Research, Society and Development, v. 10, n. 8, e7110817141, 2021
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v10i8.17141

Characterization of the seeds of a landrace popcorn (*Zea mays* L. subsp. *mays*) cropped in an organic system via Family Farming

Caracterização de sementes de uma variedade crioula de milho pipoca (*Zea mays* L. subsp. *mays*) cultivada em sistema orgânico pela Agricultura Familiar

Caracterización de semillas de una variedad criolla de maíz palomero (*Zea mays* L. subsp. *mays*) cultivada en un sistema orgánico por la Agricultura Familiar

Received: 06/13/2021 | Reviewed: 06/19/2021 | Accept: 06/22/2021 | Published: 07/05/2021

Loanda Maria Gomes Cheim
ORCID: https://orcid.org/0000-0002-5065-5211
Universidade Federal de Mato Grosso, Brazil
E-mail: loandac@hotmail.com
Flaviane Malaquias Costa
ORCID: https://orcid.org/0000-0002-8402-5701
Universidade de São Paulo, Brazil
E-mail: flavianemcosta@hotmail.com
Natália Carolina de Almeida Silva
ORCID: https://orcid.org/0000-0003-3399-8420
Universidad Tecnológica del Uruguay, Uruguay
E-mail: natalia.dealmeida@utec.edu.uy
Carlos Caneppele
ORCID: https://orcid.org/0000-0002-6678-371X
Universidade Federal de Mato Grosso, Brazil
E-mail: caneppele@ufmt.br
Ana Luiza Trovo Marques de Souza Cesar
ORCID: https://orcid.org/0000-0002-2725-3169
Universidade Federal de Mato Grosso, Brazil
E-mail: analuizatrovo@hotmail.com
Paulo Afonso Rossignoli
ORCID: https://orcid.org/0000-0002-2284-4306
Universidade Federal de Mato Grosso, Brazil
E-mail: parossi@terra.com.br
Alexandre Magno de Melo Faria
ORCID: https://orcid.org/0000-0001-6584-1925
Universidade Federal de Mato Grosso, Brazil
E-mail: melofaria@ufmt.br

Abstract
Popcorn consumption is increasing progressively worldwide. Landrace popcorn (LP) are cultivated in family farming. The objective of this study was to characterize a LP in an organic system by family farmers. LP was analysed for the phenotypic characterization and race identification, germination and vigor, thickness/width ratio, circularity index, sphericity, diameter ratio, geometric mean diameter, volume, surface area, angle of repose (AR), hectoliter weight (HW), apparent specific gravity (ASG), thousand kernel weight (TKW), color, and classification according to identity and quality requirements. LP is of an indigenous Guarani origin and belongs to the *Avatí Pichingá Ihú* race. The variety yields a high germination and vigor and can be used as seeds. The dimensions and calculated indices had important variations among the grains, demonstrating a wide genetic diversity, typical of landraces. The low AR, associated with the dimensions, revealed the small size of the LP grains. Higher values for HW, ASG, and TKW indicated higher levels of vitreous endosperm, hardness, and starch content. The coordinates a * and b * respectively indicate the red and yellow colors while the low value for the parameter L * indicates the intense color of the LP. Corn was classified as type 1 according to the percentage of physical defects, however, the expansion capacity presented a value below the reference for commercialization. The potential of the studied variety is verified to be used by industries, mainly the food sector. Its cultivation can be stimulated by family farming, ultimately impacting grain production and promoting the rescue of germplasm.
Keywords: Popcorn landraces; Phenotypic characterization; Racial characterization; Physiological quality; Physical characteristics.

Resumo
O consumo de pipoca aumenta progressivamente em todas as regiões do mundo. Variedades crioulas de milho pipoca são cultivadas pela agricultura familiar. Objetivou-se caracterizar uma variedade crioula de milho pipoca (VCP) cultivada em sistema orgânico pelos agricultores familiares. Análises realizadas: caracterização fenotípica e identificação da raça, germinação e vigor; relação espessura/largura, índice de circularidade, esfericidade, diâmetro médio geométrico, relação de diâmetro, volume, área de superfície, ângulo de repouso (AR), massa específica (MEA), peso hectolitro (PH), peso de mil grãos (PMG), cor e classificação conforme requisitos de identidade e qualidade. A VCP é de origem indígena Guarani e pertence à raça *Avatí Pichingá Ihú*. A variedade apresentou elevado percentual de plântulas normais e pode ser utilizada como semente. As dimensões e os índices calculados apresentaram variação importante entre os grãos, demonstrando ampla diversidade genética, típico de variedades crioulas. O AR baixo, associado às dimensões, caracterizou os grãos da VCP de tamanho pequeno. Os valores superiores para PH, MEA e PMG indicaram maiores teores de endosperma vítreo, dureza e conteúdo de amido. As coordenadas a* e b* indicaram cor vermelha e tendência ao amarelo, respectivamente. O valor baixo para o parâmetro L* indicou cor intensa da VCP. O milho foi classificado como tipo 1 conforme percentual de defeitos físicos, porém a capacidade de expansão apresentou valor abaixo da referência para comercialização. Verifica-se o potencial da variedade estudada para ser usada pelas indústrias, principalmente alimentícia. Pode-se estimular seu cultivo pela agricultura familiar, causando impacto na produção regional do grão e promovendo o resgate do germoplasma.
Palavras-chave: Variedade crioula de milho pipoca; Caracterização fenotípica; Caracterização racial; Qualidade fisiológica; Características físicas.

Resumen
El consumo de palomitas de maíz está aumentando progresivamente en todo el mundo. Las variedades criollas de maíz palomero son cultivadas por la agricultura familiar. El objetivo fue caracterizar una variedad criolla de maíz palomero (VCP) cultivada en un sistema orgánico por agricultores familiares. Análisis realizados: caracterización fenotípica e identificación de raza, germinación y vigor; relaciónes pesor/ancho, índice de circularidad, esfericidad, diámetro medio geométrico, relación de diámetro, volumen, área de superficie, ángulo de reposo (AR), masa específica (MEA), peso hectolitro (PH), peso de mil granos (PMG), color y clasificación según requisitos de identidad y calidad. VCP pertenece a la raza *Avatí Pichingá Ihú*. La variedad mostró un alto porcentaje de plántulas normales. Las dimensiones e índices calculados mostraron variación entre granos, demostrando una amplia diversidad genética. El bajo AR, asociado a las dimensiones, caracterizó el pequeño tamaño de los granos de VCP. Los valores más altos de PH, MEA y PMG indicaron niveles más altos de endospermo vítreo, dureza y contenido de almidón. Las coordenadas a * y b * indicaron color rojo y amarilla, respectivamente. El valor bajo para el parámetro L * indicóun color intenso del VCP. El maíz se clasificó como tipo 1 según el porcentaje de defectos físicos, sin embargo, la capacidad de expansión presentó un valor abajo del valor de referencia para la comercialización. Existe el potencial de la variedad estudiada para ser utilizada por industrias, principalmente alimenticias. Su cultivo puede ser estimulado por la agricultura familiar, impactando la producción de semillas y promoviendo el uso del germoplasm.
Palabras clave: Variedad criollas de maíz palomero; Caracterización fenotípica; Caracterización racial; Calidad fisiológica; Características físicas.

1. Introduction

Corn is one of the most produced and consumed cereals worldwide (Food and Agriculture Organization of the United Nations Statistics Division [FAO], 2018). It is used by the food, chemical, textile, and cosmetic industries. The food sector that most uses the grain, due to the diversity of products that can be derived from it. Corn can be used as a grain; to prepare cake, *broa*, bread, pie, cookie, hominy, cream, popcorn, *polenta*, porridge, *angú*, *munguzá*, couscous, soup, snacks, cornflakes, tortilla and animal feed; as a thickener, stabilizer, gel-forming agent, and as an encapsulating agent (Cárdenas et al., 2013; Macedo et al., 2020).

For the 2020/21 harvest, the United States Department of Agriculture estimates a worldwide increase in the production of 72.1 million tons (t) and the consumption of 35.5 million tons of grain. The forecast is that the United States will have a production of 406.3 thousand tons, maintaining its place as the first producer globally, followed by China and Brazil, with production of 260.0 and 106.0 thousand tons, respectively (Companhia Nacional de Abastecimento [CONAB], 2020). In the state of Mato Grosso (MT), based on the climate conditions and the high investments made in the crop, the expected average yield is 8.398 kg/ha, which should result in the state production of 438.4 thousand tons, 26.9% higher than the 345.6 thousand tons harvested last season (CONAB, 2021). Despite the increase in demand and supply of popcorn, in the national and international market, there is no publication of official statistical data related to the area of cultivation and the yield and consumption of this type of corn. This is because the National Supply Company and the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística [IBGE]), which carry out a systematic survey of agricultural production in Brazil, collect popcorn data and common corn data. According to the systematic survey of agricultural production in MT, of the total corn produced in the state (26,200 t), in the 2017/2018 crop, only 1% was popcorn. The main producer is Campo Novo do Parecis (53.4%), followed by Sapezal (15.4%) and Campos Júlio with 9.8% of production (IBGE/Reunião Estadual de Estatísticas Agropecuárias de Mato Grosso [REAGRO/MT], 2019).

The popcorn grain expands when it is heated, and its pressure and internal temperature reach 930.79 kPa (135 p.s.i.) and 180 °C, respectively, with the evaporation of water inside and the expansion of the vitreous endosperm and pericarp (Hoseney et al., 1983; Paraginski et al., 2016a; Silva et al., 1993). Popcorn consumption as a salty snack, exclusively by humans, is increasing globally. The low cost and easy preparation using microwaves, electric popcorn pans or the conventional method, in pans, with or without oil and butter, contribute to this increase. Another reason is the interest and demand of consumers for food with higher nutritional, functional, and sensory qualities. Popcorn is considered a healthy snack, compared to other snacks, such as potato chips, mainly due to its dietary fiber content (17.79%) and low calorie content (25 to 55 kcal in 250 mL), when prepared without oil or butter, and by the presence of phytochemicals with antioxidant capacity (Paraginski et al., 2016a, 2016b; Park, et al., 2000; Ziegler et al., 2020). The consumption of whole grains has been associated with several health benefits, including reduced risk of chronic diseases, such as type 2 diabetes, coronary heart disease, hypertension, and cancer (Coco Jr. & Vinson, 2019; Colombo et al., 2021; Lillioja et al., 2013; Paraginski et al., 2016b; Urias-Lugo et al, 2015; Zhao, et al., 2005; Ziegler et al., 2020; Zhu, 2018). The popcorn kernel consists of carbohydrates (72.3%), mainly starch and protein (9.9%), located in the endosperm; lipid (2.8%) located in the germ; and dietary fiber (11.1%), a large part located in the pericarp, providing approximately 355.2 kcal/100 g (Sweley et al., 2012). However, this composition can vary depending on genetics, climate, cultivation conditions, harvest periods, post-harvest conditions, and grain processing (Moreira et al., 2015; Mutlu et al., 2018).

