Effects of boiling on the functional, thermal and compositional properties of the Mexican jackfruit (*Artocarpus heterophyllus*) seed Jackfruit seed meal properties

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ABSTRACT

The effect of boiled on the functional properties, thermal and chemical composition of the seed Mexican jackfruit (*Artocarpus heterophyllus*) was evaluated. In raw jackfruit seed meal (RJSM) and boiled jackfruit seed meal (BJSM), the chemical composition, color (L*, a*, b*, C* and h° and ΔE), pH, water absorption capacity (WAC), water solubility capacity (WSC), oil absorption capacity (OAC), foaming capacity (FC) and stability (FS), bulk density (BD), least gelation concentration (LGC), swelling power (SP) and thermal properties were evaluated. RJSM and BJSM do not show significant differences ($P > 0.05$) on protein content (13.52 g/100 g on average) and raw fiber (3.81 g/100 g on average). BJSM showed significant effect ($P < 0.05$) in all parameters evaluated, causing increased L* (76.68), WAC (3.34 g/g), WSC (14.65%) and decrease in a* (3.23), b* (17.15), C* (17.45), h° (79.34), pH (6.32), BD (0.59 g/cm³), LGC (8%, is w/v), besides not to show FC. The greatest SP was observed in RJSM, with values between 5.82% at 90 °C and 5.22% at 80 °C. Two endothermic transitions were observed on RJSM which correspond at to starch gelatinization (71.82 at 87.57 °C) and at break of amylose-lipid complex (113.60 a 120.56 °C), while BJSM only presents the endothermic transition corresponding to the breakdown of amylose-lipid complex (113.62 a 119.25 °C). The results show that the jackfruit meal can be used in formulations or composite meals as the main ingredient in the development of new products.

Keywords: *Artocarpus heterophyllus;* Breadfruit; Meal; Water absorption capacity

INTRODUCTION

Breadfruit or jackfruit (*Artocarpus heterophyllus*), as it is commonly known in Southeastern Mexico, belongs to the family *Moraceae* and the genus *Artocarpus,* and hundreds of varieties of these trees grow in diverse parts of the world, particularly in the Pacific, Southeast Asia, the Caribbean, and Central America. Some jackfruit seed varieties have been studied and are appreciated for their nutritional properties because they are rich in carbohydrates, lipids and proteins (Akanbi et al., 2009; Pua et al., 2010). Jackfruit seeds also contain many minerals, lignans, isoflavones, saponins, and phytonutrients (James and Friday, 2010; Tran et al., 2015). Thus, jackfruit seeds are used as ingredients in many culinary preparations (Tran et al., 2015). According to Sandhu et al. (2015), thermal processing is the most extensively used method, for improving their texture, palatability and nutritive value by gelatinization of starch, denaturation of proteins, increased nutrient availability, inactivation of heat labile toxic compounds and other enzyme inhibitors. However, cooking by immersion favors the hydration and gelling of starch, the denaturation of enzymes, the partial solubilization of minerals and the degradation of some vitamins (Moncada and Gualdrón, 2006). Therefore, the functional properties of potential food additives are studied to obtain a global view of their

possible application in the formulation of foods (Hernádez-Santos et al., 2015), because food additives can specifically influence the appearance and functional behavior of the food. Hydration capacity, foam formation, emulsification, gelation and other characteristics associated with proteins and other food components are functional properties of food additives (Rodríguez-Miranda et al., 2012). 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 (Gómez-Aldapa et al., 2009). Therefore, the objective of this study was to evaluate the effects of boiling on the functional and thermal properties as well as the chemical composition of the Mexican jackfruit seed (*Artocarpus heterophyllus*).

MATERIALS AND METHODS

Jackfruit seeds (*Artocarpus heterophyllus* L.) were acquired from a local market in the community of San Juan Bautista Tuxtepec, which is located at 18º05'24"N 96º06'50"W at an altitude of 20 meters above sea level in Oaxaca State, Mexico.

