Journal of Agricultural, Food Science & Biotechnology

JAFSB, 1(3), 243-253, 2023
https://doi.org/10.58985/jafsb.2023.v01i03.29
ISSN (Print): 2959-3417

Research Article

Variability in seed physical characteristics, mill-ability and flour quality attributes of some grain legumes used as food ingredients in Nigeria

Paul Yahaya Idakwo[1]*, **Danbaba Nahemiah[2]**, **Rukkaya Zanna Abba[1]** and **Kumba Ibrahim[1]**

1. Department of Food Science and Technology, Faculty of Engineering, University of Maiduguri, Nigeria.
2. National Cereals Research Institute, Badeggi, PMB 8, Bida, Niger State, Nigeria.

Article Information
Received: 08 September 2023
Revised: 14 October 2023
Accepted: 16 October 2023

Academic Editor
Gian Carlo Tenore

Corresponding Author
Prof. Dr. Paul Yahaya Idakwo
E-mail:
paulidakwo@unimaid.edu.ng

Keywords
Variability, mill-ability; flour quality; grain legumes; physical characteristics

Abstract

Grain legumes are cheap sources of high quality plant protein and are traditionally utilized in the preparation of diverse traditional cuisines in Nigeria either as whole grain, splits or flour. However, information is not available on the dimensional characteristics, milling behaviour and flour qualities of the major grains traded and consumed in the country. The main objective of this study was to evaluate the dimensional characteristics, milling quality and flour particle size distribution as well as color attributes of various grain legumes. The dimensions of the investigated grains correspond to 8.39-11.00 mm, 17.05 mm and 12.05-13.32 mm lengths for cowpea, lima bean and bambara groundnut (BGN) respectively. Thousand seed weight and length to diameter ratio significantly ($p<0.05$) varies between 16.01-32.60 g, 112.77g and 92.80-108.21 g and 1.36-1.46, 1.43 and 1.13-1.81 respectively among cowpea, lima bean and BGN. The decortications efficiency analysis values varied from 88.20-93.30% (cowpea), 82.00% in lima bean and 84.20-90.30% in BGN. Split yield was 64.10 to 83.10% for cowpea, 67.20% lima bean and 77.40 to 81.60 for BGN. The percent retention of flour on pan after sieve analysis varied between 3.26 to 11.98%, 10.30% and 0.02 to 0.22% in cowpea, lima bean and BGN respectively. Color characteristics of flour varied in parameters L*, a*, b*, C* and h*, 60.28-63.08, 7.00-7.84, 32.22-33.00, 33.16-33.76 and 1.33-1.36 in cowpea, 60.48, 7.56, 32.74, 33.61 and 1.34 for lima bean and 60.66-61.82, 6.12-6.98, 32.58-33.42, 33.32-34.10 and 1.36-1.39 in BGN flour respectively. Cluster analysis results indicated grouping of all the samples into 3 main clusters. This data is critical for producers, processors and consumers in Nigeria and may also provide guidance in terms of breeding, processing and retail of these seeds and the flour from them for traditional dishes.

1. Introduction

Grain legumes, also called pulses are plants belonging to the family *Leguminosae* which are cultivated mainly for their edible seeds. The seeds of grain legumes are harvested matured and traded as dry seeds or processed into splits or flour to be used in varied traditional cuisines. The United Nations General Assembly declared 2016 as the International Year of Pulses (IYP) with the aim of increasing public awareness of nutritional benefits of pulses as a part of sustainable food production aimed towards improved food and nutrition security [1] especially in developing countries. This special consideration may be related to the fact that grain legumes are cheap sources of high quality vegetable protein (18 – 32%)

with satisfactory digestibility (69 – 90%), low fat content (0.8-1.5%) and glycaemic index(GI) and lack of gluten. It is also effective on heart and blood vessels, diabetes, obesity, cancer diseases when properly processed and frequently consumed [2]. Traditionally in West Africa and indeed Nigeria, grain legumes are used for the preparation of different traditional cuisines which are consumed either as whole cooked, roasted or fried grains, or milled and used in soups, cakes and snacks [3]. Apart from this, pulses when properly milled and refined into good quality flour are used in composite flour for the preparation of bread, baby foods, candies, breakfast cereals, meat analogues, and in the pharmaceutical industry as reinforcing agents [4, 2].

For grain legumes to be used in the preparation of the diverse traditional food recipes as consumed in Nigeria and indeed neighbouring countries with similar food habits, pulses are processed into splits, wet milled or ground into flour. The physical characteristics and mill ability of the seeds are critical considerations in the formulation of grain legumes into flour which are used as value added ingredients. The process of converting grains into flour may induce mechanical and chemical changes to the components of the ingredients [5]. In addition to the physical qualities and milling behaviour, the particle size distribution and colour characteristics of flour produced from the pulses to a greater extent determine its suitability for utilization as food ingredients and application in traditional cuisines [6. 7, 8]. Individual seed physical qualities when properly understood is fundamentally applied in the design of machines required for cleaning, sorting, classification or grading and processing into flour [7]. A previous study has shown significant variability in the seed physical characteristics of some cowpea varieties marketed and consumed in Nigeria [7], while functional, nutritional and sensory characteristics of Nigerian cowpea cultivars were investigated by [9] and the effect of pre-decortication conditions on the milling and flour characteristics of some cultivars of BGN varying in seed coat colour was also reported in our earlier studies [3].

Traditionally, the method of processing pulses for the preparation of traditional cuisines are cumbersome, tedious and time consuming [7], this limits its industrial processing and acceptability. However, several authors including [7, 10, 11] were of the opinion that if locally cultivated pulses are properly characterized and processed into high quality flour, new processing methods could be developed that will improve the acceptability of the processed products and widen processing industrially. Similarly, impact studies [12, 13] in sub-Saharan Africa showed that enhancing the processing of indigenous pulses such as cowpea and bambara groundnut (BGN) can significantly reduce the vulnerability of rural households to food and nutrition insecurity since these pulses prominently feature in subsistence farming systems throughout the sub region and are main ingredients in traditional cuisines. The current investigation was undertaken with the sole aim of characterizing the physical, milling, flour particle distribution and colour characteristics of common pulses (cowpea, lima bean and bambara groundnuts) cultivars marketed in the northern parts of Nigeria and used in the preparation of traditional recipes as a strategy to enhance its processing to the industrial level.