Despite the increase in the production and consumption of popcorn in Brazil, most popcorn cultivars used by Brazilian producers for commercial purposes are imported from the United States and Argentina. In general, these varieties have been developed by breeding programs to produce popcorn with a good appearance, crunchy texture, and high yield (Isnaini et al., 2020). However, there is a diversity of maize landraces cultivated by family farmers, indigenous peoples, and traditional communities in Brazil (Costa et al., 2021; Silva et al., 2017). Landraces, also known as traditional varieties, local variety, and ethnovarieties, are varieties developed, adapted or produced by family farmers, settled by agrarian reform or indigenous, with well-defined phenotypic characteristics. These varieties are recognized by the respective communities and which, at the discretion of the Ministry of Agriculture, Livestock and Supply (Ministério da Agricultura, Pecuária e Abastecimento [MAPA]) who also considers the sociocultural and environmental descriptors, are not characterized as substantially similar to commercial cultivars (Brasil, 2003). These varieties are important because they constitute a source of genetic variability and their use has benefits associated with the sustainability of production, such as resistance to diseases, pests, and climatic imbalances. Further, they enable the storage of seeds for the subsequent crops, reducing production costs. Creole species have a great advantage over conventional corn seeds, as most of the latter are hybrids and must be purchased annually, as they lose their genetic quality when reused for the next crop (Araújo et al, 2015; Costa et al., 2021; Silva et al., 2017).

In Brazil and adjacent areas (Argentina, Paraguay, Uruguay, Chile, Lowlands of Bolivia and Guyanas), the diversity of corn races was initially described by Cutler (1946), expanded by Brieger et al., (1958) and supplemented by Paterniani and Goodman (1977) and Silva et al., (2020). Paterniani and Goodman (1977) identified 34 races organized in four groups, according to the adaptation period: Indigenous, Old Commercials, Recent, and Exotic Commercials. The classification of popcorn races was based on studies by Brieger et al., (1958), who reported that, possibly, only the Guarani, among the indigenous ethnic groups that still inhabit the lowlands of South America, cultivated races of popcorn, which are: *Avatí Pichingá* with pointed grains and *Avatí Pichingá Ihú* with round grains. Its distribution included southern Brazil, part of Argentina, lowlands of Bolivia, and practically all of Paraguayan territory. Anderson and Cutler (1942) defined the maize race as 'a group of related populations, with enough characteristics in common to allow its recognition as a group'. These authors considered that the morphological characters of the ear and the kernel were essential to the classification of races. Subsequently, Brieger et al. (1958) expanded the concept and defined maize races as 'a set of populations in *panmixis* occupying a defined geographical area'. Therefore, the concept is based on grouping of similar populations with respect to morphological characters and geographical origin.

The high energy demand for obtaining synthetic fertilizers as well as the high costs of hybrid seeds increase the cost of production, making it unfeasible it is for small farm. Considering the rich diversity of landraces with little known potential, the low availability of popcorn cultivars and seeds in the Brazilian market, and the limited resources to invest in technology for cultivation, genetic improvement, and synthetic fertilizers, the cultivation of creole seeds in the organic system by family farmers will provide greater market autonomy, without paying royalties to multinationals, and enable food self-sufficiency for families. Altogther, these advantages will strengthen the relationship between labor and property management, which may lower the cost of production, making the family farmer more resilient and the agricultural system more economically viable owing to adoption of a less expensive farming system, ultimately creating value for family farming and the local economy. In addition, genetic diversity can be maintained through conservation of a local variety (Araújo et al., 2015).

Creole seeds are exchanged or traded at events promoted among farmers, at seed associations and fairs. Public agencies can also purchases, without a bidding process, to attend programs that aim to promote access to food and encourage family farming, such as the Food Acquisition Program (Programa de Aquisição de Alimentos [PAA]), which purchases food produced through family farming for people with food and nutritional insecurity and those served by the social assistance network, by the public food and nutrition security equipment as well as public and philanthropic school network; and the National School Feeding Program (Programa Nacional de Alimentação Escolar [PNAE]), which determines that at least 30% of the amount transferred to states, municipalities, and the Federal District by the National Fund for the Development of Education for PNAE must be used to purchase foodstuffs from family farming and from rural family entrepreneur or their organizations, prioritizing agrarian reform settlements, traditional indigenous communities, and quilombola communities. Seeds purchased by the PAA must comply with the current certification standards, in addition to being tested for transgenics, purity, germination, and vigor. Of note, the purchase of genetically modified seeds is prohibited (PAA, 2021; PNAE, 2021).

Creole seeds are exempted from registration with the National Cultivar Registry (Registro Nacional de Cultivar [RNC]). To be registered with the RNC and receive all the benefits of the seed laws, the cultivar must be homogeneous and stable in terms of descriptors through successive generations. To be homogeneous, the cultivar must have minimal variability based on its descriptors, which are defined for each cultivar, considering its characteristics (plant height, leaf width, flowering period, pigmentation, etc.). To be stable, the cultivar must maintain its homogeneity through successive generations (Brasil, 2003). Landraces do not meet these criteria, as they have a wide genetic diversity, which is demonstrated by the heterogeneity of phenotypic descriptors. However, for production and commercialization, popcorn maize seeds must meet minimum standards, such as the percentage of germination (Brasil, 2013).

The use of seeds of good physiological quality is important to ensure that after sowing, the grains continue to develop and become productive (Catão et al., 2019; Lopes et al., 2018). All stages, from seed selection to cultivation, harvest, and post-harvest, when not conducted properly, can negatively affect the nutritional and technological quality of the grains. The determination of indices that make it possible to evaluate the physical properties of agricultural products, such as grains and seeds, enables the physical characterization and processing of grains according to the purpose of use, in addition to enabling the qualitative assessment of drying, heating, and cooling conditions; the adequate dimensioning and improvement of equipment, and the optimization of industrial processes and aerodynamic studies of agricultural products (Botelho et al., 2019; Ribeiro et al., 2002).

The objective of this research was to identify the race and to understand the physiological and physical characteristics of a landrace popcorn (LP), available for cultivation by family farmers, and to add relevant knowledge to compose banks of information systems that enhance the conservation and use of genetic material from South America. In addition to passing on this knowledge to farmers as well as encouraging the cultivation of these seeds, the final cost of production can be reduced through the use of local seeds, adapted to the cultivation conditions employed by farmers and that are more resistant to biotic and abiotic stresses.

2. Methodology

2.1 Plant Material

The seeds of the LP were cultivated by cooperative family farmers from COOPERANGI (Settlement Farmers Cooperative Agroana-Girau), located in the Agroana-Girau Rural Settlement, in the municipality of Poconé found in the transition area of Cerrado and Pantanal, whose matrix of the variety has an unknown origin. The color and shape of the seeds varied. The predominant color was purple; however, there were variations between light yellow, dark yellow, brown, orange, gray, purple, wine, and black, and rounded and pointed shapes. The cultivation system practiced by the cooperative is organic, characterized by the use of hand tools and products certified for production in the organic cultivation system, such as fertilizer FA 100 and chicken litter for enrichment from soil, and the biological insecticide DIPEL WP®. The variety is crop for own consumption and non-commercial purposes; such variety is called colorful popcorn by family farmers in the settlement.

2.2 Plant Material Multiplication

LP was cropped in an organic system between December 2017 and May 2018 at the Experimental Farm of the Federal University of Mato Grosso (Universidade Federal de Mato Grosso [UFMT]), Santo Antônio de Leverger - Mato Grosso (MT), located 33 km from Cuiabá, delimited by geographic coordinates 15 ° 51'S; 56 ° 06'W and 140 m altitude. The soil in the area is Cambisol Hawaiian with a sandy texture (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2006). According to the Köppen classification, the climate of the region is Aw, tropical, with dry winter. The average monthly temperature ranges from 22.0 °C to 27.2 °C and the average annual precipitation is 1,320 mm (Da Silva, 2019). Seeding took place between December 26 and 29, 2017 and harvesting was carried out in May 2018 when the moisture content of the grain was approximately 20%, as measured by an indirect method in equipment (Gehaka model G810); this occurred approximately 120 days after seeding. Phenotypic characterization and race identification, germination and vigor, thickness/width ratio, circularity index, sphericity, diameter ratio, geometric mean diameter, volume, surface area, AR, HW, ASG, TKW, color, and classification according to identity and quality requirements, were conducted in the Fruits and Vegetables laboratories of the Faculty of Nutrition and the Center for Grain Storage Technology (Núcleo de Tecnologia em Armazenagem [NTA]) of the Faculty of Agronomy and Zootechnics, both located at UFMT. After harvesting, the corn was threshed and the moisture was measured (18.9%). The seeds were placed on a stainless-steel table and kept at 24 °C ± 2 until the ideal humidity, of approximately 13% (Luz et al., 2005), was achieved. Subsequently, the grains were separated according to color, vacuum packed in a 15 µm polyethylene plastic bag, and stored frozen until the analysis was performed. A second seeding was necessary to obtain complete ears (grains and ears) for phenotypic characterization and race identification. This second seeding took place in October 2019 and was harvested in February 2020. During cropping, only hand tools and products certified for production in the organic cultivation system were used, such as fertilizer FA 100 and chicken litter for enrichment from soil, and the biological insecticide DIPEL WP® to combat caterpillar infestation, which occurred in the first crop. The activity of access to associated traditional knowledge was registered with the National System of Management of Genetic Heritage and Associated Traditional Knowledge (Sistema Nacional de Gestão do Patrimônio Genético e do Conhecimento Tradicional Associado [SisGen] nº A21A2A3) in the Ministry of the Environment.

2.3 Phenotypic Characterization and Race Identification of the LP

The characterization of the variety was based on phenotypic descriptors of maize (IPGRI, 1991) for ear and kernel characters. The variables were selected according to the concept of races proposed by Anderson and Cutler (1942). Fifteen ears and ten consecutive kernels of each ear were evaluated, extracted from the same row, according to the descriptors presented in Table 1. Identification of the LP race was carried out according to the methodology proposed by Silva et al. (2020). Briefly, a cluster analysis was performed based on the similarity distance of Gower (1971), which enables the combination of quantitative and qualitative variables. The morphological characterization data were analyzed using descriptive statistics to characterize the genetic diversity of the variety. For qualitative variables, the absolute frequencies of each variation/category were obtained within the character, and the most frequent value (mode) was adopted to characterize the variety for that variable. Mathematical averages were calculated for the quantitative variables. The analysis included data from 20 popcorn varieties collected under the Lowland Corn Races Project in South America and the LP. A cluster analysis was performed using the Ward method (hierarchical) with a cut-off point established using the methodology of Mojena (1977) to evaluate the phenotypic association of LP with one of the three groups of popcorn identified by Silva et al. (2020).

Table 1 - Morphological descriptors for the phenotypic characterization of ears and kernels to classify the corn races.

