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ORIGINAL ARTICLE

Physical properties of ebony seed (*Pithecellobium flexicaule*) and functional properties of whole and defatted ebony seed meal

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Abstract A partial characterization was done of ebony (*Pithecellobium flexicaule*) seed physical properties, and how defatting affected some functional properties of ebony seed meal. Average seed dimensions were 13.02 mm length, 8.78 mm width and 9.65 mm thickness. Geometric diameter was 10.76 mm, volume was 530 mm^3, surface area was 364.33 mm^2, sphericity was 83.26 % and aspect ratio was 68.24 %. Thousand-seed weight was 0.70 Kg, of which 0.42 Kg (60 %) represented the kernel. Defatted ebony seed meal differed from whole meal in all measured parameters, particularly in its protein (44.72 g/100 g) and carbohydrates (44.12 g/100 g) proportions. The defatted meal had higher water absorption capacity (1.28 g/g sample), water solubility capacity (26.06 %), oil absorption capacity (2.04 g/g sample), emulsifying capacity (53.78 %) and gelling capacity (8 % w/v) than the whole meal. Ebony seed physical properties may prove useful in designing post-harvest processing equipment and in quality control. The high protein content of defatted ebony seed meal suggests its use as a natural alternative ingredient in numerous food industry applications.

Keywords *Pithecellobium flexicaule* · Ebony · Functional properties · Hexane · Defatted · Meal

Introduction

Ebony (*Pithecellobium flexicaule*) is a tree of the Fabaceae family, and is a typical native species of southern Texas (United States) and northeast Mexico. Its branches are small, between 6 and 10 cm thick, and extend no more than 6 m from the trunk. Maximum tree height ranges from 10 to 15 m (Correl and Johnston 1970). Ebony seeds occur in a protective pod. They are used as a complement in human diets either cooked fresh or toasted after ripening. They are also ground for use as a coffee substitute (Alanis et al. 1998). This seed has about 35 % protein content and nutritional and protein quality comparable to commercial legumes (Alanis et al. 1998; Rocas 1990). However, no studies have been published on ebony seed physical (linear and geometric) properties or the functional properties of ebony seed meal.

Functional properties of possible food additives are studied to produce an overall profile of their potential uses and application in food formulations (Badui 2006). These specifically influence appearance and performance and include properties such as hydration; foaming capacity; emulsification and gelification, among others. These are associated with a raw material's proteins and other components (Ogundele and Aladesanmi 2010; Rodríguez-Miranda et al. 2012). Functionality is associated with physicochemical and structural properties of the raw material (Gómez-Aldapa et al. 2009), as well as how it is processed and stored (Ogundele and Aladesanmi 2010). The physical properties of a raw material normally include shape, size, volume, surface area, grain weight, density, porosity and angle of repose. All are important in the design of processing systems for separating, handling, storing and drying raw materials (Tabatabaeefar

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2000), particularly for designing and optimizing processing equipment for agricultural products (Mohsenin 1986; Stroshine and Hamann 1993; Ospina-Machado 2001; Cetin 2007). Size and shape are vital to electrostatic separation of undesirable material and in the design and sizing of classification machinery (Mohsenin 1986). Shape is also important for analytical prediction of drying performance (Işik and Ünal 2007). The present study objective was to describe some physical properties of ebony (*Pithecellobium flexicaule*) seeds and evaluate the effect of defatting on ebony seed meal functional properties.

Materials and methods

Ebony seeds (*Pithecellobium flexicaule*) were acquired from a local market in Reynosa, Tamaulipas state, Mexico. Seeds were roasted for 10 min at 80–90 °C.

Physical properties

Linear dimensions

Seed linear dimensions were measured according to Mpotokwane et al. (2008). One hundred (100) seeds were selected from a handful of seeds taken randomly from a container full of seeds. Using a Vernier caliper, length (L), width (W) and thickness (T) of each selected seed were measured to an accuracy of 0.001 mm. These data were then used to calculate geometric diameter, sphericity, volume, surface area and aspect ratio.

