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RESEARCH ARTICLE

Physicochemical properties of *Muntingia calabura* fruit and its effect on the quality characteristics of cookies

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ABSTRACT

The objective of this investigation was the physical characterization of the *Muntingia calabura* fruit and physicochemical property evaluation of its meal for use in the formulation of cookies and the physicochemical and sensory characterization of the optimized cookies. The fruit showed a length, width, and thickness of 12.75 mm, sphericity of 99.79%, and an average weight of 1.72 g. *Muntingia calabura* meal had a high content of protein (26.29 g/100 g) and fiber (13.33 g/100 g), a water solubility capacity of 24%, an oil absorption capacity of 2.17 g/g, and an emulsifying capacity of 16.03%. Cookies were made with different *Muntingia calabura* meal concentrations (MMC) (0-35 g/100 g) and added water amounts (17-27 g/100 g). Two optimal conditions were obtained (C1 = MMC 8.07 g/100 g and C2 = MMC 6.05 g/100 g, both with 28.46 mL/100 g of added water). The C1 cookie had a higher protein content (28.99 g/100 g), both cookies had the same degree of acceptance.

Keywords: *Muntingia calabura*; physical properties; physicochemical properties; cookies

INTRODUCTION

Muntingia calabura is a tree that is 8 to 20 m tall has a diameter of 8.5 to 30 cm, with grayish-brown branches, simple laminated leaves with a jagged edge, and flowers in pendulous fascicles (Figueiredo et al., 2008). The fruit of *Muntingia calabura* is small reddish or yellowish, round, edible, juicy, and sweet, and it contains numerous tiny yellow seeds immersed in a watery aril (Zakaria et al., 2007). It is naturally distributed in some tropical regions of Mexico (Nayarit, San Luis Potosí, Veracruz, Oaxaca, Chiapas, and the Yucatan Peninsula) through Central America and the Antilles to Venezuela, Brazil, and Peru in South America. It is cultivated for its fruit in Florida and as an ornamental in the Antilles. The ripe fruits are very sweet and are consumed fresh and in the form of jelly, jams, syrups, and honey. In traditional medicine, is the fruits are used as an antitussive for bronchopleural conditions (Zakaria et al., 2010). It should be noted that there are no published works on the linear and geometric properties of the fruit and the functional properties of the meal, much less its incorporation in food development. It is important to understand the functional properties of raw materials with potential use in the food industry to obtain a global overview of their possible use or application in food development (Torruco-Uco et al., 2019) and the influence of the fruit appearance and behavior. Among the functional properties of this species are its hydration ability, foam formation, emulsification, gelation, and other characteristics that generally have been related to proteins and other components present in food (Ogundele & Aladesanmi, 2010; Rodríguez-Miranda et al., 2012; Téllez-Morales et al., 2020; Téllez-Morales et al., 2021). Functionality is related to the conditions of processing and storage and the physicochemical and structural characteristics of the materials. (Pensamiento-Niño et al., 2019). Knowledge of characteristics such as shape, size, volume, surface area, grain weights, density, porosity, and angle of repose is important for the design of different separation systems, handling, storage, and drying (Pensamiento-Niño et al., 2019). In this sense, some investigations have been carried out on the physical characterization of the seeds and the physicochemical and functional characterization of the flours. Hernández-Santos et al. (2015) carried out a partial characterization of the physical properties of ebony seeds (*Pithecellobium flexicaule*) and evaluated some functional properties of the flour. Pensamiento-Niño et al. (2019) studied the physical

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and mechanical properties of the seed and almonds of the Mexican pink pine (*Pinus pinea* L.), as well as the physicochemical characteristics of the defatted flour. However, they only performed the characterization of the samples without making a food product. Therefore, cookie making could be an option. In the world, the consumption of cookies in the last year has increased in countries such as France by 61%, UK 55%, Japan 52% South Africa 48%, Italy 38%, Australia 33%, Mexico and Canada 29%, and the global cookie consumption increased 31.6% during COVID-19 (Cookies Report, 2021). Traditionally, cookies are made with wheat flour (Singh et al., 2011), which has a high gluten content. Gluten is a mixture of proteins with low nutritional value because of deficiencies in essential amino acids, and gluten has also been linked to celiac disease. Currently, people look for gluten-free products; therefore, various studies have been carried out on the incorporation of new additives in the bakery industry (Mancebo et al., 2016; Bourekoua et al., 2018; Moro et al., 2018), such as cereal flours or starches, to give special flavors or structural properties and to replace gluten with proteins of higher nutritional value. Thus, cookies made from the *Muntingia calabura* meal could be an option to 1) increase knowledge on this fruit known and encourage its cultivation and 2) incorporate it as an ingredient in the bakery industry. Therefore, the objective of this study was the physical characterization of the *Muntingia calabura* fruit and determination of the physicochemical properties of the meal for use in making cookies and the physicochemical and sensory characterization of the optimized cookies.

MATERIALS AND METHODS

The general scheme of the determinations made for the physical characterization of the fruit, the physical-chemical characterization of flour and cookies, and optimization in the preparation of the cookies can be seen in Fig. 1.

Raw material

Muntingia calabura fruits were collected in the town of Vega del Sol municipality of Santa Maria Jacatepec, Tuxtepec, Oaxaca, México. They were kept in polyethylene bags and placed in a portable refrigerator at 4 ºC for transport to the laboratory for determinations.