	Ear (n=15)	**Kernel (n=150)**
Descriptors qualitatives	Color uniformity in the kernel crown Kernel color (crown) Texture of kernel (crown) Ear shape Kernel arrangement in rows Cob color	Pericarp color Endosperm color Shape of kernel Shape of kernel surface
Descriptors quantitatives	Number of kernels per row Ear length (cm) Ear diameter (cm) Cob diameter (cm) Diameter of the rachis (cm) Number of rows per ear	Kernel length (mm) Kernel width (mm) Kernel thickness (mm)

Source: Authors.

The three groups described by the authors belong to the popcorn races, *Avatí Pichingá* (pointed kernels popcorn) and *Avatí Pichingá Ihú* (round kernels popcorn), which are races of popcorn from Brazil described by Brieger et al. (1958) and Paterniani and Goodman (1977); and *Pisingallo* round, a popcorn race from Uruguay described by María et al. (1979) and Fernández et al. (1983), which are of Guarani indigenous origin. Cluster analysis was performed with the aid of the statistical program R (R Development Core Team, 2014), and vegan package (Oksanen et al., 2016). Quantitative morphological descriptors are presented as mean and standard deviation, and the minimum and maximum values for each variable were obtained.

2.4 Physiological Properties of the LP

Germination and accelerated aging tests were performed to verify the physiological quality of the seeds. The tests were carried out with seeds that had a moisture content of 11.8%, obtained with the whole seeds by the greenhouse method at 105°C, according to the methodology described in the Seed Analysis Rule (Regras para análise de sementes [RAS], Brasil, 2009). The germination test was carried out in a BOD incubator with alternating photoperiod (ACBLabor® brand) at a constant temperature of 24°C ± 2, with eight replicates containing 25 seeds each, distributed on a paper towel substrate (Germitest) moistened with a volume of distilled water equivalent to 2.5 fold the weight of the substrate. The evaluations were carried out seven days after seeding, and the results are expressed as a percentage of normal seedlings containing all essential structures (Brasil, 2009). For the accelerated aging test, 213 seeds (42.142 g) were distributed over the aluminum mesh tray of a transparent plastic box (gerbox type, 11 × 11 × 3.5 cm), with 40 mL of distilled water at the bottom of the box, which was then kept in a BOD incubator for 96h at 42ºC. Subsequent germination was evaluated on the seventh day, under the conditions described in the germination test (Marcos Filho, 1999).

2.5 Physical Properties of the LP

A King Tools® digital caliper with 0.001 mm resolution was used to measure the three dimensions of the popcorn kernel. The length (L) was defined as the distance from the tip cap to the kernel crown. Width (W) was defined as the widest point to point measurement taken parallel to the face of the kernel. Thickness (T) was defined as the measured distance between the two kernels faces as described by Pordesimo et al. (1990). The dimensions of the ear and kernel were used to identify the race of the popcorn and to calculate the indices for physical characterization. The thickness/width ratio and the cariosis circularity index (CCI) were calculated according to the following formula (Gonçalves et al., 2019):

$$\text{Thickness/width ratio} = T/W$$

$$CCI = \frac{T}{W + L}$$

The diameter ratio, geometric mean diameter (Dg) and sphericity (Φ) of the seed was calculated by using the following relationship (Mohsenin, 1987):

$$\text{Diameter ratio} = L/T$$

$$Dg = (LWT)^{1/3}$$

$$\Phi = \frac{(LWT)^{1/3}}{L}$$

Jain and Bal (1997) have stated kernel volume (V) and kernel surface area (S) may be given by:

$$V = \frac{\pi B^2 L^2}{6\,(2L - B)}$$

$$S = \frac{\pi B L^2}{2L - B}$$

where $B = (WT)^{0,5}$

The indices calculated from the seed dimensions were presented as mean and standard deviation, and the minimum and maximum values were obtained for each variable.

To determine the angle of repose (AR), apparent specific gravity (ASG), hectoliter weight (HW), thousand kernel weight (TKW) and color, samples of the refrigerated LP, from the first cultivation in which the grains were used, were separated according to their color. The seeds were kept at 24 °C ± 2 for seven h, until a temperature of 25 °C and a humidity of 13% were achieved, as measured by an indirect method (Gehaka model G810). The sample was then passed through a circular sieve 5 mm in diameter and shaken for 30 s to standardize the grains. AR was determined according to the methodology described by Benedetti e Jorge (1987). The experiment was conducted in a device consisting of a rectangular wooden box with glass sides. One side of the box contained a gate equipped with a silo-shaped container that allowed the flow of the grains in a continuous flow when opened. With the aid of a ruler, measurements of the base and height of the right triangle formed with the unloaded grains were measured. The analysis was performed in quintuplicate, and the mean values and standard deviation are presented. The angle of repose is expressed by the following formula:

$$\alpha = \text{arc tg } x \ \frac{h}{c}$$

where h is the height of the slope and c is the distance to which the seed flows horizontally.

The ASG was determined using a mass scale of the hectoliter weight of the Dalle Molle® brand (model TYPE 40), which is based on the determination of the mass of grains contained in a container of volume of ¼ L (Botelho et al., 2018). The results are expressed in kg/hL for HW and converted to $kg \cdot m^{-3}$ to express ASG. The analysis was performed in quintuplicate, and five measurements were performed for each replicate. The average value and standard deviation were calculated, disregarding the highest and lowest values when the difference was above 0.5.

The TKW was determined by counting 100 kernels, in electronic seed counter model ESC 2011 (sanick®), and weighing them in an semi-analytical balance and then multiplied by 10 to give the mass of 1000 kernels. The sample was divided into five subsamples, which were subjected to eight measurements, consisting of 100 seeds each (Brasil, 2009). The results are presented as mean and standard deviation.

Color parameters (L*, a* e b*) of the kernels were measured with the CIELAB system by using the CR-400 Chroma Meter (Konica Minolta®, Japan) (McLaren, 1976). The analysis was performed in quintuplicate, for each replicate five measurements were performed. The results are presented as mean and standard deviation.

2.6 Identity and Quality Classification of the LP According to the Regulations of the MAPA

Considering that a single variety was studied, we decided to use MAPA classification as a reference for comparative purposes. In Brazil, the popcorn for commercialization must meet the official classification standard defined by Normative

Instruction (Instrução Normativa [IN]) nº 61 of MAPA. The classification is based on the identity and quality requirements. The identity of the popcorn grain is defined by the species of the product, while the quality requirements of popcorn are defined as a function of color (yellow, white, colors, and mixed), classifying it into class; and the expansion capacity of the grains and the maximum tolerance limits established for the presence of defective grains (damaged, broken, and attacked by woodworm), classifying them into three types, or even as out of type and unclassified. In this study, the amount of sample used for classification was 62.5 g; this was employed as tests carried out at NTA demonstrate that there was no significant difference between this amount and the amount (125 g) recommended by MAPA. EC was calculated as the ratio of popcorn volume (mL) to grain mass (g), and the result was expressed in $mL \cdot g^{-1}$. The mass of the expanded grains was 30 g, and the volume resulting from the expansion was measured in a 2,000 mL beaker. To obtain the popcorn, a microwave device with a capacity of 30 L, LG® model MS3047G, with a maximum power of 1,000 W was employed for 2 min and 10 s. The analysis was carried out in quintuplicate; for each replicate, six measurements were obtained; the first of each replicate was discarded to obtain the mean and standard deviation (Brasil, 2011).

3. Results and Discussion

3.1 Genetic Diversity of the LP

The descriptive analysis, based on the phenotypic characterization of the LP ear and grain, revealed that 80% showed color uniformity in the kernel crown (smooth), still in the ear, and 20% multicolored, with five categories for the crown color grain: 33.3% wine, 26.7% purple, 20% yellow, 13.3% bronze, and 6.7% black. For the ear shape, the conical cylindrical shape (60%) predominated, followed by the cylindrical shape (40%). For the arrangement of rows, 60% of the population showed a regular arrangement, 20% spiral, 13.3% interlaced, and 6.7% irregular. The average number of rows per ear was 14 (40%). The color of the cob was 53.3% purple, 20.0% white, 13.3% pinkish, 6.7% brown, and 6.7% wine. Regarding the shape of the grains, 37.3% were classified as obovate, 31.3% rounded, 15.3% trapezoidal, 7.3% acuminate, 6.7% globose, and 2.0% cuneiform. The shape of the rounded kernel edge predominated (87.3%) among the population, followed by the aristated (7.3%), flat (2.7%), and slightly contracted (2.7%) forms. The color of the pericarp was 35.3%, 27.3%, 17.3%, 13.3%, and 6.7% for wine, purple, cream, bronze, and black, respectively. The yellow endosperm (66%) prevailed over cream (20.7%) and white (13.3%). Based on these characteristics, we verified the wide genetic diversity that exists within this single variety, which is characteristic of landraces that, in general, have high internal diversity (Costa et al., 2017).

Regarding the quantitative variables (Table 2), LP presented mean ear length values of 13.93 cm, number of row/ear of 12.73, number of grains/row of 29.24, ear diameter of 3.14 cm, cob diameter of 2.07 cm, and rachis diameter of 1.12 cm. The grains presented the following average values for dimensions: 8.72 mm length, 6.63 mm width, and 4.07 mm thickness. The quantitative morphological characteristics that showed the greatest variation were the number of grains per row (±9.13), ear length (±2.68), number of rows/ear (±2.22), and grain length (±1.3), with emphasis on the number of grains/row, with a minimum number of grains of 13 and a maximum of 44 per row.

Table 2 – Average, standard deviation (SD), and the minimum (Mín.) and maximum (Máx.) values of the quantitative phenotypic descriptors of the ear and grain of the organically-grown LP harvested in 2019 and 2020.

Quantitative descriptor	Average	SD	Min.	Max.
Ear (n=15)				
Length (cm)	13.93	2.68	9.63	19.67
Number of rows per ear	12.73	2.22	10.00	18.00
Number of kernels per row	29.24	9.13	13.00	44.00
Diameter (cm)	3.14	0.35	2.61	3.99
Cob diameter (cm)	2.07	0.16	1.87	2.35
Diameter of the rachis (cm)	1.12	0.15	0.84	1.36
Grain (n=150)				
Length (mm)	8.72	1.30	5.72	11.76
Width (mm)	6.63	0.65	5.10	8.26
Thickness (mm)	4.07	0.74	2.80	7.01

Source: Authors.

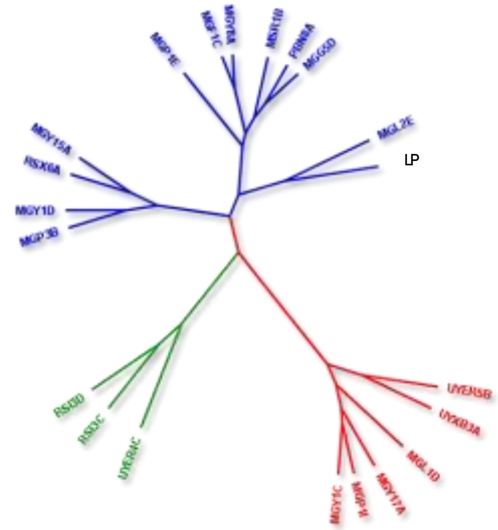
The dimensions of the LP ranged from 5.72-11.76 mm for grain length; 5.10-8.26 mm for width, and 2.80-7.01 mm for thickness. These values were consistent with those presented by Ceylan and Karababa (2001) and Karababa (2006), and higher than those reported by Ertas et al. (2009) for popcorn samples. Higher values were found by Cárdenas et al. (2013) with popcorn from ancient indigenous races in Mexico, which found mean values of 10.1 mm, 6.7 mm, and 5.0 mm for length, width, and thickness, respectively, for the evaluated races (*Palomero Toluqueño, Arrocillo Amarillo, Chapalote and Nal-Tel*).

