Agriculture and Food

AIMS Agriculture and Food, 7(2): 265–281.
DOI: 10.3934/agrfood.2022017
Received: 01 October 2021
Revised: 06 April 2022
Accepted: 26 April 2022
Published: 06 May 2022

http://www.aimspress.com/journal/agriculture

Research article

Effects of Bambara groundnut and Butternut blending on functional and sensory properties of sorghum flour porridge

Rosemary Kobue-Lekalake, Geremew Bultosa*, Oduetse Daniel Gopadile, Gulelat Desse Haki, Moenyane Molapisi, Eyassu Seifu, Bonno Sekwati-Monang, John Gwamba, Kethabile Sonno and Boitumelo Mokobi

Department of Food Science and Technology (FST), Botswana University of Agriculture and Natural Resources (BUAN), P. Bag 0027, Gaborone, Botswana

*** Correspondence:** Email: geremewbultosa@gmail.com; gbultosa@buan.ac.bw; Tel: +2673650128; +26773328240; Fax: +2673928753.

Abstract: Food-to-food fortification to refined sorghum flour (SF) for porridge making has an influence on the desirable properties of the porridge. In view of this, the effects of Bambara groundnut (BG) (15%, 25%, 35%) and dried butternut (BU) powder (23%) blending on functional and sensory properties of porridge were investigated using 100%SF as a control. With the blending by BG and BU, water binding capacity (WBC), water solubility index (WSI), oil absorption capacity (OAC) and gel water solubility index (GSI) increased ($p < 0.05$), whereas swelling power (SP) and gel water absorption index decreased. Blended flours were characterized by low -WBC and -SP, high -WSI, -OAC and -GSI which are desirable for processing of less bulky, nutrient and energy dense, digestible porridge suitable as a weaning food. In the descriptive sensory properties evaluation, overall aroma and after-taste intensity were rated better for the control sorghum porridge ($p < 0.05$), while texture (roughness/smoothness, firmness, stickiness, and springiness) differences were insignificant ($p > 0.05$) and specks appearance is very low in all porridges. The porridges color varied significantly ($p < 0.05$) and less brownness and high yellowness was observed in the blended flours than for the control sorghum flour. Even though improvement in the functional properties with the blending levels at 25% and 35% BG to the sorghum flours was observed, porridge over all aroma and aftertaste was superior for the refined 100% sorghum flour porridge.

Keywords: Bambara groundnut; butternut; functional; sensory; sorghum porridge

1. Introduction

In Africa, sorghum flour is used widely for porridge making. Ting, a fermented sorghum porridge (bogobe) is regarded as a national staple in Botswana [1]. Fermented and non-fermented sorghum porridge are often consumed with milk, sour milk (madila), meat and/or vegetable relishes.

The refined sorghum flour used for porridge making is limited in the micronutrients and dietary fibers because of bran removal on dry milling of the sorghum grains [2,3]. In addition, sorghum grains are limited in the essential amino acids such as lysine and essential omega-3 fatty acids [4]. Due to more crosslinking of the sorghum major protein kafrins on cooking, the inherently poor protein digestibility becomes even poorer [5]. Use of sorghum, maize, or cassava flours alone in the porridge making are known to result into high bulky viscous porridge that limit nutrients and energy density, particularly for children of weaning age [6] and frequent intake of such meal can expose to protein energy malnutrition and micronutrient deficiency diseases [7]. Micronutrient deficiency particularly iron and zinc also in part are contributed when diets from crops grown over degraded and micronutrient depleted soils are consumed [8]. The refined sorghum flour proteins and micronutrients can be improved by food-to-food fortification such as with legumes [9,10]. Among the underutilized crops, Bambara groundnut and butternut can be a potential for food-to-food fortification to improve the refined sorghum flour porridge nutrients and bioactive compounds.

In Botswana 90% of farmers cultivate Bambara groundnut by the name “ditloo” [11] which is consumed as roasted, cooked alone or with maize samp (decorticated stamped maize) as “dikgobe” [12]. Bambara groundnut is high in protein content (24–25%) [13] with better protein quality score (79.7%) than for soyabean (73.6%) and cowpea (64.2%) [14]. Bambara groundnut has high potential to improve lysine (0.99–8.54 g/100 g) [15,16] since this essential amino acid is the most limited in the sorghum grains (0.20–0.31 g/100 g) [17]. Whereas the sorghum grain flour meal can complement the sulfur containing amino acids (cysteine) [18] limited in the Bambara groundnut [15]. Bambara groundnut also bears significant bioactive compounds such as soluble and insoluble dietary fibers, phenolics and peptides which are beneficial toward prevention of diseases such as various cardiovascular diseases, diabetes, and colon cancer [19].

Butternut (*Cucurbita moschata*, Duchesne) is rich in antioxidant carotenoids (pro-vitamin A carotenoids and lutein), phenolic compounds and pectins [20]. Fortification of sorghum meal with butternut for porridge making has a potential to improve the pro-vitamin A carotenoids, phenolics and dietary fibers to support human wellness and health. Vitamin A deficiency was indicated to affect about 190 million children under five years from low- and middle-income countries [21]. Vitamin A deficiency can impair visual system, cell function for growth, epithelial cell integrity, red blood cell production, immunity, reproduction and exposes to conditions of xerophthalmia (dry eyes), night blindness, susceptibility to infectious diseases (diarrhoea, measles, and respiratory diseases), stunting, anaemia and eventually may cause death [21].

In the past, sorghum-cowpea [10,22,23], sorghum-sugar beans [24], marama-sorghum grains [25] and sorghum-cowpea micronized-extrusion cooked supplemented with cooked cowpea leaves for improvement in the porridge nutrients and functional properties were reported [26]. Even though the nutrients and bioactive compounds were shown improvement, challenges on some aspects of sensory acceptability were indicated. Among the sorghum porridge sensory attributes, texture (firm, non-sticky, cohesive), good keeping quality followed by taste, aroma and color were indicated as good quality indicators for porridge sensory acceptability [27,28].