Preparation of raw jackfruit seed meal (RJSM)
Seeds were cut into 0.5 cm thick slices and dried at 60 °C in an oven for 25 h (Binder, mod. ED 115, D-78502 Tuttlingen, Germany). The dried seeds were ground in a coffee mill (Krupps Model GX4100 2121 Eden Road Millville, NJ 08332 USA) until meal with a particle size of 0.59 mm (No. 30 mesh screen, U.S.A. standard test sieve ASTM E-11 Specification W.S. Tyler, USA) was obtained. The obtained meal was placed in sealed polyethylene bags and stored at 4 ± 0.5 °C until further analysis.

Preparation of boiled jackfruit seed meal (BJSM)
The seeds were cleaned and cooked in an open pan at 98 °C for 60 min at ratio of 1:5 sample: water (w/v) (Park et al., 2010), and then, they were cut, dried and ground using the conditions described above to obtain a meal for the subsequent analyses.

Chemical composition
The chemical analyses of the RJSM and the BJSM was performed in triplicate according to the standard methods of the AOAC (2005); the moisture (934.01), ash (942.05), protein (960.52), fat (948.22), crude fiber (978.10) and carbohydrate contents were obtained by determining the differences compared to the levels of the other components. The total energy was calculated using the methods described by Ekanayake et al. (1999).

Color and pH
The color parameters were measured with a tristimulus colorimeter (MiniScan 45/0L, Hunter Lab, Hunter Associates Laboratory 11491, Sunset Hills Road Reston, Virginia 20190, USA). Lightness (*L**), red/green chromaticity (*a**) and yellow/blue chromaticity (*b**) were measured, and the differences in the chromaticity (C*), the hue angle (hº) and the total color (ΔE) were calculated from those results. The pH was measured by dispersing the flours in distilled water at 25 °C.

Functional properties
Water absorption capacity (WAC) and water solubility capacity (WSC)
The WAC and WSC were determined using the methods described by Anderson et al. (1969). One gram of ground product was sieved to 0.59 mm (No. 30 mesh screen, U.S.A. standard test sieve ASTM E-11 Specification W.S. Tyler, USA) and dispersed in 10 mL of room temperature water (25 ± 1 °C). The resulting suspension was gently stirred by hand for 30 min, and then, the samples were centrifuged at 1,006 $x\,g$ for 15 min (Universal Compact Centrifuge HERMLE 211 Labortechnik GmbH Mod Z 200A, Siemensstr. 25 D-78564 Wehingen Germany). The supernatant was decanted into a tarred aluminum pan. The WAC was calculated as the weight of the obtained sediment or gel after the removal of the supernatant per unit weight of the initial dry sample. The WSC was the weight of the dry solids in the supernatant expressed as a percentage of the original weight of the dry sample.

Oil absorption capacity (OAC)
The OAC was measured using the method described by Beuchat (1977). One gram of sample was combined with 10 mL of corn oil, and the mixture was thoroughly stirred with a vortex (Vortex-2 Genie, Model G-560, Cole-Parmer, Vernon Hills, IL. USA). The obtained slurry was occasionally stirred over a period of 30 min and subsequently centrifuged at 1,006 $x\,g$ for 15 min. The volume of the decanted supernatant fluid was measured, and the OAC was expressed as grams of retained oil per gram of sample.

Emulsification capacity (EC)
The emulsification capacity was determined according to the method described by Yasumatsu et al. (1992). Distilled water (20 mL) was mixed with 1 g of sample, and the mixture was stirred with a vortex (Vortex-2 Genie, Model G-560, Cole-Parmer, Vernon Hills, IL. USA) for 15 min and then brought to a volume of 25 mL with distilled water. The stirred mixture was then blended with 25 mL of corn oil for 3 min using a blender (Oster, Model 465, LLC, 5200 Blue Lagoon Drive, Suite 470, Miami, FL 33126 USA) and then centrifuged (Universal Compact Centrifuge HERMLE 211 Labortechnik GmbH Mod Z 200A, Siemensstr. 25 D-78564 Wehingen Germany) at 1,006 $x\,g$ for 15 min. The EC was expressed as a percentage of the height of the emulsified layer divided by the total liquid content.