The heterogeneity observed among the grains of the studied variety demonstrates the wide genetic diversity of LP, a common characteristic of landraces. This diversity may be due to the time of cultivation and the genotype-environment interaction, as the adaptive and cultural aspects can be incorporated during the selection cycles carried out by the farmers, enabling specific characteristics of LP and its physical properties (Silva, 2015; Vázquez-Carrillo et al., 2019).

3.2 Race Identification of the LP

Figure 1 shows the twenty varieties characterized by Silva et al. (2020), including LP, the object of this research, structured in three genetic groups. The red varieties (6) make up group 1 (G1), which has round grains, except for the MGL1D variety, which has pointed grains. Group 2 (G2), in green, is composed of three varieties characterized by round grains. LP, together with 11 other genetic varieties, constitute group 3 (G3), in blue, which is characterized by predominantly pointed grains, with the exception of the RSX6A, MGP3B, MGY1D, and LP varieties, which have round grains.

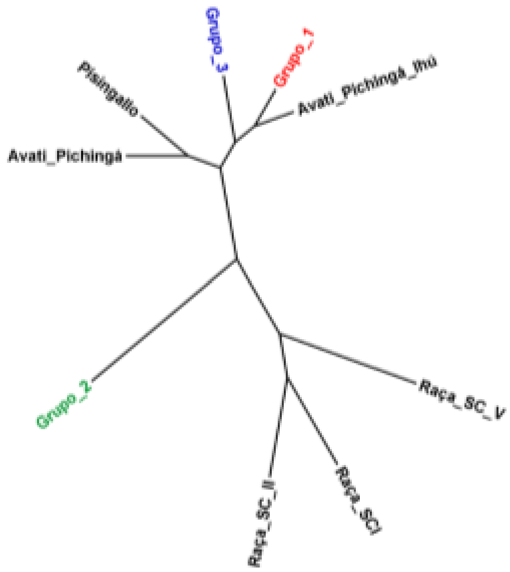
Figure 1 - Cluster analysis by the Ward method, based on the Gower Index, estimated from the ear and grain phenotypic descriptors.



The colors indicate the different groups: G1 (red), G2 (green) and G3 (blue). Source: Authors.

The joint grouping analysis (Figure 2) showed that groups G1, G2, and G3 were associated with the old races, forming a single conglomerate, separate from the new races (Silva et al. 2017) that were described for diversity microcenters in the Far West of Santa Catarina (Costa et al., 2017). This indicates that the variety assessed in this study is included within the range of phenotypic variability of the old races, with no characteristics that can be used for its distinction as a "new" race.

Figure 2 - Joint cluster analysis (groups + races) by the Ward method, based on the Gower Index, estimated fromthe phenotypic characteristics of the ear and grain, considering the three structured groups and the races described in the literature.



Source: Authors.

The following race that is currently conserved in Brazil and Uruguay is considered: i) Pointy popcorn from Brazil, belonging to the *Avatí Pichingá* race, locally recognized as *Alho* maize; ii) round popcorn from Brazil, belonging to the *Avatí*

Pichingá Ihú race, generically recognized as "Pipoca"; and iii) round popcorn from Uruguay, belonging to the *Pipoca redondo* race, locally recognized as "Pipoca" "Picoca" (Silva, Vidal, Costa & Veasey, 2020).

Therefore, LP belongs to the *Avatí Pichingá Ihú* race, which is predominantly characterized by conical cylindrical ears, with 10 to 16 rows of grains arranged in a regular manner, white cob, ear length between 12 and 19 cm and diameter of 2.3 to 3.5 cm, cob diameter between 1.5 and 2.0 cm, and rachis diameter ranging from 0.7 to 1.3 cm. The predominant characteristics of the grains of this variety are popcorn-type endosperm, smooth and multicolored crown, white crown, purple and black; grain shape oblong and rounded with rounded edge, colorless pericarp and burgundy; endosperm white, cream, and black; length between 8 and 9.2 mm, width from 4.5 mm to 6.9 mm, and thickness between 2.9 and 4.5 mm. The differences between some of the phenotypic descriptors presented by LP and those found in the literature (Silva et al., 2021), which characterized the *Avatí Pichingá Ihú* race, demonstrate the wide genetic diversity of LP, which may represent an evolution of the variety due to growing time and genotype-environment interaction, as the adaptive and cultural aspects can also be incorporated during the selection cycles carried out by farmers (Silva, 2015; Vázquez-Carrillo et al., 2019).

3.3 Physiological Properties of the LP

The LP displayed 92% of normal seedlings in the germination test, with a decrease in this percentage after 96 h of aging (84%). This reduction was expected because, as the period of exposure of seeds to high temperature and humidity increases, the percentage of normal seedlings decreases (Marcos Filho, 1999). The same result was observed by Stefanello (2014) with the seeds of native maize varieties subjected to different periods and storage conditions. Rodrigues et al. (2018) observed that the red genotype of landrace popcorn stood out from the others, with an average germination rate of 94%, similar to that obtained in this study. The high germination test results do not necessarily mean that the seeds have high vigor, considering that the germination test is carried out under favorable environmental conditions of temperature, humidity, and light, allowing the expression of the maximum potential for the production of normal seedlings (Marcos Filho, 1999). Although the percentage reduction was verified, the LP seeds had a high percentage of normal seedlings in both tests, which is possibly due to the ability of landraces to adapt to abiotic stress conditions, which occurs during accelerated aging. A similar result to this work was observed in the study by Idikut et al. (2012), who evaluated germination under different temperatures and salt concentrations, and found that the popcorn landraces had higher germination and vigor values than the seeds of commercial hybrid maize varieties. Landraces are described in the literature as being resistant to diseases, in addition to presenting good tolerance and adaptation to stressful abiotic conditions (Araújo et al., 2015; Idikut et al., 2012; Pineda-Hidalgo et al., 2015; Zulkadir & Ídikut, 2021). In terms of good performance, LP seeds are classified as vigorous (Marcos Filho, 1999), are stored in good conditions (packaging, temperature, and humidity), and can be used for propagation in the form of seeds, thereby exceeding the minimum required (70%) for commercialization in Brazil (Brasil, 2013).

3.4 Physical Properties of the LP

The physical characteristics of the LP grains are presented in Table 3. The thickness/width ratio, circularity index, sphericity, diameter ratio, geometric mean diameter, volume, and surface area were calculated from the dimensions of the grains, as shown in Table 2.

The values obtained for the thickness/width ratio and CCI of LP were 0.62 (0.39-1.01) and 0.27 (0.18-0.48), respectively. By studying popcorn landraces in southern Brazil, Gonçalves et al. (2019) and Seledes et al. (2019) reported CCI values between 0.28-0.30 and 0.27-0.35, respectively; and between 0.60-0.82 for the thickness/width ratio observed by Gonçalves and colleagues. These indices indicate the rounded shape of the grains and have a positive correlation with the expansion capacity. Grains with greater symmetry between dimensions had CCI values close to 0.5 (Seledes et al., 2019). A close value was observed for some LP grains (0.48). More productive ears contain a greater number of grains, and consequently have less space for grain growth, interfering with their shape (Gonçalves et al., 2019). This observation may be a hypothesis that would justify the variation in grain size and shape observed in the LP, in addition to the heterogeneity characteristic of landraces. However, the ear yield was not measured in this study.

Table 3 – Average, standard deviation (SD), and the minimum (Mín.) and maximum (Máx.) values referring to the physical properties of organically-grown landrace popcorn harvested in 2017 and 2018.

Physical properties		**Average**	**SD**	**Min.**	**Max.**
Thickness/width ratio		0.62	0.13	0.39	1.01
Circularity index		0.27	0.06	0.18	0.48
Sphericity		0.71	0.10	0.53	0.93
Diameter ratio		1.32	0.19	0.91	1.87
Geometric mean diameter (mm)		6.13	0.51	4.86	7.41
Volume (mm^3)		89.00	24.43	43.47	180.88
Surface area (mm^2)		101.72	17.18	62.98	156.34
Angle of repose (°)		18.51	0.66	-	-
Hectoliter weight (kg/hl)		81.15	0.25	-	-
Apparent specific gravity ($kg\cdot m^{-3}$)		811.47	2.48	-	-
Thousand kernel weight (g)		164.71	4.86	-	-
Color	L*	27.49	1.64	-	-
	a*	16.89	2.22	-	-
	b*	10.27	0.84	-	-
Physical defects (%)					
Moldy		0.22	0.00	-	-
Total damaged		2.10	0.21	-	-
Attacked by woodworm		1.77	0.62	-	-
Broken		0.17	0.00	-	-
EC ($mL\cdot g^{-1}$)		23.94	0.74	-	-

Source: Authors.

The sphericity and diameter ratio obtained for the LP showed significant variation among the grains (0.53-0.93 and 0.91-1.87, respectively). Results close to the averages obtained in this study for sphericity (0.71) and diameter (1.32) were presented by other authors (Ceylan & Karababa, 2001; Ertas et al., 2009; Sweley et al., 2012) in research on popcorn. Pordesimo et al. (1990; Ceylan & Karababa 2001; Vázquez-Carrillo et al., 2019) observed that smaller, shorter, wider, and rounder grains have larger sphericities and diameters, resulting in a greater expansion volume. Sphericity is used as a shape descriptor; however, some authors correlate it with other measures. Dai et al. (2017) showed that the angle of repose decreased when sphericity increased (Dai et al., 2017 as cited in Al-Hashemi & Al-Amoudi, 2018, p. 411).

The mean values observed for geometric mean diameter, volume, and surface area were 6.13 mm, 89 mm^3, and 101.72 mm^2, respectively, for LP. Karababa (2006) obtained similar results and found that, similar to the other dimensions, they increased linearly with the moisture content in the grain. The indices presented from the grain dimensions are used to physically characterize them; however, in isolation, they do not define the quality of the grains. The variation observed between the grains may be due to the cultivation time and the genotype-environment interaction, considering that the adaptive and cultural aspects can be incorporated during the selection cycles carried out by the farmers, giving specific characteristics to LP and its physical properties. Small popcorn kernels are preferred by end consumers for household consumption as they generally produce softer flakes and little husk. Larger grains are chosen by suppliers that sell ready-made popcorn, as they produce visually more attractive flakes and are considered more resistant, reducing breakage during handling and distribution (Ademiluyi & Mepba, 2009; Ceylan & Karababa, 2004).