Primarily the sorghum porridge texture is influenced by the starch granules properties change on cooking process (swelling, gelatinization, pasting, gel formation and retrogradation tendency). The starch granules X-ray diffraction patterns of Bambara groundnut is A or C-types and for amylose 20 to 35%, from low to moderate swelling power of gelatinization temperature in the range 68 to 84 ℃ were reported [29]. The X-ray diffraction patterns of sorghum starch granules are A-type with amylose 21 to 30% [30] of moderate swelling power, gelatinization temperature in the range 68 to 78 ℃ were reported [31]. Even though the water-up take on gelatinization of the two types of starch granules may vary, somewhat similarity in the amylose contents and gelatinization temperature ranges may favor the sorghum and Bambara groundnut blend flours to make synergy on the porridge texture formations. The taste and aroma of porridge is influenced by the flour constituents' interaction, Maillard and caramelization reaction products formed on porridge cooking. The color of the porridge is primarily influenced by color of the flour used.

Apart from the sensory attributes, the nutrients and energy density characteristics of the porridge is important when used for example as meal for weaning and young child feeding. The high oil absorption capacity of porridge could be beneficial for incorporation and retention of shortening, flavor/aroma imparting compounds profile, fat-soluble vitamins and bioactive compounds. The high-water solubility index in the porridge paste is an indicator of high digestible nutrients (albumin type proteins, soluble components leached from starches and sugars) in the porridge as a meal.

The functional properties of flour used for porridge making and sensory properties of the porridge are important for the acceptability and use of the porridge as meal. In view of this, in this work, the effects of Bambara groundnut and dried butternut powder blending on the flour functional properties and descriptive sensory properties of the sorghum based composite porridge are reported.

2. Materials and methods

2.1. Food sample sources

Sorghum flour commonly used for porridge making labelled Earth Grown, Botswana Agricultural Marketing Board (BAMB), was purchased from a supermarket in Gaborone, Botswana. Bambara groundnut (brown color) was purchased from BAMB, Gaborone. Butternut variety F1 Sweetmax of yellow-orange flesh color was purchased from a supermarket in Gaborone (JGA Fourie Boerdery, Pty Ltd, produce of South Africa).

2.2. Sample preparation

Bambara groundnut was cleaned (dust, broken chaff, broken grain, malformed grains), washed with distilled water and dried in an oven cabinet drier at 60 ℃ for 24 h. The dried Bambara groundnut was milled to flour using a Cross Beater Mill (SK 300, RETSCH, Germany) fitted with 500 µm sieve.

Butternut was washed thoroughly with tap water, skin was peeled and removed, the remaining part was sliced with sharp knife and then seeds were removed. The yellow-orange flesh pulp was sliced (1.5–2.0 mm thick) in a cube and blanched in hot water (90 ℃ for 1 min). The blanched pieces were strained and cooled with running tap water for about 1 min without direct contact with the sample and wiped with clean lint free absorbent tissue. The edible pulp was homogenized using a kitchen food processing machine, dried (72 ℃ for 24 h) in an oven on a stainless-steel tray and milled to powder using a Cross Beater Mill (SK 300, RETSCH, Germany) fitted with 500 µm sieve.

2.3. Experimental design

The blending of Bambara groundnut flour, butternut powder to sorghum flour was as shown in Table 1 on a dry matter basis. Sorghum flour 100% was used as a control.

Table 1. Experimental design.

Blends	Sorghum flour (%)	Bambara groundnut flour (%)	Butternut powder (g)
B1	85	15	30
B2	75	25	30
B3	65	35	30
Control	100	0	0

All the flour samples after preparations were packed in zip lock plastic bag covered with paper board and then stored in a refrigerator (4 ℃) until used for analysis. Note: butternut powder in the blend in terms of percentage was (30g/130g * 100 = 23%).

2.4. Flour functional properties analysis

2.4.1. Flour water binding capacity (WBC) and water solubility index (WSI)

Sample (2 g) was mixed vigorously with 20 mL water for about 30 min in a dry pre-weighed centrifuge tube, centrifuged (2000 x g for 10 min) at room temperature and WBC was evaluated as g of water retained per g of solid after removal of the supernatant [32]. The supernatant collected was dried (105 ℃, overnight) from which water solubility index (WSI) was determined.

WBC (g/g) = [(Sediment weight + Weight of test tube) − (Weight of test tube)/Sample mass (db)].

WSI (%) = [Weight of dried supernatant/Sample mass (db)] * 100.

2.4.2. Flour oil absorption capacity (OAC)

Sample 0.1g (wi) was dispersed in 1 mL of sunflower oil in a test tube using wire rod, vortex mixed for 30 min. and centrifuged (3000 × g, 4 ℃ for 10 min) [33]. The supernatant oil was removed by Pasteur pipette, the sample tube was inverted on a lint free tissue paper for 25 min to drain unbound oil. The residue was weighed (wr), and OAC was expressed as g of oil bound per g of sample (db).

$$\text{OAC (g/g)} = wr/wi \tag{1}$$

2.4.3. Flour gel water absorption index (GWAI), gel water solubility index (GWSI) and swelling power (SP)

The gel WAI, WSI and SP were determined as described in [33]. Flour 1 g was dispersed in 20 mL water in a centrifuge tube, cooked at 90 ℃ for 10 min while stirring with glass rod. The cooked paste was cooled in an ice bath for 10 min., centrifuged (3000 × g, 4 ℃ for 10 min). The GWAI was evaluated as g of water retained in the sediment gel per g of solid dry matter basis (db).

The supernatant collected into pre-weighed aluminum box was dried at 105 °C overnight from which GWSI was evaluated.

$$\text{GWAI (\%)} = [(\text{Weight of test tube} + \text{Gel sediment weight}) - (\text{Weight of test tube})/\text{Sample mass (db)}] * 100 \quad (2)$$

$$\text{GWSI (\%)} = [\text{Weight of dried supernatant separated from gel}/\text{Sample mass (db)}] * 100 \quad (3)$$

The gel swelling power (SP) was calculated taking the mass of gel sediment weight (wg), dried supernatant mass (ws) and initial flour mass dry matter basis (wi) as follows:

$$\text{SP (g/g)} = (wg)/(wi-ws) \quad (4)$$

2.5. Descriptive sensory analysis of porridge samples

2.5.1. Preparation of sample

Porridge samples were prepared by using 125g flour and 500 mL water (1:4, w/v). To ensure uniform cooking time, four stainless steel pot with a thick base were used and mixing was done at the same time. To water heated to near boiling (96.6 °C) point, flour was vigorous mixed and cooked on stove (Model DSS 430, DEFY Appliance Ltd, RSA) to avoid lumps formation. After initial cooking, the heat was reduced to about 60 °C while mixing at an interval of 3 min. to help achieve uniform product consistency. In between mixing, the pot was closed to avoid open loss of water on cooking. Cooking was brought to a stop when the desired smell, aroma, color and paste consistency level for the sorghum porridge was achieved (approx. 20 min).