2. Materials and methods

2.1 Material sourcing

Samples were collected from local markets in Bida and Minna in Niger State and Maiduguri Monday market in Borno State and comprised of 5 BGN, 4 cowpeas and 1 lima bean cultivars (Fig 1). All samples were sorted and stored at room temperature (32 ± 2^{o}C) until required for analysis. Laboratory equipment and apparatus were used for the research work.

2.2 Description of samples

Brown white eye bean CP1, Light brown white eye bean CP2, White black eye bean CP3, Cream black eye bean CP4, Lima bean LB1, Black white eye BGN1, Cream non eyed BGN2, Brown spotted white eye BGN3, Dark cream stripped BGN4, Creamed striped black eye BGN5 (Fig 1)

2.3 Methods

2.3.1 Physical characterization of seeds

From each seed bulk, 3 groups of samples were randomly drawn and 100 individual seeds were randomly picked, mixed together and the 300 seeds thus obtained from the three replicates were thoroughly mixed again. Finally, 30 seeds were randomly selected from each cultivar and their principal dimensions, namely length (L), width (W)

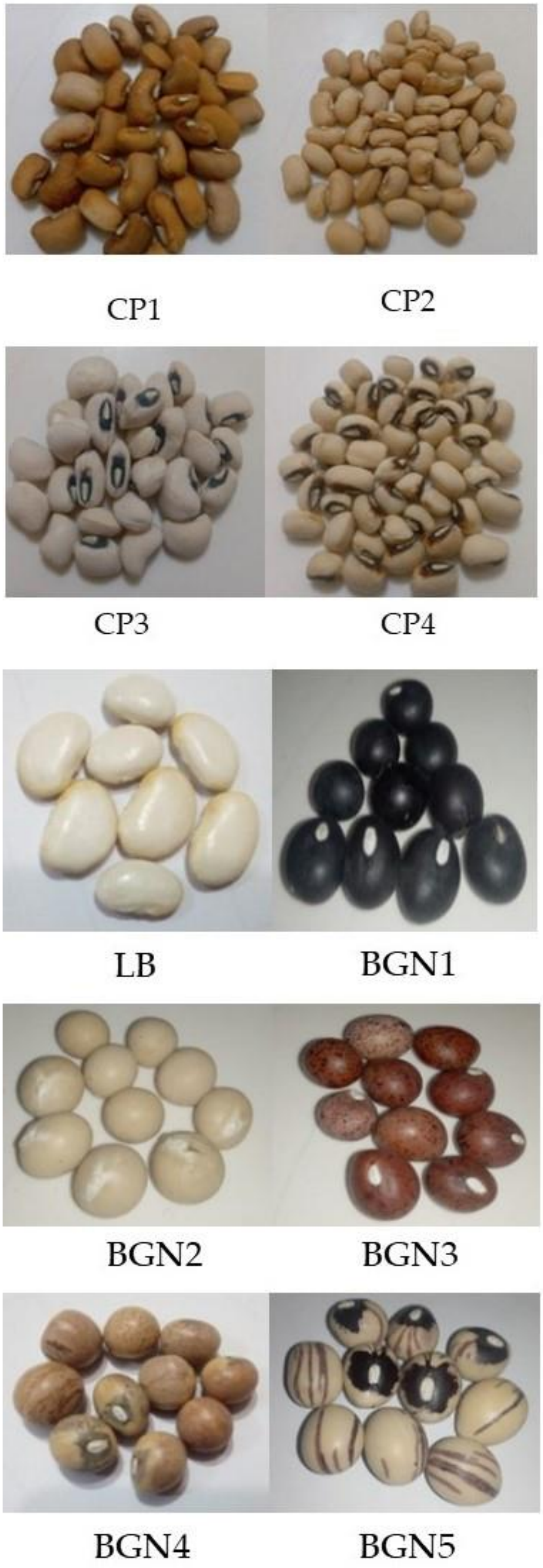


Figure 1. Sample of pulse seeds evaluated in the study

and thickness (T) were measured using Vernier calliper (0.001 mm). Geometric mean diameter (GMD) and arithmetic mean diameter (AMD) were calculated based on the principal dimensions using relationships reported by [14] (Eq. 1 and 2), while the square mean diameter (SMD) and equivalent mean diameter (EMD) were calculated using the mathematical expression (Eq. 3 and 4) assuming the seed for ellipsoidal bodies (Fig. 2) [15-17].

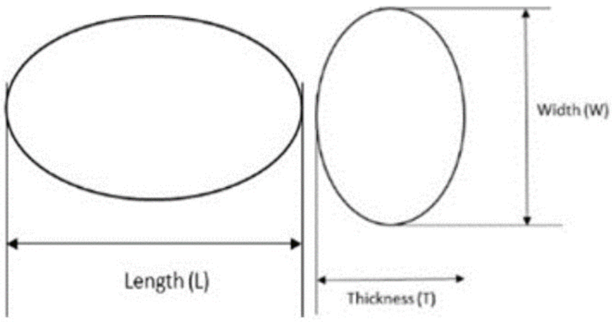


Figure 2. Assumptive ellipsoidal schematic representation of the geometrical dimensions of pulse seed

$$GMD\ (mm) = (LWT)^{1/3} \qquad (1)$$
$$AMD\ (mm) = \frac{(L+W+T)}{3} \qquad (2)$$
$$SMD\ (mm) = (\frac{LW+WT+TL}{3})^{1/3} \qquad (3)$$
$$EMD\ (mm) = (\frac{GMD+AMD+SMD}{3}) \qquad (4)$$

Sphericity (S_c) which is the ratio of surface area of sphere having the same volume as that of seed to surface area of seed was calculated as described by [14]:

$$Sc = \frac{(LWT)^{1/3}}{L} = \frac{GMD}{L} \qquad (5)$$

The surface area S_a (mm^2) was calculated from previously recorded variables L, W, and T as described by [18] and [19] (Eq. 6):

$$Sa\ (mm^2) = \frac{\pi\ x\ [(WxT)^{\frac{1}{2}}]\ x\ L}{2\ x\ L - [(WxT)^{\frac{1}{2}}]} \qquad (6)$$

The aspect ratio (R_a) was calculated using the formula outlined in Eq. 7 [19]:

$$Ra = \frac{W}{L} \qquad (7)$$

2.3.2 Seed volume and 1000-seed weight determination

Volume of grain (VOL) (mm^3) and 1000-seed weight (TSW) were calculated by the formula mentioned by [19] as follows

$$Vol = \frac{1}{4}\ x\ \left[\left(\frac{\pi}{6}\right) x\ L\ x\ (WxL)^2\right] \qquad (8$$

The 1000 seed weight (g) was measured by randomly selecting one hundred seeds of each cultivar and carefully weighed on digital scale (Kern 572- 30) and multiplied by 10 to obtain the final weight in grams. The procedure was repeated three times, and average value was taken.