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Foaming capacity (FC) and foam stability (FS)

The FC and FS of the RJSM and the BJSM were also determined. Both meals (2 g) were air-dried (65 ºC) to a constant weight. The FC was measured according to the methods described by Coffman and García, (1977) The samples were dispersed in distilled water (10 mL) to a concentration of 3% (w/v), adjusted to pH 7.0 with 0.1 N NaOH, whipped for 5 min with a blender (Oster, Model 465, LLC, 5200 Blue Lagoon Drive, Suite 470, Miami, FL 33126 USA) at the highest speed, and then poured into a 250 mL graduated cylinder. The results were expressed as the percent increase in volume. The foam volumes were recorded at intervals of 10, 15, 30, 45 and 60 min to study the FS of the samples (Joshi et al., 2015).

Bulk density (BD)

The BD was determined as described by Joshi et al. (2015). The flour samples were added to a 10 mL graduated cylinder (a minimum of 0.5 mL). The bottom of the cylinder was softly tapped 5 times until there was no further diminution of the sample level, the BD was calculated as the mass of the sample per unit volume of the sample (g/cm^3).

Least gelation concentration (LGC)

This parameter was determined using the method described by Sathe and Salunkhe (1981). Sample dispersions of 4, 8, 12 and 14% (w/v) were prepared in 300 mL of distilled water. Each dispersion was adjusted to pH 7.0 with 0.1 N NaOH and mixed in a blender at the highest speed for 2 min. The dispersions were poured into test tubes in aliquots of 5 mL (three test tubes per concentration). They were then 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 in an ice bath. The lowest concentration at which all the triplicates formed a gel that did not collapse or slip from the inverted test tube was reported as the Least Gelation Concentration (LGC).

Swelling power (SP)

Distilled water (10 mL) was added to a 1 g of sample in centrifuge tubes, and the mixture was heated to 60, 70, 80 and 90 °C for 30 min and centrifuged (Universal Compact Centrifuge HERMLE 211 Labortechnik GmbH Mod Z 200A, Siemensstr. 25 D-78564 Wehingen Germany) at 1,006 x g for 15 min (Sathe and Salunkhe, 1981). The SP was calculated as the weight of the obtained sediment or gel after the removal of the supernatant per unit weight of the initial dry sample, multiplied by one hundred, and was expressed as a percentage.

Differential scanning calorimetry

The thermal properties of the flours were determined using a Differential Scanning Calorimeter (DSC Q 2000, TA Instruments, 109 Lukens Drive, New Castle DE 19720, USA) calibrated with indium (T$_o$ = 156.4 °C, DH = 28.4 J g^{-1}). The samples (2–3 mg) were weighed out into 40-µL aluminium trays (Cat. No. ME-27331; Mettler-Toledo), and distilled water was added with a microsyringe until a 1:4 sample: water (w/v) ratio was achieved. The samples were analyzed within a range of 30 – 130 ºC using a heating velocity of 5 ºC min^{-1} and a nitrogen flow of 20 mL min^{-1}. All analyses were performed in triplicate and were reported as average values.

Statistical analysis

The results were analyzed by one-way analysis of variance (ANOVA), and the differences between the calculated means were obtained using a least significant difference test with a 95% confidence level. All analyses were performed with the Statistical software ver. 8.0 (StatSoft, Inc. 2300 E 14th St, Tulsa, OK 74104, USA).

RESULTS AND DISCUSSION

Chemical composition analysis

The boiling process did not show significant effect ($P > 0.05$) on the protein (13.86 g/100 g) and raw fiber (3.72 g/100 g) contents in the BJSM (Table 1). The results in this study are consistent with those reported by Oladunjoye et al. (2010) in Nigerian breadfruits (*A. altilis*) boiled with and without peel (protein contents of 4.79 and 4.63 g/100 g and fiber contents of 5.22 and 5.20 g/100 g, respectively). On the other hand, Eke-Ejiofor et al. (2014) evaluated different processing methods for Nigerian jackfruit (*A. heterophyllus*) (boiled, dried, roasted, germinated and autoclaved) and obtained values for the protein and fiber contents that were similar to those observed in this study. The RJSM showed higher ash (3.80 g/100 g) and carbohydrate (73.44 g/100 g) content than the BJSM. A higher lipid content was observed in the BJSM (6.56 g/100 g). The observed difference ($P < 0.05$) in the ash content might be due to the leaching of certain minerals into the water during boiling.