The cooked porridge samples were cooled for 10 min and then about 50 g porridge samples were served to panelists in a sample glass cup randomly labelled with 3-digit codes covered with aluminum foil to avoid the loss of taste and aroma.

2.5.2. Descriptive sensory analysis by panels

A trained sensory panel of eight (5 female and 3 male students) regular sorghum porridge consumers were recruited from the Botswana University of Agriculture and Natural Resources (BUAN) to evaluate the porridge samples. Smokers, pregnant women, and those who were sick were excluded during the recruitment process. The descriptive sensory evaluation was conducted based on the generic descriptive sensory analysis [34] as described for ugali (thick porridge) [35]. The panelists were trained for five days. The first two days of training involved the training in the development of descriptive lexicon of sensory attributes of the basic raw materials (sorghum, Bambara groundnut and butternut) used to develop the porridge and reference samples. The last three days training were used to develop the descriptive lexicon for the attributes of the porridges from the composite flours to be evaluated. Attributes developed were mutually agreed upon by consensus as predominant and important and were used in the development of the assessment tool that was subsequently used for the evaluation of the porridges. The training was conducted to ensure consistency in response, discriminatory ability and to assure validity of responses.

Accordingly, the panel developed a lexicon of 16 descriptive words shown in Table 2 upon which they evaluated on the likert scale that best described the intensity on the sensory lexicons of the porridge. Water was taken by the panelists before and after tasting each sample to cleanse their palates. The panelists evaluated porridge samples for three consecutive days. Each sample were evaluated three times by each member of the panel giving 24 data scores for each sensory lexicon per sample.

Table 2. Sensory lexicon developed by panellists for porridge.

	Sensory attributes	Definition	Reference	Scale
A	*Aroma intensity*			
1	Overall porridge aroma	Intensity of porridge aroma		1 = not intense, 9 = very intense
2	Sorghum porridge aroma	Intensity of cooked sorghum aroma	9 = thick sorghum porridge aroma	1 = not intense, 9 = very intense
3	Bambara groundnut aroma	Intensity of cooked Bambara groundnut	9 = intensity of Bambara groundnut roasted-cooked	1 = not intense, 9 = very intense
4	Butternut aroma	Intensity of butternut cooked aroma	9 = intensity of dried and cooked butternut	1 = not intense, 9 = very intense
B	*Color degree*			
5	Degree of brownness	Degree of lightness to brownness	Creamy white (thick porridge from white maize flour = 1), dark brown (thick porridge from brown sorghum flour = 9)	1 = light brown, 9 = dark brown
6	Degree of yellowness	Degree of yellowness	Creamy white (thick porridge from white maize flour = 1) and pale yellow (thick porridge from whole yellow dent maize flour = 9)	1 = light yellow, 9 = dark yellow
C	*Appearance (lumps/specks number)*			
7	White lumps/specks	Quantity of white specks visible on porridge		1 = none, 9 = many
8	Dark lumps/specks	Quantity of dark specks visible on porridge		1 = none, 9 = many
9	Yellow specks/lumps	Quantity of yellow specks visible on porridge		1 = none, 9 = many
	After taste intensity			
10	Taste of sorghum in the porridge	Intensity of cooked sorghum taste	9 = thick sorghum porridge taste	1 = not intense, 9 = very intense
11	Taste of Bambara groundnut in the porridge	Intensity of cooked Bambara groundnut taste	9 = intensity of Bambara groundnut dried cooked taste	1 = not intense, 9 = very intense

Continued on the next page

	Sensory attributes	Definition	Reference	Scale
12	Taste of butternut in the porridge	Intensity of butternut cooked taste	9 = intensity of blanched and dried cooked butternut taste	1 = not intense, 9 = very intense
D	*Texture*			
13	Porridge smoothness/roughness	Porridge surface degree of roughness when visually perceived	1 = smooth peanut butter, 9 = thick porridge from coarse brown sorghum flour	1 = smooth, 9 = rough
14	Porridge firmness	Compression of lump of porridge when chewed in the mouth	1 = thin sorghum porridge from sorghum meal, 9 = thick sorghum porridge from sorghum meal	1 = not firm, 9 = very firm
15	Porridge stickiness	Degree of porridge adhered to mouth/teeth	1 = thick sorghum porridge from sorghum meal, 9 = thick-cooked maize starch	1 = not sticky, 9 = very sticky
16	Porridge springiness	Degree to which compressed porridge sample can return to its original shape	1 = thick sorghum porridge from sorghum meal, 9 = white bread from wheat flour dough	1 = not springy, 9 = very springy

2.6. Statistical analysis

The data generated were analyzed by the descriptive statistics and one-way analysis of variance (ANOVA) using IBM®Corporation [36] SPSS® Statistics Version 25 (USA) and the results were expressed as mean ± standard deviation. For functional properties analysis, the mean differences were separated using Duncan's Multiple Range test while for the sensory evaluation by Tukey HSD at $p < 0.05$.

3. Results and discussion

3.1. Functional properties of flour and gel

Sorghum flour improvement through food-to-food fortification has a potential to improve the nutritional quality of the sorghum porridge. However, the functional and sensory acceptability of the porridge matters on the use of the porridge. Evaluation of flour functional properties such as water and oil binding capacity, water solubility index, gel swelling and solubility are important for predicting the technological utilization of the flour for product processing such as porridge, bread, extruded products, nutrient and bioactive carrier potentials and digestibility. The functional properties of the flour, among others are influenced by the particle size, compositions, polar and non-polar nature, and structures of the flour chemical components [37].

3.1.1. Flour water binding capacity (WBC)

The WBC (1.78 to 2.00 g/g) of blended flours were higher than for sorghum control flour (1.60 g/g) and were significantly ($p < 0.05$) varied among the blended flours and the control (Table 3). The WBC in the blended flours is contributed from the flour particles of Bambara groundnut and butternut, in addition to the sorghum flour. The WBC for Bambara groundnut flour reported varies for example for raw and pre-treated (dry roasted, soaking-drying, soaking- roasting and seed coat removal) flours 0.51 g/g to 1.12 g/g by Mubaiwa et al. [38], for water soaked-dried and seed coat removed flours: 2.27 mL/g by Sirivongpaisal [39] and 2.6 g/g by Adebowale et al. [40]. The WBC was found highest when the Bambara groundnut flour was blended at 15% and decreased with Bambara groundnut flour blending increased up to 35%. This is in part because starches content in the sorghum flour [15] is higher than in the Bambara groundnut flour [13] and with increase in the Bambara groundnut flour in the blend, starches in the blend decreases which could lead to WBC decrease because of reduced number of starches polar hydroxyl sites for water binding capacity by hydrogen bonding. The Bambara groundnut flour proteins, starches, non-starch carbohydrates from the seed coat can contribute to WBC since it was prepared from whole grain dried (60 ℃ for 24 h.) Bambara groundnut. The drying actions can increase the WBC of the flour because as proteins denatured, polar site to bind water increases [38].