2.3.3 Milling characteristics analysis

In this study, "milling" is referred to as the removal of the seed coat of grain legumes to produce polished seed (dehulling) and cleavage of the two cotyledons to produce split seeds (splitting) as they are the most common milling operations in grain legumes [20]. For the milling study, cowpea seeds were soaked in water at room temperature (32 ± 2°C) and decorticated after standing for 30 min, while BGN and lima beans were soaked in warm water (50 ± 2°C). The splits, seed coat and broken fractions were separated after drying to an average of 12.08% moisture level. The methods proposed by [21] were used for the determination of the milling characteristics of each pulse seed. The decortication efficiency (DE), split yield (SY) and percentage of broken cotyledons (kibbles) were estimated using Eq. 9, 10 and 11 respectively.

$$\text{Decortication efficiency (DE\%)} = \frac{\text{WDS+WDD}}{\text{OWS}} x\ 100 \quad (9)$$

$$\text{Split yield (SY\%)} = \frac{\text{WDS}}{\text{OWS}} x\ 100 \quad (10)$$

$$\text{Broken cotyledons (Kibbles) \%} = \frac{\text{WK}}{\text{OWS}} x\ 100 \quad (11)$$

Where, WDS = weight of decorticated dried seeds, WDD = weight of decorticated dried dhal (splits) and OWS = original weight of sample and WK = weight of kibbles.

2.3.4 Flour colour analysis

After the analysis of DE, SY and kibbles, the splits were milled and the flour colour and particle size distribution were analysed. For the determination of colour characteristics of flour, Monilta Colour Reader (CR-10, Monilta Co. Ltd., Tokyo, Japan) based on the International Commission on Illumination (CIE) L*, a*, b* colour system was used. Where L* values measure absolute black (0) to pure white (100), a* values measure redness (+a*) and b* values measure yellowness when positive. Chroma (C*) and Hue values were calculated using Eq. 12 and 13 respectively [22].

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (12)$$

$$\text{Hue angle (H*)} = tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (13)$$

2.3.5 Flour particle size distribution analysis

Particle size distribution of the flour samples was carried out following the sieve method of American Society of Agricultural and Biological Engineers (ASABE) Standard S319.4 [23] where 100 g of flour was placed on the topmost sieve of a set of sieves of successively decreasing sizes. The sieves were 63, 150, 250, 300, 425, 500, 710, 850 µm, 1mm and the pan. The weight of the empty sieve was recorded before the particle size analysis. The whole set-up was placed on a mechanical shaker which shakes the column for 20 min. After the shaking period, the weight of the flour retained on each sieve was measured and the value then divided by the total weight to give a percentage retained on each sieve (Eq. 14).

$$Retention\ (\%) = \frac{\text{Weight retained (g)}}{\text{Total weight (g)}} x\ 100 \quad (14)$$

2.4 Data analysis

A completely randomized experimental design (CRD) was used to analyse the characteristics of the seeds. Single seed characteristics were performed in 30 repeated measurements, while grain weight and other measurements were in triplicate. Data from each test were analysed for statistical significance using Statistical Tool for Agricultural Research (STAR, ver. 2.0.1, International Rice Research Institute, IRRI., Manila, Philippines). Significant means were compared using Tukey's honestly significant difference test in STAR.

3. Results and discussion

3.1 Physical characteristics of grain legumes

Table 1 shows the physical characteristics of the grain legume cultivars at 11-12% moisture content. The length was observed to vary significantly ($p<0.05$) among the seeds with CP3 having the highest (11.00 mm) and CP4 the least (8.39 mm) among the cowpea cultivars, while BGN5 was observed to have the highest (13.32 mm) and BGN4 the least (12.05 mm) among the BGN cultivars. The lima bean length was expectedly greater (17.05 mm) than both the highest values recorded in cowpea and BGN. Among the cowpeas, the width was observed to be significantly higher in CP3 (7.89 mm) and lowest (6.19 mm) in CP4, while there was no significant difference ($p>0.05$) in terms of the width of BGN. The lima bean width was higher than both CP and BGN. There seems to be a direct relationship between cowpea length and diameter, but similar relationship was not observed

Table 1: Physical characteristics of common pulse seeds (n = 30) used in traditional cuisines of Nigeria.

Pulses	Length (mm)	Width (mm)	Thickness (mm)	Specific seed weight (g)	Thousand seeds weight (g)	Length to diameter ratio
Cowpea cultivars						
CP1	10.02 ±1.02^{d}	7.26±0.44^{cd}	5.17±0.60^{d}	0.24±0.0224^{f}	22.04±0.78^{de}	1.42 ± 0.01^{ab}
CP2	10.12±0.75^{d}	6.93±0.35^{de}	4.96±0.38^{d}	0.24±0.0201^{f}	22.02±0.40^{de}	1.46 ± 0.02^{a}
CP3	11.00±1.11^{d}	7.89±1.06^{c}	6.22±0.60^{c}	0.34±0.0452^{e}	32.60±1.73^{d}	1.40 ± 0.01^{ab}
CP4	8.39±0.78^{e}	6.19±0.42^{e}	4.68±0.49^{d}	0.17±0.0182^{f}	16.01±0.43^{e}	1.36 ± 0.01^{ab}
LB1	17.05±1.99^{a}	11.96±0.99^{a}	5.79±0.61^{c}	1.26±0.1838^{a}	112.77±9.45^{a}	1.43 ± 0.03^{ab}
Bambara groundnut cultivars						
BGN1	12.87±1.09^{bc}	10.54±1.82^{b}	11.22±0.82^{ab}	0.98±0.1004^{c}	92.80±6.03^{b}	1.23 ± 0.02^{cd}
BGN2	12.15±0.44^{c}	10.71±0.82^{b}	11.13±0.58^{ab}	1.08±0.0721^{bc}	108.21±8.51^{a}	1.13 ± 0.02^{d}
BGN3	12.66±1.77^{bc}	10.11±1.05^{b}	10.64±1.12^{b}	1.09±0.1805^{b}	104.03±6.81^{ab}	1.21 ± 0.03^{cd}
BGN4	12.05±0.95^{bc}	10.26±0.81^{b}	10.79±0.76^{b}	1.01±0.1341^{bc}	93.47±1.46^{b}	1.81 ± 0.01^{d}
BGN5	13.32±1.61^{b}	10.08±0.75^{b}	11.42±0.96^{a}	0.82±0.1189^{d}	75.63±2.32^{c}	1.32 ± 0.03^{c}
Mean	12.03	9.19	8.20	0.72	67.96	1.30
CV (%)	9.80	9.94	8.82	15.01	7.44	2.52