The observed protein and lipids contents were lower than those reported in other varieties of jackfruit, such

Table 1: Chemical composition (dry basis) of raw (RJSM) and boiled (BJSM) jackfruit seed meal

Component (g/100 g)	RJSM	BJSM
Protein (N x 6.25)	13.18±0.40[a]	13.86±0.35[a]
Fat	5.69±0.19[a]	6.56±0.30[b]
Crude fibre	3.90±0.25[a]	3.72±0.14[a]
Ash	3.80±0.05[a]	3.05±0.07[b]
Carbohydrates[1]	73.44±0.45[a]	72.82±0.07[b]
Total energy (kJ/100 g dm)	1660.96±4.66[a]	1694.81±6.49[b]

Means±standard deviation. Different letter superscripts in the same row indicate significant difference (*P*<0.05). dm=Dry matter. [1]Obtained by difference.

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as Akubor and Badifu (2004)in Decne African *Treculia africana* (17.06 and 11.00 g/100 g, respectively), Ajayi (2008) in Nigerian *A. heterophyllus* (20.19 and 11.39 g/100 g, respectively), and higher than those reported by Oladunjoye et al. (2010) in Nigerian *A. altilis* (4.79 y 2.90 g/100 g, respectively). However, the protein content was similar to that reported by Ocloo et al. (2014) in Ghana *A. heterophyllus* (13.50 g/100 g) and that reported by Eke-Ejifor et al. (2014) in Nigerian *A. heterophyllus* (12.45 − 13.48 g/100 g).

The raw fiber content was higher than that reported for *Decne Treculia africana,* 2.50 g/100 g, (Akubor and Badifu, 2004) and *A. heterophyllus,* 3.19 g/100 g (Ocloo et al., 2014) lower than that reported by Ajayi (2008) in *A. heterophyllus,* (7.10 g/100 g) and that reported by Oladunjoye et al. (2010) in *A. altilis* (5.22 g/100 g), and within the range registered by Eke-Ejiofor et al. (2014)in *A. heterophyllus* (3.53 − 4.70 g/100 g). Significant differences were observed in the carbohydrate content ($P < 0.05$) between samples; these values are similar to the values reported by other authors for different varieties of jackfruit (Oladunjoye et al., 2010; Eke-Ejiofor et al., 2014; Akubor and Badifu, 2004; Ajayi, 2008; Ocloo et al., 2014). The proximal chemical composition of *A. heterophyllus* of Mexican origin shown in this study was different from that reported in the literature, and could be due to the variety and maturation of seeds and planting soil conditions (Ocloo et al., 2014). The results showed that the protein content does not depend on thermal processing because thermal processing did not affect the nutritional value of Mexican jackfruit meal. Significant differences were observed in the caloric value (total energy) of the RJSM and the BJSM (Table 1) ($P < 0.05$); the highest value of 1694.81 kJ/100 g of dry matter (dm) was observed in the BJSM, because the BJSM presents a greater lipid content (Table 1), which contributes more energy per gram than proteins and carbohydrates (Rodríguez-Miranda et al., 2012). These results are comparable with those of other studies, which observed that the energy levels were significantly increased by boiling compared to the raw samples (*Dioscorea alata*) (Oulaï et al., 2013; Ezeocha and Ojimelukwe, 2012). However, the energy value of the BJSM was below that reported by Tan et al. (2013) in *A. odoratissimus* (2043.15 − 2080.83 kJ/100 g dm), and was higher than that reported by Akinmutimi (2006)in *A. heterophyllus* (1222.54 -1310.46 kJ/100 g dm) and Oulaï et al. (2013) in *A. altilis* (1415.80 kJ/100 g dm).

Colour and pH

The results shown in Table 2 indicated that the boiling of the seeds affected the colour of the meal, and compared with the RJSM, the BJSM showed significant differences ($P < 0.05$) in the parameters L*, a*, b* and C* but not in h°. The BJSM showed the highest value of the parameter L* (75.68), indicating a whiter colour than that of the

Table 2: pH values and Hunter colour values of raw (RJSM) and boiled (BJSM) jackfruit seed meal

Parameter	RJSM	BJSM
pH	6.39±0.03[a]	6.32±0.03[b]
L*	75.11±0.01[a]	76.68±0.01[b]
a*	3.38±0.01[a]	3.23±0.01[b]
b*	17.99±0.01[a]	17.15±0.01[b]
Eliminate colour		
C*	18.30±0.01[a]	17.45±0.01[b]
h°	79.36±0.04[a]	79.34±0.02[a]
ΔE		1.78±0.00