Geometric diameter, sphericity, volume, surface area and aspect ratio

Seed geometric diameter (D_g) and sphericity (Ø) were calculated using the equations of Mohsenin (1986):

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

$$\text{Ø} = \frac{(\boldsymbol{L\ W\ T})^{1/3}}{\boldsymbol{L}} \times 100$$

where L = seed length, W = seed width and T = seed thickness in mm. Volume (V) and surface area were determined by analogy with a sphere of the same mean geometric diameter. Surface area (S in mm^2) was calculated with the equations of McCabe et al. (1986):

$$\boldsymbol{S} = \pi \boldsymbol{D_g^2} \tag{3}$$

$$\boldsymbol{V} = \frac{\pi \boldsymbol{B}^2 \boldsymbol{L}^2}{6(2\boldsymbol{L} - \boldsymbol{B})} \tag{4}$$

$$\boldsymbol{B} = (\boldsymbol{WT})^{0.5} \tag{4.1}$$

Seed shape was further described via the aspect ratio (R) (Maduako and Faborode 1990):

$$\boldsymbol{R} = \frac{\boldsymbol{W}}{\boldsymbol{L}} \times 100 \tag{5}$$

Thousand-seed weight

Thousand-seed weight (TSW) was measured following Mpotokwane et al. (2008). The mass of one thousand seeds was measured with an electronic balance (accuracy= 0.0001 g) in triplicate.

Raw material preparation

Seeds were manually dehulled with a nutcracker, and undamaged seeds selected for further processing. These were ground in a coffee mill (Krupps Model GX4100) until the particles passed through a No. 30 mesh screen (0.59 mm, U.S.A. standard test sieve ASTM E-11 Specification W.S. Tyler, USA). The resulting meal was placed in sealed polyethylene bags and stored at 4±0.5 °C until use.

Meal defatting

The seed meal was defatted according to Rodríguez-Miranda et al. (2012). Briefly, hexane was added to 25 g of sample at a 1:20 (w/v) ratio and kept under agitation for 10 min at 60 °C. The solution was filtered, the defatted meal dried at 25 °C for 2 h and then at 50 °C for 2 h (ED 115 Binder Oven). It was screened through No. 30 (0.59 mm) mesh, placed in polyethylene bags, sealed under vacuum and stored at 4±0.5 °C until use.

Chemical composition

Proximate composition of the whole and defatted ebony seed meals (WESM and DESM, respectively) was determined in triplicate following standard AOAC methods (AOAC 1990): moisture (925.10); ash (923.03); protein (920.87); and fat (920.39). Crude fiber was determined by acid-alkaline digestion (Tejeda 1992), and carbohydrates by difference. Gross energy was calculated following Ekanayake et al. (1999).

Color and pH

Color parameters were measured with a tristimulus colorimeter (MiniScan 45/0 L, Hunter Lab). Lightness (L^*), red/green chromaticity (a^*) and yellow/blue chromaticity (b^*) were measured and chromaticity (C*), hue angle (h°) and total color difference (ΔE) calculated from these results. The pH was measured by dispersing the WESM and DESM meals in distilled water at 25 °C.

Functional properties

Water absorption capacity (WAC) and water solubility capacity (WSC)

Distilled water (10 mL) was added to 1 g of sample, agitated in a vortex (Vortex-2 Genie, Model G-560) for 30 s and centrifuged at 1,006 × g for 15 min (Universal Compact Centrifuge HERMLE Labortechnik GmbH Mod Z 200A). The supernatant was decanted into a tared porcelain capsule. Water solubility capacity was calculated as sediment weight after supernatant removal per unit of initial solids weight in a dry base (d.b). Water absorption capacity was calculated as the dry weight of the dried supernatant solids as a percentage of original sample weight (d.b). Results were expressed as a percentage of the grams of water retained per gram of sample for WAC and WSC (Anderson et al. 1964).

Oil absorption capacity (OAC)

Oil absorption capacity (OAC) was measured according to Beuchat (1977). One gram of sample was combined with 10 mL corn oil and thoroughly vortexed. The resulting slurry was stirred occasionally over a period of 30 min and then centrifuged at 1,006 × *g* for 15 min. The volume of decanted supernatant fluid was measured and OAC expressed as grams of retained oil per gram of sample.