Brown white eye bean = CP1, Light brown white eye bean = CP2, White black eye bean = CP3, Cream black eye bean = CP4, Lima bean = LB1, Black white eye = BGN1, Cream non eyed= BGN2, Brown spotted white eye = BGN3, Dark cream stripped = BGN4, Creamed striped black eye = BGN5.

among the BGN (Table 1). Seed thickness was greatest among the BGN cultivars, varying between 10.64 mm (BGN3) and 11.42 mm (BGN5) with no significant difference (p>0.05) among BGN 1 to 4. Among the cowpea samples, CP3 recorded the highest diameter (6.22 mm) and the lowest (4.68 mm) in CP4. The specific weight which defines the average individual seed mass was observed to be significantly different among the pulses. Among the CPs, the highest value of 0.34g was observed in CP3 and the least (0.17g) in CP4.

Values are means of 30 measurements for length, width, thickness and specific weight, but 3 readings for 1000-seed weight ± standard deviation. Means in the column followed by similar superscript are not significantly different (P>0.05) according to Turkey's Honestly Significant Difference (HSD) test.

For the BGN cultivars, the weight was highest (1.09g) in BGN3 and the lowest (0.82g) in BGN5. Lima bean has the highest weight (1.26g) than both CP and BGN cultivars. For the thousand seeds weight, variation similar to the specific weight was observed in all pulses, this is probably because the thousand seed weight is measured from the individual weight of the thousand seeds. Measuring seed dimensional and gravimetric properties is the first step in characterising seed quality and the data may facilitate decision on the clearance between abrasive surfaces for the decortication of seeds and also in the engineering design of seed grading and cleaning equipment. The physical properties data are also useful in defining and quantifying heat transfer during thermal processing of the seeds [14,7]. Gravimetric properties such as specific weight and 1000-seed weight are all necessary in analysis of separation, design of hopper and blower [7]. In this study, the variability observed in the physical properties of the different grain legumes reveals that processing machine parameters such as grading screen and aperture size, air flow rate, abrasive surface roughness and hopper would be different for each grain legume seed and therefore need to be taken into consideration when designing or selecting equipment for postharvest processing. [24] Made similar observations when reviewing the current status of the milling of pulses and technologies.

3.2 Milling characteristics of grain legumes

Fig. 3, 4 and 5 show the milling behaviour of cowpea, lima bean and BGN cultivars respectively. The dehulling efficiency (DE) of the CPs was observed to be highest in CP1 (93.3%) and least (88.20%) in CP4 (Fig. 3). BGN3 recorded the highest (90.30%) and BGN1 the lowest (84.20%) among the BGN cultivars (Fig. 5). LB1 was observed to have the least DE (82.00%) (Fig. 4) when compared with both CP and BGN samples.

Dehulling of grain legumes prior to processing or preparation for human consumption plays an important role in the utilization of grain legumes in the daily diet of the people [25]. The significantly

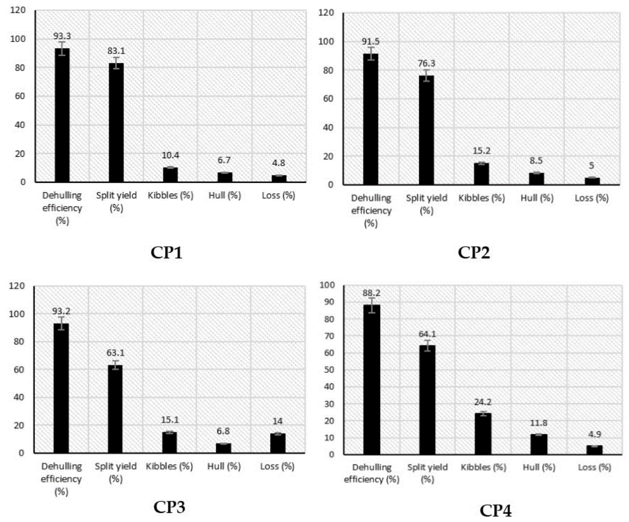


Figure 3. Milling characteristics of cowpea cultivars

higher DE among the cowpeas followed by BGN and lima bean may be due to the variability in the chemical nature and quantity of gums between the hull and cotyledon [11, 24]. The chemical nature and quantity of the gums determine the strength of the hull and cotyledon attachment, and, therefore play an important role in dehulling [11]. High DE is a critical aspect of pulse processing for use in traditional recipes and therefore, the yield of dehulled seeds (split) is an important quality characteristic for grain legumes which breeders, processors, and exporters consider critical [24].

The split yield (SY) of the grain legumes ranges between 64.10% and 83.10%, with that of cowpea samples varying from 64.10% for CP4 to 83.10% for CP1 (Fig. 5), while BGN split yield was highest in BGN1 (81.60%) and least in BGN2 (77.40%) (Fig. 5). The results indicated that cowpea decortication results in average less split (76.65%) when compared to mean value of 80.36% observed among the BGN samples, but both mean values are higher than 67.20% observed for lima bean (Fig. 4). This finding is corroborated by [24], who stated that feasible theoretical SY is between 84.6 to 95.1% and this variability is dependent on the cultivar, method and machine used for decortication. Since the same method and equipment were used for all the grains, the variation may be attributed to the cultivar [26], mentioned SY varying between 65 – 75% in traditional processing of grain legumes, while [28] reported a range of 74.0 – 83.0%. In this study, CP1, CP3, BGN1, BGN4 and BGN5 recorded SE that is within the feasibly theoretical potentials for grain legumes.

