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The Effect of Pre-Milling Treatments on Functional and Rheological Properties of *Brachystagia eurycoma* (Achi) Seed Flour and Gum

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ABSTRACT

Brachystegia eurycoma has good gelation properties which can impact a gummy texture when used in soups. The aim of this study is to explore the effect of pre-milling treatments on the functional and rheological properties of B. eurycoma seed flour and gum which will enhance the knowledge on utilizing Achi as a versatile ingredient in various food products. This study evaluates the effect of pre-milling treatments on the functional and rheological properties of B. eurycoma (achi) seed flours and gums. Batches (1kg) of B. eurycoma (Achi) seeds were subjected to four different pre-milling treatments (soaking, boiling, toasting, and fermentation) at various time intervals followed by processing steps to obtain fine flour and gum samples. Locust bean flour and gum were used as control. The results from the different pre-milling treatments of B. eurycoma seed flours and gum showed that the wettability of the flour and gum samples were high and rapid which ranged from 35.33±0.58s to 327.33±6.43s and 46.67±1.06s to 99.67±2.08 respectively, hence it tends to reduce clumping, ensuring efficient functionality. The Modulus of elasticity of B. eurycoma flours and gums were also high with a range of 75.47±0.00N/mm^2 to 182.42±0.01N/mm^2, this indicates a relatively incompressible fluid. Gums from seeds boiled for 30min and 45min had the highest emulsion capacity, foaming capacity and wettability (B30 = 72.87%, B45 = 76.50%; B30 = 23.83%, B45 = 27.40% and B30= 91.33 s, B45= 99.67 s respectively), hence, can be said to be the best gum with high stability for commercial purposes. Gum samples from seeds fermented for 18 hrs had low viscosity with high shear rate (44.66 NS/mm^2 and 41.04 NS/mm^2; 0.26S^{-1} and 0.28S^{-1}) hence, can be said to show a pseudoplastic or shear thinning behavior of B. eurycoma gum. This will enhance the texture, mouth feel, stability and uniformity of the gums when incorporated into a food system. This study revealed that B. eurycoma flours and gums from different pre-milling treatments will be very useful for the large-scale manufacturers and consumers not just because it is economical but is also a natural additive.

Keywords: Flours, gums, soaking, boiling, toasting, fermentation

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INTRODUCTION

Brachystegia eurycoma is among the trees found in the tropical and sub-tropical regions of the world. This plant is known to have existed in different parts of the world mainly in Nigeria, and it is commonly grown along river banks. Different tribes and ethnic groups across Nigeria have distinct names for it. *Brachystegia eurycoma* is called 'achi' by the Ibos; 'akolodo' by Yorubas, 'ukung' by the Efiks; and 'akpakpo' by Ijaws (Adewale and Mozie, 2010). *Brachystegia eurycoma* belongs to the family Caesalpinaceae, phylum spermatophyte and order fabacea. Other species include *Brachystegia allanii, Brachystegia leonnsis, Brachystegia lussel, and Brachystegia kenedy* (Ezeoke, 2010). *Brachystegia eurycoma* seed flour has good gelation properties and imparts a gummy texture when used in soup which is a desirable attribute of such food for eating (Nwosu, 2012). This gummy texture enables it to act as a good emulsifying, stabilizing, thickening and flavouring agent. They are not true gums but are of simpler structures and it can swell in water, influencing the viscosity of the liquid when crushed into flour. When used as additives in foods, *Brachystegia eurycoma* can impact desirable textural and functional properties to the finished food product especially the "convenience foods" (Ajayi *et al*., 2006).

The nutritional value of *Brachystegia eurycoma* seed can be improved by soaking, boiling, roasting or fermentation (Ohenhen and Ikenbomeh, 2007) as this leads to several components broken down into simpler compounds which tends to alter its texture, aroma, flavour and taste. When foods are fermented, anti-nutrients are eliminated, nutritive values of digested sugars are increased, free fatty acids, amino acids and vitamins are synthesized. *Brachystegia eurycoma* seed flour also has the ability to imitate and replace fat in processed food and so has been shown to be an essential component in low-fat and fat-free products.

Seed flours and gums of *Brachystegia eurycoma* are commonly used as thickening, emulsifying or stabilizing ingredients in soups, sauces and many functional foods. Unfortunately, pre-milling treatments, including soaking, fermenting, boiling and toasting of the seeds influences these properties. At present, there is no established standardized pre-milling condition to achieve flour and gum of optimum emulsifying, stabilishing and thickening properties of seeds, hence the need for the study. This study will establish the best pre-milling treatment for food thickening, emulsifying and stabilizing properties of flours and gums of the underutilized *Brachystegia eurycoma* seeds in conventional and functional foods. The main objective of this study is to evaluate the effect of pre-milling treatments on nutrient composition and functional properties of flours and gums from *Brachystegia eurycoma*.

The specific objectives are:

i. Produce flours and gums from soaked, toasted, fermented and boiled seeds of *Brachystegia eurycoma.*
ii. Evaluate the functional properties of the seed flour and gum.
iii. Evaluate the rheological composition of the seed flours and gums.

In our knowledge, until now, there is no established standardized pre-milling condition to achieve flour and gum of optimum emulsifying, stabilizing and thickening properties of seeds, therefore, exploring the effect of pre-milling treatment on the functional and rheological properties of *B. eurycoma* seed flour and gum enhances the knowledge on utilizing Achi as a versatile ingredient in various food products

MATERIALS AND METHODS

Sample collection

Mature, dry seeds of *B. eurycoma* were purchased from local stockers at Eke-Atta market in Imo State during the raining season in the year 2017. Commercial locust bean flour and gum was purchased from Folak Nigeria Limited, a Nigerian Locust bean supplier. The reagents, equipment and other materials used for the study was obtained from the Department of Food Science and Technology, Michael Okpara University of Agriculture Umudike, Umuahia in Abia State and from Divine Chemicals and Analytical Laboratory, Nsukka.

Sample preparation

Immature seeds and dirt were manually removed from the seed sample. The seeds were winnowed manually, washed, drained and subjected to different pre-milling treatments (soaking, fermentation, toasting and boiling) before drying in a hot air oven at 55 ^{o}C for 10 min. The dried seeds were then packed in a black polyethene bag and stored in an airtight plastic container.

Pre-milling treatment and processing of seed flour

The clean dried seed samples (4 kg) were divided into four groups of 1kg each and each one was subjected to a particular pre-milling treatment before being processed into flour.