The mean AR obtained for the LP was 18.51°. With a moisture content similar to that in our study, Pereira et al. (2014) observed that of the three brands of popcorn studied, the brand with the highest AR value (21.23°) also had the highest moisture content (13.06%). The authors believe that this may be due to the fact that products with a higher moisture content have a greater cohesion between the particles, which tend to aggregate and consequently, increase internal friction (Pereira et al., 2014). This linear and positive correlation between AR and moisture content was also observed by Karababa (2006). AR is a physical property used in designing processing systems and sizing silos, tanks, hoppers, and bunkers to determine the capacity and required volume of seed storage and transport. It is also related to the free flow properties of bulk particulate materials. Very small, smooth, rounded granules, which exert little friction on each other, flow freely and tend to form piles with shallower sides, resulting in low AR, usually less than 30 °. Fine, rougher, or sticky granules, which adhere tightly together and do not flow freely, tend to form piles with steeper sides and a higher AR, greater than 55 °(Al-Hashemi & Al-Amoudi et al.,2018**)**. The size, shape, orientation of the particles, and external constitution of the grain are factors that can influence AR (Botelho et al., 2019; Mohsenin, 1987). The AR of the LP was measured with grains presenting ideal moisture (13.01%) and without foreign materials and impurities. In this sense, LP presents small grains, verified by the lowest AR value, by the measurements of length, width, and thickness, and the calculated indexes. Silva (2015) reported that the grain size of popcorn is generally quite small compared to that of common corn. These varieties have a grain size similar to that of rice; other varieties have seeds of comparable size to durum maize seeds.

LP presented an average HW of 81.15 Â kg/hL, similar to the value (81.29 Â kg/hL) observed by Cihangir and Oktem (2019), with popcorn produced from sources of organic nutrients; and higher value than those found by Vázquez-Carrillo et al. (2019) and Pineda-Hidalgo et al. (2015) in samples of maize from indigenous races, whose values ranged from 65.4-79.2 Â kg/hL and 73.8-76.6 Â kg/hL, respectively. This observed difference may be related to the grain moisture at the time of HW measurement or the higher content of vitreous endosperm, which may indicate greater hardness and starch content, providing higher quality to the LP. HW is accepted as an indicator of the physical quality of cereals in international trade due to its simple and fast measurement, providing an estimated measure of the hardness and composition of the endosperm, type of grain, and nutritional value of corn. HW values are generally determined after harvest. Higher HW values are associated with lower ash, fiber, and protein content and higher vitreous endosperm content, providing better quality and yield to the grains and defining a higher market price (Agama-Acevedo et al., 2011; Mutlu et al., 2018; Pineda-Hidalgo et al., 2015; Čuklić et al., 2015 as cited in Kljak et al., 2020, p. 544). In contrast, low values indicate lower levels of starch, fat, and vitreous endosperm (Kljak et al., 2020). Stress factors during the grain growth stage, damage (physical, insect, and microbiological), adverse weather events such as frost, rain-induced field germination, presence of foreign materials, and defective grains (wrinkled or immature); moisture content; and drying methods negatively affect HW, reducing its value, which can also vary due to genetic differences, structure, and chemical composition of the grains. The drying process reduces the moisture content and empty space in the grain endosperm and consequently, increases the HW and grain density. In this sense, ASG is considered a more suitable index for determining the moisture content and establishing the market price of the grain (Kljak et al., 2020; Okuyama et al., 2020; Sweley et al. 2012; Vázquez-Carrillo, 2019).

In this study, the mean value obtained for ASG was 811.47 kg·m^{-3}, which is higher than that reported by Ertas et al. (2009), whose values ranged from 750.0-777.0 kg·m^{-3}. Pereira et al. (2014), as well as other authors (Ceylan & Karababa, 2004; Karababa, 2006), observed lower ASG values in grains with higher moisture content. According to the observation by Botelho et al. (2019), the content of impurities in the grains increases the value of corn ASG. Reductions in the levels of carbohydrates, proteins, and lipids during storage lead to loss of organic material, causing reductions in specific mass and dry matter, ultimately resulting in damage to seed quality and reduced value (Elias et al, 2002). Knowledge of this physical property is important for sizing silos, dryers, warehouses, and transport systems, and can be used to determine moisture levels and damage caused by insects and pests, causing loss of dry matter in stored grains (Ascheri & Germani, 2004). ASG is considered a physical property indicative of quality, it is used to define prices in the marketing of grains and seeds (Botelho et al., 2018). Considering that the LP moisture was within the recommended content (13.01%) and free of impurities when the ASG was measured, the relatively high value observed in our study may be due to the content of vitreous endosperm, which has a matrix dense protein with structured protein bodies that surround the starch granules, forming a compact structure (Coelho et al., 2018; Delcour & Hoseney, 2010). Therefore, ASG and HW are associated with corn quality and are used in the assessment of nutrient content and grain yield, and the determination of market price (Mutlu et al., 2018; Okuyama et al., 2020).

A large part of the corn grain is constituted by empty space in the endosperm; therefore, the TKW becomes a more accurate measure than the HW (Kljak et al., 2020). The mean TKW of LP was 164.711 g, which is higher than that obtained for popcorn crop in an organic system by Cihangir and Oktem (2019); higher than that values found by Ertas et al. (2009) in three yellow popcorn cultivars; and higher than the results presented by Karababa (2006), whose values ranged from 122.48-138.65g, 124.38-134.46g, and 136.0-157.0g, respectively. However, the mean TKW of LP was lower than for the ancient indigenous races of popcorn observed by Cárdenas et al. (2013), whose value was 186.6 g. Pereira et al. (2014) observed that TKW increased proportionally with increasing moisture content. Agama-Acevedo et al. (2011) and Dubal et al., (2020) reported that the differences observed between the studies may be due to genetic and environmental factors and the growth conditions of the product. The TKW indicates the starch, protein, and fiber content of the grains, and is positively correlated with starch content and grain yield; therefore, it is an excellent indicator of both characteristics. Higher TKW values demonstrate high starch and protein content and a low fiber content (Somavat et al., 2016). The high protein content (14.58%) presented by LP compared to those obtained by other researchers with unmodified varieties and some hybrids (between 8.56% and 13.46%) (Agama-Acevedo et al., 2011; Paraginski et al., 2016b; Prasanthi et al., 2017; Ranathunga et al., 2016; Sweley et al., 2012; Vázquez-Carrillo et al., 2019) may justify the higher TKW obtained in this study. Another justification for the value obtained is the positive correlation between the TKW and the hardness of the grain, implying a greater vitreous endosperm (Coelho et al., 2018; Delcour & Hoseney, 2010; Kljak et al., 2020). The value of this index is influenced by genetic and environmental factors, cultivation conditions, and grain storage (Agama-Acevedo et al., 2011; Mutlu et al., 2018). Paraginski et al. (2015) reported that the lower TKW values observed in their study were due to the reduction in humidity and the increase in the respiratory and metabolic processes of the grains, which reduced the germination percentage and increased the electrical conductivity of the grains, particularly at a temperature of 35 °C, even with reductions in water content that caused a reduction in grain weight.

Some grain dimensions can affect HW and TKW (Dubal et al., 2020; Kljak et al., 2020; Okuyama et al., 2020; Sweley et al. 2012; Vázquez-Carrillo, 2019). Vàzquez-Carrillo et al. (2019) observed a positive correlation between HW and sphericity. These authors reported that HW decreases with grain length and width, but increases with sphericity. A study by Kljak et al. (2020) revealed grains with greater length and width (12.34 mm; 8.3 mm, respectively) and smaller sphericity (0.64) and HW (74.67 Â kg/hL). These researchers concluded that larger grains generally have a lower HW than small grains. The opposite was observed for TKW (332 g) by these researchers. These results corroborate those obtained for LP, which had shorter length (8.72 mm) and width (6.63 mm), higher values of sphericity (0.71) and HW (81.5 Â kg/hL), and lower TKW (164.71 g).

Regarding the color parameters L *, a *, and b *, positive values were observed for the coordinates a * (16.89) and b * (10.27), representing red and yellow colors, respectively. The parameter L * (27.49) showed a low value, indicating a very intense color of the LP (L * = 0, black). The predominance of red, purple, and black colors in LP indicates the presence of anthocyanins, which are flavonoid pigments responsible for the colors observed in vegetables. Their coloring capacity and biological activities have beneficial effects on health (anticarcinogenic, antioxidant, anti-inflammatory, hypolipidemic, anti-aging, and improved intestinal health) and are widely studied and recognized in the literature, providing greater quality and commercial value to LP (Colombo et al., 2021; Urias-Lugo et al, 2015; Zhu, 2018).

3.5 Identity and Quality Classification of the LP According to the Regulations of the MAPA

Table 3 shows the percentage of defective grains and the expansion capacity of the grains used to classify the LP. Because of its ability to pop, turning into popcorn when subjected to a temperature of approximately 180ºC, the studied corn kernels were identified as popcorn from the species *Zea mays* L. subsp. *mays*. Based on the color of the grain, LP was classified as a mixed class owing to variations in colors, such as wine (33.3%), purple (26.7%), yellow (20.0%), bronze (13.3%), and black (6.7%), with no predominance of at least 95% by a single color.

The physical defects found and the percentages of these in the LP were: 0.22%, moldy; 2.10%, totally damaged; 1.77%, attacked by woodworm; and 0.17%, broken. These defects were present below the maximum tolerance limit; therefore, the grains were classified as type 1. In industry, the final grain yield is associated with the absence of cracks, fissures, broken grains, and impurities, in addition to factors such as genetics, type (hard, semi-hard, soft), and grain shape. Mechanical damage, which occurs during harvesting, transport, storage, and/or thermal damage owing to the use of high temperatures during the drying of grain, results in cracks and contamination with foreign matter and impurities. These defects compromise the mass of stored grains, which reduces their market value. Furthermore, they decrease the nutritional value of the grains owing to the loss of nutrients and increased susceptibility to contamination by fungi and insects (Ascheri & Germani, 2004; Kljak et al., 2020).

The mean value obtained for EC (23.94 $mL \cdot g^{-1}$), which is below the minimum limit (<30 $mL \cdot g^{-1}$) for commercialization, classifies LP as out of type. The ability to pop is a specific feature of popcorn. Commercially, expansion volume is an important quality criterion, as grain is sold by weight; however, popcorn is marketed by volume. The expansion volume is influenced by several factors. Researchers have investigated its relationship with physical properties (length, width, thickness, size, pericarp color, variety, genotype, weight) (Cabral et al., 2016; Ertas et al. 2009;Saito et al., 2021; Srdić et al., 2017; Zulkadir & Idikut, 2021), moisture content (Ceylan & Karababa, 2001; Luz et al., 2005; Singh et al., 2017), and the preparation method (aluminum pan, popcorn popper, and microwave); the addition of ingredients to the preparation of the kernel popcorn (Ceylan & Karababa, 2004; Ertas et al., 2009; Paraginski et al., 2016a; Ranathunga, et al., 2016; Vàzquez-Carrillo et al., 2019); and the environment used for the cultivation of popcorn and different sources of nutrients used in the soil (Cihangir & Oktem, 2019; Gonçalves et al., 2019; Sweley et al., 2012; Zulkadir & Idikut, 2021).