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

RJSM (75.11). Both samples showed positive values for the parameter a*, which is located in the quadrant containing the red tones. The RJSM displayed the highest value, indicating a redder tone than that of the BJSM. The parameter b* was located in the quadrant containing the yellowish tones, and the BJSM displayed the maximum value of 17.99. The greatest chromaticity (C*) was observed in the RJSM (18.30) compared with the BJSM. No significant difference was observed ($P < 0.05$) in h°, with a ΔE of 1.78. The differences observed between the meals are because the jackfruit seed is rich in fructose, sucrose, glucose, and β-carotene (Setiawan et al., 2001). Therefore, heat treatment (boiling) and drying could induce the Maillard reaction and the caramelization of the reducing sugars and amino acids, leading to the formation of a brown colour. β-carotene, the main pigment is responsible for the colour of the fruit, is sensitive to light and heat (Pua et al., 2010).The reduction of β-carotene during drying may increase the rate of oxidation of the unsaturated chemical structure of β-carotene (Jayaraman et al., 1995). The colour change in the BJSM may be advantageous in terms of its incorporation in certain foods such as crackers and extruded snacks, where a gold or brown may be desirable (Ma et al., 2011). On the other hand, the pH of the BJSM (6.39) was higher ($P < 0.05$) than that of the RJSM (6.32), although both are within a slightly acidic range (6 - 6.5). It is possible that the high temperature employed here could produce thermal transformation of the glucose units in the starch to simple organic acids could account for the observed pH shifts (Hamlet et al., 2003).

Functional properties
Water absorption capacity (WAC)
The greatest value of WAC was observed in the BJSM (3.34 g of H_2O per g of sample), and significant differences were observed ($P < 0.05$) between samples (Table 3). This result showed that heat processing affected the WAC of the native protein in the RJSM. This effect might be due to differences in the structural physics of the BJSM, which allow greater porosity, fluid trapping and/or higher water binding properties by the subunits

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Table 3: Functional properties of raw (RJSM) and boiled (BJSM) jackfruit seed meal determined at 25°C.

Functional properties	RJSM	BJSM
WAC (g H_2O/g sample)	3.12±0.07[a]	3.34±0.02[b]
WSC (%)	13.35±0.16[a]	14.65±0.08[b]
OAC (g oil/g sample)	1.87±0.06[a]	2.06±0.02[b]
FC (%)	31.75±2.75[a]	0.00±0.00[b]
BD (g/cm³)	0.65±0.01[a]	0.59±0.01[b]
LGC (%)	10.00±0.00[a]	8.00±0.00[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; FC=foaming capacity; BD=Bulk density; LGC=Least gelation concentration

or exposed amino acid residues as a result of protein denaturation (Ma et al., 2011; Giménez et al., 2012). In addition, starch gelatinization and raw fiber swelling during heating can also help increase the WAC (Aguilera et al., 2009). BJSM with high WAC values could be considered suitable for bakery products because it allows a greater amount of water to be added to the dough, thus improving the handling characteristics and freshness of the bread (Ma et al., 2011). The WAC is described as an important processing parameter that has implications on viscosity (Niba et al., 2002). In addition, WAC adds volume and consistency to foodstuffs; thus, it would be advisable to use foodstuffs with a high WAC in the baking industry. The observed WAC values were within the range of 4 - 6 g/g sample reported by Eke- Ejiofor et al. (2014) in *A. heterophyllus*; however, they were higher than those reported by Odoemelam (2005) with 2.3 g/g sample, and Tulyathan et al. (2002) with 2.05 g/g sample, in the same variety of *A. heterophyllus*.

