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Physical, chemical, tecno-functional, and thermal properties of *Leucaena leucocephala* seed

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Abstract

The objective of this investigation was to study the physical, tecno-functional, chemical, and thermal properties of the *Leucaena leucocephala* seed. The physical properties revealed that the pod had an average weight of 2.14 g, a length of 13.67 cm, and an average of 20 seeds per pod. The seed had an average weight of 0.07 g with a volume of 30.02%. The sphericity was 52.14%, ovoid in shape, and presented with an apparent density and real density of 0.81 and 0.68 g/cm^3, respectively, and a porosity of 15.64%. The seed had a green hue, whereas the flour had a light brown hue. The seed presented with a high-fat content of 31.78 g/100 g, protein of 26.56 g/100 g, and fiber of 15.49 g/100 g. The flour showed a water absorption capacity of 4.64 g/g, water solubility capacity of 16.20%, water activity of 0.35, oil absorption capacity of 2.03 g/g, and emulsifying capacity of 48.06%. It also showed foam formation ability (48.06%), gelling capacity (4.00%), swelling power (4.5-5.2%), and a pH of 6.7. The thermal properties showed the presence of three endodermic peaks, indicating the presence of protein-amylose and lipid-amylose interactions, in addition to the gelatinization temperature of the starch present in the flour.

Keywords: *Leucaena leucocephala*; physical properties; seed; thermal properties.

Practical Application: Knowledge of its physical properties is necessary for designing separation, handling, storage, and drying systems as well as for optimizing the equipment required for the processing stages of an agricultural product. In this study, the information generated on the physical properties can be used for the design of post-harvest processing equipment and quality control of this seed. In addition, the functional properties suggest that the *Leucaena leucocephala* flour is a potential source of oil, protein, and fiber, which can be used in food formulations.

1 Introduction

Leucaena leucocephala (known as peladera, liliaque, huaje, or guaje) is an arboreal species belonging to the Leguminous or Fabaceae family. It produces edible pods known by the same name. The seed is flattened in shape and is used in various dishes such as huaxmole. This tree grows wild in warm areas between 800 and 1700 m above sea level. It is native to Mexico and is mainly found in the southern states such as Guerrero, Morelos, Oaxaca, and Chiapas but has also been introduced from Central America to northern South America (Badal, 2017; Wardatun et al., 2020; Balderas-León et al., 2021). Although the seeds are edible, their cultivation is used as green manure and forage, so characterizing this fruit will give it added value and determine its use in the food industry. Some of the investigations that have been carried out on the possible uses of Leucaena seed are the following: Sotolu & Faturoti (2008) examined the nutrient potentials of processed *Leucaena* seed meals in the diet of *Clarias gariepinus* for sustainable aquaculture production. They concluded that soaking in water and later sun-drying *Leucaena* seeds is a better method of processing it for use in the preparation of fish feed. Ahmed & Abdelati (2009) determined the chemical composition and amino acids profile of *Leucaena* seeds and their effect on broiler performance. Aye & Adegun (2013) determined the chemical constituents, anti-nutritional factors, and some functional properties of leaf meals obtained from *Leucaena leucocephala*. Nehdi et al. (2014) carried out the extraction and characterization of Leucaena seed oil, reporting that linoleic acid was found in higher proportions followed by oleic, palmitic, and stearic acid. Suggesting that the results showed that this new seed oil can be used as an ingredient in cosmetic or pharmaceutical preparations. Zarin et al. (2016) utilized and investigate the biological activities of extract from *L. leucocephala*. ferric reducing antioxidant power (FRAP), DPPH radical scavenging assay, and ABTS radical scavenging assay was determined, antimicrobials against *Staphylococcus aureus* (MRSA), *Staphylococcus aureus*, *Staphylococcus epidermidis, Pseudomonas aeruginosa, Acinetobacter anitratus, Bacillus subtilis, Escherichia coli, Proteus vulgaris, Serratia marcescens, Enterococcus faecium, Streptococcus faecalis, Candida albicans, Candida tropicalis, and Aspergillus nig*er, and cytotoxic activities toward human breast adenocarcinoma (Mcf-7), human colon carcinoma (HT29), human cervical carcinoma (HeLa) and human liver carcinoma (HepG2) cell lines, and purity of the compound were confirmed by 13C NMR spectroscopy. However, there are no reports on the physical and functional characteristics of this seed, which is why it is considered important for the design of processing equipment and its possible use in the food industry. Likewise,