Soaking: The first batch of 1kg was divided into 2 equal portions of 500g each which was soaked in excess clean water for 5 h.

Fermentation: The second group of 1kg was further divided into two equal portions of 500 g each which was soaked in excess clean portable water but subjected to different fermentation times of 12 h and 18 h respectively.

Toasting: The third group of 1 kg was divided into two equal portions of 500 g each. The two portions were toasted (100^{o}C) in a hot oven.

Both portions were toasted at different time intervals of 15 and 30 min. respectively.

Boiling: The fourth group of 1 kg was divided into two equal portions of 500 g each. The two portions were boiled in boiling water (100^{o}C) at different time intervals of 30 and 45 min. respectively. After pre-milling processes, the soaked, boiled and fermented samples were drained while the toasted sample was allowed to cool. Each sample was then dehulled manually, washed in excess clean portable water, drained and then oven dried at 55^{o}C for 18 h. Each sample was milled and sieved through 60-µm (British standard) mesh sieve to get fine flour. The flour was packaged in black polyethene bags and each bag was put in a labeled air-tight plastic container.

Extraction of *B. eurycoma* seed gum from flour

Extraction of gum from the seed flours was carried out according to the method of Adikwu and Enebeke (2007). Flours of the pre-treated *B. eurycoma* seeds were defatted with n-hexane (50g/250ml, w/v basis) for 6 h at room temperature (26 $\pm$ 2°C) using maceration technique.

Determination of bulk density

The method as described by Onwuka (2005) was adopted. A graduated cylinder 10ml was weighed dry (M_1) and gently filled with the flour samples (soaked, boiled, toasted and fermented). The bottom of the cylinder was then tapped gently on a laboratory bench several times to eliminate spaces between the flour and the level noted to be the volume of the sample (V_o) and then weighed with the cylinder (M_2). Triplicate determinations were made and the mean values reported. The bulk density was calculated by this formula;

$$Bulk\ density\ =\ \frac{M_2 - M_1}{V_0}$$ Where,

M_1= the mass in grams of the measuring cylinder
M_2= the mass in grams of the measuring cylinder and its contents
V_0= the volume in litres of the measuring cylinder as determined to the nearest 10 ml.

Determination of oil absorption capacity

Oil absorption was measured using the method developed by Moorthy *et al.* (1996) by dispersing 2 g of each sample mixed with 20 ml of oil in a 50 ml centrifuge tube. The content was stirred for 30 seconds every 5 minutes, and after 30 minutes the tubes were centrifuged at 1600 rpm for 25 minutes and the supernatant was carefully decanted. Density of water is taken to be 1g/ml and that of oil determined to be 0.93 g/mL. Means of triplicate determinations were reported.

Determination of water absorption capacity

The method of Abbey and Ibeh (1998) was adopted for determination of water absorption capacity. . Flour sample (1 g) of each treatment was weighed separately (also together with a clean, dry centrifuge tube, into which it was placed). Distilled water was mixed with the flour to make up to 10ml of dispersion. It was then centrifuged at 3500 rpm for 15 min. The supernatant was discarded and the tube with its contents reweighed as gram of water absorbed per gram of sample. The gain in mass is the water absorption capacity of the flour sample. Triplicate determinations were made and the mean values reported.The density of water was assumed to be 1 g/ml.

$$WAC\ =\ \frac{volume\ of\ distilled\ water\ absorbed}{weight\ of sample\ used} \times 100$$

Determination of foaming capacity

The foaming capacity of the flour samples was determined according to the method described by Makri*et al.* (2005). For stability, the flour sample (0.5 g) was blended for 30 min in distilled water (40 ml) at top speed in a blender. The whipped mixture was transferred into 100ml graduated cylinder. The blender was then rinsed with 10 ml distilled water and then gently added to the graduated cylinder. Foam volume in the cylinder was recorded per sample after 30 min standing. Triplicate measurements were taken for each sample and mean values recorded.

% foaming capacity

$$= \frac{volume\ after\ homogenization - volume\ before\ homogenization\ X\ 100}{volume\ before\ homogenisation}$$

Determination of swelling index

3g portions (dry basis) of each of the flour samples were transferred into clean, dry graduated (50 ml) cylinders. The flour samples were gently leveled into it and the volumes noted. Distilled water (30 ml) was added to each sample; the cylinder was swirled and allowed to stand for 60 min while the change in volume (swelling) was recorded every 15 min. The swelling power of each flour sample was calculated as a multiple of the original volume as done by Ukpabi and Ndimele (1990). Triplicate determinations were made and the mean values were reported for each of the samples.

Determination of solubility

The solubility of the different samples was determined using the cold water extraction method, as described by Udensi and Onuora (1992). Flour dispersion (10 % w/v, db) was prepared with each of the flour samples by dispersing 1 g (dry basis) of flour in 5 ml distilled water and making it up to 10 ml. It was then left for 60 min while it was stirred every 10 min. It was allowed to settle for 15 min after which 2 ml of the supernatant was weighed in a dry Petri dish, evaporated to dryness and re-weighed. The difference in mass is the total soluble solids. Triplicate determinations were made and the mean values reported. Solubility was calculated as follows:

$$\text{Solubility} = \frac{TSS\,(\%)\,(VsMe - Md)\times 100}{2Ms}$$

Where,
Vs = Total supernatant/ filtrate
M_d = Mass of empty, dry Petri dish
M_e = Mass of Petri dish plus residual solid after evaporative drying
M_s = mass of flour sample used in the preparation of the dispersion.

Determination of emulsion capacity

Emulsion capacity was determined according to AOAC (2000). A flour sample (2 g) and distilled water (100 ml) was blended for 30 sec at high speed of 100 rpm. After complete dispersion, peanut oil was added from a burette in streams of about 5 ml. Blending continued until there appeared separation into two distinct layers (emulsion breakpoint). Emulsion capacity was expressed as grams of oil emulsified by 1 g flour. Triplicate measurements were made and average results taken.

Determination of wettability

The method described by Onwuka (2005) was used. Into a 25 ml graduated cylinder with a diameter of 1 cm, 1 g of sample was added. A finger was placed over the open end of the cylinder which was inverted and clamped at a height of 10 cm from the surface of a 600 ml beaker containing 500 ml of distilled water. The finger was removed and the rest material allowed to be dumped. The wettability is the time required for the sample to become completely wet. Triplicate determinations were made and the mean values reported.