Physical properties

Linear dimensions

According to the methods described by Mpotokwane et al. (2008), 100 fruits were randomly selected. Length (L), width (W), and thickness (T) were measured using a Vernier caliper with a precision of 0.001 mm. The geometric diameter (Dg), geometric diameter (D_g), equivalent diameter (D_e), sphericity (Ø), aspect ratio (Ra), flakiness ratio (Fr) and elongation ratio (Er) were calculated according to Pensamiento-Niño et al. (2019), Pathak et al. (2019) and Sonawane et al. (2020). The surface area (S) was calculated analogous to a spherical surface (SA = mm^2) according to Vivek, et al. (2018). The projected area perpendicular to length (P_L), projected area perpendicular to width (P_W), projected area perpendicular to thickness (P_T), and criteria projected area (CPA) were determined according to Sonawane et al. (2020). The volume (V), ellipsoid volume (V_{ellip}), prolate spheroid volume (V_{pro}) and oblate spheroid volume (V_{osp}) were determined according to Hernández-Santos et al. (2015) and Sonawane et al. (2020).

Weight of 100 fruits

The mass of 100 fruits was obtained using an electronic balance with an accuracy of 0.0001 g according to Mpotokwane et al. (2008). The apparent density (AD), true density (TD), and porosity (P) were determined according to Sonawane et al. (2020) and Vivek et al. (2018).

Obtaining the meal

The fruits were dried (Binder stove, mod. ED 115, Germany) at 60 ± 2 °C for 24 h and ground in a coffee mill (Krups Model GX4100, USA) until a particle size of 0.59 mm (30 mesh, standard test sieve Astm E-11 Specification W.S. Tyler, USA).

Chemical analysis

The proximal chemical composition (PCC) of the *Muntingia calabura* meal was determined according to the methods of the AOAC (2015): moisture (934.01), ash (942.05), protein (2001.11), fiber (962.09), and fat (954.02). Total carbohydrates were calculated by difference values. Total energy was calculated according to Torruco-Uco et al. (2019). Three determinations were made per treatment.

Color and pH

The color (L^* (Luminosity), a^* (red-green chromaticity) and b^* (yellow/blue chromaticity)) of the meal and cookies was determined using a tri-stimulus colorimeter Hunter lab (MiniScan Hunter Lab, model 45/0L, Hunter Associates Lab., Ind., Reston, Va. USA). The chromaticity (C^*) and hue angle (h°) values were calculated. The pH was measured by dispersing the flours in water at 25 °C. Four measurements were made per sample.

Meal functional properties

The water absorption capacity (WAC), water solubility capacity (WSC), oil absorption capacity (OAC), emulsifying capacity (EC), foaming capacity (FC) and foam stability (FS), least gelation concentration (LGC), bulk density (BD), and swelling power (SP) were determined according to Rodríguez-Miranda et al. (2012). Three determinations were made per treatment.

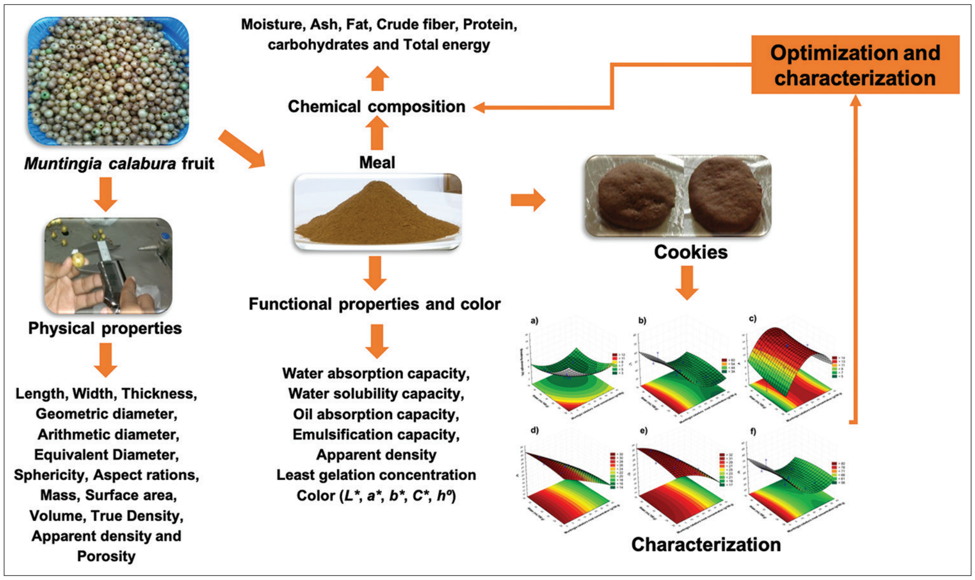

Fig 1. General diagram of physical characterization of the fruit, the physicochemical of the flour, the characterization, and optimization of the cookies.

Cookie making

The cookies were made according to the formula of Pérez et al. (2013): wheat meal (200 g), sucrose (68 g), margarine (45 g), whole egg (10 g), sodium bicarbonate (1 g), ammonium bicarbonate (1 g), and water. Wheat flour was partially replaced by *Muntingia calabura* meal according to the design of the experiments (Table 1). All ingredients were mixed for 5 min. Then, the mass was rolled out to a thickness of 2 mm and left to rest for 1 min. The mass was cut with a mold that was 6 cm in diameter and baked at 220 °C for 8 min.

Cookie evaluation

The ratio of the diameter (D) and thickness (T) was determined according to Singh et al. (2011). Ten cookies from each batch were measured using a Vernier. This ratio was calculated as D/T, and weight was calculated. Three measurements were made per sample.