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knowledge of some important physical properties such as shape, size, volume (V), surface area (S_A), grain weight, density, porosity, and angle of repose are necessary for designing different separation, handling, storage, and drying systems (Rodríguez-Miranda et al., 2016). Physical properties are important for designing and optimizing the equipment required for *Leucaena* seed processing stages. Likewise, the shapes of the pod and seed are also important for the analytical prediction of its drying behavior. However, in the literature, there are no published works on the physical properties (linear and geometric) of the *Leucaena* pod and seed, and even less on its techno-functional properties. The techno-functional properties of possible food additives are studied to obtain a global vision of their possible use or application in food formulation, influencing in a specific way their appearance and behavior, which have generally been associated with proteins and other components present in the food (Rodríguez-Miranda et al., 2012; Torruco-Uco et al., 2019). The functionality is associated with the type of processing and storage to which the raw material is subjected, as well as the physicochemical and structural properties of the materials (Téllez-Morales et al., 2021), while the thermal properties contribute to determining the parameters of the drying, cooling, heating, and freezing processes (Singh et al., 2019). Therefore, the objective of this research was to partially characterize some of the physical properties of the pod and seeds, as well as the chemical composition, techno-functional and thermal properties of the flour of the huaje seed (*Leucaena leucocephala*).

2 Materials and methods

Leucaena leucocephala was collected from the town of San Juan Bautista Tuxtepec, Oaxaca, Mexico (location: 18°5′24″ N, 96°6′50″ W, to 20 m above sea level), which has a warm and humid climate with an average temperature of 25.6 °C.

2.1 Physical properties

One hundred randomly selected *Leucaena leucocephala* pods were taken for the estimation of physical properties. The pods were opened manually, and 150 seeds were selected that had no observable physical damage.

2.2 Dimensional properties

The length (Lp), width (Wp), and thickness (Tp) of the pods were measured, and the number of seeds per pod was counted. The length (L), width (W), and thickness (T) of the seeds were also determined (Figure 1).

The arithmetic means diameter (D_a), geometric mean diameter (D_g), and equivalent mean diameter (D_e) of the seed were calculated using Equations 1-3 (Pensamiento-Niño et al., 2019; Sonawane et al., 2020).

$$D_a = \frac{(L + W + T)}{3} \tag{1}$$

$$D_g = (L\,W\,T)^{1/3} \tag{2}$$

$$D_e = \left[\frac{\left\{L(W + T)^2\right\}}{4}\right]^{1/3} \tag{3}$$

Sphericity (Ø), aspect ratio (Ra), flakiness ratio (Fr), elongation ratio (Er), and eccentricity (*e*) were calculated using Equations 4-8 (Pensamiento-Niño et al., 2019; Pathak et al., 2019; Sonawane et al., 2020).

$$Ø = \frac{(L\,W\,T)^{1/3}}{L} * 100 \tag{4}$$

$$R_a = \frac{W}{L} \tag{5}$$

$$F_r = \frac{T}{W} \tag{6}$$

$$E_r = \frac{L}{W} \tag{7}$$

Figure 1. *Leucaena leucocephala* pods (left) and seeds (right).

$$e = \left[1 - \left(\frac{W}{L}\right)^2\right]^{1/2} \tag{8}$$

The S_A was calculated by analogy to a spherical surface (S_A = mm^2) using Equation 9 [12]. 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 calculated using Equations 10-13 (Sonawane et al., 2020).

$$S = \pi\left(D_g\right)^2 \tag{9}$$

$$P_L = \frac{\pi L W}{4} \tag{10}$$

$$P_W = \frac{\pi W^2}{4} \tag{11}$$

$$P_T = \frac{\pi T W}{4} \tag{12}$$

$$CPA = \frac{P_L + P_W + P_T}{3} \tag{13}$$

The V, ellipsoid volume (V_{ellip}), prolate spheroid volume (V_{pro}), and oblate spheroid volume (V_{osp}) were determined using Equations 14-18 (Hernández-Santos et al., 2015; Sonawane et al., 2020).