Determination of rheological properties

The elasticity and viscosity of each of the sample solutions were measured as a function of oscillating shear rate by using an oscillatory rheometer (Viscoelastic Analyzer, Vilastic 3, VilasticScientic Inc., Austin TX) which was specially engineered to measure the viscosity of fluids. Precise resolution of magnitude and phase of the pressure and volume flow allows calculation of the shear stress, shear rate and shear strain at the tube wall (Thurston, 1996). The viscosity was determined at a frequency of 2 Hz (Thurston, 1996) within a shear-rate range of 0.8-20 sec^{-1}. Triplicate determinations were made the mean values reported and the calculations made as shown below.

Modulus of elasticity (K) = $- dp / (dV / V_0) = - (p_1 - p_0) / ((V_1 - V_0) / V_0)$

Where,

K = Modulus of elasticity (Pa, N/m^2)
dp = Differential change in pressure on the object (Pa, N/m^2)
dV = Differential change in volume of the object (m^3)
V_0 = Initial volume of the object (m^3)
p_0 = Initial pressure (Pa, N/m^2)
p_1 = Final pressure (Pa, N/m^2)
V_1 = Final volume (m^3)

Shear rate = Shear stress / Viscosity (S^{-1})

Elasticity = Velocity X tan ø (N/m^2)

Where,
tan ø = 90°
Stress = Modulus of elasticity X Strain

Statistical analysis

Analytical values for all the measurements are based on the mean and standard deviation of triplicates. Two-way Analysis of variance (ANOVA) was used for the data analysis (SPSS, version 20.0, 2017 model). When the F-values were significant *(P<0.05)* in ANOVA, Duncan's multiple range test was used to compare treatment means at 95% confidence level.

RESULTS

Effect of pre-milling treatment on bulk density, wettability and solubility of *B. eurycoma* (achi) seed flour and gum

Table 1 shows bulk density, wettability and solubility of flours and gums from *B. eurycoma* seeds. Bulk density of *B. eurycoma* seed flour ranged from 1.01 g/ml - 2.64 g/ml from seeds boiled for 45 min and seeds soaked for 5h respectively. This range of values was significantly (*P*<0.05) lower than the control sample (LB= 3.29 g/ml). On the other hand, the gum samples ranged from 2.44

Table 1: Effect of pre-milling treatment on bulk density, wettability and solubility of *B. eurycoma* (Achi) seed flour and gum.

Pre-milling treatment	BD (g/ml) Flour	Gum	Wettability (S) Flour	Gum	Solubility (%) Flour	Gum
Boiled 30 Min (B30)	1.16^{cd}±0.00	5.18^{d}±0.00	327.33^{a}±6.43	91.33^{bc}±11.72	12.50^{a}±0.02	47.76^{c}±0.12
Boiled 45 Min (B45)	1.01^{e}±0.00	2.62^{g}±0.00	311.67^{a}±12.58	99.67^{b}±2.08	10.27^{b}±1.05	47.81^{c}±0.80
Toasted 15 Min (T15)	1.19^{c}±0.00	2.44^{h}±0.00	238.00^{d}±12.17	67.67^{d}±2.52	7.70^{c}±0.45	60.92^{b}±5.27
Toasted 30 Min (T30)	1.18^{c}±0.01	5.23^{c}±0.00	250.67^{cd}±9.02	83.33^{cd}±4.16	8.24^{c}±1.10	60.88^{b}±4.77
Fermented 12h (F12)	1.14^{d}±0.00	5.03^{f}±0.00	263.33^{c}±25.17	82.33^{cd}±2.52	3.29^{de}±0.11	35.07^{d}±0.22
Fermented 18h (F18)	1.19^{c}±0.00	5.59^{b}±0.01	289.00^{b}±3.61	82.67^{cd}±4.62	3.15^{de}±0.12	46.53^{c}±0.14
Soaked 5h (S5)	2.64^{b}±0.00	5.12^{e}±0.00	35.33^{e}±0.58	46.67^{e}±1.06	2.60^{e}±0.09	8.46^{e}±0.17
Locust bean flour and gum (LBF, LBG)	3.29^{a}±0.05	8.21^{a}±0.02	52.33^{e}±8.15	109.67^{a}±20.50	3.75^{d}±0.22	82.23^{a}±0.11

Values are mean ± standard deviation of triplicate determinations. Means in the same column bearing different superscripts are significantly (*P*<0.05) different.

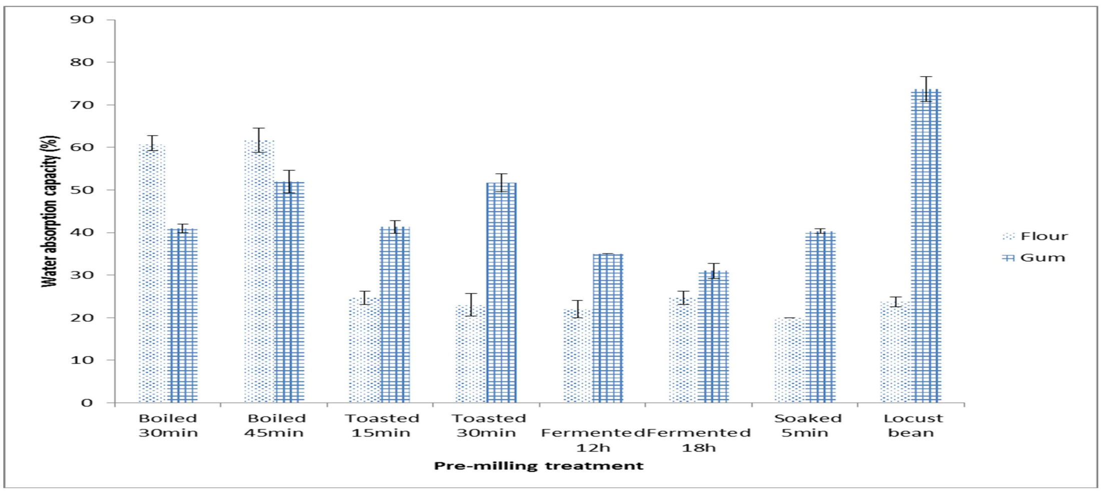

Figure 1: Effect of pre-milling treatment on the water absorption capacity of *B. eurycoma* seed flour and gum compared with locust bean seed flour and gum.

g/ml – 5.59 g/ml for seeds toasted for 15mins and seeds fermented for 18min respectively. This range was significantly *(P*<0.05*)* lower than the control (LB=8.21 g/ml)**.** Nwosu *et al.* (2011) reported a bulk density for *B. eurycoma* flour sample as 1.44 g/ml, which was within the range reported in this research while Nwakaudu *et al.* (2017) reported values (0.82 g/ml) which was below the range. Wettability of *B. eurycoma* seeds subjected to different pre-milling treatments ranged from 35.33 s to 327.33 s from seeds soaked for 5 h and seeds boiled for 45 min. On the other hand, the wettability of the gum samples ranged from 46.68 s to 99.67 s from seeds soaked for 5h (S5) and seeds boiled for 45 min respectively. These range of values was significantly *(P*<0.05) lower than the control (LBG = 109.67 s).