In the butternut flour, the large WBC is contributed by pectins, sugars, cell wall polysaccharides [41] and other soluble polysaccharides such as soluble hemicelluloses and oligosaccharides [42]. The WBC is important for the processing of food product where grain flour is cooked into porridge, dough/batter are baked, and in the extruded products in the production of weaning foods. In the weaning foods, high water binding and absorption capacity can lead to bulk porridge volume of less nutrients and energy dense products, which is not desirable. The WBC observed were somewhat higher than the WBC (1.28 to 1.42 g/g) of weaning food processed from sorghum malt, green gram, and sesame kernels [43] but lower than the WBC (2.14 to 3.51 g/g) reported [44] for weaning foods processed from local sorghum grains and soybean blends. In this respect, the flour could be potentially suitable for weaning porridge preparation because the water binding was not too high.

3.1.2. Flour water solubility index (WSI)

The WSI (15.19 to 18.15%) of blended flours were higher than for the sorghum control flour (3.12%) and were significantly ($p < 0.05$) varied among the blended flours and the control sorghum flour (Table 3). The WSI increased with the increased Bambara groundnut flour levels and butternut flour addition. The WSI in the blended flours were high because WSI indicates the potential of the soluble components such as soluble: proteins, sugars and fibers, which are known to be high in legume flours [45] and butternut pulp powder [41]. This also reflects high sugars and water-soluble proteins (like albumins) of high digestible potential meal [46]. In this respect, the blended flours have potential to be used as meal for a child of weaning age.

3.1.3. Flour oil absorption capacity (OAC)

The OAC of blended flours ranged from 1.82 to 2.14 g/g and a significant difference ($p < 0.05$) was observed when 35% of Bambara groundnut flour in the blend which is at statistical par with sorghum flour control OAC (2.1%) (Table 3). The OAC is influenced by the non-polar hydrophobic flour components (lipids and hydrophobic side chain amino acids). Elsewhere low OAC of 1.71 to 1.77 g/g for weaning food formulated from banana, rice and kidney bean blend flour [47]; and for the composite flour processed from wheat, rice, green gram and potato flour (1.30 to 1.56 g/g) [48] were reported. The high OAC of the flour indicate, there is a high potential for the flour structural components interaction to shortening (fats/oils), non-polar flavor compounds retention and their shelf-life extension in the product formulation. In addition, the high OAC property is also important to metabolize liposoluble vitamins (A, D, E and K) and bioactive compounds [49].

Table 3. Functional properties of flour (WBC, WSI, OAC), SP and gel (WAI, WSI,) of sorghum (S), Bambara groundnut (BG) and butternut (BU) flour blends and the control sorghum flour (C) on dry matter basis.

Blends	WBC (g/g)	WSI (%)	OAC (g/g)	SP (g/g)	GWAI (%)	GWSI (%)
B1	2.00 ± 0.04^{a}	15.19 ± 0.60^{c}	1.82 ± 0.04^{b}	7.30 ± 0.10^{b}	6.40 ± 0.12^{b}	12.33 ± 0.44^{c}
B2	1.93 ± 0.03^{b}	16.82 ± 0.49^{b}	1.90 ± 0.05^{b}	7.23 ± 0.42^{b}	6.41 ± 0.10^{b}	13.27 ± 0.35^{b}
B3	1.78 ± 0.01^{c}	18.15 ± 0.41^{a}	2.14 ± 0.11^{a}	7.18 ± 0.06^{b}	6.11 ± 0.04^{c}	14.86 ± 0.27^{a}
C	1.60 ± 0.01^{d}	3.12 ± 0.10^{d}	2.10 ± 012^{a}	8.25 ± 0.15^{a}	7.97 ± 0.12^{a}	3.43 ± 0.38^{d}
Range	1.60–2.00	3.12–18.15	1.82–2.14	7.18–8.25	6.11–7.97	3.43–14.86
$p < 0.05$	0.000	0.000	0.006	0.001	0.000	0.000

Where B1 = 85% S :15% BG, B2 = 75% S :25% BG, B3 = 65% S :35% BG, C = control 100% sorghum flour and BU = 23% constant in the blend, WBC = water binding capacity, WSI = water solubility index, OAC = oil absorption capacity, SP = gel swelling power, GWAI = gel water absorption index and GWSI = gel water solubility index. Means in the same column followed with different letters are significantly different at $p < 0.05$.

3.1.4. Flour swelling power (SP) and gel water solubility index (GWSI)

No significant difference ($p > 0.05$) in the SP in the range 7.18% to 7.30% was observed among the blended flours but was not for the control sorghum flour SP (8.25%) ($p < 0.05$). The water uptake and swelling on heating to gelatinization temperature are influenced by nature of the starch granules such as by the nature of bonding in the crystalline lamella of starch granules, starch granules size, compositions, and molecular interactions among the flour components. The SP was high in the sorghum flour because water uptake is high for refined flour where bran is removed by milling because bran components like lipids from germ and aleurone layer are repellent to water. In the blended flours, high amylose% of Bambara groundnut, strong molecular bond in the Bambara groundnut starches as legumes [50], high proteins and the presence of lipids could play toward restrictive effects of water uptake. Elsewhere similar restrictive two-stage swelling pattern was reported for Bambara groundnut flour starches [39].

3.1.5. Flour gel water absorption index (GWAI)

The GWAI ranged from 6.11 to 6.40% and significantly varied from the control sorghum flour gel water absorption capacity (7.97%) ($p < 0.05$). The GWAI is related to the starch swelling, gelatinization and holding of water when heated beyond the gelatinization temperature of sorghum (68 to 78 ℃) [31] and Bambara groundnut (68 to 84 ℃) [29] flour starch granules. In part, it is also influenced by proteins denaturation and those flour components that limit water uptake into the crystalline lamella of starch granules such as amylose, fibers and lipid components. The GWAI decreased as the Bambara groundnut flour increased in the blend because the starch content (50%) in the Bambara groundnut flour [38] is lower than starch content in the sorghum flour (68%) [18]. The lower GWAI for the blended flour could help to process less bulky porridges of nutrients and energy dense products than the control sorghum flour.