$$V = \frac{\pi B^2 L^2}{6(2L - B)} \tag{14}$$

$$B = (WT)^{0.5} \tag{15}$$

$$V_{ellip} = \frac{\pi 4}{3}\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)\left(\frac{T}{2}\right) \tag{16}$$

$$V_{pro} = \frac{\pi 4}{3}\left(\frac{L}{2}\right)^2\left(\frac{W}{2}\right) \tag{17}$$

$$V_{osp} = \frac{\pi 4}{3}\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)^2 \tag{18}$$

2.3 Gravimetric properties

The mass of 100 seeds was recorded using the balance to calculate the average mass of the seeds. The gravimetric properties including the AD (ρb), real density (ρt), and porosity (ε) were determined according to Equations 19-21 (Sonawane et al., 2020; Vivek et al., 2018).

$$p_b = \frac{\textit{Weight of seed in container}(g)}{\text{Volume of container}\left(\text{cm}^3\right)} \tag{19}$$

$$p_t = \frac{\textit{Weight of seed dipped in water}(g)}{\text{Volume of } \textit{water displaced}\left(\text{cm}^3\right)} \tag{20}$$

$$\varepsilon = \left(1 - \frac{p_b}{p_t}\right) \times 100 \tag{21}$$

2.4 Obtaining the meal

The seeds were dried at 55 °C/12 h, and milled to obtain a uniform particle size capable of passing through a No. 35 mesh (0.59 mm) (Hernández-Santos et al., 2015).

2.5 Proximate composition

Moisture (925.10), protein (920.87), fat (920.85), and ash (923.03) contents were determined according to the methods of the Association of Official Analytical Chemists (2012), and carbohydrate content was determined by subtracting the sum of the weights of protein, lipid, and ash and expressed in g/100 g. Total energy was calculated following the methods described by Hernández-Santos et al. (2015).

2.6 Determination of color, pH, and water activity

The color was measured with a Hunter lab tristimulus colorimeter (MiniScan Hunter Lab, model 45/0L, Hunter Associates Lab., Ind., Reston, Virginia USA).

The L^* (Luminosity), a^* (chromaticity (+) red to (-) green) and b^* (chromaticity (+) yellow to (-) blue) values were obtained, from which the chromaticity (C^*), Hue angle (h^o), and color index (CI) (Sonawane et al., 2020), were calculated using Equations 22-24. The pH was measured by dispersing 1 g flour in 10 mL distilled water at 25 °C. The water activity (Aw) was determined in an electronic hydrometer with temperature control using the AquaLab Water Activity Meter (Model 3TE; Decagon Devices, Inc. 2365 NE Hopkins Court Pullman WA 99163, USA) at 25 °C.

$$C^* = \sqrt{\left(a^*\right)^2 + \left(b^*\right)^2} \tag{22}$$

$$h^o = tan^{-1}\left(\frac{b^*}{a^*}\right) \tag{23}$$

$$CI = \frac{1000\, a^*}{L^* b^*} \tag{24}$$

2.7 Techno-functional properties

The water absorption capacity (WAC) and water solubility capacity (WSC) were determined as described by Rodríguez-Miranda et al. (2012), using Equations 25-26.

$$WAC = \frac{\textit{Gel weight}(g)}{\textit{Sample weight}(g)} \tag{25}$$

$$WSC = \frac{\textit{Solids solubles weight}(g)}{\textit{Sample weight}(g)} \times 100 \tag{26}$$

The oil absorption capacity (OAC) was determined as described by Hernández-Santos et al. (2015), using Equation 27.

$$OAC = \frac{\textit{Gel weight with oil}(g)}{\textit{Sample weight}(g)} \tag{27}$$

The emulsifying capacity (EC) was determined as described by Rodríguez-Miranda et al. (2016). The emulsion is expressed in percentage as the height of the emulsified layer with respect to the total height of the liquid column using Equation 28.

$$EC = \frac{\textit{Height of the emulsified layer}(cm)}{\textit{Total height}(cm)} \times 100 \tag{28}$$

Apparent density (AD) was determined as described by Hernández-Santos et al. (2015). (Equation 29)

$$AD = \frac{\textit{Weight of meal in container}(g)}{\text{Volume of container}\left(\text{cm}^3\right)} \tag{29}$$

The least gelation concentration (LGC) was determined using the method described by Rodríguez-Miranda et al. (2016). The lowest concentration at which all triplicates formed a gel that did not collapse or slip from the inverted test tube was considered the LGC.