Emulsification capacity (EC)

Emulsification capacity was determined following Yasumatsu et al. (1992). Distilled water (20 mL) was mixed with 1 g sample, vortexed for 15 min and completed to 25 mL with distilled water. Using a blender (Oster Model 465), 25 mL of this solution was mixed with 25 mL corn oil during 3 min and centrifuged (Universal Compact Centrifuge HERMLE Labortechnik GmbH Mod Z 200A) at 1,006 × *g* for 15 min. Emulsifying capacity (EC) was expressed as a percentage of the height of the emulsified layer versus total liquid content.

Gelling capacity (GC)

Gelling capacity were determined according to Coffman and García (1977). Sample dispersions of 4, 8, 12, 16 and 18 % (w/v) were prepared in 300 mL distilled water. Each dispersion was adjusted to pH 7.0 with 0.1 N NaOH and mixed in a blender at high speed for 2 min. The dispersions were poured into test tubes in 5 mL aliquots (three test tubes per concentration), heated to 100 °C in a water bath (Julabo TW8 EcoTemp, Labortechnik GMBH D-77960 Seelbach, Germany) for 1 h and cooled to 4 °C on an ice bath. The lowest concentration at which all the triplicates formed a gel which did not collapse or slip from the inverted test tube was reported as the Least Gelation Concentration (LGC).

Bulk density (BD)

Bulk density was determined by weighing 50 g sample into 100 mL graduated cylinders, tapping the cylinders 10 times against the palm of the hand and expressing the final volumes as g/cm^3. Cool water dispersability was estimated by stirring 50 g sample into 350 mL cool deionized water and subjectively noting ease of dispersion (Okaka and Potter 1979).

Statistical analyses

Results were analyzed with a one-way analysis of variance (ANOVA) and differences between the means calculated using a least significant difference test with a 95 % confidence level. All analyses were done with the Statistica ver. 8.0 program (StatSoft, Inc.).

Results and discussion

Physical properties

Linear dimensions and geometric properties

Seeds had an average length of 13.02 mm, an average width of 8.78 mm and an average thickness of 9.65 mm (Table 1). These dimensions are much smaller than reported for morama bean (*Tylosema esculentum*), groundnut (*Arachis hypogea L.*), jack bean (*Canavalia ensiformis*) and Egyptian peanut (*Arachis hypogaea*), but larger than those of Bambara groundnut (*Vignea subterranea*), chickpea (*Cicer arietinum*), African breadfruit (*Treculia africana*) and pistachio (*Pistacia vera* L.) (Table 2). The L/D$_a$ (1.21) and L/W (1.50) results showed ebony seed thickness to be closely linked to length (Table 1). This has also been reported for the seeds of millet (Baryeh 2002), coriander (CoşKuner and Karababa 2007), algarrobo (Ogunjimi et al. 2002) and morama (Jideani et al. 2009). The importance of dimensions is in determining the aperture size of machines, particularly in separation of materials (Omobuwajo et al. 1999). These dimensions may be useful in estimating the size of machine components.

Ebony seed geometric diameter was 10.76 mm, average sphericity was 83.26 %, surface area was 364.33 mm^2, aspect ratio was 68.24 % and volume was 530 mm^3 (Table 1). Surface area in irregular shaped seeds plays an important role in determining the projected area of the seeds moving in turbulent air stream and thus useful in designing the seed cleaners, separators and conveyors. Increased surface area to volume ratio elevates heat and mass transfer rate of seeds or

Table 1 Ebony seed linear dimensions and geometric properties

Dimension	Mean (mm)	Range (mm)	L/W	L/T	L/D_a
L	13.02±1.39	11–18	1.50±0.25	1.19±0.13	1.21±0.10
W	8.78±0.81	7–10			
T	9.65±1.20	10.8–11.3			
Geometric diameter (mm)	Surface area (mm^2)	Seed volume (mm^3)	Sphericity (%)	Aspect ratio (%)	
10.76±0.47	364.33±31.58	530.13±66.39	83.26±6.19	68.24±9.02	