The GWSI (12.33 to 14.86%) of the blended flours were higher than for the sorghum control flour (3.43%) and were significantly ($p < 0.05$) varied among the blended flours and the control sorghum flour (Table 3). The soluble components comprised small molecules such as soluble proteins, water soluble fibers, sugars, and those small molecules leached from starch granules on starches swelling and gelatinization. Blending with Bambara groundnut and butternut flours significantly contributed to the soluble components. The more soluble components from the porridge gel, there could be the less tendency for starches retrogradation and the less water syneresis from the gel because of the interruption by soluble components on the tendency of amylopectin re-crystallization [51]. This possibly improves the palatability of cooked porridge during some storage duration. Notwithstanding this, the soluble components from the gel was lower than that from the flour, which shows some soluble components could interact with the swelled and gelatinized starches, denatured proteins, and non-starch polysaccharides in the gelatinized flour starches gel system. The more soluble components from the flour gel, the more easily digestible components in the porridge gel [44] and in this regard the flour blended with 35% Bambara groundnut are superior.

3.2. Sensory evaluation of the porridges

Descriptive sensory evaluation was conducted on the porridges processed from the blended flours and the control was prepared from plain refined sorghum flour. Among the 16 descriptive sensory attributes evaluated, non-significant difference ($p > 0.05$) was observed only for porridge textures (roughness, firmness, stickiness, and springiness) (Table 4).

3.2.1. Porridge aroma

The panelists evaluated the overall aroma of the control sorghum flour porridge as very intense whereas for the porridge processed from the blending of Bambara groundnut and butternut flour to the sorghum flour as low in intensity with no significant difference ($p > 0.05$) among the blending levels (Table 4). The same was observed on the intensity of the sorghum porridge aroma. This shows that the sorghum porridge aroma was intense for the sorghum alone than the porridge processed by blending. Similar decline but better than this in the sorghum-cowpea blend porridge aroma intensity was reported [35]. With the increasing of Bambara groundnut flour in the blend, the aroma intensity of Bambara groundnut increased as expected. For the butternut aroma, since the same amount of butternut was added, it was surprising that the aroma intensity decreased in intensity for porridge samples processed at the higher level of Bambara groundnut flour blending, while it was not surprising that in the sorghum control porridge it was almost not detected. The Bambara groundnut flour seemed to mask the butternut aroma.

Table 4. Porridge descriptive sensory evaluation of sorghum (S), Bambara groundnut (BG) and butternut (BU) flour blends and the control sorghum flour (C).

Sensory attributes	B1	B2	B3	C	Range	$p < 0.05$
*Aroma intensity**						
Overall porridge aroma	4.7 ± 1.4^{b}	4.7 ± 1.1^{b}	4.5 ± 1.4^{b}	8.3 ± 1.7^{a}	4.5 − 8.3	0.000
Sorghum porridge aroma	4.4 ± 1.4^{b}	4.3 ± 1.3^{b}	4.1 ± 1.5^{b}	8.3 ± 1.2^{a}	4.1 − 8.3	0.000
Bambara groundnut aroma	4.3 ± 0.9^{b}	5.0 ± 0.9^{b}	6.9 ± 1.8^{a}	1.2 ± 0.7^{c}	1.2 − 6.9	0.000
Butternut aroma	7.2 ± 1.4^{a}	5.0 ± 1.1^{b}	3.9 ± 0.7^{c}	1.1 ± 0.5^{d}	1.1 − 7.2	0.000
Color degree						
Degree of brownness&	4.3 ± 1.2^{b}	4.2 ± 1.1^{bc}	3.5 ± 1.1^{c}	7.2 ± 1.2^{a}	3.5 − 7.2	0.000
Degree of yellowness@	5.5 ± 1.4^{a}	4.5 ± 0.9^{b}	3.2 ± 0.8^{c}	1.2 ± 0.0^{d}	1.2 − 5.5	0.000
Appearance (lumps/specks number)#						
White lumps/specks	2.4 ± 0.6^{a}	2.5 ± 0.7^{a}	2.4 ± 0.6^{a}	1.9 ± 0.7^{b}	1.9 − 2.5	0.009
Dark lumps/specks	2.6 ± 1.2^{ab}	2.6 ± 0.8^{ab}	2.3 ± 0.9^{b}	3.3 ± 1.5^{a}	2.3 − 3.3	0.033
Yellow lumps/specks	2.8 ± 1.2^{a}	2.6 ± 0.9^{a}	2.6 ± 1.1^{a}	1.2 ± 0.7^{b}	1.2 − 2.8	0.000
*After taste intensity**						
Taste of sorghum in the porridge	4.2 ± 1.0^{b}	4.5 ± 1.1^{b}	4.2 ± 1.1^{b}	8.4 ± 0.9^{a}	4.2 − 8.4	0.000
Taste of Bambara groundnut in the porridge	4.3 ± 1.0^{c}	5.2 ± 0.8^{b}	7.0 ± 1.7^{a}	1.0 ± 0.0^{d}	1.0 − 7.0	0.000
Taste of butternut in the porridge	7.3 ± 1.3^{a}	5.1 ± 0.9^{b}	4.0 ± 0.9^{c}	1.0 ± 0.0^{d}	1.0 − 7.3	0.000
Texture						
Porridge roughness$	3.5 ± 1.4^{a}	4.0 ± 1.4^{a}	3.6 ± 1.2^{a}	4.5 ± 1.9^{a}	3.5 − 4.5	0.093
Porridge firmness$^{\alpha}$	2.7 ± 1.1^{a}	3.3 ± 1.0^{a}	3.0 ± 1.2^{a}	3.2 ± 1.4^{a}	2.7 − 3.3	0.296
Porridge stickiness$^{\Delta}$	2.5 ± 1.1^{a}	2.8 ± 1.3^{a}	3.0 ± 1.4^{a}	3.0 ± 1.2^{a}	2.5 − 3.0	0.554
Porridge springiness$^{\Psi}$	2.0 ± 1.6^{a}	1.8 ± 1.3^{a}	1.8 ± 1.1^{a}	1.5 ± 1.0^{a}	1.5 − 2.0	0.715

Where B1 = 85% S :15% BG, B2 = 75% S :25% BG, B3 = 65% S :35% BG, C = control 100% sorghum flour and BU = constant 23% in the blended flour. Means in the same row followed by different superscript letters are significantly different at $p < 0.05$. Descriptive sensory analysis scale where: * = (1=not intense, 9=very intense); & (1 = light brown, 9 = dark brown); @ (1 = light yellow, 9 = dark yellow); # (1 = none, 9 = many); $ (1 = smooth, 9 = rough); α (1 = not firm, 9 = very firm); Δ (1 = not sticky, 9 = very sticky) and Ψ (1 = not springy, 9 = very springy).