Swelling power (SP) was determined as described by Rodríguez-Miranda et al. (2012). The results are expressed as the percentage of water retained per gram of sample, using Equation 25.

2.8 Differential scanning calorimetry

The thermal properties of the meal were determined according to Juárez-Barrientos et al. (2017), using a Differential Scanning Calorimeter (DSC Q 2000, TA Instruments, 109 Lukens Drive, New Castle DE 19720, USA) calibrated with indium (To 156.4 °C, ΔH 28.4 J g^{-1}). The samples (3-4 mg) were weighed in 40 µL aluminium trays (Cat. No. ME-27331; Mettler-Toledo), and distilled water was added with a micro syringe until a 1:4 sample:water (w/v) ratio was achieved. The samples were analyzed within a range of 30-180 °C using a heating velocity of 5 °C min^{-1} and a nitrogen flow of 20 mL min^{-1}. All analyses were performed in triplicate and reported as average values.

2.9 Statistical analysis

All results are presented as the mean and standard deviation, and were determined by linear correlation analyses (Pearson correlation in the ratios (L/W, L/T, L/M, L/Da, T/M and W/M)), both run Statistica software version 10.0 (StatSoft, Inc., Tulsa, OK, USA).

3 Results and discussion

3.1 Physical properties

The average values of Lp, Wp, and Tp in the pods were 13.37, 1.53, and 0.95 cm, respectively (Table 1), and there was an average of 20 seeds per pod. The seeds had average L, W, and T values of 8.84, 5.17, and 2.02 mm, respectively (Table 2). The frequency distribution (Figure 2) for the dimensions (L, W, T, and M) had a moisture content of 6.40% of seeds.

The frequency graph indicates that the seventh interval had the highest number of seeds for L and M; the fifth interval had the highest frequency for W; and the fourth, sixth, seventh, and eighth intervals had the same number of seeds for T. Table 2 shows the results of the physical properties evaluated. The average weight of the pods was 2.14 g (Table 1), while the average weight of the seeds was 0.06 g.

The D_a, D_g, and D_e were 5.37, 4.52, and 4.85 mm, respectively. The Ø of the seed was 52.14%, and thus was considered an ovoid seed. The Ø values help to design separators and dimension equipment, while the aspect ratio indicates the extent of elongation of the fruit or seed (Singh et al., 2019).

The Ra, Fr, Er, and e of the seed were 0.59, 2.57, 0.39, and 0.04, respectively. The higher the Ø value, the better the tendency of the seed to roll rather than slide on a specific surface. The SA of the *Leucaena* seed was 64.44 mm^2; the P_L, P_W, and P_T were 36, 21.18, and 8.26 mm^2, respectively; and the CPA was 21.81 mm^2. The V, V_{ellip}, V_{pro}, and V_{osp} of the seed were 30.02, 48.97, 213.22, and 125 mm^3, respectively. The dimensional properties play an important role in the design of conveyor systems, sieve opening

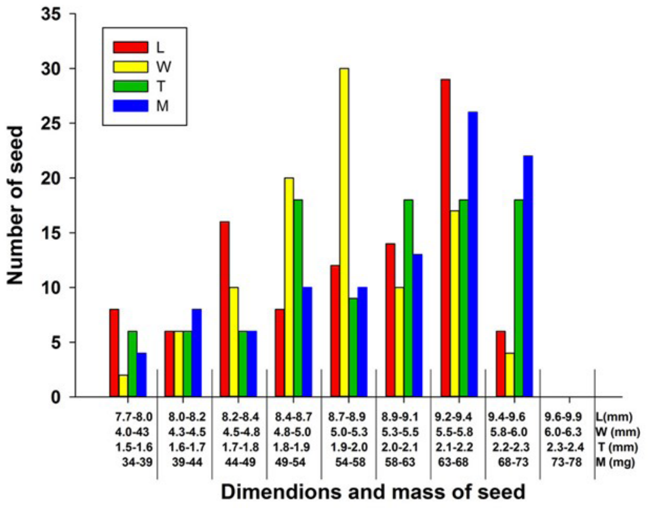

Figure 2. Frequency distribution graph of Leucaena leucocephala seed at 6.40% moisture content. L = length, W = width, T = thickness, M = mass.

Table 1. Linear dimensions of the *Leucaena leucocephala* pods.