Solubility of the flour samples from the different pre-milling treatments ranged from 2.60% – 12.50% from seeds soaked for 5h and seeds boiled for 30 min respectively. The control (3.750%) sample had values within this range. Their gum counterparts on the other hand ranged from 8.46% – 60.92% from seeds soaked for 5h and seeds toasted for 15 mins. This range of values was significantly lower (*P*<0.05) than the control (82.23%) reported in this study. Solubility increased tremendously in the gum values compared to the flour. Banigo and Mepba (2008) suggested that water penetration into the granules of a food material can be achieved at elevated temperatures.

Effect of pre-milling treatments on water absorption capacity of *B. eurycoma* seed flours and gums

Figure 1 shows the effect of pre-milling treatments on water absorption capacity of *B. eurycoma* seed flour and gum. Water absorption capacity of flour subjected to different pre-milling treatment ranged from 20.00 g/100g – 61.67 g/100g from samples soaked for 5 h and samples boiled for 45 min. The control sample (LBF = 23.67 g/100g) had values within this range. Flours from F12 and F18 seeds had 22.00 g/100g and 24.67 g/100g respectively while the toasted seeds had 24.67 g/100g for T15 and 23.00 g/100g for T30. On the other hand, their gum counterparts ranged from 31.00 g/100g – 52.00 g/100g from seeds fermented for 18 h (F180 and seeds boiled for 45 min (B45). This range of values was significantly (*P*<0.05) lower than the control (73.74 g/100g). Gums from seeds toasted for 15 min (T15) and seeds toasted for 30 min (T30) had values of 41.33

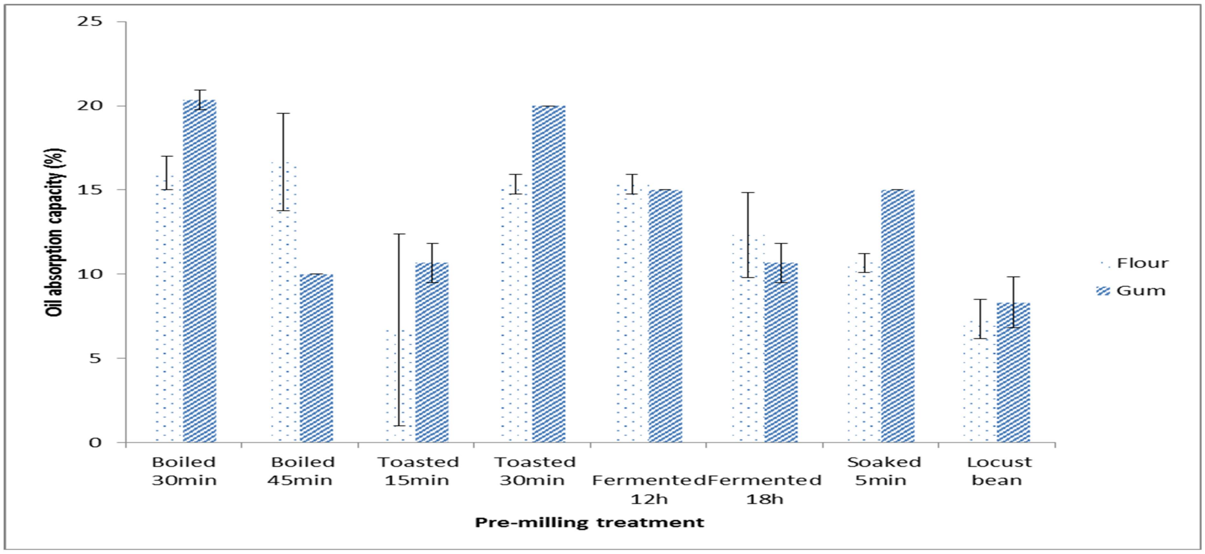

Figure 2: Effect of pre-milling treatment on the oil absorption capacity of B. eurycoma seed flour and gum compared with locust bean seed flour and gum.

g/100g and 51.67 g/100g respectively. Gums from 5h soaked seeds had a significantly (*P*<0.05) lower value of 40.33 g/100g. There was no significant (*P*<0.05) difference between the water absorption capacity of flours from B30 and B45 seeds, the values for T15, T30, and F12 seeds, the values for F18, and T30 seeds, and finally between the values for F12, S5 seeds and the control locust bean. There was also no significant (*P*<0.05) difference between the gum samples from B30, T15 and S5 seeds.

Effect of pre-milling treatments on oil absorption capacity of *B. eurycoma* seed flours and gums

Figure 2 shows the effect of pre-milling treatments on oil absorption capacity of *B. eurycoma* seed flours and gums. The oil absorption capacity of *B. eurycoma* seed flour subjected to different pre-milling treatments ranged from 6.71 g/100g to 16.67 g/100g from seeds toasted for 15 min (T150 and seeds boiled for 45 min (B45). Flours from F12 and F18 seeds had values of 15.33 g/100g and 12.33 g/100g. Seeds soaked for 5 h had flour value (10.67 g/100g) which was significantly (*P*<0.05) higher than the control (7.33 g/100g). There was no significant (*P*<0.05) difference between the flours from B30, B45, T15, T30 and F18 seeds. The seeds from T30, F12, F18 and S5, seeds from T15, S5 and the control (LBF) also had values that were not significantly (*P*<0.05) different. On the other hand, their gum counterparts had a range of 10.00 g/100g – 20.33 g/100g from B45 and B30 seeds respectively. Gums from seeds fermented for 12h (F12) and fermented for (F18) had values 115.00 g/100g and 10.67 g/100g. Also, gums from T15 and T30 seeds had values of 10.67 g/100g to 20.00 g/100g oil absorption capacity while S5 seeds had gum values of 15.00 g/100g which was significantly higher (*P*<0.05) than the control (8.33 g/100g). Flour samples were significantly (*P*<0.05) lower than most of the gum samples except seeds boiled for 45 min (B45) and seeds fermented for 18 h (F18), which had a higher oil absorption capacity for flour samples compared to the gum samples (B45 = 16.67, GB45 = 10.00; FF18 = 12.33, GF18 = 10.67).