3.2.2. Porridge color

The porridge color for the control sorghum porridge was more intense brown and brownness decreased with Bambara groundnut increase in the blend; the color was lighter brown. The brownness color degree is influenced by color of the raw materials and the brown color compounds generated by the Maillard and caramelization reactions on the porridge cooking. The brownness color in the porridge processed by blending were most likely masked by the yellowish-reddish color of the butternut flour in the blend. Indeed, the yellowness color intensity decreased as the Bambara groundnut flour in the blend increased in the blended samples.

The control sorghum porridge recorded insignificant (virtually not detected) yellowness color intensity. This was not surprising since butternut was not added to the control sample. Yellowness color significantly decreased with increased Bambara groundnut. The Bambara groundnut seemed to mask the yellowness of the porridges. Like the control sorghum porridge of this study, sorghum porridges processed from brown sorghum in the past studies was described as light to dark brown to reddish tinge, influenced by the degree of polyphenolic compounds present in the flour [27,35].

3.2.3. Porridge appearance

The appearance of white specks in the porridge was significantly ($p < 0.05$) high for the porridge processed from the blended flours as compared to the sorghum flour control porridge. However, no significant differences ($p > 0.05$) in the number of white specks were observed due to variations in the blending levels by Bambara groundnut flour. In the number of dark specks, no significant differences ($p > 0.05$) were observed in the control sorghum porridge and porridge samples processed by blending with Bambara groundnut flour except at 35% blending levels. This is probably related to the Bambara groundnut flour starches restricted water uptake [39] contributing to non-even hydration of specks appearance in the porridge. In terms of the number of yellowness specks, significant difference ($p < 0.05$) was observed only for the control sorghum porridge because yellowness is imparted by butternut flour that were added at the constant levels in the porridge processed by blending. Specks formation in the porridge is a defect in the porridge quality, and it is a manifestation of improper mixing, uneven hydration of flour particles to uniform porridge consistency on the cooking. However, all the porridge samples had low number of specks appearance (≤3) which means they can have better porridge appearance for the consumer acceptance.

3.2.4. Porridge aftertaste

The control sorghum porridge had a strong sorghum taste while the blended sorghums porridge has a less intense sorghum taste ($p < 0.05$), which was to be expected because of the addition of Bambara groundnut and butternut. Similar aftertaste intensity difference was reported between control sorghum porridge and sorghum-cowpea blend porridge [35]. In other study, improvement in the sensory attributes as compared to the traditional sorghum porridge for the porridge processed from the composite of sorghum and sugar beans was reported [24]. Bambara groundnut and butternut aftertaste was not detected in the control porridge as expected. The Bambara groundnut taste increased with increased Bambara groundnut in the porridge blends, as expected. Butternut taste in the blended samples was not expected to differ because the same amount was added to all the treatments. However, with Bambara groundnut increase, the butternut taste intensity was reduced, and intense butternut aftertaste was recorded in B1 at low level of Bambara groundnut in the blend. The porridge aftertaste is one strong driving factor for the porridge acceptability by the consumers [25] and hence for those accustomed to sorghum porridge, the porridge processed by blending with Bambara groundnut and butternut flours bears limitation but can be suppressed by incorporating those known to improve porridge aftertaste such as by using low to moderate levels of salt, fat, and/or spices.

3.2.5. Porridge texture

The porridges processed were smooth rather than rough textures. The control sorghum porridge was significantly ($p < 0.05$) less smooth as compared to the porridges processed by blending with Bambara groundnut and butternut flours except blending at the 25% Bambara groundnut flour. No significant difference ($p > 0.05$) was observed in the porridge firmness texture among the porridge samples and all samples were evaluated as less firm which indicate easy palatability. The porridge stickiness to the tooth was low and no significant difference ($p > 0.05$) was found among the porridge samples. Similarly, the porridge springiness was evaluated as almost no springiness for all the porridge samples. Porridges with smooth, less- firm, -sticky and -springe textures are indicators of the porridge good quality. Thus, in terms of texture attributes, the Bambara groundnut and butternut flours blended porridges are similar as that of the control sorghum flour porridge which is promising for the acceptance of porridge texture.

4. Conclusions

The refined sorghum flour blended with three levels of Bambara groundnut (BG) flour (15%, 25% and 35%) and constant level dried butternut powder (23%) were evaluated for functional and porridge descriptive sensory properties using 100% refined sorghum flour as a control. The functional properties evaluated showed that porridges processed from the blended flours have features of less bulky, nutrient and energy dense, digestible as a weaning food. The porridge overall aroma, aftertaste and brown color were more intense in the control sorghum porridge ($p < 0.05$). However, porridge with insignificant specks count and the texture (roughness/smoothness, firmness, stickiness, and springiness) similar with the control refined sorghum porridge can be processed by blending at 25 and 35% BG.

Acknowledgments

The research was supported by BUAN Grant from Research, Technology Development and Transfer Committee (RTDTC, RPC-42) and article publishing charge was covered by Grant number RTDTC (Cost code- 2658).

Conflict of interest

Authors have no conflict of interest to declare.