Physical properties	Unit	N	Mean	Range of Values	Standard Deviation
Length (L_p)	cm	50	13.37	6.2 0-17.05	2.05
Width (W_p)	cm	50	1.53	1.10-2.20	0.31
Thickness (T_p)	cm	50	0.95	0.61-1.64	0.30
Mass (Mp)	g	50	2.14	0.70-6.48	0.80
Number of seeds per pod	--	50	20	9-27	3.53

to manufacture the separation, dimensioning, and classification equipment, as well as for modeling of the heat and mass transfer study, to determine the respiration rate, water loss, cooling, heating, and gas permeability (Vivek et al., 2018; Singh et al., 2019; Sonawane et al., 2020).

The AD, real density, and porosity of the seed were 0.81, 0.68 g/cm^3, and 15.64%, respectively. Bulk density, true density, and porosity are useful parameters for hopper design and flow control in equipment used for processing, grading, transporting, and packaging (Sonawane et al., 2020). The porosity value is an important property about the inter-granular space of the seed to the general occupied space (Singh et al., 2019). The seed color parameters are shown in Table 2.

Color is an important quality factor in food, is useful to analyze the ripeness of fresh and processed fruits and seeds, and is a determining factor in consumer acceptance. The seed showed an L^* of 52.87, a^* of -19.51, b^* of 35.15, C* of 5.58, h^o of 61.03, and CI of -10.61. These data show that the *Leucaena leucocephala* seed has a green hue, which can be seen in the color chart (Table 2). The relationships and correlation coefficients between the seed and its dimensions showed a highly significant correlation between L with W, T, and Da, indicating that the W, T, and D_e were positively correlated with the L of the seeds of *Leucaena leucocephala*, whereas no significant correlation with M was observed (Table 3). This behavior is similar to that reported by Pradhan et al. (2013) in bottle gourd seeds.

3.2 Chemical composition

Leucaena leucocephala flour has a high content of fat, protein, and fiber (Table 4), which suggests that it is a good unconventional source of these components and that they can be an alternative in the food industry. The protein content found in this study was higher than that reported in *Leucaena* grown in Indonesia (19.75 g/100 g) (Pradhan et al., 2013), but below that reported by Angelis et al. (2021) cultivated in Sudan (31.1 g/100 g) and Afza et al. (2007) from Pakistan (32.16 g/100 g), and Sotolu & Faturoti (2008) cultivated in Nigeria (22-36 g/100 g). The fat content

Table 2. Physical properties of *Leucaena leucocephala* seed at 6.40% moisture content.

Physical properties	Unit	N	Mean	Value range	Std dev
Length (L)	mm	100	8.84	7.76-9.66	0.51
Width (W)	mm	100	5.17	4.05-6.07	0.44
Thickness (T)	mm	100	2.02	1.52-2.34	0.21
Arithmetic mean diameter (D_a)	mm	100	5.37	4.60-5.90	0.32
Geometric mean diameter (D_g)	mm	100	4.52	3.80-5.04	0.31
Equivalent mean diameter (D_e)	mm	100	4.85	4.05-5.45	0.32
Sphericity (Ø)	%	100	51.14	46.73-56.60	2.23
Aspect ratio (R_a)	--	100	0.59	0.50-0.68	0.05
Flakiness ratio (F_r)	--	100	2.57	2.16-3.14	0.24
Elongation ratio (E_r)	--	100	0.39	0.32-0.46	0.04
Eccentricity (e)	--	100	0.33	0.27-0.38	0.03
Surface area (S_A)	mm^2	100	64.44	45.47-79.71	8.69
Projected area perpendicular to length (P_L)	mm^2	100	36.00	25.89-44.81	4.32
Projected area perpendicular to width (P_W)	mm^2	100	21.18	12.88-28.94	3.50
Projected area perpendicular to thickness (P_T)	mm^2	100	8.26	5.31-10.68	1.32
Criteria projected area (CPA)	mm^2	100	21.81	14.70-28.14	2.94
Volume (V)	mm^3	100	30.02	17.15-41.62	6.13
Ellipsoid volume (V_{ellip})	mm^3	100	48.97	28.83-66.92	9.68
Prolate spheroid volume (V_{pro})	mm^3	100	213.22	137.16-280.83	35.49
Oblate spheroid volume (V_{osp})	mm^3	100	125.30	69.91-181.34	24.42
Mass (M)	g	100	0.06	0.03-0.07	0.01
Bulk density (ρ_b)	g/cm^3	100	0.81	0.80-0.81	0.01
True density (ρ_t)	g/cm^3	100	0.68	0.68-0.69	0.01
Porosity (ε)	%	100	15.64	15.40-15.75	0.20
Color values					
L^*	--	30	52.87	46.65-59.72	4.93
a^*	--	30	-19.51	-24.53-16.43	2.63
b^*	--	30	35.15	32.75-41.12	3.09
Chroma (C^*)	--	30	5.58	4.93-6.07	0.38
Hue angle (h^o)	--	30	61.03	57.83-63.81	2.24
Color index (CI)	--	30	-10.61	-8.79-12.81	1.61
Color square	--	--	🟩		