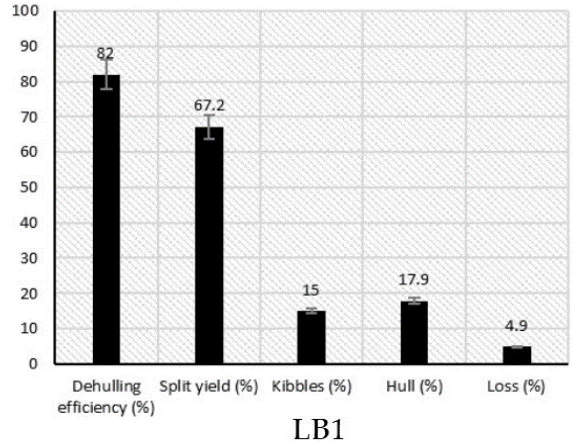


Figure 4. Milling characteristics of lima bean

The average hull content of the cowpea samples was observed to vary between 6.8% in CP3 and 11.8% CP4 (Fig. 3), while that of LB1 was 17.9% (Fig. 4), and ranges between 9.7% (BGN2) and 15.8% (BGN1) among the BGN seeds (Fig. 5), indicating higher average hull weight in LB1 followed by the BGN and CP seeds respectively. It was reported [28], average hull content of grain legumes ranging from 4.9% for *kabuli* chick pea to 14.4% for pigeon pea. The percentages of hull in grain legumes to a greater extent determine its market value since the seeds are traded in weight. The higher the hull weight the less the profit if seeds are to be processed before utilization as food. Hull weight also affects split (dhal) yield. [28], reported that since the dhal yield includes dehulled whole cotyledons and dehulled dhals, the feasible theoretical dhal yield may be significantly affected by the hull yield.

During the milling of grain legumes, the formation of broken cotyledons (kibbles) and powdered particles (loss) are considered milling losses because they are not used for human consumption [24]. In this study, it was observed that the kibbles range between 10.4% in CP1 and 24.2% in CP4 among the cowpea samples (Fig. 3), while 15.0% was recorded in lima bean (Fig. 4). For BGN samples, it was observed that the value ranges from 2.9% in BGN1 to 9.7% in BGN2 (Fig. 5). The powdery loss was highest in CP4 and least (4.8%) in CP1 among the cowpea samples (Fig. 3), while LB1 recorded a loss of 4.9% (Fig. 4) and the highest value of 8.4% (BGN3) and least (1.7%) value was observed in BGN4 within the BGN samples (Fig. 5). These values are within 9.0 – 24.6% reported by [27] and 8 – 20% by [29]. The amount of losses during the milling of grain legumes is often used for the classification of grain into either easy or difficult-to-mill categories.

Table 2. Flour particle size distribution for cowpea and bambara groundnut cultivars of Nigeria

Samples	Sieve sizes (µm)										Total	Loss
	1mm	850	710	500	425	300	250	150	63	Pan		
Cowpea cultivars												
CP1	19.42	4.38	5.14	10.70	6.98	9.32	5.12	13.30	11.54	11.98	97.88	2.12
CP2	33.02	2.86	5.66	9.22	4.62	2.62	5.62	18.36	12.70	3.26	97.94	2.06
CP3	38.22	3.62	3.38	4.64	1.88	3.06	3.52	20.24	15.42	4.10	98.08	1.92
CP4	24.38	3.50	5.22	13.56	6.22	5.22	3.34	19.72	14.24	3.40	98.80	1.20
LB1	20.76	2.48	3.38	5.54	1.50	5.44	7.78	21.56	18.86	10.30	97.60	2.40
Bambara groundnut cultivars												
BGN1	67.56	5.58	3.96	10.32	1.80	1.86	2.24	3.54	0.84	0.08	97.78	2.22
BGN2	53.06	8.18	5.62	9.94	4.38	2.84	3.10	7.04	3.38	0.22	97.76	2.24
BGN3	10.26	1.64	26.82	39.84	4.70	2.40	2.16	7.66	3.14	0.06	98.68	1.32
BGN4	52.06	2.14	3.74	13.36	9.12	3.26	3.28	7.52	2.24	0.02	96.74	3.26
BGN5	46.42	8.92	9.50	12.28	5.56	2.28	3.04	5.88	3.62	0.08	97.58	2.42
Mean	36.52	4.33	7.24	12.94	4.67	3.83	3.92	12.48	8.58	3.35	97.84	2.12
SD	18.16	2.50	7.11	9.90	2.46	2.27	1.75	6.92	6.60	4.43	0.58	0.58
CV (%)	49.74	57.74	98.17	76.55	52.62	59.26	44.59	55.46	76.72	132.17	0.59	27.39

Brown white eye bean = CP1, Light brown white eye bean = CP2, White black eye bean = CP3, Cream black eye bean = CP4, Lima bean= LB1, Black white eye = BGN1, Cream non eyed= BGN2, Brown spotted white eye = BGN3, Dark cream stripped = BGN4, Creamed striped black eye = BGN5.

Irrespective of the pre-treatment employed, these losses are lower in easy-to-mill than difficult-to-mill seeds [30, 31, 24], implying that BGN seeds in this study are easy-to-mill than both CP and LB1 samples.

3.3 Flour particle size distribution and color characteristics

The splits when ground, produced flour that was a heterogeneous mixture of particles of different sizes. The difference in percent flour retained on each sieve used for the study is shown in Table 2. It was observed that the grain legumes were reduced to approximately 63µm at different percentages. Among the cowpea, CP3 was observed to be the highest (15.42%) and CP4 the least (11.54%) indicating that CP1 has the highest fine particles. When compared with BGN, cowpea produced more fine particles, as the percent retention ranges between 0.84% in BGN2 and 3.62% in BGN5 (Table 2). Comparatively, LB1 recorded percent retention (18.86%) than both cowpea and BGN samples.

The variation in the percent retention is an indication of the applicability of flour from these grains for the production of different traditional cuisines. Particle size distribution is an important quality parameter of flour and greatly affects processing techniques and end product quality [32]. CP1 and LB1 which produce 11.98% and 10.30% retention on the pan may be said to be easy-to-mill and may be possibly as a results of softness of their cotyledons. Flour particle size is significantly influenced by the hardness of the grains [32] and strength of the bonds between its components [33]. Grain with weak bonds between starch and protein components results in smaller particles when grounded [34, 35] indicating that the bonds between the components of CP1 and LB1 may be weaker when compared with the other samples and therefore produce higher retention at the pan.