Effect of pre-milling treatments on foaming capacity of *B. eurycoma* seed flours and gums

Figure 3 shows the effect of pre-milling treatments on the foaming capacity of *B. eurycoma* seed flours and gums. The flour values ranged from 2.00 % - 8.57 % from seeds toasted for 30 min, and seeds boiled for 30 and 45 min (B30 and B45) respectively. Flours from T15 and T30 seeds had values of 2.6% and 2.00 % respectively and flours from seeds soaked for 5 h had values of 2.30% which was significantly (*P*<0.05) higher than the control sample (LBG = 3.87%). For the flour samples from all the pre-milling treatments, there was significant (*P*<0.05) difference in the values of B30 and B45 seeds. On the other hand, their gum counterparts had a range of 8.43% - 27.40 % from S5 and B45 seeds respectively. The control sample, LBG had values (27.40%) which were within this range. Gums from T15 and T30 seeds had values of 12.43 % and 12.23% respectively, while F12 and F18 seeds had values 16.70% and 17.57 % respectively.

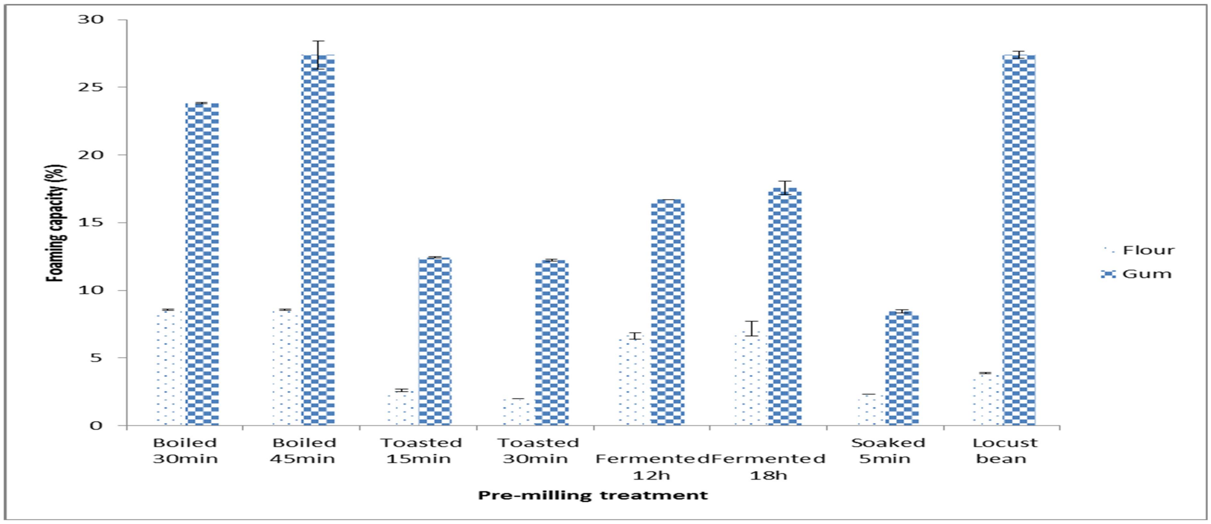

Figure 3: Effect of pre-milling treatment on foaming capacity of *B. eurycoma* seed flour and gum compared with locust bean seed flour and gum.

There was no significant (P<0.05) difference in the gum samples from T15 and T30 seeds.

Effect of pre-milling treatments on emulsion capacity of *B. eurycoma* seed flours and gums

Figure 4 shows effect of pre-milling treatments on emulsion capacity of *B. eurycoma* seed flours and gums**.** The emulsion capacity for the flour samples ranged from 43.63% - 58.47% from T15 and B45 seeds respectively. Flours from F12 and F18 seeds had values of 47.63% and 49.83% respectively while flours from S5 seeds had 45.77% emulsion capacity. There was no significant (P<0.05) difference in the flour samples of B30 and B45 seeds. Flours from T30 and F18 seeds, and flours from T30, F12 and S5 seeds also had no significant (P<0.05) difference. On the other hand, their gum counterpart had a range of values for S5 and B45 seeds as 56.33% - 76.50% respectively. This range of values are significantly (P<0.05) higher than the control (LBG = 45.32%). Gums from T12 and T30 seeds had values of 64.57% and 67.70% respectively while flours from F12 and F18 seeds had values of 58.51% and 62.47% respectively.There was no significant (P<0.05) difference in the gum samples of T15 and F18 seeds and between F12 and S5 seeds.

The solubility of proteinous foods is usually affected by emulsifying activity, this could be a result of its hydrophobic balance that depends on the surface active agent to form or stabilize the amino-acid composition (particularly the protein emulsion) by creating electrostatic repulsion on oil surfaces (Moure *et al.*, 2006). Nwosu *et al.* (2011) reported values for emulsion capacity (45.5%) which was within the range of values for flour samples reported in this research.

Effect of pre-milling treatments on rheological properties of *B. eurycoma (*Achi) seed flour and gum

Tables 2 and 3 show the effect of pre-milling treatment on rheological properties of *B. eurycoma* (achi) seed flour and gum respectively. Shear stress for the flour samples ranged from 6.19 N/mm^2 – 21.22 N/mm^2 from seeds boiled for 30 min (B30) and seeds toasted for 30 min (T30) respectively. The control sample LBF had values (15.72 N/mm^2) within this range. Flours from F12 and F18 seeds had values of 8.42 N/mm^2 and 11.50 N/mm^2 respectively. Flours from S5 seeds had 13.71 N/mm^2 shear stress. There was significant (P<0.05) difference within most of all the flour samples subjected to different pre-milling treatments except for T15 and F18 seeds which showed no significant (P<0.05) difference. The gum samples, on the other hand, had a range of 3.10 N/mm^2 -13.26 N/mm^2 shear stress from T15 and B30 seeds respectively. This range of values were significantly (P<0.05) higher than the control sample (LBG = 2.56 N/mm^2). Gums from F12 and F18 seeds had values of 7.96 N/mm^2 and 8.85 N/mm^2 respectively. Gums from seeds soaked for 5h also had shear stress values of 12.82 N/mm^2. There was significant (P<0.05) difference among all the gum samples from seeds of *B. eurycoma* subjected to different pre-milling treatments.
Shear strain values ranged from 0.07 – 0.17 from seeds toasted for 15 min (T15) and seeds soaked for 5 h (S5) respectively. Flours from B30 and B45 seeds had values of 0.09 and 0.08 respectively while flours from F12 and F18 seeds had shear strain values as 0.09 and 0.07 respectively. The control sample LBF had values (0.17) that was within this range. There was no significant (P<0.05) difference between flours from B30 and F12 seeds; between flours from B45 and F18 seeds and