N = number of seed used for analysis.

Table 3. Ratios and coefficient of correlation (r) values of *Leucaena leucocephala* seed dimensions.

Particulars	Mean	Value range	Std dev	r
L/W	1.72	1.46-2.01	0.13	0.456*
L/T	4.35	1.78-5.48	0.52	0.394*
L/M	152.10	15.61-267.06	43.13	0.063
W/M	88.72	9.85-155.64	24.69	0.197
T/M	35.84	3.39-82.19	12.39	-0.031
L/D_a	1.65	1.40-1.76	0.06	0.816*

*Correlations significant at $P < 0.05$. L = length; W = width; T = thickness; M = mass; D_a = arithmetic mean diameter.

Table 4. Chemical composition, Aw, pH, Hunter color values and functional properties of *Leucaena leucocephala* meal.

Property	*Leucaena leucocephala meal*
Chemical composition (g/100 g)	
Moisture	(5.67 ± 0.12)
Fat	34.75 ± 0.20
Protein	28.16 ± 0.51
Fiber	16.43 ± 0.50
Ash	5.38 ± 0.52
Carbohydrates	15.29 ± 1.74
Total energy (kJ/100 g)	2,035.70 ± 12.75
Physicochemical	
Aw	0.35 ± 0.00
pH	6.70 ± 0.03
*L**	66.26 ± 0.01
*a**	3.59 ± 0.01
*b**	19.70 ± 0.01
*C**	20.02 ± 0.01
h°	79.66 ± 0.01
CI	2.75 ± 0.01
Color square	🟫
Techno-functional properties	
WAC (g H_2O/g sample)	4.64 ± 0.04
WSC (%)	16.20 ± 1.49
OAC (g oil/g sample)	2.03 ± 0.11
EC (%)	48.06 ± 1.81
LGC (%)	4.00 ± 0.00
AD (g/cm^3)	0.81 ± 0.00
SP (%)	
60 ºC	4.48 ± 0.06^a
70 ºC	4.44 ± 0.10^a
80 ºC	4.86 ± 0.13^b
90 ºC	5.18 ± 0.06^c

The results are the average of three determinations ± standard deviation. Values are expressed on dry basis, except moisture. Aw = water activity; CI = color index; WAC = water absorption capacity; WSC = Water solubility capacity; OAC = oil absorption capacity; EC = emulsification capacity; LGC = least gelation concentration; AD = apparent density; SP = swelling power. The different superscript letters in the means of the SP indicate significant differences ($p < 0.05$).

was below that reported by Afza et al. (2007) (11.43 g/100 g), Sotolu & Faturoti (2008) (5.18-6.12 g/100 g), Rosida et al. (2016) (5.58 g/100 g) and by Angelis et al. (2021) (5.6 g/100 g).

These differences were mainly due to climatic, environmental, and growing conditions, which differ among countries. Fiber is another important component in human nutrition; this value was above that reported by Angelis et al. (2021) (13.2 g/100 g), Sotolu & Faturoti (2008) (7-11.38 g/100 g), and by Afza et al. (2007) (10.09 g/100 g). Therefore, the high fiber content of *Leucaena* (Table 4) could be an alternative for the preparation of functional foods rich in fiber.