Values represent the average of 100 replicates±standard deviation

L Length, *W* Width, *T* Thickness

kernels facilitating drying, cooling and heating operations (Vishwakarma et al. 2012). Geometric diameter for ebony seed was less than reported for morama, groundnut and jack bean, and greater than those of Bambara groundnut, chickpea, African breadfruit and pistachio (Table 2). Average geometric diameter was less than length but greater than width and thickness; this is also true of coriander seed (CoşKuner and Karababa 2007). A sphericity greater than 70 % indicates a seed or grain is spherical (Eke et al. 2007), placing ebony seeds well within the classification of spherical. Their sphericity was lower than that of morama bean, Bambara groundnut and chickpea seeds but higher than that of jack bean, African breadfruit, groundnut and pistachio seeds. In seeds, the quality of being spherical allows them to roll, a trait to be considered in the design of hoppers, ramps and other storage installations (Mpotokwane 2008). Ebony seed surface area (364.33 mm^2) was greater than reported for *C. edulis* (134.64 mm^2)*, C. vulgaris* (161.28 mm^2) and *C. lanatus* (142.23 mm^2) (Davies 2010), and pistachio (289.16 mm^2) (Nazari-Galedar et al. 2010), but lower than those of morama bean (10,752 mm^2) (Jideani et al. 2009) and *Parkia speciosa* (786.86 mm^2) seeds (Abdullah et al. 2011). Aspect ratio for ebony seed (68.24 %) was lower than for morama, Bambara groundnut, chickpea and jack bean, but higher than for African breadfruit seeds (Table 2). Seed or grain specific mass is a vital parameter in product storage, transport, handling and processing (Alcali et al. 2006). Average TSW for ebony seed was 0.70 Kg, of which the kernel accounted for 0.42 Kg, that is, 60.06 % of seed weight. This weight is lower than reported for morama seeds (2.3 Kg) and coffee grains (2.2 kg) (Jideani et al. 2009). The size determines occupation of space, which is based on the seed morphometric dimensions (e.g. length, breadth and thickness). The size, surface area and volume have to be considered in bulk handling and processing operations especially in heat and mass transfer (Eke et al. 2007).

Table 2 Comparison of ebony seed *(Pithecellobium flexicaule)* physical properties with those of other seeds

Property	Ebony seed[a]	Morama[b]	Groundnut[c]	Jack bean[d]	Egyptian peanut[e]	Bambara groundnut[e]	Chickpea[f]	African breadfruit[g]	Pistachio[h]
L (mm)	13.02	18.6	20.83	18.66	35.86	11.48	10.2	11.91	13.98
W (mm)	8.78	17.0	11.08	13.14	14.96	9.66	7.74	5.69	8.76
T (mm)	9.65	13.1	8.94	10.22	16.34	9.17	7.66	4.64	7.25
Geometric diameter (mm)	10.76	15.9	12.71	13.56	–	9.81	8.46	6.80	9.75
Sphericity (%)	83.26	84.1	61.12	72.7	–	85.8	82.9	57.1	69.34
Aspect ratio (%)	68.24	92.5	–	70.6	–	84.6	75.6	47.8	–

[a] This research

[b] Jideani et al. 2009

[c] Firouzi et al. 2009

[d] Eke et al. 2007

[e] MpotoKwane et al. 2008

[f] Tabatabaeefar et al. 2003

[g] Omobuwajo et al. 1999

[h] Nazari-Galedar et al. 2010

L Length, *W* Width, *T* Thickness

Proximate composition

The WESM and DESM differed ($P<0.05$) in all the measured chemical parameters (Table 3). Due to defatting, protein increased from 38.51 in the WESM to 44.72 g/100 g in the DESM, while carbohydrate content increased from 29.36 g/100 g in the WESM to 44.12 g/100 g in the DESM. As expected, fat content decreased from 28.16 g/100 g in the WESM to 6.03 g/100 g in the DESM. Ash (4.61 g/100 g) and crude fiber (0.51 g/100 g) contents in the DESM were also higher than in the WESM (ash=3.63; crude fiber=0.34 g/100 g). This effect of defatting on the different chemical parameters coincides with that reported in other studies (Alobo et al. 2009; Rodríguez-Miranda et al. 2012).

