statistical software suite R Studio (v. 4.1.2), using libraries *ggplot2*, *factoextra*, *cluster* and *purrr*.

RESULTS AND DISCUSSION

The highest values of plant height were found in the 'Elotes de Sinaloa' race, the races with the lowest plant height were 'Arrocillo' and 'Nal-Tel' (Table 1). These results are

Table 1. Comparison of means of agronomic, morphological and biochemical variables of 25 pigmented maize races.

Landrace	AP (m)	AM (m)	DT (cm)	NH (Adim)	PMG (g)	AG (cm)	CAT (μg g^{-1})
Ancho	1.74	0.68abc	1.9b	12a	352cd	0.53a	309b
Arrocillo	1.53	0.50bc	1.8b	9a	333cde	0.67a	391ab
Arrocillo Amarillo	1.63	0.37c	2.2ab	11a	331cdef	0.51a	385ab
Azul	1.78	0.74abc	2.5a	13a	314def	0.57a	315b
Bofo	1.73	0.67abc	2.1ab	11a	352c	0.55a	325b
Bolita	1.75	0.75abc	2.1ab	13a	308efg	0.5a	273b
Cacahuacintle	1.8	0.82a	2.4ab	14a	394bc	0.48a	348b
Celaya	1.6	0.60abc	2.4ab	12a	405bc	0.6a	243b
Chalqueño	1.74	0.69abc	2.1ab	11a	363c	0.57a	367b
Cónico	1.71	0.64abc	2.1ab	11a	365c	0.53a	301b
Cónico Norteño	1.86	0.68abc	2.0b	11a	326cdef	0.57a	313b
Cristalino de Chihuahua	1.8	0.75abc	2.2ab	13a	311defg	0.6a	343b
Elotes Cónicos	1.69	0.62abc	2.0b	11a	358c	0.57a	324b
Elotes de Sinaloa	1.9	0.80ab	2.4ab	14a	446ab	0.53a	347b
Elotes Occidentales	1.82	0.73abc	2.0b	12a	439b	0.52a	330b
Maíz Dulce	1.8	0.75abc	1.6c	12a	283fg	0.47a	595a
Mushito	1.87	0.77ab	2.1ab	13a	323cdef	0.44a	305b
Nal-Tel	1.53	0.53abc	1.9b	9a	244g	0.64a	292b
Olotillo	1.73	0.65abc	2.2ab	12a	401bc	0.59a	272b
Oloton	1.69	0.65abc	2.1ab	12a	471a	0.57a	368b
Pepitilla	1.8	0.75abc	2.1ab	12a	403bc	0.66a	349b
Reventador	1.73	0.66abc	2.0b	11a	298efg	0.48a	261b
Tabloncillo	1.7	0.65abc	2.0b	12a	325cdef	0.51a	267b
Tepecintle	1.74	0.62abc	1.9b	11a	386c	0.5a	280b
Tuxpeño	1.68	0.61abc	2.0b	11a	285fg	0.56a	357b

AP: plant height (non-significant difference); AM: height to the first ear; DT: stem diameter; NH: number of leaves per plant; Adim: dimensionless; PMG: weight of one-thousand grains; AG: grain width; CAT: total anthocyanin content. Means with different letters indicate statistical difference ($p \leq 0.05$).

similar to those presented by Arellano-Vázquez *et al.* (2003) in native varieties of blue-grain maize of poor adaptability in five localities of the highlands of Central Mexico, with plant height values between 1.36 m and 1.51 m; non-significant difference was found in the variable height to the first ear.

The highest stem diameter was found in the 'Azul' race with 2.6 cm and the smallest was obtained by the 'Maiz Dulce' race with 1.6 cm, these values are similar to those obtained by Verde-Aquino and Santolalla-Ruíz (2021) in a research on the adaptation of 30 double-cross hybrids of maize for forage with an overall average of 1.88 cm. The number of leaves ranged from 9 to 14, with a mode of 11 and an average of 11.7; these values are similar to those obtained by Cutiño-Mendoza *et al.* (2022) in the agronomic evaluation of three varieties of maize where they recorded 12 leaves per plant of native maize.