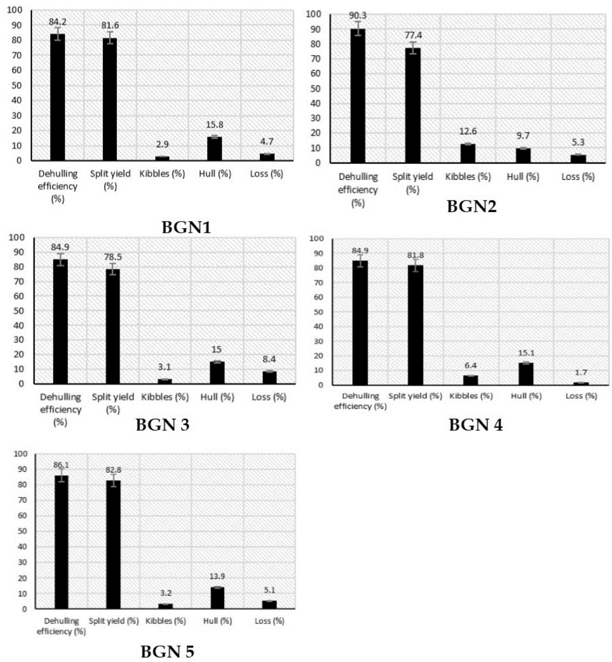


Figure 5. Milling characteristics of bambara groundnut cultivar

Table 3. Color characteristics of different pulses flour

Sample	L*	a*	b*	Chroma (C*)	Hue (h*)
Cowpea cultivars					
CP1	60.28±1.33^{b}	7.10±0.72^{a}	33.00±0.60^{abc}	33.76±0.05^{ab}	1.36±0.06^{a}
CP2	61.10±1.08^{ab}	7.84±0.79^{a}	32.22±0.64^{c}	33.16±0.50^{bc}	1.33±0.05^{a}
CP3	63.08±2.55^{a}	7.00±0.12^{a}	32.82±0.33^{abc}	33.56±0.32^{b}	1.36±0.04^{a}
CP4	61.26±0.83^{ab}	7.54±0.58^{a}	32.58±0.19^{bc}	33.44±0.16^{b}	1.34±0.05^{a}
LB1	60.48±1.07^{b}	7.58±0.54^{a}	32.74±0.27^{abc}	33.61±0.22^{b}	1.34±0.05^{a}
Bambara groundnut cultivars					
BGN1	61.70±0.48^{ab}	6.78±0.41^{a}	33.42±0.0.15^{a}	34.10±0.13^{a}	1.37±0.04^{a}
BGN2	61.82±0.53^{ab}	6.12±0.57^{a}	33.30±0.21^{ab}	33.86±0.19^{a}	1.39±0.05^{a}
BGN3	61.72±0.53^{ab}	6.76±0.58^{a}	33.12±0.31^{ab}	33.80±0.27^{a}	1.37±0.05^{a}
BGN4	61.52±0.88^{ab}	6.98±0.29^{a}	32.58±0.50^{bc}	33.32±0.42^{bc}	1.36±0.06^{a}
BGN5	60.66±0.46^{b}	6.96±0.75^{a}	33.28±0.40^{ab}	34.00±0.38^{a}	1.36±0.06^{a}
Mean	61.36	7.07	32.91	33.66±0.30	1.36±0.02
CV	1.86	10.62	1.20	-	-

Brown white eye bean = CP1, Light brown white eye bean = CP2, White black eye bean = CP3, Cream black eye bean = CP4, Lima bean = LB1, Black white eye = BGN1, Cream non eyed = BGN2, Brown spotted white eye = BGN3, Dark cream stripped = BGN4, Creamed striped black eye = BGN5.

3.4 Color characteristics of grain legume flours

Color is a characteristic of product that attracts a consumer to it and significantly helps in impulse purchase [36]. Color is usually considered as the most important quality attribute of food appearance [37], especially if it is associated with flour intended for baking. In this study, the results of color characteristics of the different flours obtained from the grain legumes are presented in Table 3. Lightness (L*) color index was observed to vary between 60.28 (CP1) and 63.08 (CP3) among the cowpeas and 60.66 (BGN5) and 61.82 (BGN2) among the BGN cultivars, while lima bean recorded a value of 60.48 (Table 3). There was no significant difference ($p>0.05$) among the samples in terms of this color attribute. L* is an approximate measurement of luminosity, which is the property according to which each color quality of a product can be considered as equivalent to a member of the grey scale between absolute black (0) and pure white (100) [38]. It can be concluded from this study therefore, the color of the flours is above 60 on the CIELAB coordinate (L*a*b*) color scale and is significantly white.

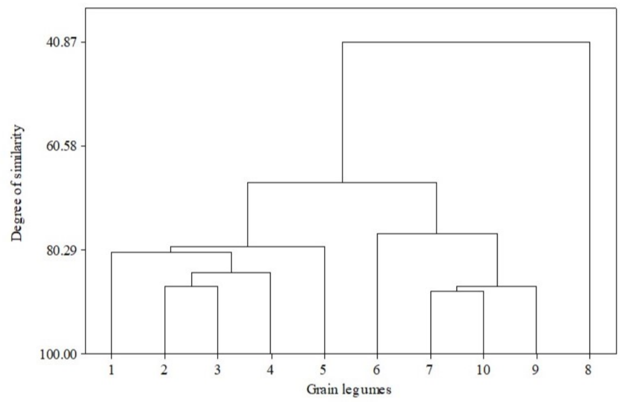
For the redness color index (a*), it was observed that for the cowpea cultivars, the value non significantly ($p>0.05$) ranges among all the grain legumes, though all the cowpea samples and lima bean are greater or equal to the mean (7.07), but the BGN samples are slightly less than the average (Table 3). The* takes positive values for reddish color and negative values for greenish, indicating slight level of red tint in the white color of the flours. Yellowness color parameter (b*) was observed to be highest (33.00) in CP1 and lowest (32.22) in CP2 among the cowpeas and 32.74 in lima bean. However, for the BGN samples, the value was highest (33.42) in BGN1 and the lowest (32.58) in BGN4. Statistical analysis indicated significant difference ($p<0.05$) among the samples in terms of this color attribute. The positive value of the b* color attribute is an indication of presence of yellowness and absence of blueness in the flour samples.

Values are mean ± standard deviation of 5 repeated measurements. Mean in the same column bearing the same super script, are not significantly different ($p>0.05$) according to new Duncan's Multiple Range Test (nDMRT).

The chroma (C*) value which defines the quantitative attributes of colorfulness and used to determine the degree of difference between colors of two materials (eg deep blue, light green etc) were significantly ($p<0.05$) different among the flours from the different grain legumes (Table 3). It was observed that the C* values were highest (33.76) in CP1 and least (33.16) in CP2 when considering cowpea samples, but 34.10 was highest among the BGN samples and was observed in BGN1, while the lowest (33.32 was recorded in BGN4. Lima bean recorded a value of 33.61. The significantly high mean C* values (>33.0) are an indication of high intensity of the color attributes of the samples as perceived by the human eyes. [39], observed that, the higher the C* values, the higher the color intensity of samples perceived by humans. For the hue value (h*), there was no significant difference among all the samples in terms of these color attributes, recording a mean value of 1.36. The h* value is considered the qualitative attribute of color, and traditionally color has been defined based on it such as reddish, greenish, whitish etc. [39] reported that a higher h* is an indication of lesser yellowness in the assays. This confirms our earlier observation in terms of b* as being slightly higher indicating moderate level of yellow characteristics in the flour. On the overall, the results indicated that the color attributes of the grain legume flours are white (high lightness) with less red tent and slightly moderate yellow characteristics.