Texture

The maximum compression breaking strength was determined in the cookies according to the method reported by Singh et al. (2011) in a universal Texturometer Texture Analyzer TA-XTplus (Texture Technologies Corp., Scarsdale NY/stable Microsystems, Haslemere, Surrey, UK), with a pretest speed of 2.0 mm/s, a test speed of 0.5 mm/s, a speed after the test of 10.0 mm/s, and a cut distance of 5 mm. The maximum force was reported as the fracture resistance in Newtons (N). Fifteen measurements were made per sample.

Optimized product characterization

The optimized cookies were determined by PCC, total energy, color, breaking strength, weight, width, thickness, spread ratio W/T, WAC, and WSC, according to the methodology mentioned above. Water activity (*Aw*) was determined using AQUALAB (Model: Series 3 TE, Decagon Devices, Inc. Pullman, Wash., USA).

Sensory evaluation

The criteria for selection were that consumers should (i) consume cookies, (ii) have no allergies to cookies, and (iii) approve screening discriminatory tests. The results of the discriminatory tests were processed using sequential analysis (ISO standard 16820:2004), and consumers were selected according to the number of correct answers obtained in their screening discriminatory test (recognition of aromas (ISO standard 5496:2005), triangular discrimination tests (ISO standard 4120:2004) and duo-trio test (ISO standard 10399:2004) (Ramon-Canul et al., 2021; Ramírez-Rivera et al., 2020). A preference assessment was conducted with 50 untrained panelists to determine optimal products using a 9-point hedonic scale (1 = I truly dislike it, to 9 = I like a lot), according to some quality characteristics such as color, texture, flavor and general acceptability (Gan et al., 2007).

Experimental design and data analysis

The composite central experimental design was used to make the cookies, with two independent variables using a statistical program (Design-Expert 7.0.0 Statease Inc., Minneapolis, MN, USA). The independent variables were *Muntingia calabura* meal concentration (MMC = 0 - 35 g/100 g) (X_1) and added water (17 - 27 g/100 g) (X_2). The response variables were texture and color. Multiple linear regression was used to analyze the results (Equation 1). Analysis of variance (ANOVA) was used to determine the statistical significance of the regression terms in the responses.

Table 1: Experimental design and experimental texture and color results, and coefficients estimated by multiple linear regression of characterization of cookies made with different *Muntingia calabura* meal concentrations and water.

Run	MMC (g/100 g) X_1	Water (mL/100 g) X_2	BS (N)	Cookie color				
				L^*	a^*	b^*	C^*	h°
1	5.13 (-1)	28.46(-1)	8.78 ± 1.54^{g}	54.15 ± 6.86^{f}	11.16 ± 3.15^{b}	29.47 ± 1.75^{e}	31.63 ± 2.20^{f}	69.45 ± 5.17^{g}
2	29.87 (+1)	28.46 (-1)	5.59 ± 0.42^{e}	36.78 ± 3.11^{b}	11.79 ± 0.77^{bc}	20.23 ± 2.15^{b}	23.44 ± 1.99^{b}	59.58 ± 2.99^{abc}
3	5.13 (-1)	35.54(+1)	5.60 ± 0.94^{e}	49.39 ± 3.36^{e}	12.36 ± 1.10^{cd}	29.86 ± 1.81^{ef}	32.35 ± 1.63^{f}	67.47 ± 2.51^{g}
4	29.87 (+1)	35.54 (+1)	3.95 ± 1.00^{d}	35.81 ± 5.12^{ab}	11.71 ± 1.80^{bc}	19.47 ± 4.03^{ab}	22.77 ± 4.17^{b}	58.30 ± 4.51^{a}
5	0.00 (-1.41)	32.00 (0)	7.93 ± 1.74^{f}	73.32 ± 2.55^{g}	2.37 ± 1.88^{a}	31.18 ± 1.41^{f}	31.32 ± 1.50^{f}	85.72 ± 3.26^{h}
6	35.00 (+1.41)	32.00 (0)	3.65 ± 0.52^{bc}	34.08 ± 2.83^{a}	11.08 ± 0.81^{b}	18.25 ± 1.62^{a}	21.36 ± 1.68^{a}	58.68 ± 1.84^{ab}
7	17.50 (0)	27.00 (-1.41)	7.81 ± 1.26^{f}	42.38 ± 3.73^{cd}	12.31 ± 0.90^{cd}	25.05 ± 1.81^{cd}	27.94 ± 1.43^{cd}	63.71 ± 3.06^{f}
8	17.50 (0)	37.00 (+1.41)	2.57 ± 0.44^{a}	40.14 ± 3.34^{c}	13.59 ± 0.84^{e}	23.87 ± 2.80^{c}	27.51 ± 2.40^{c}	60.07 ± 3.87^{abcd}
9	17.50 (0)	32.00 (0)	3.26 ± 0.40^{abc}	41.96 ± 3.02^{cd}	13.40 ± 1.12^{e}	25.20 ± 1.75^{cd}	28.59 ± 1.32^{cde}	61.91 ± 3.28^{def}
10	17.50 (0)	32.00 (0)	5.69 ± 0.70^{e}	42.90 ± 4.72^{d}	12.56 ± 1.08^{d}	25.07 ± 2.25^{cd}	28.10 ± 1.75^{cde}	63.22 ± 3.79^{ef}
11	17.50 (0)	32.00 (0)	3.36 ± 0.70^{bc}	42.22 ± 6.22^{cd}	13.78 ± 0.82^{e}	25.78 ± 3.62^{d}	29.32 ± 2.95^{e}	61.46 ± 4.62
12	17.50 (0)	32.00 (0)	4.52 ± 0.66^{d}	40.44 ± 5.99^{c}	13.30 ± 1.20^{e}	23.96 ± 3.77^{c}	27.51 ± 3.12^{c}	60.46 ± 5.38^{bcd}
13	17.50 (0)	32.00 (0)	3.17 ± 0.38^{ab}	41.80 ± 5.52^{cd}	13.68 ± 0.98^{e}	25.49 ± 3.24^{d}	29.00 ± 2.63^{de}	61.43 ± 4.40^{cde}