The carbohydrate content was 15.29 g/100 g; this value was below that reported by Angelis et al. (2021) and Afza et al. (2007) (40.5 g/100 g and 39.53 g/100 g, respectively). The ash content in this study was higher than that reported by Angelis et al. (2021) and Afza et al. (2007) (4.5 g/100 g and 3.86 g/100 g, respectively) in *Leucaena* cultivated in Sudan and Pakistan, respectively, and similar to that reported by Rosida et al. (2016) (5.66 g/100 g) and Sotolu & Faturoti (2008) (5.98 g/100 g) grown in Indonesia and Nigeria, respectively. The *Leucaena* flour presented with an Aw of 0.35, which indicates that the *Leucaena* flour has high storage stability. It also showed an alkaline pH, but this value was below that reported for other seeds such as pink pinion seeds (7.23) reported by Pensamiento-Niño et al. (2019), and *Leucaena* grown in Pakistan (5.6), ebony meal (5.96), and talipot palm meal (5.44) reported by Afza et al. (2007), Hernández-Santos et al. (2015) and Navaf et al. (2020), respectively.

3.3 Physicochemical properties

Regarding the color (Table 4), the *L** of the *Leucaena* flour was higher than that reported by Pensamiento-Niño et al. (2019) in pink pinion flour (*L** 51.59) and by Pathak et al. (2019) in *Terminalia chebula* flour (*L** 54.89) and below that reported by Navaf et al. (2020) and Hamid et al. (2015) in talipot palm flours (*L** 89.9) and cowpea (*L** 85.24), respectively. In parameter *a**, the values reported for pink pinion and Terminalia flours were higher (*a** 7.85 and 6.40, respectively) than those found for *Leucaena* (Table 4). In parameter *b**, a higher value was shown compared to that reported for the flours of a pink pinion (*b** 16.62), talipot palm (*b** 5.36), and cowpea (*b** 13.14), and below the value reported for the flour of *Terminalia chebula* (*b** 29.57). Likewise, *Leucaena* flour showed greater color saturation compared to pink pinion, talipot palm, and cowpea flours reported by Pensamiento-Niño et al. (2019), Navaf et al. (2020), and Hamid et al. (2015), respectively. For *hº*, a high value was also observed, indicating that the *Leucaena* flour shows a light brown color as indicated in the color chart (Table 4). These results are of great interest for their application in the food industry, because the pigmentation can influence the final product to which it is applied as well as its acceptability.

3.4 Techno-functional properties

In Table 4, higher values of WAC and OAC were observed compared with other seeds such as talipot, pink pinion, and *Cucurbita fisifolia* (1.70, 1.07, and 1.4 g H_2O/g sample, respectively), as reported by various authors (Navaf et al., 2020; Pensamiento-Niño et al., 2019; Rodríguez-Miranda et al., 2016). These differences are due both to geographical conditions and to the process of obtaining flour, due to the pressure and temperature exerted. Likewise, it is affected by the protein concentration and the presence of other components such as hydrophilic polysaccharides, fats, and salt, and storage conditions. Whereas for OAC, fat binding is affected by particle size. Protein in powder form with a low density and small particle size can absorb and trap more oil than a high-density protein (Rosida el at., 2016). For the WSC, a higher value was also observed (Table 4) compared to that reported for other seeds such as *Cucurbita fisifolia* (10.09%) (Rodríguez-Miranda et al., 2016) but was lower than that reported by Pensamiento-Niño et al. (2019) in pink pinion (42.19%). A high value was also found in emulsification capacity (CE) compared to that reported in melon seed (30%) by Mallek-Ayadi et al. (2019) and in cowpea seed (35%) reported by Hamid et al. (2015), as well as in *Cucurbita fisifolia* (22%) reported by Rodríguez-Miranda et al. (2016). The formation of emulsions by proteins is influenced by two factors: 1) internal such as pH, ionic strength, temperature, molecular weight surfactants, and the type of protein; and 2) external such as the type of equipment used and the speed of agitation (Rosida et al., 2016). While for LGC, the higher the protein concentration, the higher the firmness of the gel, because the protein concentration is an important factor for the formation and firmness of the gel, and especially a higher proportion of globular proteins. Therefore, gelling is closely related to the amount and type of protein in addition to non-protein constituents such as starch in flour (Hernández-Santos et al., 2015; Pensamiento-Niño et al., 2019).