Water solubility capacity (WSC)

The greatest value of WSC (14.65%) was observed in the BJSM (Table 3). Significant differences were observed (*P* < 0.05) between the samples. WSC indicates that the presence of soluble molecules is higher in the boiled sample than in the raw sample because boiling ruptures the intermolecular bonds (hydrogen bonds) and subsequently opens the chains to allow water molecules to enter the structures. Moreover, over the range of gelatinization temperatures, the starch granules exhibit limited swelling, which solubilizes a certain amount of carbohydrates, but as the temperature increases above the gelatinization temperature, there is an increase in the swelling capacity (Agunbiade and Longe, 1999; Madruga et al., 2014). The increased solubility may be attributed to the fact that amylose tends to solubilize and leach into the swollen starch granules as the temperature increases when the seeds are boiled, whereas the amylose-lipid and protein-starch complexes formed during the heating process could affect the WSC (Sathe et al., 1982; Du et al., 2014). However, the WSC values obtained in this study were within the range reported for jackfruit meal (*Artocarpus heterophyllus* L.)

13.20 - 17.08% (Eke-Ejiofor et al., 2014; Mukprasirt and Sajjaanantakul, 2004).

Oil absorption capacity (OAC)

A significant difference in the OAC between samples was observed (*P* < 0.05) (Table 3), and the highest value was observed in the BJSM (2.06 g/oil g sample). This result is due to the denaturation and dissociation of the constituent proteins during heating, which discovers nonpolar residues from within the protein molecule (Narayana and Narasinga, 1982). The oil absorption mechanism is mainly attributed to the physical retention of fat by capillary attraction and the link established with the apolar proteic chain (Du et al., 2014), thus the hydrophobicity of proteins plays an important role in oil absorption (Ramírez et al., 2012). However, the value observed in boiled sample was within the range (2-3.1 g/oil g sample) reported for jackfruit (Eke-Ejiofor et al., 2014; Odoemelam, 2005) and above that reported (0.93 - 1.38 g/oil g sample) in some legumes (Lentil, lima bean, mung bean, chickpea and black bean) (Du et al., 2014). Therefore, the heat treatment improved the OAC, which may suggest that this treatment could be used to prepared frozen precooked products that are ready for frying, and in formulations of meats, soups and cookies.

Foaming capacity (FC) and foam stability (FS)

The BJSM did not present an FC, while the RJSM presented a 31.75% FC (Table 3). This effect is probably because the proteins are thermolabile; thus, denaturation occurs during the cooking process. This effect was also observed by Ma et al. (2011) in boiled samples of two varieties of chickpeas (Desi and Kabuli) and yellow peas. Yasumatsu et al. (1992) have reported that the native protein provides greater stability to the foam-denatured protein. The FC of the raw sample was higher than that reported by Akubor and Badifu (2004) in African breadfruit (20%) and that reported by Sandhu et al. (2015) in oat 8-22%. The foam volume (Fig. 1) was reduced by half in 15 min and was stable from 20 to 45 min in only the RJSM, with values close to an 18% FC. This phenomenon can occur because the FC is related to the amount of native protein (Odoemelam, 2005). The FC and the FS depend on two different groups of molecular properties. The FC is affected by the rate of absorption, flexibility and hydrophobicity of the proteins, whereas the FS depends on the rheological properties of the protein film. The proteins of most foods are composed of mixtures of different molecular species; therefore, their foaming properties are determined by the interaction between the proteic components in the interface (Fennema, 2000). A stable foam is produced when the surface tension decreases with increasing viscosity on the surface of the colloidal solution, forming a resistant amorphous film (solid surface) (Rodríguez-Miranda et al., 2012).

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Bulk density (BD)
The RJSM showed a higher BD (0.65 g/cm³) (*P* < 0.05) than the BJSM (0.59 g/cm³) (Table 3). The BD represents the behavior of the material and is an important parameter that can determine requirements for product packaging, packaging systems, or packaging and material handling (Mohamed et al., 2009). Odoemalan (2005)reported the same reduction in the BD of 0.61 to 0.54 g/cm³ after breadfruit meal was heat treated. The values obtained in this study were within the range reported for breadfruit 0.54 – 0.80 g/cm³ (Akubor and Badifu, 2004; Ocloo et al., 2014; Odoemelam, 2005). Low BD values are desirable for packaged samples because they do not lose volume during storage (Ikpeme et al., 2010).