Energy content in the DESM (1,755.71 kJ/100 g DM) was lower than for the WESM (2,232.55 kJ/100 g d.b.), probably due to defatting since lipids provide more energy per gram than proteins and carbohydrates combined (Alobo et al. 2009). The WESM value was higher than the 1,507.19–1,613.46 kJ/100 g d.b. reported for jack bean (Doss et al. 2011), but below that reported for morama seed meal and 2,343 kJ/100 g d.b (Jideani et al. 2009) and pumpkin seed flour 2,611.07 kJ/100 g d.b (Rodríguez-Miranda et al. 2012). Energy intake above the actual requirements is harmful, leading to hazards of obesity and its health consequences. On the other hand, energy intake is far below the requirement level leads to under-nutrition and loss of body weight (Doss et al. 2011).

Protein content in the WESM was higher than in other edible seeds such as squash *Cucurbita pepo* (26.5, g/100 g) (Al-Khalifa 1996), African oil bean *Pentaclethra macrophylla* (34.1 g/100 g), morama bean (33.76 g/100 g) (Jideani et al. 2009), jack bean (29.8–32.2 g/100 g) (Doss et al. 2011), cowpea *Vigna unguiculata L. Walp* (32.15 g/100 g) (Appiah et al. 2011) and chickpea *Cicer arientum* L. (23.08 g/100 g) (Ionescu et al. 2009).

Lipids content in the WESM was lower than in morama (36.4–39 g/100 g) (Jideani et al. 2009) and pumpkin seed (49.14 g/100 g) (Rodríguez-Miranda et al. 2012), and higher than in jack bean (3.1–6.0 g/100 g) (Doss et al. 2011), cowpea (2.77 g/100 g) (Appiah et al. 2011) and chickpea (6.65 g/100 g) (Ionescu et al. 2009). Although the crude fat content of the flour were low, could be useful in improving palatability of foods in which it is incorporated. Crude fiber content in the WESM was much lower than reported for other seeds (e.g. jack bean, 7.34–9.98 g/100 g (Doss et al. 2011); cowpea, 5.32 g/100 g (Appiah et al. 2011); pumpkin seed, 2.30 g/100 g) (Rodríguez-Miranda et al. 2012). In contrast, WESM ash content was higher than in other seeds (e.g. jack bean, 3.56–5.93 g/100 g (Doss et al. 2011); cowpea, 3.27 g/100 g (Appiah et al. 2011); chickpea, 3.21 g/100 g (Ionescu et al. 2009); morama, 2.9–3.2 g/100 g) (Jideani et al. 2009). The high ash content indicate that could be important sources of minerals for consumers. Carbohydrate content in the WESM was lower than in jack bean (50.77–54.28 g/100 g) (Doss et al. 2011), cowpea (56.49 g/100 g) (Appiah et al. 2011) and chickpea (57.88 g/100 g) (Ionescu et al. 2009), but higher than in morama bean (18.5–24.2 g/100 g) (Jideani et al. 2009).

In the DESM, protein content was higher than in other defatted seed byproducts such as neem *Azadiracha indica* (24.10 g/100 g) (Romero and Vargas 2005), rapeseed *Brassica olerácea* L. (32.85 g/100 g) (Gonçalvess et al. 1997) and chickpea (23.53 g/100 g) (Ionescu et al. 2009), but lower than those of peanut *Arachis hypogaea* L. (46.6 g/100 g) (Ferreyra et al. 2007), cashew *Anacadium occidentale* (46.50 g/100 g) (Alobo et al. 2009) and pumpkin seed (64.13 g/100 g) (Rodríguez-Miranda et al. 2012). According to Bressani (2002), higher level of protein content of seed materials has nutritional significanse, since moderate intake of these sedes will greatly increase the total dietary protein intake of the consumers. Its utilization as a protein ingredient in the animal feeds will reduces the over-dependence on the conventional protein supplements, notably soybean and other common legumes. The DESM's protein content makes it a potential ingredient for increasing the nutritional value of new food products.