3.5 Similarity and clustering among the grain legumes

Fig. 6 is the cluster analysis grouping of the different grain legumes based on the dimensional characteristics. Among the 10 grain legumes, cluster analysis resulted in three (3) clusters. The clustering pattern indicated that cowpea cultivars CP1, CP2, CP3, CP4 and bambara groundnut BGN2 were aggregated in cluster I, while BGN1, BGN3, BGN4 and BGN5 were grouped into cluster II. Cluster III comprised of only lima bean.



1=CP1, 2=CP2, 3=CP3, 4=CP4, 5=BGN2, 6=BGN4, 7=BGN1, 8=LB1, 9=BGN3, 10=BGN4

Figure 6. Hierarchical clustering of the different grain legumes based on grain physical characteristics

The diagram indicated that the maximum distance of dissimilarity was highest (40.87) between lima bean and both cowpea and bambara groundnut cultivars, followed by a distance 67.58 between the cowpea group and BGN, except BGN2 which was closely grouped with cowpeas. The cluster analysis results provided us with a complete view of the variation present among the 10 grain legume cultivars and it might be used for the plant breeders for the genetic improvement of the grains or classification by postharvest specialist in selecting appropriate processing machinery that is dependent on dimensional characteristics. The dendogram revealed that significant adjustment may be needed when adopting processing equipment used in cowpea processing for BGN such as screen for grader and cleaning.

4. Conclusions

This study represents an extensive information gathering on the physical, milling, flour particle distribution and color characteristics of cowpea, lima bean and bambara groundnut cultivars grown and utilized in the preparation of Nigerian traditional legume-based cuisines. The study has shown significant variability in the principal dimensions of the seeds. Major variations in the dimensional characteristics are particularly important in the appropriate design and optimization of decortication, cleaning and milling machines. The dehulling efficiency was generally above 80%, and as it is important consideration in traditional recipe preparation, grain legume breeders and indeed processor may consider this for the development of the industry. Processing losses were significantly less than the reported values of between 8-24% as the highest loss was 4.8%, 4.9% and 8.4% respectively among cowpea, lima bean and bambara groundnut samples used in this study. Significantly higher percent flour particle retention was observed among the cowpeas and lima bean samples than the bambara groundnut cultivars, indicating possible variability in the grain hardness and strength of the bond between major components of the grains. Color characteristics of flours was estimated based on the CIE laboratory system and the results showed close range of recorded values for L*, a*, b*, C* and h* within sample types. Cluster analysis based on the physical attributes resulted in 3 clusters implying that significant adjustment may be needed when adopting processing equipment used in cowpea processing for BGN such as screen for grader and cleaning. The grain legume characteristics reported in this study are critical for producers, processors and consumers in Nigeria and may guide in terms of breeding, processing and retail of these seeds and the flour from them.

Authors' contributions

Preliminary investigations, experimentations, data collection, analysis and report writing, P.Y.I. and D.N.; Sample collection, laboratory analyses and literature searches, R.A.Z. and K.I.; Supervised, data interpretation and final correction of the manuscript, D.N.

Acknowledgements

We are grateful to the Department of Food Science and Technology for the conducive environment provided for the laboratory analyses.

Funding

This research received no external funding.

Availability of data and materials

All data will be made available on request according to the Journal policy.

Conflicts of interest

The authors declare no conflict of interest.

References

1. ICRISAT. International Crops Research Institute for the Semi-Arid Tropic Catch the pulse. Pp31, 2016.
2. Pekmez, H. Pulse processing technology. The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), October 26 - 29, 2017 Antalya/Turkey. Vol. 1: 336-338, 2017
3. Danbaba, N.; Idakwo, P.Y.; Kassum, A. L.; Malgwi, S. D.; Igwegbe, O.A.; Lawan, H.K.; Maijalo, A.I; Nkama, I. Effects of pre-decortication treatments on the milling properties and flour characteristics of bambara groundnut (*Vignasubterranea* L.) varying in seed coat colour. J. Adv. Food Sci. Technol. 2019, 6(4), 21–32.
4. Erdil, D.N. Application studies of pulses in bakery products. Healthy Nutrition and Healthy Life with Pulses Platform Project. İstanbul, Turkey. 2016.
5. Scalon, J.A.; Thakur, S.; Tyler, T.; Milani, A.; Der, T.; Paliwal, J. The critical role of milling in pulse ingredient functionality. Cereal Foods World, AACCI Press vol. 63, (5) 201-206, 2018.
6. Hillocks, R.J.; Bennett, C.; Mponda, O.M. Bambara Nut: a review of utilization, market potential and crop improvement. Afr. Crop Sci. J. 2011, 20(1),1–16.
7. Olapade A.A; Okafor, G.I.; Ozumba, A.U; Olatunji, O. Characterization of common Nigerian Cowpea (*Vigna unguiculata* L. Walp) varieties. J. Food Eng. 55 (2002), 101–105.
8. Adeboye, O.C.; Singh, V. Physic-chemical properties of the flours and starches of two cowpea varieties (*Vigna unguiculata* (L.) walp). Innovative food science and emerging technologies 2008, 9 (1), 92-100.
9. Onayemi, O.; Osibogun, O.A.; Obembe, O.E. Effect of different storage and cooking methods on some biochemical, nutritional and sensory characteristics of Cowpea (*Vigna unguiculata* L. Walp) J. Food Sci. 2006, 51(1), 153-156. DOI: 10.1111/j.1365 2621.1986.tb10858.x
10. Sefa-Dedeh, S.; Stanley, D.W. Textural Distribution of nutrients in anatomical parts of implications of the micro structure of legumes. food common Indian pulses. Cereal Chem. 1979. 45, 13-18.
11. Tiwari, B.K., Singh, N. Pulse Chemistry and Technology. RSC Publishing, Croydon, England, Page 224, 2012.
12. Matsa, W., Mukoni, M. Traditional science of seed and crop yield preservation: exploring the contributions of women to indigenous knowledge systems in Zimbabwe, 2013.
13. Mubaiwa, J., Fogliano, V., Chidewe, C., Linnemann, A.R. Bambara groundnut (*Vigna subterranean* L. Verdc.) Flour: A functional ingredient to favour the use of an unexploited sustainable protein source. PLoS ONE, 2018, 13(10), e0205776. https://doi.org/10.1371/journal.pone.0205776.
14. Mohsenin, N.N. Thermal Properties of Foods and Agricultural Materials. New York: Gordon and Breach Science, p. 407, 1980.
15. Ciro, V.H.J. EstudioDinamico de la cafe para el Desanolla de la cosechamecanicapor vibracion. Thesis BSc (Agric. Engineering). Universidad Nacinal de Colombia, 1997.
16. Perez-Alegria, L.R.; Ciro, H.J.; Abud, L.C. Physical and thermal properties parchment coffee bean. Transactions of the ASAE, 2001, 44(6), 1721-1726.
17. Simonyan, K.J., Yiljep, Y.D., Oyatoyan, O.B., Bawa, G.S. Effects of Moisture Content on Some Physical Properties of *Lablab purpureus* (L.) Sweet Seeds" Agric. Eng. Int. 2009, XI, 1279.
18. Mohsenin N.N., Physical Properties of Plant and Animal Materials. Structure, Physical Characteristics and Mechanical Properties. 2. Aufl. 891 Seiten, zahlr. Abb. und Tab. Gordon and Breach Science Publishers, New York u. a. Preis: 140.—£H.-D. Tscheuschner First published:1987. https://doi.org/10.1002/food. 19870310 724,1986.
19. Nádvorníková, M.; Banout, J.; Herák, D.; Verner, V. Evaluation of physical properties of rice used in traditional Kyrgyz Cuisine. Food Sci. Nutr. 2018, 00, 1–10. https://doi.org/10.1002/fsn3.746
20. Wood, J.A.; Malcomson, L.J. Pulse Milling Technologies. In Pulse Foods (Second Edition) Processing, Quality and Nutraceutical Applications pp 213-263, 2021.
21. Burridge, P., Hensing, A.; Petterson, D. Australian