Coefficients		BS	L^*	a^*	b^*	C^*	h°
Intercepto		4.000*	41.865*	13.343*	25.100*	28.504*	61.697*
Linear	X_1	-1.361*	-10.804*	1.537	-4.739*	-3.981*	-7.159*
	X_2	-1.530*	-1.113	0.366	-0.255	-0.070	-1.051
Quadratic	X_{12}	1.016*	5.055*	-2.829*	-0.150	-0.953*	4.414*
	X_{22}	0.719	-1.168	0.284	-0.278	-0.261	-0.742
Interaction	X_1X_2	0.385	0.948	-0.320	-0.288	-0.348	0.175
R^2		0.875	0.918	0.743	0.987	0.968	0.886
p of F (model)		0.0047	0.001	0.048	<0.001	<0.001	0.003
Lack of Fit		0.7491	0.002	0.002	0.797	0.350	0.006

*Bold numbers indicate estimates of significant parameters ($P < 0.05$). Different letters in the same column indicate significant differences ($P < 0.05$).
MMC = *Muntingia calabura* meal concentration; BS = breaking strength.

$$y = B_0 + B_0X_0 + B_1X_1 + B_2X_2 + B_{11}X_1^2 + B_{22}X_2^2 + B_{12}X_1X_2 \quad (1)$$

The characterization of *Muntingia calabura* meal was analyzed using one-way analysis of variance (ANOVA), and differences between means were determined with a least significant difference test (LSD) and a confidence level of 95% using the statistical program Statistica Version 8.0 (StatSoft, Inc. 1984-2008, USA).

Optimization

The numerical optimization was performed according to the maximums and minimums found to determine maximum texture and an intermediate luminosity, and all other color parameters were kept in the found range. These were established in the Design Expert 7.0 program (Stat-Ease Inc., Minneapolis, MN, USA) to obtain the optimal cookie values. The MMC and water were kept within the desired range.

RESULTS AND DISCUSSION

Physical properties

The *Muntingia calabura* fruits had an average length (L), width (W) and thickness (T) of 12.75 mm (Table 2). The frequency distributions for L, W and T are presented in Fig. 2, showing that for L, the highest frequency was found in the fifth interval, while for W and T, the highest frequency was found in the fourth interval; and the mass was found in the second interval. On the other hand, D_g, D_a, and D_e showed very similar values (Table 2). The *Muntingia calabura* fruit can be considered a spherical fruit since it presented a Ø = 99.79%. The mean values of AR, F_r, and E_r were 1.01, 1.01, and 1, respectively. These properties provide an idea about the shape of the fruit since they represent the ratio between its width and length. Different areas of the *Muntingia calabura* fruit were determined, showing an average value of SA = 511 mm^2, while for P_L, P_W, P_T, and CPA, the values were very similar (Table 2). These areas were used in mathematical modeling studies to determine the respiration rate, water loss, gas permeability, and ripening index (Pathak et al., 2019; Vivek et al., 2018). Similarly, mean values of V, V_{ellip}, V_{pro}, and V_{osp} ranging between 1092.16 and 1118.25 mm^3 were found (Table 2). These dimensional properties are of prime importance for calculating the densities of fruit during the storage and postharvesting of crops (Pathak et al., 2019). The apparent and true densities were found in intervals of 0.57 - 0.59 g/cm^3 and 0.41 - 0.42 g/cm^3, respectively, and the porosity was 28% on average. Apparent density, true density, and porosity are parameters used to design hoppers and control the flows in the equipment used

Table 2: Linear dimensions and geometric properties of the fruit of the *Muntingia calabura*.

Physical properties	Average	Range	Standard deviation
Length = L (mm)	12.75	11.01 - 14.17	0.66
Width = W (mm)	12.75	10.00 - 14.81	1.27
Thickness = T (mm)	12.70	10.00 - 14.86	1.33
Geometric diameter = Dg (mm)	12.72	11.03 - 14.20	0.97
Arithmetic diameter = Da (mm)	12.73	11.04 - 14.21	0.96
Equivalent diameter = De (mm)	54.20	41.14 - 65.92	7.04
Sphericity = Ø (%)	99.79	83.21 - 109.39	6.07
Aspect rations = AR	1.01	0.88 - 1.33	0.10
Flakiness ratio = Fr	1.01	0.94 - 1.23	0.04
Elongation ratio = Er	1.00	0.81 - 1.06	0.03
Surface area = SA (mm^2)	511.22	382.45 - 633.70	77.41
Projected area perpendicular to length = PL (mm^2)	127.93	97.59 - 157.68	16.16
Projected area perpendicular to width = PW (mm^2)	128.95	78.54 - 172.27	25.11
Projected area perpendicular to thickness = PT (mm^2)	128-39	80.97 - 169.36	25.42
Criteria projected area = CPA (mm^2)	128.42	87.94 - 164.51	21.95
Volume = V (mm^3)	1118.25	1684.75 - 587.29	328.06
Ellipsoid volume = Vellip (mm^3)	1096.06	703.30 - 1500.02	245.62
Prolate spheroid volume = Vpro (mm^3)	1092.16	742.33 - 1431.70	177.51
Oblate spheroid volume = Vosp (mm^3)	1100.09	695.34 - 1549.43	241.78
Mass = M (g)	1.72	1.13 - 2.35	0.37
True Density = TD (g/cm^3)	0.42	0.41-0.42	0.01
Apparent density = AD (g/cm^3)	0.58	0.57-0.59	0.01
Porosity = P (%)	28.48	27.73 - 29.26	0.54
Ratios			
L/W	1.01	0.88-1.33	0.10*
L/T	1.01	0.85-1-31	0.10*
L/M	7.71	5.75-11-71	1.54*
W/M	7.59	6.26-10.64	0.98*
T/M	7.55	6.07-9.21	0.88*
L/D_a	1.00	0.91-1.19	0.06*
L/D_g	1.01	0.91-1.20	0.07*