Gonçalves et al. (2019) obtained a mean EC of 26.3$mL \cdot g^{-1}$ and 25.5 $mL \cdot g^{-1}$ with local varieties crop in Florianópolis and Anchieta, respectively. To sample a local variety of the Chapalote race, in Mexico, Vázquez-Carrillo et al. (2019) found values ranging from 4.2-9.2 $mL \cdot g^{-1}$ using the pan for popcorn preparation; and between 6.4-26.1$mL \cdot g^{-1}$ when the preparation was made in the popcorn popper. Using popcorn popper, Ceylan and Karababa (2001) obtained a greater volume of expansion in the variety of yellow pearl type popcorn (29.8 $mL \cdot g^{-1}$) than in the rice type varieties (21.2 $mL \cdot g^{-1}$, 22.0 $mL \cdot g^{-1}$, and 25.5 $mL \cdot g^{-1}$ for the colors red, yellow and white, respectively). Ertas et al. (2009) obtained a greater volume with the traditional method than with the use of microwaves, with the three corn cultivars studied. Ceylan and Karababa (2004) used microwaves to prepare popcorn and obtained the maximum volume of expansion by adding 4.4% salt, 5.9% vegetable oil, and 16.4% butter. Studies have shown negative correlations between grain length (Saito et al., 2021) and both length and width, and a positive correlation between grain thickness (Cabral et al., 2016) and expansion capacity. Srdić et al. (2017) observed that larger grains and higher TKW produced less expansion volume and a greater volume of popcorn was produced by grains of smaller size and TKW value. These results were attributed to the higher content of farinaceous endosperm present in these grains. According to Luz et al. (2005), the optimum moisture content for achieving maximum corn expansion varies between 12.8% and 13.1%. The low moisture content in grains causes overheating of the water inside and does not promote complete expansion of the endosperm and disruption of the pericarp, whereas high moisture content weakens the pericarp, causing the early release of internal pressure, which does not reach the minimum value of 930.79 kPa required to promote the pop (Ademiluyi & Mepba, 2009). Therefore, the environmental conditions, the popcorn cultivation method, and the physical characteristics of the variety used, such as the dimensions and size of the grain, sphericity, color values, seed weight, moisture, and popcorn preparation (temperature, method, duration, ingredient addition), significantly affect the volume of expansion (Ceylan & Karababa, 2001; Ertas et al., 2009; Luz et al., 2005; Silvia et al., 2016; Singh et al., 2017; Vàzquez-Carrillo et al., 2019; Zulkadir & Idikut, 2021).

According to Singh et al. (2017), the volume of expansion depends on the moisture content in starch, which is converted into steam to increase the internal pressure in the endosperm, causing it to burst. In this sense, corn with lower carbohydrate content, and consequently starch, may have a lower expansion volume. This hypothesis can be evaluated in future studies as LP was found to have a higher protein content (14.58%) and lower carbohydrate content non-fibrous (58.66%) (data obtained by the authors, not disclosed). Therefore, genetics, cultivation form, moisture, preparation method, higher protein content, and lower carbohydrate content may be, alone or together, the factors that influence the lower expansion volume obtained for the LP. Costa et al. (2017) characterized the diversity of local maize varieties in southern Brazil based on the tradition and knowledge of farmers. The local varieties of popcorn were found to present other values, in addition to expansion capacity and yield, such as flavor, nutritional value, softness, crispness, flakes dry, white, and without thick husk when popped. Therefore, although the expansion capacity of LP has been shown to be less than the minimum limit required for commercialization, LP can present these characteristics, which adds value to landraces, in addition to the possibility of being used in participatory maize breeding programs.

The characteristics of LP identified in this research suggest that its cultivation and commercialization can be potentiated by family farming, indigenous peoples, and traditional communities. The popcorn market is concentrated on commercial hybrid varieties; however, creole seeds can also gradually occupy market niches that seek to appeal to products of social biodiversity origin, based on organic production. In addition, there is a consumer market that seeks to avoid products of transgenic origin, which is guided by the concept of sustainability. Thus, this adoption could be an opportunity for these farmers to establish themselves in this segment. Finally, the offer of seeds of a landrace popcorn could occupy part of the 30% quota of institutional acquisitions of the Brazilian government in the PAA and PNAE programs, allowing the conservation and replication of the species by a crescent number of producers of social origin.

4. Conclusion

LP belongs to the *Avatí Pichingá Ihú* race, which is of indigenous Guarani origin. The wide diversity presented by phenotypic descriptors is characteristic of landraces and may be due to the time of cultivation and genotype environment interaction, as the adaptive and cultural aspects can be incorporated during the selection cycles carried out by the farmers. The variety showed adequate germination and vigor, indicating that the seeds could be used for the next sowing. LP presents small grains, verified by the lowest AR value, based on measurements of length, width, and thickness, and the calculated indices. The higher TKW value may be due to the higher protein content and/or higher vitreous endosperm content, hardness, and starch content, reinforced by the higher HW and ASG values. Therefore, owing to its genetic constitution and adaptability to a low-tech environment, the cultivation of LP in an organic system makes the activity less costly and contributes to the optimization of areas and the diversification of agriculture, which represents an opportunity for family farmers, indigenous peoples, and traditional communities, and promote the rescue and valorization of regional germplasm. Considering its potential use, studies that aim to expand current knowledge of this variety can be useful for breeding programs and the development of biofilms, colorants, thickeners, stabilizers, gel-forming agents, encapsulating agents, and nutraceuticals by the food, chemical, textile, and cosmetic industries.

We suggest future studies that evaluate composition of nutrients and phytochemicals in these landraces popcorn before and after processing. The proximate and mineral composition, as well as the functional characterization, with determination of the profile of tocopherols, carotenoids, anthocyanins, and total, free and bound phenolic compounds contents, and their antioxidant capacities are the suggested analyses. This knowledge can offer new opportunities of improvement and commercial production of value-added cultivars, rich in bioactive compounds, and their use as functional foods.

Acknowledgments

The authors would like to thank agronomists Paulo Otávio Aldaves dos Santos Guedes from NTA, and Sinibaldo Junior from the enterprise, O Classificador Ltda, for their technical support, and are grateful to Universidade Federal de Mato Grosso for the infrastructure to carry out the work.

References

Ademiluyi, T. F., & Mepba, H. D. (2009). Effects of Engineering Properties on the Poppability of Nigerian Popcorn. *International Journal of Food Engineering*. 1-16. https://doi.org/10.2202/1556-3758.1335

Agama-Acevedo, E., Salinas-Moreno, Y., Pacheco-Vargas, G., & Bello-Pérez, L. A. (2011). Características Físicas y Químicas de dos Razas de Maíz Azul: Morfología del Almidón. *Revista Mexicana de Ciencias Agrícolas*, 2(3), 317-329. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-09342011000300002&lng=es&tlng=es

Al-Hashemi, H.M.B., & Al-Amoudi, O.S.B. (2018). A review on the angle of repose of granular materials. *Powder Technology* 330, 397–417. https://doi.org/10.1016/j.powtec.2018.02.003

Anderson, E., & Cutler, H. C. (1942). Races of Zea mays: I. Their recognition and classification. *Annals of the Missouri Botanical Garden*, *29*:69–88. https://www.jstor.org/stable/pdf/2394331.pdf?refreqid=excelsior%3A754d51a36d0a83e16c8446c2fad01745

Araújo Junior, B. B., Melo, A. E., Matias, J. N. R., & Fontes, M. A. (2015). Avaliação de Variedades Crioulas de Milho para Produção Orgânica no Semiárido Potiguar. *HOLOS*, Ano 31, Vol. 3, 101-108. https://doi.org/10.15628/holos.2015.2277

Ascheri, J. L. R., & Germani, R. (2004). Protocolo de Qualidade de Milho. Rio de Janeiro: *Embrapa Agroindústria de Alimentos*, 23 p. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/76481/1/doc59-2004.pdf

Benedetti, B. C. & Jorge, J. T. (1987). Influência da variação do teor de umidade sobre os pesos específicos, aparente e real, e a porosidade de vários grãos. *Engenharia Agrícola*, *11*, 7-16.

Botelho, F. M., Botelho, S. C. C., & Sobreira, M. C. A. (2019). Influência do teor de impurezas nas propriedades físicas de milho, soja e arroz em casca. *Scientific Electronic Archives*. 12 (1), 52-58. https://sea.ufr.edu.br/SEA/article/view/632

Botelho, F. M., Faria, B. M. E. M., Botelho, S. C. C., Ruffato, S., & Martins, R. N. (2018). Metodologias para Determinação de Massa Específica de Grãos. *Revista Agrarian*,11, 251-259. 10.30612/agrarian.v11i41.7922

Brasil. (2011). Instrução Normativa nº 61, de 22 de Dezembro de 2011. *Regulamento Técnico do Milho Pipoca*. http://sistemasweb.agricultura.gov.br/sislegis/action/detalhaAto.do?method=visualizarAtoPortalMapa&chave=263800632

Brasil. (2003). Lei nº 10.711, de 5 de Agosto de 2003.*Sistema Nacional de Sementes e Mudas*. https://www.planalto.gov.br/ccivil_03/leis/2003/l10.711.htm

Brasil. (2009). *Teste de Germinação*. In Regras para análise de sementes (pp. 147-224). https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/arquivos-publicacoes-insumos/2946_regras_analise__sementes.pdf

Brasil. (2013). Instrução Normativa n° 45, de 17 de Setembro de 2013. *Padrões para produção e comercialização de sementes de milho (Zea mays L.).* https://pesquisa.in.gov.br/imprensa/jsp/visualiza/index.jsp?data=20/09/2013&jornal=1&pagina=18&totalArquivos=200

Brieger, F. G., Gurgel, J. T. A., Paterniani, E., Blumenchein, A., & Alleoni, M. R. (1958). Races of Maize in Brazil and Other Eastern South American Countries. *National Academic of Sciences*. https://www.ars.usda.gov/ARSUserFiles/50301000/Races_of_Maize/RoM_Brazil_0_Book.pdf

Cabral, P. D. S., Amaral Júnior, A. T., Freitas, I. L. J., Ribeiro, R. M., & Silva, T. R. C. (2016). Relação Causa e Efeito de Caracteres Quantitativos sobre a Capacidade de Expansão do Grão em Milho-Pipoca. *Revista Ciência Agronômica*, 47, 108-117. 10.5935/1806-6690.20160013

Cárdenas, J. D. F., González, D. E. N., Sánchez, A. M., Taba, S., Martínez, M. G., Medina, J. J. V., Sánchez, F. R., & Cuevas, F. A. (2013). Propiedades Físicas del Grano y Calidad de los Grupos Raciales de Maíces Nativos (Criollos) de México. *Rev. Fitotec. Mex.* Vol. 36 Supl. 3-A, 305-314. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0187-73802013000500007&lng=es&tlng=es

Catão, H. C. R. M., Caixeta, F., Castilho, Í. M., Marinke, L. S., Martins, G. Z., & Menezes, J. B. C. (2019). Potassium Leaching Test in Evaluation of Popcorn Seed Vigor. *Journal of Seed Science*, 41, 461-469. http://dx.doi.org/10.1590/2317-1545v41n4222939

Ceylan, M., & Karababa, E. (2001). Comparison of sensory properties of popcorn from various types and sizes of kernel. *Journal of the Science of Food and Agriculture*, 82: 127-133. https://doi.org/10.1002/jsfa.1000

Ceylan, M., & Karababa, E. (2004). The Effects of Ingredients on Popcorn Popping Characteristics. *International Journal of Food Science and Technology*, 39, 361–370. https://doi.org/10.1111/j.1365-2621.2004.00793.x

Cihangir, H., & Oktem, A. (2019). The Effect of Different Organic Nutrients on Some Quality Properties of Popcorn (*Zea mays* L. everta). *Asian Food Science Journal* 7(2): 1-9. 10.9734/afsj/2019/v7i229965

Coco Jr, M. G., & Vinson, J. A. (2019). Analysis of Popcorn (*Zea Mays* L. var. Everta) for Antioxidant Capacity and Total Phenolic Content. *Antioxidants*, 8(1), 22, 1-10. https://doi.org/10.3390/antiox8010022.