pulse quality laboratory manual SARDI Grain Laboratory for GRDC, Urrabrae, 2001.

22. Pankaj, B.P., Opara M.L.; Al-Said F.A. Colour measurement and analysis in fresh and processed foods: A Review. Food Bioproc. Technol. 2013, 6, 36-40. https://doi.10.1007/s11947-012-0867-9.
23. ASABE Standards. S319.4: Method of determining and expressing fineness of feed materials by sieving. St. Joseph, Mich.: ASABE, 2008.
24. Vishwakarma, R.K.; Uma Shanker, S.; Ram Kishore. G.; Deep Narayan, Y.; Arvind, J.; Priyanka P. Status of pulse milling processes and technologies: A review, Critical Rev. Food Sci. Nutr. 2017. http://dx.doi.org/10.1080/10408398.2016.1274956
25. Singh, N. Relationships between selected properties of Seeds, Flours and Starches from different Chickpea cultivars. Int. J. Food Prop. 2006, (9), 597-608.
26. TNAU Agritech Portal. Postharvest Technology, Agriculture and Pulses www.agritech.tnau.ac.in 2019.
27. Singh, U.; Santosa, B.A.S; Rao, P.V. Effect of dehulling methods and physical characteristics of grains on dhal yield of Pigeon pea (*Cajanus cajan* L) genotypes. J. Food Sci. Technol. 1992, 29, 350–353.
28. Narasimha, H.V.; Ramakrishnaiah, N.; Pratape, V.M. Milling of Pulses. In: Chakraverty, A.; Mujumdar, A.S.; Raghavan, G.S.V.; Ramaswamy, H.S. Editors: Handbook of Postharvest Technology, Cereals fruits, vegetables, Tea and spices. New York: Marcel Dekker, pp.427-454, 2003.
29. Ramakrishnaiah, N.; Kurien, P.P. Variability in dehulling characteristics of Pigeon pea (*Cajanus cajan* L) J. Food Sci. Technol. 1983, 20, 287-291.
30. Tiwari, B.K.; Patras, A.; Brunton, N.; Cullen, P.J.; O' Donnell, C.P. Effect of ultrasound processing on anthocyanins and colour of red Grape juice. Ultrason. Sonochem. 2010, 13(3), 598-604.
31. Joyner, J.J.; Yadav, B.K. Optimization of continuous hydrothermal treatment for improving the dehulling of black gram. J. Food Sci. Technol. 2015, 52 (12), 7817–27. doi: 10.1007/s13197-015-1919-8.
32. Sullivan, B.; Engebreston, W.E.; Anderson, M.L. The relation of particle size of certain flour characteristics. Cereal Chem., 1960, 37 (4), 436-455.
33. Patwa, A.; Malcolm, B.; Wilson, J.; Ambrose R.P.K. Particle size analysis of two distinct classes of wheat flour by sieving. Transactions of the ASABE, 2014, *57*(1), 151-159. https://doi.10.13031/trans.57.10388.
34. Kim, W.; Choi, S.G.; Kerr, W.L.; Johnson, J.W.; Gaines, C.S. Effect of heating temperature on particle size distribution in hard and soft wheat flour. J. Cereal Sci., 2004, 40(1), 9-16. http://dx.doi.org/10.1016/ j.jcs. 2004.04.005.
35. Pauly, A.; Pareyt, B.; Fierens, E.; Delcour, J.A. Wheat (*Triticum aestivum* L. and *T.turgidum*L. ssp. Durum) kernel hardness: II. Implications for end-product quality and role of puroindolines therein. Comp. Rev. Food Sci. Food Saf. 2013, 12 (4), 427-438. http://dx.doi.org/10.1111/154 4337.12018.
36. Crisosto, H.C.; Crisosto, G.; Bowerman, E. Understanding consumer acceptance of peach, nectarine and plum cultivars. International Society for Horticultural Science. Act. Hortic. 2003, 604.
37. Francis, F.J.; Clydesdale, F.M. Food Colorimetry: Theory and Applications: The Avi Publishing Company Inc., Westport Connecticut USA. PP131-224, 1975.
38. Granato, D.; Masson, I.M. Instrumental colour and sensory acceptance of Soy-based emulsions: A response surface approach. Ciene. Technol. Aliment, Campinas, 2010, 30(4), 1090-1096.
39. Pathare, P.B.; Opara., U.L.; Al-Said, F.A. Colour measurement and Analysis in fresh and processed foods: A review. Food Bioproc. Technol. 2013, 6, 36-60. DOI: 10.1007/S11947-012-0867-9.