Values represent the average of 100 measurements ± standard deviation. *Correlations significant at $P < 0.05$

to process sort, transport, and package fruits. Porosity is an important property for maintaining the storage temperature of fruits (Pradhan et al., 2010). These results are superior to those reported by other authors for ebony and *Cucurbit ficifolia* seeds (Hernández-Santos et al., 2015; Rodríguez-Miranda et al., 2016) and are also higher than those reported by Coşkuner and Gokbudak (2016) for palm fruit. On the other hand, Tewari et al. (2019) reported similar values for the fruit of *Emblica officinalis* from India. The relationships and correlation coefficients between the *Muntingia calabura* fruit and its dimensions showed a low correlation between L and W, T, Da, and Dg, while with M, a high positive correlation was observed, indicating that the mass is closely related to its length (Table 2). Similar behavior was observed in the palm fruit (Coşkuner and Gokbudak, 2016) and in the fruit of *Emblica officinalis* from India (Tewari et al., 2019).

Chemical composition, color and functional properties of meal

Muntingia calabura meal presented three major components, carbohydrates (44.18 g/100 g), protein (26.29 g/100 g) and crude fiber (13.33 g/100 g), suggesting that it could be a potential source of these macromolecules (Table 3). Tewari et al. (2019) reported low values of protein (3.80 - 4.51 g/100 g) and fiber (11.68 - 15.98 g/100 g) relatively high value of carbohydrates (77.18 - 81.93 g/100 g) in the fruit of *Emblica officinalis* from India. The pH of the meal was 5.7, similar to that of ebony seed meal (5.96) (Hernández-Santos et al., 2015). The color parameter L^* was 44, $a^* = 7$, $b^* = 10$, $C^* = 13$ and $h° = 55.06$, which indicated that the meal is dark with low color saturation, probably owing to the high content of sugars that could have been affected during the drying of the fruit causing a brown coloration to the meal (Table 3). These values are within those reported by Tewari et al. (2019) for the fruit of *Emblica officinalis* from India. The meal showed an A_w of 0.48, which indicates that the meal has good storage stability. Additionally, the meal had a low WAC and high solubility and EC, similar to that found by Hernández-Santos et al. (2015) for ebony seed meal (WAC = 1.04 g/g; WSC = 24.55%). Additionally, it was observed that the meal had an EC (Table 3) and SP above 2.2 g/g at the four temperatures tested, decreasing with increasing temperature (2.6 g/g (60 °C) to 2.2 g/g (90 °C) (Fig. 3); however, FC or LGC was not observed. This is because these properties are mainly influenced by lipids and proteins, so the interaction of proteins with fiber and lipids caused depression in the foam and in not only the amount of lipids but also the type of lipids present that may affect EC and FC.

Effect of MMC and water on BS and color

Significant differences ($P < 0.05$) were found in all the cookie formulations in the BS; the lowest value was at a ratio of 17.5 g/100 g of MMC and a water content of 37 mL/100 g, while the highest value was found at flour concentrations of 5.13 and 28.46 mL/100 g (Table 3). The regression model adjusted to the experimental results of BS showed a value of the correlation coefficient (R^2) = 0.875 with a significant regression model ($P < 0.0047$), and there was no lack of adjustment (Table 1), indicating the validity of the model to predict the response.