Least gelation concentration (LGC)
The LGC was 8% in the BJSM and 10% in the RJSM (Table 3). This result could be because gelation is an aggregation of denatured protein molecules (Kisambira et al., 2015). The gel forming capacity in flour has been attributed to the denaturation, aggregation and thermal degradation of starch, as well as the physical competition for water between the gelling proteins and starches (Enwere and Ngoddy, 1986; Singh, 2001). The LGC obtained in this study was lower than that reported in African and Nigeriana breadfruit, which was 12% (Eke-Ejiofor et al., 2014; Odoemelam, 2005)as well as some seeds, such as

almond (14%), chickpea (12%), soybean (16%) and sesame (16%) (Joshi et al., 2015). According to the obtained LGC values, the jackfruit flour could be a good gelling agent that may be useful in the development of products such as puddings, sauces and soups.

Swelling power (SP)
Significant differences between the BJSM and the RJSM were observed (*P* < 0.05) at all temperatures evaluated (Fig. 2). However, in the flours, a tendency to increase the percentage of swelling as the temperature increased was observed. A higher SP was observed in the RJSM, with values ranging from 5.22% at 80 °C to 5.82% at 90 °C, whereas the SP values at 80 and 90 °C (4.34 and 4.38%, respectively) were higher in the BJSM. This behavior may be because the SP is dependent on the temperature and composition of the samples due to the effects of protein denaturation, starch gelatinization and their interaction with the lipid matrix, which causes slow water absorption and the formation of protein corpuscles in the amorphous regions of the starch (amylose) that are less organized and more accessible. As the temperature increases, more water is retained, and the pellet begins to swell and increase in volume (Hernández-Santos et al., 2015). Additionally, the SP can be influenced by the ability of the proteins present in the formulation to form a gel. However, the SP observed in this study was lower than that reported by Eke-Ejiofor
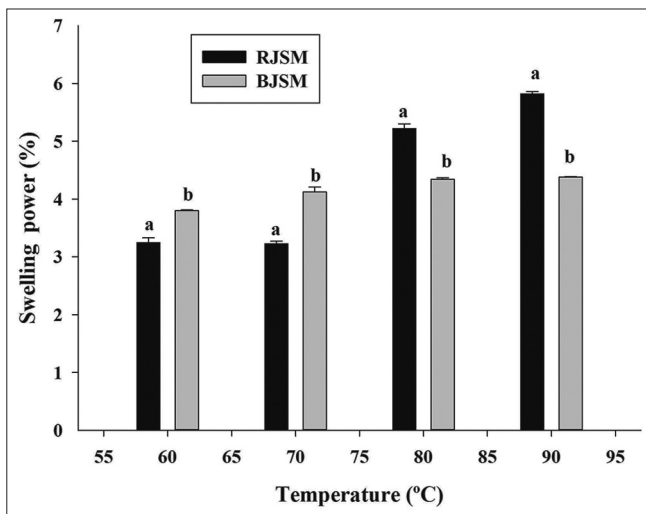

Fig 1. Foam stability of raw (RJSM) and boiled (BJSM) jackfruit seed meal at different time. Values represent the average of three replicates ± standard deviation.
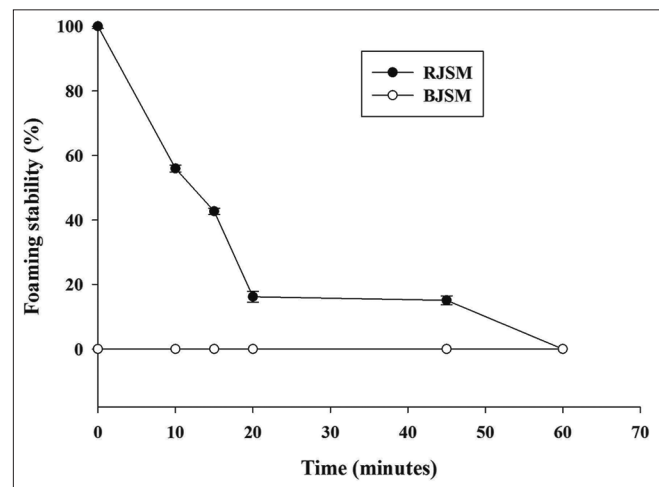

Fig 2. Swelling power of raw (RJSM) and boiled (BJSM) jackfruit seed meal at different temperature. Values represent the average of three replicates ± standard deviation. Different letters in the same temperature indicate significant difference (*P* < 0.05).