Coelho, R. S., Fugita, G. S., Rediss, W. B., Timm, N. S., Ferreira, C. D., Eicholz, E. D., Elias, M. C., & Oliveira, M. (2018). Propriedades Físicas de Diferentes Grãos de Milho. *Anais da VII Conferência Brasileira de Pós-Colheita*. Associação Brasileira de Pós-colheita, Londrina (PR). https://eventos.abrapos.org.br/anais/paperfile/910_20181103_02-32-38_806.pdf

Colombo, R., Ferron, L., & Papetti, A. (2021). Colored Corn: An Up-Date on Metabolites Extraction Health Implication, and Potential Use. *Molecules*, 26, 199. https://doi.org/10.3390/molecules26010199

Companhia Nacional de Abastecimento (2020, Abril/Maio). *Analise Mensal de Milho*. https://www.conab.gov.br/info-agro/analises-do-mercado-agropecuario-e-extrativista/analises-do-mercado/historico-mensal-de-milho/item/13710-milho-analise-mensal-abril-maio-2020

Companhia Nacional de Abastecimento (2021, abril). *Acompanhamento da Safra Brasileira de Grãos. v. 8, safra 2020/21, n. 7, sétimo levantamento*. https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos

Costa F. M., Silva, N. C. A., Vidal R., & Clement, C. R. (2021). Entrelaçado, a Rare Maize Race Conserved in Southwestern Amazonia. *Genetic Resources and Crop Evolution* ,68, 51–58. 10.1007/s10722-020-01008-0

Costa, F. M., Silva, N. C. A., & Ogliari, J. B. (2017). Maize Diversity in Southern Brazil: Indication of a Microcenter of *Zea mays* L. *Genet Resour Crop Evol.*64, 681–700. https://doi.org/10.1007/s10722-016-0391-2

Cutler, H. C. (1946). Races of maize in South America. Bot Mus Leafl Harv Univ 12:257–291. https://www.ars.usda.gov/ARSUserFiles/50301000/Races_of_Maize/RoM_South-America_0_Book.pdf em 28/05/2021

D. A. Urias-Lugo, J. B. Heredia, M. D. Muy-Rangel, J. B. Valdez-Torres, S. O. Serna-Saldívar,, & J. A. Gutiérrez-Uribe. (2015). Anthocyanins and Phenolic Acids of Hybrid and Native Blue Maize (Zea mays L.) Extracts and Their Antiproliferative Activity in Mammary (MCF7), Liver (HepG2), Colon (Caco2 and HT29) and Prostate (PC3) Cancer Cells. *Plant Foods Hum Nutr*, 70:193–199. DOI 10.1007/s11130-015-0479-4

Da Silva, A. L. (2019). *Desempenho Agronômico e Fisiológico do Amaranto sob Restrição Hídrica* [Dissertação de mestrado, Universidade Federal de Mato Grosso].

Delcour, J. A., & Hoseney, R. C. Principles of Cereal Science and Technology. Editora AACC International, 2010. 270p. https://issuu.com/scisoc/docs/27632

Dubal, Í. T. P., Carvalho, I. R., Pimentel, J. R., Troyjack, C., Szareski, V. J., Jaques, L. B. A., Conte, G. G., Villela, F. A., Aumonde, T. Z., & Pedó, T. (2020). Physical and Physiological Quality of Corn Seeds. *Research, Society and Development*, 9(10), 11-22. https://doi.org/10.33448/rsd-v9i10.8687

Elias, M. C. (2002). O armazenamento de grãos no Brasil. In: Elias, M.C. Armazenamento e conservação e conservação de grãos em médias e pequenas escalas. Pelotas: UFPel, cap. 1, 14-25.

Empresa Brasileira de Pesquisa Agropecuária. (2006). *Sistema brasileiro de classificação de solos*. (2a ed.), EMBRAPA-SPI. 306 p.

Ertas, N., Soylu, S., & Bilgiçli, N. (2009). Effects of Kernel Properties and Popping Methods on Popcorn Quality of Different Corn Cultivars. *Journal of Food Process Engineering*, 32(4), 478–496. 10.1111/j.1745-4530.2007.00228.x

Fernández, G., Frutos, E., & Maiola, C. (1983). Catálogo de Recursos Genéticos de Maíz de Sudamérica - Uruguay. INTA-EERA, Pergamino.

Food and Agriculture Organization of the United Nations Statistics Division. (2018). *Production of Maize*. Available at: http://www.fao.org/faostat/Accessed on: June 12, 2021.

Gonçalves, G. M. B., Mayer, L. B., Souza, R., & Ogliari, J. B. (2019). Yield and Popping Expansion Components in Local Popcorn Varieties From SOUTHERN Brazil. *Acta Agronómica*. 68 (3), 213-221. https://doi.org/10.15446/acag.v68n3.69127

Gower, J. C. A. (1971). General coefficient of similarity and some of its properties. *Biometrics*, *27*:857–871. 10.2307/2528823

Hoseney, R. C., Zeleznak, K., & Abdelrahman, A. (1983). Mechanism of Popcorn Popping. *Journal of Cereal Science* 43-52. https://doi.org/10.1016/S0733-5210(83)80007-1

Idikut L, Dumlupinar, Z., Kara, S. N., Yururdurmaz, C., & Çölkesen, M. (2012). The Effect of Different Temperatures and Salt Concentrations on some Popcorn Landraces and Hybrid Corn Genotype Germinations. *Pak. J. Bot*., 44(2): 579-587. http://www.pakbs.org/pjbot/PDFs/44(2)/17.pdf

Instituto Brasileiro de Geografia e Estatística. Reunião Estadual de Estatísticas Agropecuárias de Mato Grosso (2019). *Levantamento Sistemático da Produção Agrícola*.https://ftp.ibge.gov.br/Producao_Agricola/Levantamento_Sistematico_da_Producao_Agricola_[mensal]/Fasciculo_Indicadores_IBGE/2021/estProdAgri_202105.pdf

IPGRI (1991). Descriptors for maize/descriptores para maiz/descripteurs pour le maı¨s. *International Board for Plant Genetic Resources*, Rome.

Isnaini, M, Sunarti, S., Andayani, N.N., & Pabendon, M. B. (2020). Genetic Characterization of Popcorn (*Zea mays* everta) Genotyping Based on SSR (simple Sequence Repeats) Markers. *Earth and Environmental Science*, 484, 1-9. 10.1088/1755-1315/484/1/012013

Jain, R. K., & Bal, S. (1997). Properties of pearl millet. *Journal of Agricultural Engineering Research*, *v.66*, p.85-91. https://doi.org/10.1006/ jaer.1996.0119

Karababa, E. (2006). Physical Properties of Popcorn Kernels. *Journal of Food Engineering*, 72, 100–107. https://doi.org/10.1016/j.jfoodeng.2004.11.028

Kljak, K., Novaković, K., Zurak, D., Jareš, M., Pamić, S., Duvnjak, M., & Grbeša, D. (2020). Physical Properties of Kernels from Modern Maize Hybrids Used in Croatia. *Journal of Central European Agriculture*, 21(3), 543-553. 10.5513/JCEA01/21.3.2865

Lillioja, S., Neal, A. L., Tapsell, L., & Jacobs, D. R. (2013). Whole Grains, Type 2 Diabetes, Coronary Heart Disease and Hypertension: Links to the Aleurone Preferred Over Indigestible Fiber. *BioFactors*, *39*, 242–258. 10.1002/biof.1077

Lopes, C. A., Carvalho, M. L. M., Vasconcelos, M. C., Ribeiro, A. M. P., & Santos, H. O. (2018). Primary Leaf Growth and Coleoptile Length in Maize Seedlings.*Acta Scientiarum*, 40, 1-8. https://doi.org/10.4025/actasciagron.v40i1.35366

Luz, M. L. S., Dalpasquale, V. A., Scapim, C. A., Lucca e Braccini, A., Royer, M. R., & Mora F. (2005). Influência da Umidade das Sementes na Capacidade de Expansão de Três Genótipos de Milho pipoca (*Zea mays* L.). *Acta Sci. Agron*., 27549-553. 10.4025/actasciagron.v27i3.1475

Macedo, L. D., Ávila, B. P., Saraiva, J. F. R., Lacerda, M. S., Domingues, B. P., Pereira, A. M., Gurino E. S. G., & Gularte, M. A. (2020). Caracterização Química e Sensorial de Cookies Formulados com Grãos Crioulos e Amido de Pinhão (Araucaria angustifolia). *Research, Society and Development*, v. 9, n. 12, 1-17. http://dx.doi.org/10.33448/rsd-v9i12.10677

Marcos Filho, J. (1999). Teste de Envelhecimento Acelerado. In Krzyzanowski, F. C., Vieira, R. D., & França Neto, J. B. (Ed.). *Vigor de Sementes: Conceitos e Testes* (pp. 3-24). ABRATES.

María, F., Fernández, G., & Zoppolo, G. (1979). Caracterización agronómica y clasificación racial de las muestras de maíz colectadas en Uruguay bajo el Proyecto IBPGR y Facultad de Agronomía. Tesis (Ingeniería Agronómica). Universidad de la República, Uruguay.

McLaren, K. (1976). XIII—The development of the CIE 1976 (L* a* b*) uniform colour space and colour-difference formula. *Journal of the Society of Dyers and Colourists, 92*(9), 338–341. https://doi.org/10.1111/j.1478-4408.1976.tb03301.x

Mohsenin, N. N. (1987). Physical Properties of Plant and Animal Materials. *Gordon and Breach Science Publishers*, 841 p. https://doi.org/10.1002/food.19870310724

Mojena, R. (1977). Hierarchical grouping method and stopping rules: an evaluation. *Computer Journal*, *20*:359-363.