The weight of one-thousand grains presented a significant difference in the 25 races of maize. The Oloton race obtained the highest value (471 g) and the Nal-Tel race obtained the lowest (244 g). Ramírez *et al.* (2020) reported a maximum value for weight of one-thousand grains of 335.78 g in a purple native maize variety. The grain width ranged from 0.44 to 0.67 cm, only the races Mushito and Maiz Dulce had a grain width less than 0.476 cm, which is the minimum acceptable reference for maize grain that is intended for the production of tortillas and nixtamal-manufactured products, as established in the Mexican standard NMXFF-034/1-SCFI-2020 (Secretaria de Economía, 2020). The minimum and maximum anthocyanin content were 243 and 595 μg g^{-1}, for the Celaya and Maiz Dulce races, with a median of 324 (Table 1).

The flotation index showed values between 18% and 75% (Table 2) for Elotes de Sinaloa and Tabloncillo, which corresponds to grains ranging from hard to soft. Nine races presented hard grains, 14 with intermediate hardness and 2 showed soft grains. Seven races exceeded the recommended flotation index value, whereas the remaining 18 races meet the recommended hardness by showing from 10% to 50% floating grains (NMXFF-034/1-SCFI-2020; Secretaría de Economía, 2020).

In the dendrogram generated based on the agronomic and morphological variables of the 25 maize races analyzed (Figure 1), four large groups are shown on the base of a Euclidean distance of 5. The first group has two subgroups; the first subgroup is composed of the races Celaya, Olotillo, Pepitilla, Elotes occidentales and Oloton, whereas the second subgroup is composed of the races Cacahuacintle, Elotes de Sinaloa, Bolita, Mushito, Azul, and Cristalino de Chihuahua.

The second group included the Maíz Dulce race alone. The third group is composed of the races Arrocillo and Nal-Tel. The fourth group is formed of the races Arrocillo Amarillo, Reventador, Tepecintle, Ancho, Tabloncillo, Tuxpeno, Elotes conicos, Bofo, Conicos, Chalqueno and Conico norteno (English transliterated).

CONCLUSIONS

We characterized 275 accessions of pigmented maize from 25 native races, that were compared through morphological, agronomic and biochemical variables. This made it possible to identify those races that comply with the Mexican standard NMXFF-034/1-

Table 2. Flotation index and grain hardness of 25 maize races.

Landrace	Flotation index	CV	Grain hardness
Ancho	44	0.76	Intermediate hardness
Arrocillo	37	0.34	Hard
Arrocillo Amarillo	30	0.16	Hard
Azul	54	0.64	Intermediate hardness
Bofo	44	0.86	Intermediate hardness
Bolita	44	0.67	Intermediate hardness
Cacahuacintle	38	0.67	Intermediate hardness
Celaya	75	0.16	Soft
Chalqueño	60	0.54	Intermediate hardness
Cónico	43	0.73	Intermediate hardness
Cónico Norteño	46	0.69	Intermediate hardness
Cristalino de Chihuahua	23	0.15	Hard
Elotes Cónicos	49	0.66	Intermediate hardness
Elotes de Sinaloa	18	0.99	Hard
Elotes Occidentales	54	0.67	Intermediate hardness
Maíz Dulce	50	0.66	Intermediate hardness
Mushito	57	0.28	Intermediate hardness
Nal-Tel	48	0.33	Intermediate hardness
Olotillo	19	0.92	Hard
Oloton	51	0.50	Intermediate hardness
Pepitilla	20	0.35	Hard
Reventador	26	0.75	Hard
Tabloncillo	75	0.42	Soft
Tepecintle	33	0.95	Hard
Tuxpeño	32	0.99	Hard

As a reference, the desirable flotation index values go from 10%-50%, according to NMXFF-034/1-SCFI-2020 (Secretaría de Economía, 2020). CV: coefficient of variation.

SCFI-2020, in terms of hardness and grain width. In addition, the median anthocyanin content was identified, as well as the maximum and minimum value.

With the variables evaluated, it was possible to group these races into four groups according to their similarity. The diversity found can be used in genetic improvement programs, as well as in production programs for the better use of these native varieties of Mexican maize.

AKNOWLEDGEMENTS

To Mexico's National Council of Humanities, Sciences and Technologies– CONAHCYT for the scholarship Num. 700733 awarded for doctoral studies. To the Federal Government MasAgro Biodiversity program, for the support provided to implement this research.