The LGC values (Table 4) were similar to those reported by Pensamiento-Niño et al. (2019) in degrased pink pinion seed meal. Likewise, the AD value (Table 4) was higher than that reported for talipot palm, melon, and *Cucurbita fisifolia* (0.7, 0.65, and 0.5 g/cm^3, respectively) by various authors (Navaf et al., 2020; Mallek-Ayadi et al., 2019; Rodríguez-Miranda et al., 2016) and below that reported for pink pinion (1.03 g/cm^3) by Pensamiento-Niño et al. (2019). However, the AD found in this study was within the AD reported for cereals and legumes (Navaf et al., 2020).

A high AD indicates that the material is more compact, and therefore has better packaging and storage behaviors. However, the AD is influenced by factors such as particle size, properties, and composition of the material, as well as by the degradation of the components of materials due to processing (Rosida et al., 2016).

In SP, significant differences ($p < 0.05$) were found in the tested temperatures. It was observed that when the temperature increased, the SP was higher, reaching up to 5.2% at 90 °C (Table 4). This is because when the temperature of the system increases, the proteins begin to absorb water more slowly. The amorphous areas of the starch that are the least organized and the most accessible (amylose), so that as the temperature increases, more water is retained and the granule swells and increases in volume. Likewise, this process is affected by the amount of lipids present in the flour and by the gel-forming capacity of the proteins present (Rodríguez-Miranda et al., 2012; Juárez-Barrientos et al., 2017). In addition to the fact that the amount of amylose, amylopectin, and its molecular weight also impact this techno-functional property (Navaf et al., 2020 above all due to the interactions that they present with lipids and proteins (Pensamiento-Niño et al., 2019). The SP in this study was higher than that reported by Hernández-Santos et al. (2015) in ebony seed (1.6%), but similar to that reported by Juárez-Barrientos et al. (2017) in jackfruit (5.82%) and below that reported by Navaf et al. (2020) in talipot palm (800%).

Table 5. Thermal properties of *Leucaena leucocephala* meal.

	T_o (°C)	T_p (°C)	T_f (°C)	ΔH (J/g)
Peak I	72.21 ± 0.71	84.35 ± 0.66	92.50 ± 0.16	0.74 ± 0.05
Peak II	97.37 ± 0.78	104.95 ± 0.01	109.41 ± 0.37	0.23 ± 0.00
Peak II	112.45 ± 0.04	114.45 ± 0.01	118.64 ± 1.56	0.17 ± 0.04

Means ± standard deviation of three determinations. T_o = onset temperature; T_p = peak temperature; T_f = end temperature; ΔH = phase transition enthalpy.

3.5 Thermal properties

Three endothermic peaks were observed (Table 5). The first peak was observed at a temperature of 72 to 92.50 °C, which corresponds to the gelatinization of the starch present in the flour. Juárez-Barrientos et al. (2017) reported similar values for jackfruit flour (71.82 to 87.57 °C) and Navaf et al. (2020) in talipot palm (79.66 to 88.33 °C), suggesting that the thermal characteristics of flour and starch are affected by the molecular arrangement of the crystalline region, the amylose-amylopectin ratio, the chain ratio, and the order of the double helix. Likewise, Masum et al. (2019) mentioned that the glass transition of powdered foods is influenced by the molecular weight of carbohydrates, and the transition temperature of high molecular weight carbohydrates is higher and vice versa. The second peak was observed in a temperature range of 97 to 109 °C, suggesting that it was due to the protein-amylose complex. Li et al. (2014) reported the transition temperatures of soy protein isolate/corn starch mixtures of 104-108 °C, indicating that as the protein concentration increases, the transition temperature increases.

While the third peak was due to the lipid-amylose complex, due to the high content of lipids that *Leucaena* flour presents, this same behavior was observed by Juárez-Barrientos et al. (2017) in chestnut flour at a temperature between 113 and 120 °C due to the formation of an amylose-lipid complex, concluding that the gelatinization transition temperature is influenced by the amylose content, the distribution of branched chains of amylopectin, the amylose-lipid complex, and the protein content.

4 Conclusion

The physical properties of the *Leucaena* pod and seed were analyzed to generate knowledge that can be used for the design and development of technologies to process this raw material. The seed has a green hue, while the flour has a light brown hue. The flour has a high content of fat, protein, and fiber, and a high-water absorption capacity, solubility, oil absorption, and emulsifying capacity. The glass transition temperatures are influenced by the high protein and lipid content. These results are of great interest for its application in the food industry, because they can influence the final product to which it is applied, as well as its acceptability. Therefore, *Leucaena* flour can be considered an alternative ingredient in the food industry.

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