Table 2: Effect of pre-milling treatment on the Rheological properties of *Brachystagia eurycoma* (Achi) seed flour

Pre-milling treatments	Shear stress (N/mm^2)	Shear strain	Extensibility (mm)	Elasticity (N/mm)	MOE (N/mm^2)	Viscosity (NS/mm^2)	Shear rate (S^{-1})
Boiled 30 Min	$6.19^{g}\pm0.00$	$0.09^{c}\pm0.00$	$1.63^{e}\pm0.00$	$107.37^{g}\pm0.00$	$75.47^{g}\pm0.00$	$75.93^{d}\pm0.03$	$0.08^{f}\pm0.00$
Boiled 45 Min	$9.29^{e}\pm0.00$	$0.08^{d}\pm0.00$	$1.51^{f}\pm0.01$	$175.00^{c}\pm0.00$	$123.76^{c}\pm0.01$	$94.56^{a}\pm0.03$	$0.10^{e}\pm0.00$
Toasted 15 Min	$11.49^{d}\pm0.00$	$0.07^{e}\pm0.00$	$1.254^{g}\pm0.00$	$260.84^{a}\pm0.04$	$182.42^{a}\pm0.01$	$50.43^{f}\pm0.03$	$0.23^{c}\pm0.00$
Toasted 30 Min	$21.22^{a}\pm0.01$	$0.14^{b}\pm0.00$	$2.75^{b}\pm0.00$	$218.19^{b}\pm0.00$	$153.74^{b}\pm0.00$	$89.84^{b}\pm0.04$	$0.09^{g}\pm0.00$
Fermented 12h	$8.42^{f}\pm0.00$	$0.09^{c}\pm0.00$	$1.75^{d}\pm0.00$	$136.00^{d}\pm0.00$	$95.64^{d}\pm0.00$	$44.66^{g}\pm0.04$	$0.26^{a}\pm0.00$
Fermented 18h	$11.50^{d}\pm0.00$	$0.07^{d}\pm0.00$	$1.51^{f}\pm0.01$	$216.67^{b}\pm0.00$	$153.23^{b}\pm0.00$	$41.04^{h}\pm0.04$	$0.28^{a}\pm0.00$
Soaked 5h	$13.71^{c}\pm0.01$	$0.17^{a}\pm0.00$	$3.25^{a}\pm0.01$	$119.24^{f}\pm0.01$	$84.07^{f}\pm0.00$	$88.37^{c}\pm0.04$	$0.15^{d}\pm0.00$
Locust bean	$15.72^{b}\pm0.16$	$0.17^{a}\pm0.01$	$2.45^{c}\pm0.17$	$123.45^{e}\pm2.99$	$89.72^{e}\pm2.26$	$62.28^{e}\pm0.26$	$0.25^{b}\pm0.00$

(Values are mean ± standard deviation of triplicate determinations. Means in the same column bearing different superscripts are significantly (P<0.05) different. MOE= Modulus of elasticity).

Table 3: Effect of pre-milling treatment on the Rheological properties of *Brachystagia eurycoma* (Achi) seed gum

Pre-milling Treatment	Shear stress (N/mm^2)	Shear strain	Extensibility (mm)	Elasticity (N/mm)	MOE (N/mm^2)	Viscosity (NS/mm^2)	Shear rate (S^{-1})
Boiled 30 Min	$13.26^{a}\pm0.01$	$0.13^{c}\pm0.00$	$2.51^{c}\pm0.01$	$150.01^{e}\pm0.01$	$106.08^{d}\pm0.00$	$38.24^{d}\pm0.04$	$0.35^{a}\pm0.00$
Boiled 45 Min	$4.36^{f}\pm0.11$	$0.05^{e}\pm0.00$	$0.89^{f}\pm0.00$	$142.05^{f}\pm0.01$	$100.46^{e}\pm0.00$	$44.76^{a}\pm0.03$	$0.10^{g}\pm0.00$
Toasted 15 Min	$3.10^{g}\pm0.00$	$0.03^{f}\pm0.00$	$0.51^{h}\pm0.01$	$175.17^{d}\pm0.29$	$123.76^{c}\pm0.00$	$14.94^{g}\pm0.05$	$0.21^{c}\pm0.00$
Toasted 30 Min	$6.64^{e}\pm0.01$	$0.15^{a}\pm0.00$	$3.07^{a}\pm0.06$	$62.65^{h}\pm0.00$	$44.21^{h}\pm0.01$	$42.52^{b}\pm0.04$	$0.16^{e}\pm0.00$
Fermented 12h	$7.96^{d}\pm0.04$	$0.06^{d}\pm0.00$	$1.26^{e}\pm0.01$	$180.04^{c}\pm0.05$	$132.61^{b}\pm0.01$	$41.37^{c}\pm0.03$	$0.19^{d}\pm0.00$
Fermented 18h	$8.85^{c}\pm0.08$	$0.07^{d}\pm0.00$	$1.32^{d}\pm0.01$	$190.85^{b}\pm0.01$	$140.32^{a}\pm0.00$	$33.51^{e}\pm0.03$	$0.26^{b}\pm0.00$
Soaked 5h	$12.82^{b}\pm0.01$	$0.14^{b}\pm0.00$	$2.85^{b}\pm0.00$	$128.05^{g}\pm0.05$	$89.64^{f}\pm0.00$	$14.43^{h}\pm1.10$	$0.06^{h}\pm0.00$
Locust Bean	$2.56^{h}\pm0.12$	$0.02^{g}\pm0.01$	$0.63^{g}\pm0.01$	$228.41^{a}\pm0.52$	$56.26^{g}\pm0.06$	$20.78^{f}\pm0.05$	$0.12^{f}\pm0.01$

between flours from S5 and LBF seeds. On the other hand, the gum samples had values ranging from 0.03 – 0.15 from T15 and T30 seeds respectively. This range of values were significantly (P<0.05) higher than the values for the control samples (LBG = 0.02). Gums from B30 and B45 seeds had values for shear strain as 0.13 and 0.05 respectively and flours from fermented samples had values of 0.06 and 0.07 for F12 and F18 seeds respectively. Gums from S5 seeds had 0.14 shear strain. There was no significant (P<0.05) difference between seeds that were fermented (F12 and F18). Seeds toasted for 15 min (T15) had the lowest shear strain for both the flour and the gum samples.