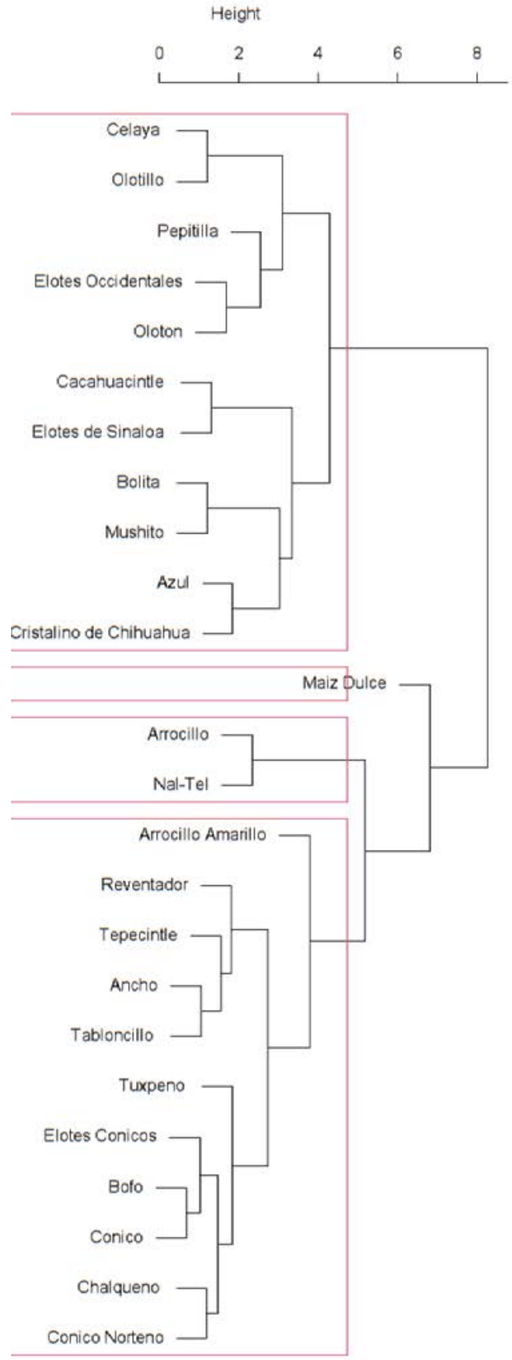

Figure 1. Dendrogram of 25 maize races, considering the variables total anthocyanin content, flotation index, weight of one-thousand grains, grain width, plant height, stem diameter, height to the first ear, and number of leaves per plant.

REFERENCES

Arellano-Vázquez, J. L., Tut-Couoh, C., María-Ramírez, A., Salinas-Moreno, Y., & Taboada-Gaytán, O. R. (2003). Maíz azul de los Valles Altos de México. I. Rendimiento de grano y caracteres agronómicos. *Revista Fitotecnia Mexicana, 26*(2), 101-101.

Bellon M. R., & Hodson D., Hellin J. (2011). Assessing the vulnerability of traditional maize seed systems in Mexico to climate change. *Proc. Natl. Acad. Sci. USA*. 108:13432-7. doi:10.1073/ pnas.1103373108

Caballero-García, M. A., Córdova-Téllez, L. & López-Herrera, A. J. (2019) Validación empírica de la teoría multicéntrica del origen y diversidad del maíz en México. *Revista Fitotecnia Mexicana* 42:357-366, https://doi.org/10.35196/rfm.2019.4.357-366

Cutiño-Mendoza, A., Vuelta-Lorenzo, D. R., Molina-Lores, L. B., Vargas-Batis, B., Fernández-Hechavarría, M., & Mustelier-Ocle, M. C. (2022). Evaluación agronómica de 3 variedades de maíz (*Zea mays* L.) en las condiciones edafoclimáticas de la finca "El Porvenir" del consejo popular "La Coronú", Contramaestre. *Revista Transdiciplinaria de Estudios Sociales y Tecnológicos, 2*(3), 49-58. https://doi.org/10.58594/rtest.v2i3.55

Guillén-Sánchez, J., Mori-Arismendi, S., & Paucar-Menacho, L. (2014). Características y propiedades funcionales del maíz morado (*Zea mays* L.) var. subnigroviolaceo. *Scientia Agropecuaria* 5: 211-217.