References

1. Adebo OA, Njobeh PB, Kayitesi E (2018) Fermentation by *Lactobacillus fermentum* strains (singly and in combination) enhances the properties of ting from two whole grain sorghum types. *J Cereal Sci* 82: 49–56. https://doi.org/10.1016/j.jcs.2018.05.008
2. Sruthi NU, Rao PS, Rao BD (2021) Decortication induced changes in the physico-chemical, anti-nutrient, and functional properties of sorghum. *J Food Comp Anal* 102: 104031. https://doi.org/10.1016/j.jfca.2021.104031
3. Hama F, Icard-Vernière C, Guyot JP, et al. (2011) Changes in micro- and macronutrient composition of pearl millet and white sorghum during in field versus laboratory decortication. *J Cereal Sci* 54: 425–433. https://doi:10.1016/j.jcs.2011.08.007

4. Xiong Y, Zhang P, Warner RD, et al. (2019) Sorghum grain: From genotype, nutrition, and phenolic profile to its health benefits and food applications. *Compreh Rev Food Sci Food Saf* 18: 2025–2046. https://doi: 10.1111/1541-4337.12506
5. Duodu KG, Taylor JRN, Belton PS, et al. (2003) Factors affecting sorghum protein digestibility: Mini review. *J Cereal Sci* 38: 117–131. https://doi:10.1016/S0733-5210(03)00016-X
6. Makame J, De Kock H, Emmambux NM (2020) Nutrient density of common African indigenous/local complementary porridge samples. *LWT-Food Sci Technol* 133: 109978. https://doi.org/10.1016/j.lwt.2020.109978
7. Alaaraj N, Soliman A, Rogol AD (2021) Growth of malnourished infants and children: how is inflammation involved? *Expert Rev Endocrinol Metab* 16: 213–216. https://doi: 10.1080/17446651.2021.1956903
8. Kihara J, Bolo P, Kinyua M, et al. (2020) Micronutrient deficiencies in African soils and the human nutritional nexus: opportunities with staple crops. *Environ Geochem Health* 42: 3015–3033. https://doi.org/10.1007/s10653-019-00499-w
9. Vilakati N, Taylor JRN, MacIntyre U, et al. (2016) Effects of processing and addition of a cowpea leaf relish on the iron and zinc nutritive value of a ready-to-eat sorghum-cowpea porridge aimed at young children. *LWT-Food Sci Technol* 73: 467e472. https://doi.org/10.1016/j.lwt.2016.06.022
10. Apea-Bah FB, Minnaar A, Bester MJ, et al. (2014) Does a sorghum-cowpea composite porridge hold promise or contributing to alleviating oxidative stress? *Food Chem* 157: 157–166. https://doi.org/10.1016/j.foodchem.2014.02.029
11. Mpotokwane SM, Gaditlhatlhelwe E, Sebaka A, et al. (2008) Physical properties of Bambara groundnuts from Botswana. *J Food Engineer* 89: 93–98. https://doi:10.1016/j.jfoodeng.2008.04.006
12. Bultosa G, Molapisi M, Tselaesele N, et al. (2020) Plant-based traditional foods and beverages of Ramotswa Village, Botswana. *J Ethn Foods* 7: 1–15. https://doi:10.1186/s42779-019-0041-3
13. Kaptso KG, Njintang YN, Nguemtchouin MMG, et al. (2015) Physicochemical and micro-structural properties of flours, starch and proteins from two varieties of legumes: Bambara groundnut (*Vigna subterranea*). *J Food Sci Technol* 52: 4915–4924. https://doi:10.1007/s13197-014-1580-7
14. Plahar WA, Yawson RM (2004) Dissemination of Improved Bambara Processing Technologies Through a New Coalition Arrangement to Enhance Rural Livelihoods in Northern Ghana, 1–50.
15. Boukid F, Zannini E, Carini E, et al. (2019) Review: Pulses for bread fortification: A necessity or a choice? *Trends Food Sci Technol* 88: 416–428. https://doi.org/10.1016/j.tifs.2019.04.007
16. Halimi RA, Barkla BJ, Mayes S, et al. (2019) Critical review: The potential of the underutilized pulse Bambara groundnut (*Vigna subterranea* (L.) Verdc.) for nutritional food security. *J Food Comp Anal* 77: 47–59. https://doi.org/10.1016/j.jfca.2018.12.008
17. Moraes ÉA, Queiroz VAV, Shaffert RE, et al. (2012) In vivo protein quality of new sorghum genotypes for human consumption. *Food Chem* 134: 1549–1555. https://doi.org/10.1016/j.foodchem.2012.03.079
18. Rashwan AK, Yones HA, Karim N, et al. (2021) Potential processing technologies for developing sorghum-based food products: an update and comprehensive review. *Trends Food Sci Technol* 110: 168–182. https://doi.org/10.1016/j.tifs.2021.01.087

19. Okafor JNC, Jideani VA, Meyer M, et al. (2022) Bioactive components in Bambara groundnut (*Vigna subterraenea* (L.) Verdc) as a potential source of nutraceutical ingredients. *Heliyon* 8: e09024. https://doi.org/10.1016/j.heliyon.2022.e09024
20. Noelia JV, Roberto MJR, de Jesús ZMJ, et al. (2011) Physicochemical, technological properties, and health-benefits of *Cucurbita moschata* Duchense vs. Cehualca: A Review. *Food Res Int* 44: 2587–2593. https://doi:10.1016/j.foodres.2011.04.039
21. Imdad A, Mayo-Wilson E, Haykal MR, et al. (2022) Vitamin A supplementation for preventing morbidity and mortality in children from six months to five years of age. *Cochrane Database Syst Rev* 3: Art. No.: CD008524. https://doi.org/10.1002/14651858.CD008524.pub4
22. Apea-Bah FB, Minnaar A, Bester MJ, et al. (2016) Sorghum-cowpea composite porridge as a functional food, Part II: Antioxidant properties as affected by simulated in vitro gastrointestinal digestion. *Food Chem* 197: 307–315. https://doi.org/10.1016/j.foodchem.2015.10.121
23. Pelembe LAM, Erasmus C, Taylor JRN (2002) Development of a protein-rich composite sorghum-cowpea instant porridge by extrusion cooking process. *Leben Wissen Technol* 35: 120–127. https://doi.org/10.1006/fstl.2001.0812
24. Jackson JC, Weatherspoon L, Nnyepi M, et al. (2013) Sorghum- bean composite porridge nutritional quality and acceptability. *Nutr Food Sci* 43: 453–461. https://doi.org/10.1108/NFS-03-2012-0024
25. Kayitesi E, Duodu KG, Minnaar A, et al. (2010) Sensory quality of marama/sorghum composite porridges. *J Sci Food Agric* 90: 2124–2132. https://doi: 10.1002/jsfa.4061
26. Vilakati N, MacIntyre U, Oelofse A, et al. (2015) Influence of micronization (infrared treatment) on the protein and functional quality of a ready-to-eat sorghum-cowpea African porridge for young child-feeding. *LWT-Food Sci Technol* 63: 1191–1198. https://doi.org/10.1016/j.lwt.2015.04.017
27. Onyango C, Wanjala GW (2018) Quality of porridge from sub-Saharan Africa evaluated using instrumental techniques and descriptive sensory lexicon-Part 1: thick (stiff) porridge. *Afri J Food Sci* 12: 86–96. https://doi:10.5897/AJFS2014.1674
28. Aboubacar A, Kirleis AW, Oumarou M (1999) Important sensory attributes affecting consumer acceptance of sorghum porridge in West Africa as related to quality tests. *J Cereal Sci* 30: 217–225. https://doi.org/10.1006/jcrs.1999.0283
29. Oyeyinka SA, Singh S, Amonsou EO (2016) Physicochemical properties of starches extracted from Bambara groundnut landraces. *Starch/Starke* 69: 1600089. https://doi.org/10.1002/star.201600089
30. Beta T, Corke H (2001) Genetic and environmental variation in sorghum starch properties. *J Cereal Sci* 34: 261–268. https://doi:10.1006/jcrs.2000.0379
31. Biliaderis CG (2009) Structural transitions and related physical properties of starch. In: BeMiller J, Whistler R (Eds.), *Starch: Chemistry and Technology*, 3rd ed, Academic Press, Imprint of Elsevier, New York, USA, 293–372. https://doi.org/10.1016/B978-0-12-746275-2.00008-2
32. AACCI (American Association of Cereal Chemists International) (2000) Approved Methods of the American Association of Cereal Chemists, St. Paul, MN, Method AACC Method 56-20.
33. Yu D, Chen J, Ma J, et al. (2018) Effects of different milling methods on physicochemical properties of common buckwheat flour. *LWT-Food Sci Technol* 92: 220–226. https://doi.org/10.1016/j.lwt.2018.02.033