Table 3 Chemical composition (dry basis) of whole ebony seed meal and defatted ebony seed meal

Component (g/100 g)	WESM	DESM
Protein (N x 6.25)	38.51±0.21^{a}	44.72±0.05^{b}
Fat	28.16±1.04^{a}	6.03±0.07^{b}
Crude fiber	0.34±0.03^{a}	0.51±0.02^{b}
Ash	3.63±0.03^{a}	4.61±0.00^{b}
Carbohydrates[1]	29.36±1.30^{a}	44.12±0.13^{b}
Gross energy (kJ/100 g d.b)	2,232.55±21.16^{a}	1,755.71±1.32^{b}

Means±standard deviation. Different letter superscripts in the same row indicate significant difference ($P<0.05$)

DM Dry matter, [1] Obtained by difference, *WESM* Whole ebony seed meal, *DESM* Defatted ebony seed meal

pH

The pH value for the DESM (5.96) was higher ($P<0.05$) than that for the WESM (5.86) (Table 4), although both were within an acid range. The difference between the meals was probably due to free fatty acid content in the oil in WESM. The defatting process would have removed these lipids and raised meal pH values.

Color

The WESM differed ($P<0.05$) from the DESM in all five color parameters (L*, a*, b*, C* and h°) (Table 4). Lightness (L*) values tending towards red have negative a* values,

Table 4 pH values and color values for whole ebony seed meal and defatted ebony seed meal

Parameter		WESM	DESM
pH		$5.96{\pm}0.01^a$	$5.86{\pm}0.01^b$
Color	*L**	$66.02{\pm}0.02^a$	$84.54{\pm}0.01^b$
	*a**	$8.19{\pm}0.02^a$	$1.88{\pm}0.02^b$
	*b**	$38.21{\pm}0.05^a$	$22.59{\pm}0.04^b$
	*C**	$9.63{\pm}0.01^a$	$7.00{\pm}0.00^b$
	h°	$1.36{\pm}0.00^a$	$1.49{\pm}0.00^b$
	ΔE	63.86±0.05	

Values represent the average of 4 replicates±standard deviation. Different letter superscripts in the same row indicate significant difference ($P<0.05$)

WESM Whole ebony seed meal, *DESM* Defatted ebony seed meal

those tending towards green have positive a* values, those tending towards blue have negative b* values and those tending towards yellow have positive b* values. The highest *L** values (84.54) were observed in the DESM probably because any pigments in the seeds were removed during defatting. Both meals had positive a* values, indicating a red tonality while the WESM had a stronger tendency towards yellow (b*=38.21) than the DESM (b*=22.59). The lower yellow tonality in the DESM may have resulted from removal of carotenoids during defatting. This process may also have produced a lower degree of color saturation (C*) in the DESM. Hue angle (h°) was only slightly lower in the DESM, meaning its tonality was somewhat less intense than that of the WESM.

Functional properties

The WESM and DESM differed ($P<0.05$) in all five evaluated functional parameters (Table 5). Water absorption capacity (WAC) was higher ($P<0.05$) in the DESM (1.28 g/g meal) than in the WESM (1.04 g/g meal), probably in response to the higher availability of polar amino acids and lower fat content in the DESM. Some studies indicate that WAC increases with defatting, since it promotes protein-water interactions, which in turn depend on the number and type of hydration sites, the physicochemical environment (pH, solutes, protein arrangement, temperature, solvents, surfactants, carbohydrates, lipids, etc.) and system thermodynamic properties (Kinsella 1982; Rodríguez-Miranda et al. 2012). The WESM's WAC was less than reported for other legumes (Ghavidel and Prakash 2006; Ahenkora et al. 1999). Differences in WAC between legumes may be caused by differences in protein polar amino acids or charged side chain contents, both of which have an affinity for water molecules (Kinsella 1982; Jitngarmkusol et al. 2008).

Table 5 Functional properties of whole ebony seed meal and defatted ebony seed meal determined at 25 °C

Functional properties	WESM	DESM
WAC (g H_2O/g sample)	$1.04{\pm}0.01^a$	$1.28{\pm}0.00^b$
WSC (%)	$24.55{\pm}0.57^a$	$26.06{\pm}0.31^b$
OAC (g oil/g sample)	$1.75{\pm}0.03^a$	$2.04{\pm}0.02^b$
EC (%)	$52.01{\pm}0.84^a$	$53.78{\pm}0.22^b$
BD (g/cm^3)	$0.85{\pm}0.01^a$	$0.78{\pm}0.01^b$

Values represent the average of 3 replicates±standard deviation. Different letter superscripts in the same row indicate significant difference ($P<0.05$)