Hellin, J., Keleman, A., López, D., Donnet, L., & Flores, D. (2013). La importancia de los nichos de mercado: Un estudio de caso del maíz azul y del maíz para pozole en México. *Revista fitotecnia mexicana*, 36, 315-328.

Hernández, Q. J. D. D., Rosales, N. A., Molina, M. A., Miranda, P. A., Willcox, M., Hernández, C. J. M., & Palacios, R. N. (2017). Cuantificación de antocianinas mediante espectroscopia de infrarrojo cercano y cromatografía líquida en maíces pigmentados. *Rev. Fitotec. Mex. 40*(2):219-225.

Hernandez-Trejo, A., López-Santillán, J. A., Estrada-Drouaillet, B., Reséndiz-Ramírez, Z., Coronado-Blanco, J. M., & Malvar, R. A. (2023). Aptitud combinatoria y efectos recíprocos de la precocidad en poblaciones nativas de maíz de Tamaulipas. *Revista mexicana de ciencias agrícolas, 14*(2), 171-183. Epub 19 de junio de 2023. https://doi.org/10.29312/remexca.v14i2.2990

ISTA (International Seed Testing Association). (2018). International rules for seed testing. International Seed Testing Association: Bassersdorf, CH-Switzerland.

Kato Y. T. A., Mapes S., C., Mera O., L. M., Serratos H., J. A., & Bye B., R. A. (2009). Origen y Diversificación del Maíz: Una Revisión Analítica. Universidad Nacional Autónoma de México, Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. México, D. F. 116 p.

López-Morales, F., García-Zavala, J. J., Corona-Torres, T., Cruz-Izquierdo, S., López-Romero, G., Reyes-López, D., Vásquez-Carrillo, M. G., & Molina-Galán, J. D. (2020). Comparación del rendimiento y cambios morfológicos en maíz Tuxpeño V-520C adaptado a valles altos en México. *Revista Fitotecnia Mexicana*. https://doi.org/10.35196/rfm.2020.2.133

Palacios, R. N. (2018). Calidad nutricional e industrial de maíz: laboratorio de calidad nutricional de maíz "Evangelina Villegas" CDMX, México: CIMMYT.

Pressoir G., & Berthaud, J. (2004). Population structure and strong divergent selection shape phenotypic diversification in maize landraces. *Heredity* 92:95-101, https://doi.org/10.1038/sj.hdy.6800388

Ramírez Reynoso, O., Escobar Álvarez, J. L., Maldonado Peralta, M. D. L. Á., Rojas García, A. R., Hernández Castro, E., & Valenzuela-Lagarda, J. L. (2020). Calidad de mazorca y grano en maíces criollos de la Costa Chica, Guerrero. *Revista mexicana de ciencias agrícolas, 11*(SPE24), 239-246.

SAGARPA (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación) (2015). Maíz punta de riego. Agenda Técnica Agrícola Guanajuato. Segunda edición. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias– INIFAP-. Servicio Nacional de Sanidad, Inocuidad y Calidad Alimentaria– SENASICA. México. pp: 225-232.

Salinas Moreno, Y., García Salinas, C., Coutiño Estrada, B., & Vidal Martínez, V. A. (2013). Variabilidad en contenido y tipos de antocianinas en granos de color azul/morado de poblaciones mexicanas de maíz. *Revista fitotecnia mexicana, 36*(Supl. 3-a), 285-294. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0187-73802013000500005&lng=es&tlng=es

Secretaria de Economía (2020). Productos alimenticios para uso humano no industrializados– cereales– maíz (*Zea mays* L.); especificaciones y métodos de prueba NMXFF-034/1-SCFI-2020 (cancela a la NMX-FF-034-2002). Secretaría de Economía, Gobierno de México. https://sidof.segob.gob.mx/notas/docFuente/5650699

SNICS (Sistema Nacional de Inspección y Certificación de semillas). (2014). Guía técnica para la descripción varietal de maíz (*Zea mays* L.).

Verde-Aquino, J., & Santolalla-Ruiz, S. H. (2021). Adaptación de 30 híbridos dobles de maíz forrajero (*Zea mays* L.) en el rendimiento de biomasa y de grano seco. *Revista Investigación Agraria, 3*(1), 52-62.