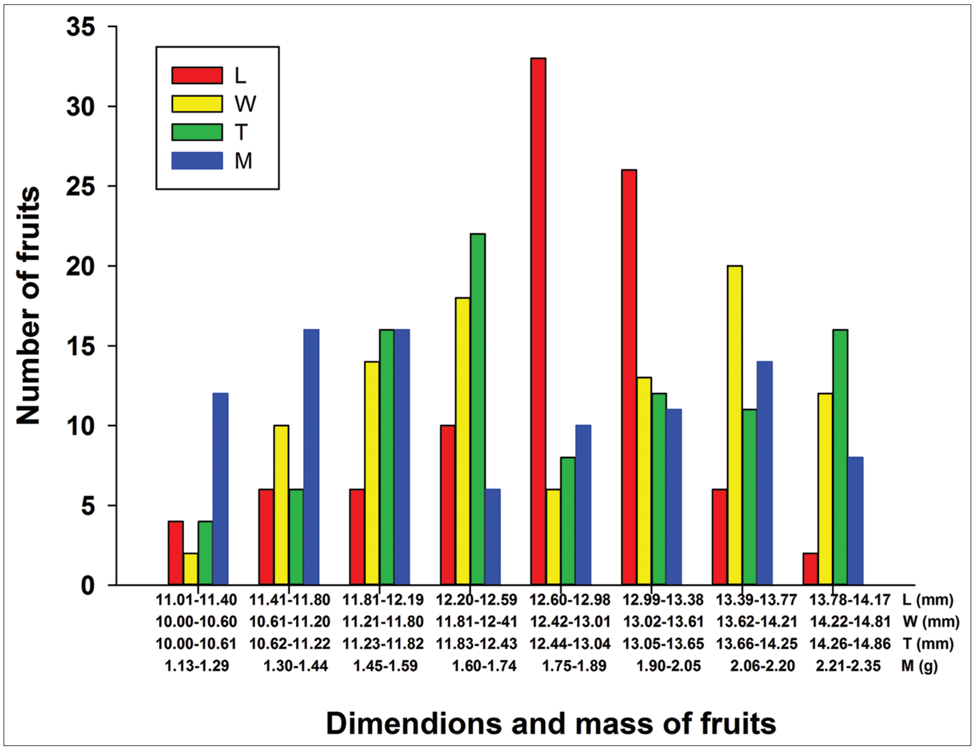

Fig 2. Dimensions and mass distribution bar chart for fruit *Muntingia calabura*.

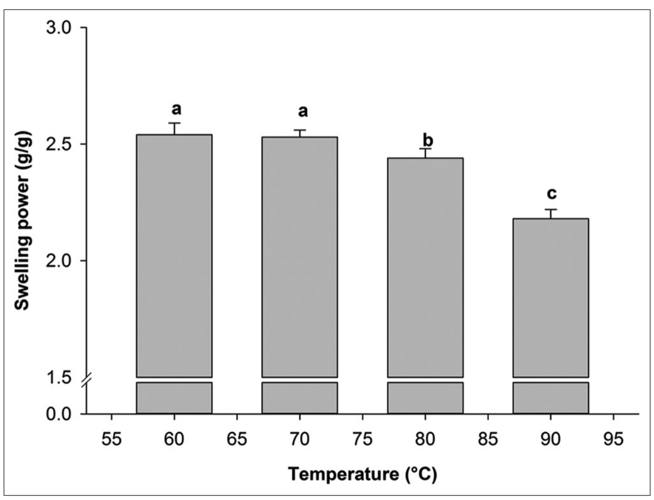

Fig 3. Swelling power of *Muntingia calabura* meal at different temperatures. The results are indicated as the mean ± standard deviation (*n*=3). Different letters indicate significant difference (*P* < 0.05).

The values represent the mean ± standard deviation of the replicates mentioned in materials and methods for each analysis. Values are expressed on a dry basis, except moisture of meal. WAC = water absorption capacity, WSC = water solubility capacity, OAC = oil absorption capacity, EC = emulsification capacity, AD = Apparent density, LGC = Least gelation concentration.

The estimated coefficients indicated that the MMC had a significant ($P < 0.05$) negative effect on the BS of the cookie, both in its linear and quadratic terms (Table 1). Fig. 4a shows that by increasing the MMC, the BS was lower, indicating that the cookie was softer because of the high protein content of *Muntingia calabura* meal. This behavior is similar to that reported by Mancebo et al. (2016), who used protein and rice starch in the mixture to prepare cookies, finding that the incorporation of proteins decreased the hardness (maximum resistance to breakage) and concluded that this behavior was due to changes in the internal structure of the cookie. The color of the cookies varied with all the formulations ($P < 0.05$) (Table 1). The determination coefficients (R^2) obtained from the regressions were found in the range of 0.743 - 0.987, indicating a high degree of correlation between the experimental results and those predicted by the model. The regression models of the color (L^*, a^*, b^* C^*, and $h°$) were significant (0.001 - 0.048), indicating the validity of the models to predict the responses. The models did not show a lack of fit (Table 1). The estimated coefficient indicated that the MMC had a significant negative effect, both in its linear and quadratic terms in L^* C^* and $h°$, which indicated that these parameters decreased with increasing MMC (Figure 4b); that is, the cookie was darker because MMC is high in carbohydrates and protein; therefore, during the baking process at high temperatures, Maillard or caramelization reactions developed. In parameter a^*, as the MMC increased, the value of a^* decreased, and the estimated coefficient indicated that the MMC had a significant ($P < 0.05$) negative effect only in its quadratic

Table 3: Chemical composition, total energy, Hunter color values, some physical properties, and sensory characteristics of the two optimized *Muntingia calabura* cookies, and meal.