34. Lawless HT, Heymann H (2010) Chapter 10. Descriptive Analysis. In: Sensory Evaluation of Food: Principles and Practices, 2nd ed., Springer, London, UK, 227–257. https://doi.org/10.1007/978-1-4419-6488-5_10
35. Anyango JO, de Kock HL, Taylor JRN (2011) Evaluation of the functional quality of cowpea-fortified traditional African sorghum foods using instrumental and descriptive sensory analysis. *LWT-Food Sci Technol* 44: 2126–2133. https://doi:10.1016/j.lwt.2011.07.010
36. IBM Corporation (2017) SPSS® Statistics Version 25 Software, NY 10504-1785, USA.
37. Hera E, de la Gomez M, Rosell CM (2013) Particle size distribution of rice flour affecting the starch enzymatic hydrolysis and hydration properties. *Carbohyd Polym* 98: 421–427. https://doi.org/10.1016/j.carbpol.2013.06.002
38. Mubaiwa J, Fogliano V, Chidewe C, et al. (2018) Bambara groundnut (*Vigna subterranea* (L.) Verdc.) flour: A functional ingredient to favour the use of an unexploited sustainable protein source. *PLoS ONE* 13: e0205776. https://doi.org/10.1371/journal.pone.0205776
39. Sirivongpaisal P (2008) Structure and functional properties of starch and flour from Bambara groundnut. *Songklanak J Sci Technol* 30: 51–56.
40. Adebowale KO, Afolabi TA, Lawal OS (2002) Isolation, chemical modification and physicochemical characterisation of Bambarra groundnut (*Voandzeia subterranean*) starch and flour. *Food Chem* 78: 305–311. https://doi.org/10.1016/S0308-8146(02)00100-0
41. Delgado-Nieblas CI, Zazueta-Morales JJ, Jacobo-Valenzuela N, et al. (2016) Production of winter squash flours rich in bioactive compounds and high-water absorption by means of a precooking-air-drying optimized process. *J Food Proces Preserv* 41: e12809. https://doi:10.1111/jfpp.12809
42. Capuano E (2017) The behavior of dietary fiber in the gastrointestinal tract determines its physiological effect. *Crit Rev Food Sci Nutr* 57: 3543–3564. https://doi:10.1080/10408398.2016.1180501
43. Kulkarni KD, Kulkarni DN, Ingle UM (1991) Sorghum malt-based weaning food formulations: preparation, functional properties, and nutritive value. *Food Nutr Bullet* 13: 1–7. https://doi.org/10.1177/156482659101300401
44. Usman MA, Bolade MK, James S (2016) Functional properties of weaning food blends from selected sorghum (*Sorghum bicolor* (L.) Moench) varieties and soybean (*Glycine max*). *Afri J Food Sci* 10: 112–121. https://doi:10.5897/AJFS2015.1406
45. Di Cairano M, Condelli N, Caruso MC, et al. (2020) Functional properties and predicted glycemic index of gluten free cereal, pseudocereal and legume flours. *LWT-Food Sci Technol* 133: 109860. https://doi.org/10.1016/j.lwt.2020.109860
46. Amagloh FK, Mutukumira AN, Brough L, et al. (2013) Carbohydrate composition, viscosity, solubility, and sensory acceptance of sweet potato- and maize-based complementary foods. *Food Nutr Res* 57: 18717. http://doi.org/10.3402/fnr.v57i0.18717
47. Borbi MA, Dolan KD, Siddiq M, et al. (2020) Development and quality evaluation of banana-rice-bean porridge as weaning food for older infants and young children, *Legume Sci* 2: e41. http://doi.org/10.1002/leg3.41
48. Chandra S, Singh S, Kumari D (2015) Evaluation of functional properties of composite flours and sensorial attributes of composite flour biscuits. *J Food Sci Technol* 52: 3681–3688. http://doi: 10.1007/s13197-014-1427-2

49. Tan Y, McClements, DJ (2021) Improving the bioavailability of oil-soluble vitamins by optimizing food matrix effects: A review. *Food Chem* 348: 129148. http://doi.org/10.1016/j.foodchem.2021.129148
50. Paliwal J, Thakur S, Erkinbaev C (2019). Protein-starch interactions in cereal grains and pulses. In: Melton L, Shahidi F, Varelis P (Eds.), *Encyclopedia of Food Chemistry*, 2: 446–452. http://doi.org/10.1016/B978-0-08-100596-5.22349-4
51. Srichuwong S, Curti D, Austin S, et al. (2017) Physicochemical properties and starch digestibility of whole grain sorghums, millet, quinoa and amaranth flours, as affected by starch and non-starch constituents. *Food Chem* 233: 1–10. http://doi.org/10.1016/j.foodchem.2017.04.019