Table 4: Thermal properties of raw (RJSM) and boiled (BJSM) jackfruit seed meal.

Sample	Peak I				Peak II			
	T_0 (°C)	T_p (°C)	T_f (°C)	ΔH (J/g)	T_0 (°C)	T_p (°C)	T_f (°C)	ΔH (J/g)
RJSM	71.82±0.33	76.85±0.06	87.57±0.64	6.32±0.31	113.60±0.31[a]	115.87±0.02[a]	120.56±0.11[a]	0.51±0.01[a]
BJSM	-------No peak-------				113. 62±0.79[a]	115.16±0.07[b]	119.25±0.71[a]	0.39±0.03[b]

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

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et al. (2014) in jackfruit (6.58 – 9.46%) and was similar to that reported by Ocloo et al. (2014) in jackfruit (4.77%).

Thermal properties

The results of the thermal properties of the samples are presented in Table 4. The RJSM showed two endothermic peaks (Fig. 3). The BJSM only showed one transition, as shown in Peak 2 of Fig. 3, and statistically significant differences ($P < 0.05$) of approximately one degree Celsius in the peak temperatures (Tp) and approximately 0.12 J/g in the transition energy (between samples) were observed. The first transmission (peak 1) observed in the RJSM resulted from starch gelatinization in the sample. The observed differences are directly related to the process of previous gelatinization during boiling of the sample, which may be the reason why the first endothermic peak was not observed in the BJSM. This effect was also observed by Tran et al. (2015) in native and gelatinized jackfruit samples (*Artocarpus heterophyllus* Lam.). The second transition (peak 2) was observed in the two samples at a higher temperature, due to the formation of an amylose-lipid complex (Wani et al., 2013). Jayakody et al. (2007) reported that the transition temperature of gelatinization is influenced by the amylose content, the distribution of branched chains of amylopectin, and the amylose-lipid complex and protein content. The formation of amylose-lipid complexes influences the agglutination, swelling and hydration properties of legume meals (Jayakody et al., 2007; Ahmadi-Abhari et al., 2013).

CONCLUSION

The boiling process does not significantly affect ($P > 0.05$) the protein and raw fiber contents in the samples of boiled and raw jackfruit seeds, which contributes to the improvements in their functional properties. The results showed that the jackfruit meal can be used in composite flour formulations or as the main ingredient in bakery and pastry products, and it might even represent a good natural additive in the formulation of new products. Moreover, it is a good gelling agent that could be useful for the development of products such as puddings, sauces and soups. The boiled jackfruit seed meal samples may be recommended for the preparation of ready-to-fry frozen precooked products and formulations of meat, soups and cookies.

Author's contributions

José M. Juárez-Barrientos, Betsabé Hernández-Santos and Jesús Rodríguez-Miranda conducted the experiments, analyzed the data and wrote the manuscript. Erasmo Herman-Lara, Cecilia E. Martínez-Sánchez and Juan G. Torruco-Uco designed the experiments. Emmanuel J. Ramírez-Rivera and José M. Pineda-Pineda, experimentation.

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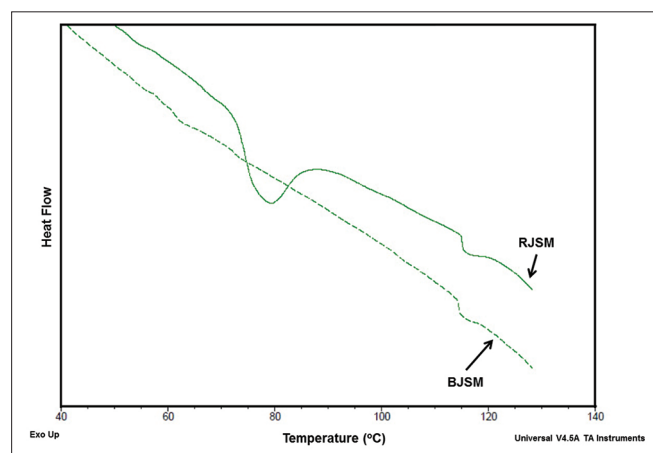Coffman, C. W. and V. V. García. 1977. Functional properties and

Fig 3. DSC glass transition thermograms of raw (RJSM) and boiled (BJSM) jackfruit seed meal

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