Property	*Muntingia calabura* meal	Cookie 1	Cookie 2
Chemical composition (g/100g)			
Moisture	15.39 ± 0.80[b]	4.98 ± 0.07[a]	4.92 ± 0.08[a]
Ash	5.18 ± 0.12[b]	1.72 ± 0.04[a]	1.64 ± 0.21[a]
Fat	11.02 ± 0.35[a]	12.01 ± 0.20[b]	14.17 ± 0.08[c]
Crude fiber	13.33 ± 0.47[c]	1.23 ± 0.04[a]	1.38 ± 0.07[b]
Protein	26.29 ± 0.59[b]	28.99 ± 0.30[c]	22.05 ± 0.16[a]
Carbohydrates	44.18 ± 0.24[a]	51.07 ± 0.50[b]	55.85 ± 0.30[c]
Total energy (KJ/100 g)	1589.59 ± 27.92[a]	1810.52 ± 1.59[b]	1927.61 ± 5.39[c]
Physicochemical			
pH	5.71 ± 0.09	--	--
*L**	44.92 ± 0.00[a]	53.70 ± 0.30[b]	56.86 ± 0.40[c]
*a**	7.65 ± 0.00[a]	10.20 ± 0.40[c]	9.17 ± 0.10[b]
*b**	10.95 ± 0.01[a]	27.48 ± 1.82[b]	29.85 ± 0.20[b]
*C**	13.36 ± 0.01[a]	30.53 ± 0.10[b]	30.85 ± 0.30[b]
h°	55.06 ± 0.02[a]	70.80 ± 0.72[b]	72.60 ±0.46[c]
# Color	#7D6558	#A07951	#A88155
Color primer			
Aw	0.48 ± 0.00[a]	0.48 ± 0.01[a]	0.47 ± 0.01[a]
Breaking strength (N)	--	8.17 ± 1.10[a]	8.71 ± 0.92[a]
Weight (g)	--	4.52 ± 0.45[b]	4.22 ± 0.51[a]
Width (mm)	--	28.40 ± 2.00[a]	29.00 ± 1.40[a]
Thickness (mm)	--	5.60 ± 0.60[a]	5.90 ± 1.00[a]
Spread ratio W/T	--	0.20 ± 0.01[a]	0.20 ± 0.02[a]
Functional properties	--		
WAC (g/g)	2.41 ± 0.04[a]	2.89 ± 0.03[b]	2.89 ± 0.07[b]
WSC (%)	24.89 ± 2.54[b]	10.95 ± 0.33[a]	10.56 ± 0.77[a]
OAC (g/g)	2.17 ± 0.12	--	--
EC (%)	16.03 ± 0.91	--	--
FC (%)	--	--	--
AD (g/cm^3)	0.58 ± 0.01	--	--
LGC (%)	--	--	--
Sensory characteristics			
Mouthfeel	--	7.32 ± 1.03[a]	7.28 ± 1.37[a]
Taste	--	7.52 ± 1.16[a]	7.60 ± 1.29[a]
Appearance	--	7.40 ± 1.32[a]	7.60 ± 1.04[a]
Color	--	7.28 ± 1.14[a]	7.16 ± 1.07[a]
Overall acceptance	--	7.56 ± 0.96[a]	7.84 ± 0.94[a]

The values represent the mean ± standard deviation of the replicates mentioned in materials and methods for each analysis. Values are expressed on a dry basis, except moisture of meal. WAC = water absorption capacity, WSC = water solubility capacity, OAC = oil absorption capacity, EC = emulsification capacity, AD = Apparent density, LGC = Least gelation concentration.

term (Figure 4c), while in parameter *b**, the MMC had a significant negative effect ($P < 0.05$) only in its linear term, which suggests that when increasing the MMC, *b** decreased (Figure 4d). Bourekoua et al. (2018), who incorporated pomegranate seed powder as a functional component of gluten-free bread, also observed that by increasing its concentration, the color parameters decreased significantly; however, the dark color of the bread was acceptable.

Krystyjan et al. (2018) also observed that when increasing the *Psyllium banana* meal in the formulation to prepare cookies, parameters *L**, *a** and *b** decreased significantly ($P < 0.05$) due to the characteristics of the meal, with a protein content that favored the Maillard reaction during baking, achieving the incorporation of 5% *Psyllium banana* meal. On the other hand, the estimated coefficient indicates that MMC had a significant negative effect ($P < 0.05$) on its linear and quadratic terms on *C** (Table 3). Figure 4e shows that as MMC increased, the value of *C** decreased; therefore, the color of the cookie was less intense. Similarly, MMC had a significant negative effect ($P < 0.05$) in its linear term and a positive effect in its quadratic term on *h*° (Table 3). Figure 4f shows that as MMC increased, the value decreased; however, at concentrations of 25 to 35 g/100 g, MMC tended to increase slightly, which was due to the moisture content of these cookies, as darkening reactions have been reported to be influenced by the activity of water, pH, temperature, type of sugar and proportion of amino compounds (Sharma et al., 2013; Stojceska et al., 2009). This behavior has also been observed by Lauková et al. (2019) when substituting sweet potato powder for wheat flour.

Cookie optimization

Based on the results obtained in the statistical analysis, optimization of the preparation of the cookies was carried out to establish the optimal conditions of the independent variables with the desirable responses. Therefore, for all responses, two optimal conditions were obtained: C1 = MMC 8.07 g/100 g and C2 = MMC 6.05 g/100 g, both with 28.46 mL/100 g of added water; the predicted values in the responses were similar between the two formulations, with desirability values of 0.94 and 0.91, respectively (Table 4).

Optimized cookie characteristics

In optimized cookies, no significant difference ($P > 0.05$) was found in their moisture and ash contents, while in the remaining components, significant differences were observed ($P < 0.05$), with the higher protein content found in C1 rather than C2 (Table 2). This was because in this cookie, the MMC was higher than that in C2, which gave it a higher protein concentration; subsequently, the content of carbohydrates and lipids were influenced by increasing MMC because of replacement of wheat meal by MMC. Cookies with the use of MMC were found to be nutritious. Because consuming around 100 g of these cookies would provide more than half of the recommended daily protein requirement (25-30 g/day), as recommended by FAO (2006) and Arshad et al. (2007) for children between 5 and 19 years old. This behavior was