Extensibility of flour of *B. eurycoma* seeds subjected to different pre-milling treatments ranged from 1.254 mm - 3.25 mm from T15 and S5 seeds respectively. Flours from B30 and B45 seeds had values of 1.63 mm and 1.51 mm respectively whereas F12 and F18 seeds had values of 1.75 mm and 1.51 mm respectively. There was no significant (P<0.05) difference between flours from B45 and F18 seeds . The gum samples on the other hand ranged from 0.51 mm – 3.07 mm from T15 and T30 seeds. The values of the control was within this range (LBG = 0.63mm). Gums from B30 and B45 seeds had extensibility values as 2.51 mm and 0.89 mm respectively, while F12 and F18 seeds had 1.26 mm and 1.32 mm values respectively. Gums from S5 seeds had 2.85 mm extensibility value. Extensibility of most of the flour samples reduced within the treatments as time of the different pre-milling treatments increased except for seeds that were toasted (T12 = 1.25 mm to T30 = 2.75 mm).

Elasticity of the different pre-milling treatments ranged from 107.37 N/mm – 260.84 N/mm from seeds boiled for 30 min (B30) and seeds toasted for 15 min (T15) respectively. The control sample LBF had values (123.45 N/mm) which were within this range. Flours from F12 and F18 seeds had values of elasticity as 136.00 N/mm and 216.67 N/mm respectively. Flours from S5 seeds had values of 119.24 N/mm elasticity. There was no significant (P<0.05) difference between flours from T30 and F18 seeds. The gum samples on the other hand ranged from 62.65 N/mm – 190.85 N/mm from T30 and F18 seeds respectively. This range of values were significantly (P<0.05) lower than the control sample LBF (228.41 N/mm). There was no significant (P<0.05) difference among all the gum samples of *B. eurycoma* seeds subjected to different pre-milling treatments. Since high elasticity is a marker for gum quality, then T15 and F18 are the best samples for flours and gums of *B. eurycoma* respectively.

Modulus of elasticity (MOE) of the flours from *B. eurycoma* seeds subjected to different pre-milling treatments ranged from 75.47 N/mm^2 to 182.42 N/mm^2 from B30 and T15 seeds respectively. The control sample LBF had values (89.72 N/mm^2) which were within this range. Flours from F12 and F18 seeds had values of 95.64 N/mm^2 and 153.23 N/mm^2 respectively, and flours from S5 seeds had 84.07 N/mm^2 value for MOE. There was no significant (*P*<0.05) difference between flours from T30 and F18 seeds. The gum samples on the other hand ranged from 44.21 N/mm2 – 140.32 N/mm^2 from seeds toasted for 30 min (T30) and seeds fermented for 18 h (F18) respectively. The control sample LBG had values (56.26 N/mm^2) within this range. Gum samples from B30 and B45 seeds had values of 106.08 N/mm^2 and 100.46 N/mm^2 respectively and gums from S5 seeds had 89.64 N/mm^2 for MOE. There was no significant (*P*<0.05) difference between all the gum samples of *B. eurycoma* seeds subjected to different pre-milling treatments.

The viscosity values for flour ranged from 41.04 NS/mm^2- 94.84 NS/mm^2 from F18 and B45 seeds respectively. The control sample LBF had values (62.28 NS/mm^2) that were within the range of values reported for the flour samples. Flours from T15 and T30 seeds had values of 50.43 NS/mm^2 and 89.84 NS/mm^2 respectively, while flours from S5 seeds had 88.37 NS/mm^2 value for viscosity. There was significant (*P*<0.05) difference between all the flours from the different pre-milling treatments. The gum samples on the other hand had values ranging from 14.43 NS/mm^2 – 44.76 NS/mm^2 from S5 and B45 seeds respectively. The control sample LBG had values (20.78 NS/mm^2) within this range. Gum samples from T15 and T30 seeds had viscosity values as 14.94 NS/mm^2 and 42.52 NS/mm^2 respectively whereas gums from F12 and F18 seeds had 41.37 NS/mm^2 and 33.51 NS/mm^2 values respectively. There was significant (*P*<0.05) difference of all the gum samples within the pre-milling treatments.

Shear rate of *B. eurycoma* seed flour ranged from 0.08 S^{-1} – 0.28 S^{-1} from B30 and F18 seeds respectively. The control samples LBF had values (0.25 S^{-1}) within this range. Flours from T15 and T30 seeds had shear rate values of 0.23 S^{-1} and 0.09 S^{-1} respectively, whereas S5 seeds had 0.15 S^{-1}values. The gum samples on the other hand ranged from 0.06 S^{-1} – 0.35 S^{-1} from seeds soaked for 5 h (S5) and seeds boiled for 30 min (B30). The control sample LBG had values (0.12 S^{-1}) within this range. Gums from T15 and T30 seeds had shear rate values as 0.21 S^{-1} and 0.16 S^{-1} while gums from F12 and F18 seeds had 0.19 S^{-1} and 0.26 S^{-1} values respectively.

DISCUSSION

From Table 1, gum samples in this research had a higher bulk density compared to the flour samples which will make it easier to handle, reduce packaging and transportation costs for the manufacturer. It is evident from this research that gums from seeds fermented for 18 h had the highest bulk density compared to the other pre-milling treatments whereas seeds soaked for 5 h had the highest bulk density for the flour samples. Hence, are the best flour and gum samples from *B. eurycoma* seeds if the bulk density is to be used as a marker of quality for flours and gums? The rate of wettability within the different pre-milling treatments in the flour samples increased as the time of treatment increased (T15 increased from 238.00s to 250.67s in T30; F12 increased from 263.33s to 289.00s in F18) apart from flours from the boiled seed which showed a decrease as time of treatment increased (B30 decreased from 327.33s to 311.67s in B45). Nwosu *et al.* (2011) reported wettability of 55s for *B. eurycoma* seed flour while Nwakaudu *et al.* (2017) reported a very high rate for wettability as 43 min 23 s. It is evident from this research that the gum samples from the different pre-milling treatments absorbed water easily and hence would be suitable for instant products where rapid dispersion is needed**.**

Solubility of flour within the pre-milling processes decreased as boiling and fermentation time increased (B30 = 12.50% to B45 = 10.27%) but increased as toasting time increased (T15 = 7.70% to T30 = 8.24%) (Tables 2 and 3). From the results of this research, the solubility of both the flour and the gum samples were low since they were less than 50% apart from gums from seeds toasted for 15 and 30mins which had 60.92±5.27% and 60.88±4.77% respectively. Toasted gum samples would therefore be termed the best gum sample using solubility as a marker of quality as solution formed will be clear and homogenous.