WAC Water absorption capacity, *WSC* Water solubility capacity, *OAC* Oil absorption capacity, *EC* Emulsification capacity, *BD* Bulk density, *WESM* Whole ebony seed meal, *DESM* Defatted ebony seed meal

Water solubility capacity (WSC) (Table 5) was higher ($P<0.05$) in the DESM (26.06 %), probably due to the presence of a greater quantity of water soluble proteins. Protein solubility is the most important physicochemical and functional property because it influences other properties directly affected by protein concentration and solubility, such as foaming capacity, emulsifying capacity and gel formation (Hye-Jung et al. 2010).

Oil absorption capacity (OAC) was also higher ($P<0.05$) in the DESM (2.04 g/g meal) than in the WESM (1.75 g/g meal). This was probably due to exposure of a larger number of non-polar sites in the proteins in the DESM which can then bind to hydrocarbon oil units, resulting in greater OAC. The WESM OAC value was slightly lower than the 3.64 g oil /g meal reported for a morama bean meal (Jideani et al. 2009).

Emulsifying capacity (EC) was also higher ($P<0.05$) in the DESM (Table 5). This capacity depends on the balance between hydrophilic and lipophilic groups in meal components (Khalid et al. 2003). This may be due to the increase in protein hydrophobic groups after defatting, which increase surface adsorption forming a cohesive interphase film between the oil and water (Mahmoud 1994). These differences in meal protein emulsifying capacity depend on a substantial decrease in interphase energy. This is caused by protein absorption in the water-oil interphase and a barrier generated by electrostatic, structural and mechanical energy that opposes destabilization. As a result, collisions between drops in the disperse phase are reduced, which retards phase separation (Makri et al. 2005). Proteins are surface-active polymers and generally form a layer mainly absorbed in the oil-water interphase (Leal-Calderon et al. 2007). Emulsion forming capacity depends on the balance between hydrophilic and lipophilic groups in the fiber components (Khalid et al. 2003) and proteins. The DESM EC values were higher than reported for other legume meals (Ahenkora et al. 1999; Okpala and Mammah 2001). Its higher EC highlights the DESM's potential applications in milk substitutes and meat analogues, or any product requiring good emulsion formation, such as sauces, creams and fat analogues, among others.

The bulk density (BD) is generally affected by the particle size is very important in the determination of a packaging or packaging system, and in material handling (Karuna et al. 1996). Bulk density (BD) is highly dependent on particle size, which was why the WESM (0.85 g/cm^3) had higher ($P<0.05$) BD than the DESM (0.78 g/cm^3) (Table 5). The values obtained are above those reported for wheat flour 0.71 g/cm3 (Akubor and Badifu 2004).

The LGC was 18 % (w/v) with the WESM and 8 % with the DESM. The DESM GC value was lower than the 14 % reported for other squash and lupine meals (Sathe et al. 1982; Olaofe et al. 1994). This difference may be related to the relative protein, carbohydrates and lipids quantities in each meal. Defatting produced higher protein and carbohydrate contents in the DESM, explaining why a lower concentration of this meal was needed for gel formation. Protein concentration is vital to gel formation and firmness, and a greater proportion of globular proteins helps to improve this process (Sathe et al. 1982). Higher protein concentration improves gel firmness. Protein denaturation and starch gelling can also influence gelling properties (Alobo et al. 2009). The fact that the DESM formed gels at low concentrations suggests its use in formulating cheese substitutes, or as an additive to promote gel formation in food products.

Conclusion

Ebony beans have an average length of 13.02 mm, a width of 8.78 mm and a thickness of 9.65 mm. Geometric volume was 10.76 mm, volume was 530 mm^3, surface area was 364.33 mm^2, sphericity was 83.26 % and the aspect ratio was 68.24 %. Average thousand-seed weight was 0.70 Kg, of which 0.42 Kg (60 %) corresponded to the kernel. These data can be used to design post-harvest processing equipment and seed quality control measures. Defatting of the seeds increased protein and carbohydrates proportions, consequently improving Functional properties. Defatted ebony seed meal could have potential applications in compound flour formulations, as a principal ingredient in bread and pastry products, or as a natural additive in new product formulations.

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