Moreira, R., Chenlo, F., Arufe, S., & Rubinos, S. (2015). Physicochemical characterization of white, yellow and purple maize flours and rheological characterization of their doughs. *J Food Sci Technol*, *52*(12):7954–7963. 10.1007/s13197-015-1953-6

Mutlu, C., Arslan-Tontul, S., Candal, C., Kilic, O., & Erbas, M. (2018). Physicochemical, Thermal, and Sensory Properties of Blue Corn (*Zea Mays* L.). *Journal of Food Science*, Vol. 83(1), 53-59. 10.1111/1750-3841.14014

Oksanen, J., Blanchet F. G., Kindt R., Legendre P., Minchin P. R., O'Hara R. B., Simpson, G. L., Solymos, P., Stevens, M. H. H., & Wagner, H. (2016). *Vegan: Community Ecology Package*. R package version 2.3.5.

Okuyama, L. A., Caramori, P. H., & Kohli, M. M. (2020). New Microchondrometer to Measure Hectoliter Weight in Small Samples of Wheat. *African Journal of Agricultural Research*, 15(4), 524-530. 10.5897/AJAR2019.14538

Paraginski, R. T., Rockenbach, B. A., Santos, R. F., Elias, M. C., & Oliveira, M. (2015). Qualidade de Grãos de Milho Armazenados em Diferentes Temperaturas. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 19, 358–363. http://dx.doi.org/10.1590/1807-1929/agriambi.v19n4p358-363

Paraginski, R. T., Souza, N. L., Alves, G. H., Ziegler, V., Oliveira, M., & Elias, M. C. (2016b). Sensory and Nutritional Evaluation of Popcorn Kernels with Yellow, White and Red Pericarps Expanded in Different Ways. *Journal of Cereal Science*, 69, 383-391. https://doi.org/10.1016/j.jcs.2016.05.013

Paraginski, R. T., Ziegler, V., Ferreira, C. D., Colussi, R., Gutkoski, L. C., Zavareze, E. R., & Elias, M. C. (2016a). Properties of Popcorn Starch Expanded in a Microwave, with and without the Presence of Vegetable Oil. *Journal of Food Processing and Preservation*, 41, 1-10. https://doi.org/10.1111/jfpp.13142

Park, D., Allen, K. G. D., Stermitz, F. R., & Maga, J. A. (2000). Chemical Composition and Physical Characteristics of Unpopped Popcorn Hybrids. *Journal of Food Composition and Analysis*, *13*, 921-934. https://doi.org/10.1006/jfca.2000.0943

Paterniani, E., Goodman, M. M. (1977). *Races of maize in Brazil and adjacent areas*. https://repository.cimmyt.org/bitstream/handle/10883/19601/50793.pdf?sequence=1&isAllowed=y

Pereira, M. T. J., Caneppele, C., Silva, S. L. S., Nunes, J. A. S., & Ormond, A. T. S. (2014). Propriedades Físicas de Marcas Comerciais de Milho Pipoca: Grão e Estourada. *Enciclopédia Biosfera*, 10(18), 2525-2532. https://conhecer.org.br/ojs/index.php/biosfera/article/view/2864

Pineda-Hidalgo, K.V., Vega-Alvarez, E., Calderon-Zamora, L., Salazar-Salas, N. Y., Gutierrez-Dorado, R., Reyes-Moreno, C., Bello-Perez, L. A., & Lopez-Valenzuela, J. (2015). Physicochemical, Structural, and Proteomic Analysis of Starch Granules from Maize Landraces of Northwest Mexico. *Cereal Chemistry*, 92(3), 320–326. https://doi.org/10.1094/CCHEM-05-14-0099-R

Pordesimo, L. O., Anantheswaran, R. C., Fleischmann, A. M., Lin, Y. E., & Hanna, M. A. (1990). Physical properties as indicators of popping characteristics of microwave popcorn. *Journal of Food Science*, *55*(5):1352-1355. https://doi.org/10.1111/j.1365-2621.1990.tb03934.x

Prasanthi, P. S., Naveena, N., Vishnuvardhana R., M., & Bhaskarachary, K. (2017). Compositional Variability of Nutrients and Phytochemicals in Corn After Processing. *J Food Sci Technol*, *54*(5), 1080–1090. 10.1007/s13197-017-2547-2

Programa de Aquisição de Alimentos. Ministério da Cidadania. Secretaria Especial do Desenvolvimento Social. http://mds.gov.br/assuntos/seguranca-alimentar/programa-de-aquisicao-de-alimentos-paa

Programa Nacional de Alimentação Escolar. Ministério da Educação. Fundo Nacional de Desenvolvimento da Educação.: https://www.fnde.gov.br/programas/pnae

R Core Team (2014) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Ranathunga, R. A. A., Gunasekara, G. T. N., & Wijewardana, D. C. M. S. I. (2016). Quality Performance, Proximate Composition and Sensory Evaluation of Developed Flavoured Instant Popcorn. *Procedia Food Science*, 6, 143 – 146. https://doi.org/10.1016/j.profoo.2016.02.034

Ribeiro, V. S., Sobral, M. C., Almeida, M. M., & Silva, G. F. (2002). Propriedades físicas de produtos agrícolas. *Revista Brasileira de Produtos Agroindustriais, Campina Grande*, *4*, 1-6. http://dx.doi.org/10.15871/1517-8595/rbpa.v4n1p1-6

Rodrigues, A. P. D. C., Dalla-Costa, D. A., Colognese, I. C., & Pereira, S. R. (2018). Qualidade Fisiológica de Sementes Crioulas de Milho Pipoca. *Revista Brasileira de Agroecologia*, 13, 255-259. https://doi.org/10.33240/rba.v13i5.22750

Saito, M. A., Alves, A. V., Kuritza, D. P. Souza, Y. P., Maioli, M. F. S. D., Amaral Júnior, A. T., Bento, A. C. B, Scapim, C. A., & Pinto, R. J. B. (2021). Influence of Agronomic and Kernel-related Properties on Popping Expansion in Popcorn. *Agronomy Journal*, 1−13. https://doi.org/10.1002/agj2.20645

Seledes, R. M., Ogliari, J. B., Melhorança, E. A. L., Souza, R., & Oliveira, W. B. S. (2019). Caracterização Fenotípica de Milho-Pipoca Conservado *in situ-on farm* no Extremo Oeste de Santa Catarina. *Agropecuária Catarinense*, 32, 56-61. http://dx.doi.org/10.22491/RAC.2019.v32n3.7

Silva, N. C. A. (2015). *Conservação, diversidade e distribuição de variedades locais de milho e seus parentes silvestres no Extremo Oeste de Santa Catarina, Sul do Brasil*. [Tese de Doutorado, Universidade Federal de Santa Catarina, Florianópolis].

Silva, N. C. A., Vidal, R., & Ogliari, J. B. (2017). New popcorn races in a diversity microcenter of Zea mays L. in the Far West of Santa Catarina, Southern Brazil. Genetic Resources and Crop Evolution, 64, 1191–1204. 10.1007/s10722-016-0429-5

Silva, N. C. A., Vidal, R., Costa, F. M., & Veasey, E. A. (2020). Classificação das Raças de Milho do Brasil e do Uruguai: Abordagem Metodológica e Principais Resultados. In Silva, N. C. A., Costa, F. M., & Vidal, R. (Org.), *Milhos das terras baixas da América do Sul e conservação da agrobiodiversidade no Brasil e no Uruguai* (pp. 86-108). Atena.

Silva, N. C. A., Vidal, R., Costa, F. M., & Veasey, E. A. (2021). Catálogo Raças de milho do Brasil e Uruguai: diversidade e distribuição nas terras baixas da América do Sul. Atena. 10.22533/at.ed.274212302

Silva, N. C. A., Vidal, R., Ogliari, J. B., Costich, D. E., & Chen, J. (2020). Relationships among American popcorn and their links with landraces conserved in a microcenter of diversity. *Genet Resour Crop Evol*, 67, 1733–1753. https://doi.org/10.1007/s10722-020-00935-2

Silva, W. J., Vidal, B. C., Martins, M. E. Q., Vargas, H., Pereira, C., Zerbetto, M., & Miranda, L. C. M. (1993). What makes popcorn pop. *Nature*, *362*, 417. https://doi.org/10.1038/362417a0

Singh, S. K., Ram, U. S., Singh, M. K., & Deshmukh, R. (2017). Effect of Planting Time, Fertility Level and Plant Population on Development, Yield, Nutrient Uptake and Quality of Winter Popcorn (Zea mays everta Sturt) under Late Sown Condition. Int.J.Curr.Microbiol.App.Sci, 6(2), 1187-1193. http://dx.doi.org/10.20546/ijcmas.2017.602.134

Somavat, P., Li, Q., de Mejia, E.G., Liu, W., & Singh, V. (2016). Coproduct yield comparisons of purple, blue and yellow dent corn for various milling processes. *Ind. Crops Prod*., 87, 266–272. https://linkinghub.elsevier.com/retrieve/pii/S0926669016302928

Srdić, J, Milašinović Šeremešić, M., Radosavljević, M., Kravić, N., & Babić, V. (2017). Evaluation Of Agronomic And Sensory Characteristics Of The Popcorn Kernel. *Journal on Processing and Energy in Agriculture*, 21(4), 185-187. 10.5937/JPEA1704185S

Stefanello, R. (2014). *Composição Química e Qualidade de Sementes de Variedades Crioulas de Milho no Armazenamento*. [Tese de Doutorado, Universidade Federal de Santa Maria].

Sweley, J. C., Rose, D. J., Jackson, D. S. (2012). Hybrid and Environment Effects on Popcorn Kernel Physiochemical Properties and Their Relationship to Microwave Popping Performance. *Journal of Cereal Science*, 55, 188-194. https://doi.org/10.1016/j.jcs.2011.11.006

Vázquez-Carrillo, M. G., Santiago-Ramosa, D., & Figueroa-Cárdenas, J. D. (2019). Kernel Properties and Popping Potential of Chapalote, a Mexican Ancient Native Maize. *Journal of Cereal Science*, 86, 69–76. https://doi.org/10.1016/j.jcs.2019.01.010

Zhao, Z., Egashira, Y., & Sanada, H. (2005). Phenolic Antioxidants Richly Contained in Corn Bran Are Slightly Bioavailable in Rats. *J. Agric. Food Chem*, *53*, 5030–5035. https://doi.org/10.1021/jf050111n

Zhu, F. (2018). Anthocyanins in cereals: Composition and health effects. Food Research International 109, 232-249. https://doi.org/10.1016/j.foodres.2018.04.015

Ziegler, V., Timm, N. S., Ferreira, C. D., Goebel, J. T., Pohndorf, R. S., & Oliveira, M. (2020). Effects of drying temperature of red popcorn grains on the morphology, technological, and digestibility properties of starch. *International Journal of Biological Macromolecules*, 145, 568–574. https://doi.org/10.1016/j.ijbiomac.2019.12.198

Zulkadir, G., & Ídikut, L. (2021). Determination of Popping Traits and Grain Quality of Landraces Popcorn Populations. *J Food Sci Technol*, 58(4):1302–1312. https://doi.org/10.1007/s13197-020-04639-4