From Figure 1, the water absorption capacity of both the flour and gum samples of *B. eurycoma* seed was low (less than 100% for 1g water per 1g flour). Therefore, the flour samples will have low water retention capabilities suitable for products where dense and crumbly texture is desired like cookies or biscuits while the gum samples will have less ability to thicken or gel hence, will be suitable in products where minimal viscosity and clarity is required such as beverages. Ikegwu *et al.* (2010) reported higher values (85.33%) for *B. eurycoma* (Achi) seed flour.

From Figure 2, the oil absorption capacities of both the flour and gum samples of B. eurycoma seed were low (less than 50% for 0.5g oil per 1g flour). The flour will have less oil retention while the gum will have limited emulsification ability which is suitable for clear beverages. The low values in the rate of oil absorption of *B. eurycoma* gums in this study may support the claims made by Olubunmi and Oremeyi (2011) that *B. eurycoma* (Achi) gum powder extracts are insoluble in chloroform, ethanol, cold water and acetone but forms cloudy-dispersion in hot water. Nwakudu *et al.* (2017) reported a lower value for oil absorption capacity of *B. eurycoma*as 2.78 g/100g.

From Figure 3, the foaming capacities of both the flour and gum samples of B. eurycoma seed were low (less than 100%). Therefore the flour samples will be suitable for denser baked goods where aeration is not desired such as cookies while the gum samples will be appropriate for products where foam stability is not required like clear beverages and certain gelled desserts. Nwosu *et al.* (2011) recorded a foaming capacity of *B. eurycoma* flour as 2.00% which was within the range reported for the flour samples in this research. The solubility of proteinous foods are usually affected by emulsifying activity, this could be as a result of its hydrophobic balance that depends on the surface active agent to form or stabilize the amino-acid composition (particularly the protein emulsion) by creating electrostatic repulsion on oil surfaces (Moure *et al.*, 2006). Nwosu *et al.* (2011) reported values for emulsion capacity (45.5%) which was within the range of values for flour samples reported in this research. It is evident from this research that flour and gum samples from seeds boiled for 45 min had the highest emulsion capacity, hence can be said to be the best gum because high emulsion capacity is used as a marker for the quality of gums.

From the results in (Tables 2 and 3), seeds boiled for 45 min had the highest viscosity for both the flour and the gum samples. Gums from seeds boiled for 30 min had low viscosity with high shear rate and vice versa for seeds boiled for 45 min. The molecular entanglements are destroyed and molecules can align in the direction of flow which leads to the decrease in viscosity when the shear rate increases. The Modulus of elasticity of *B. eurycoma* flours and gums were high which indicates a relatively incompressible fluid. The gums from toasted seeds had the highest shear strain and extensibility values as 0.15 S^{-1} and 3.07 S^{-1} (T30) respectively with a very low modulus of elasticity (T30 = 44.21 N/mm^2), low viscosity (T15= 14.94 NS/mm^2) and low elasticity (T30= 62.65 N/mm).

The gum samples from B30 and F18 seeds had low viscosity and high shear rate hence, can be said to show a pseudoplatic or shear thinning behaviour of *B. eurycoma gum.* On the other hand, gums from B45, T15, T30 and F12 seeds had a high viscosity and low shear rate which shows Newtonian flow behaviour. High temperature may affect this viscosity and reverse changes. However, Newtonian flow behaviour of LB gum solutions has also been reported at very low shear rates or concentrations by some researchers like Dakia *et al*. (2008). This statement also supports the low shear rate for the control sample (LB gum, 0.12 N/Ns) in this research. Bouzouita *et al*. (2007) clarified that purified LB gum samples showed more shear thinning behaviour than their corresponding crude LB gum stating that rheological properties of LB gum may depend upon protein, amount of galactomannan, degree of branching and its botanical origin.

Conclusion

It is evident from this study that the bulk densities of the gum samples were higher than their flour counterparts with seeds fermented for 18 h (5.59 g/mL) ranking highest for the gum samples and seeds soaked for 5 h (2.64 g/mL) ranking highest for the flour samples. These samples will be more economical for the manufacturer to incorporate in food system because high bulk density will be easier to handle with reduced packaging and transportation cost. It is evident also that the flours and gums from *B.eurycoma* (achi) seeds subjected to different pre-milling treatments compared favourably in most functional properties including water and oil absorption capacity, solubility, wettability, foaming and emulsion capacity.

The gum samples from the different pre-milling treatments absorbed water easily (wettability) and hence would be suitable for instant products where rapid dispersion is needed. The water absorption capacity was low for both the flour and gum samples (less than 100 %) hence, the flour samples will have low water retention capabilities suitable for products where dense and crumbly texture is desired like cookies or biscuit while the gum samples will have less ability to thicken or gel hence, will be suitable in products where minimal viscosity and clarity is required such as beverages

The gums from seeds boiled for 30 min and seeds fermented for 18 h had a low viscosity and high shear rate hence, can be said to show a pseudo plastic or shear thinning behaviour. On the other hand, gums from seeds boiled for 45 min (B45), seeds toasted for 15 min (T15) and 30 min (T30) and seeds fermented for 12 h (F12) had high viscosity and low shear rate which shows Newtonian flow behaviour.

All the information generated from this study on the functional and rheological properties of *B. eurycoma* flours and gums will make it very useful for the large-scale manufacturers. *B. eurycoma* (Achi) flour and gum will therefore be liked by both manufacturers and consumers not just because it is economical but is also a natural additive.

Recommendations

1.Gums produced from the different pre-milling treatments should be incorporated into different food systems like beverages, noodles, yoghurt, ketchup, candies etc and the sensory analysis conducted.
2.Boiled and fermented samples with shear thinning behaviour should be done at varying temperatures to get the best sample.

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