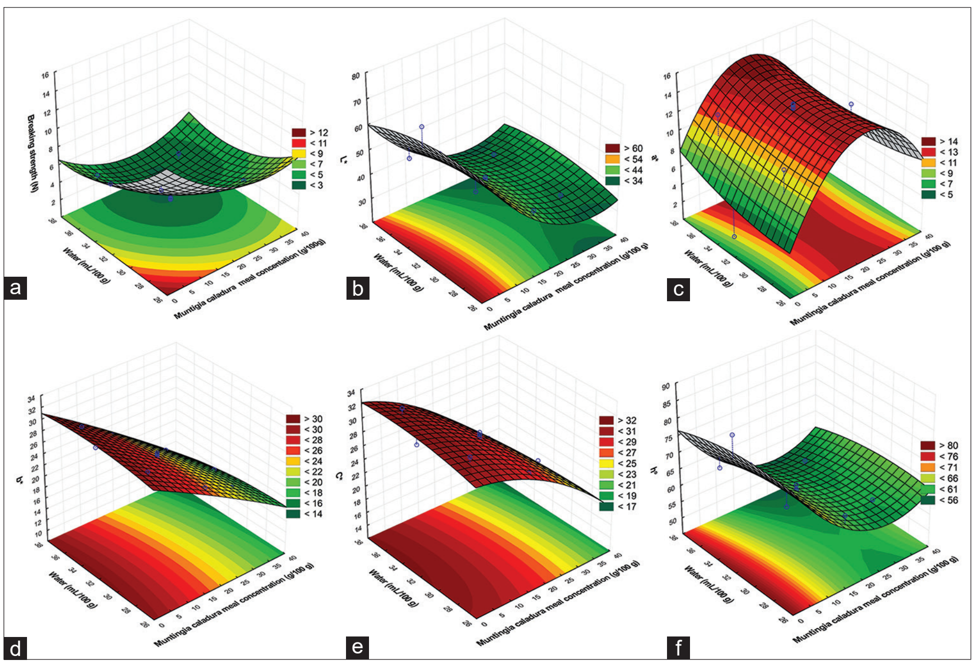

Fig 4. Response surface plots for a) breaking strength (BS), b) *L**, c) *a**, d) *b**, e) *C**, and f) *h°* as a function of Muntingia calabura meal concentration (MMC) and water.

Table 4: Optimal values of the variables studied and the response variables for the preparation of cookies.

Independent variables	Importance	Target	Experimental value		Optimum value	
			Min	Max	C1	C2
MMC (g/100 g)	3	Range	5.13	29.87	8.07	6.05
Water (mL/100 g)	3	Range	28.46	35.53	28.46	28.46
Responses					Predicted values	
Breaking strength (N)	5	Maxime	2.57	8.78	8.17	8.73
*L**	4	Is target:53.7	34.08	73.32	53.70	57.01
*a**	3	Range	2.37	13.78	10.20	9.12
*b**	3	Range	18.25	31.18	28.38	29.07
*C**	3	Range	21.36	32.35	30.53	30.86
*h*º	3	Range	58.30	85.72	70.16	72.57
ΔE	3	Range	59.78	96.86	84.37	80.67
Desirability					0.944	0.917

MMC = *Muntingia caladura* meal concentration; ΔE = total color difference; C1 = Cookie 1; C1 = Cookie 2 also observed by other authors when substituting wheat meal for chickpea meal (Soni et al., 2018). On the other hand, significant differences ($P < 0.05$) were observed in the color parameters L^*, a^* and $h°$ (Table 2). In C2, the values of L^* and $h°$ were higher than those in C1 due to having a lower proportion of MMC, and the shade of C2 was lighter brown than that of C1. However, for the breaking strength, width, thickness, dispersion ratio, and Aw, no significant differences were found ($P > 0.05$) in the functional properties of WAC and WSC. For the sensory characteristics, cookies showed a value of 7.16 to 7.84 for all evaluated attributes. This value corresponded to "I like it moderately", and no significant differences ($P > 0.05$) were observed for the attributes mouthfeel, taste, appearance, color, and overall acceptance among the samples. Although C1 showed a darker color, consumers did not perceive the difference, and the degree of acceptance was the same. This is a great advantage since integral products or products with benefits for health generally tend to be less liked because of the modification in the texture, appearance, and flavor, attributes that the functional ingredients contribute to this type of food.

CONCLUSION

The *Muntingia calabura* fruit has a sphericity of 99.79%, an average weight of 1.72 g, surface area of 511.22 mm^2, porosity of 28.48%, and volume of 1118.25 mm^3. The *Muntingia calabura* meal showed a high content of protein and fiber, and the results of the functional properties suggest that the meal could be used in the bakery industry, which was tested when making cookies with a mixture of *Muntingia calabura* and wheat flour. The proportions of *Muntingia calabura* meal did not alter the technological characteristics of the cookies since consumer acceptance was favorable, and the protein contents of the cookies were similar to that of *Muntingia* meal. Therefore, *Muntingia calabura* meal could be used as an alternative functional ingredient in the bakery industry.

Author's contributions

Jesus Rodriguez-Miranda and José Manuel Juárez-Barrientos: Data curation-Equal, Formal analysis-Equal, Investigation-Equal, Methodology-Equal, Software-Equal, Validation-Equal, Writing- original draft-Equal. Johana Hernández-Canseco and Mónica Rivera-Rivera: Data curation-Equal, Validation-Equal, Visualization-Equal, Writing-original draft-Equal. Betsabe Hernandez Santos: Conceptualization-Equal, Funding acquisition-Equal, Investigation-Equal, Methodology-Equal, Project administration-Equal, Validation-Equal, Visualization-Equal, Writing-original draft-Equal, Writing-review and editing-Equal.

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