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Chemical, antioxidant and sensory properties of pasta from fractionated whole wheat and Bambara groundnut flour

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ABSTRACT

Pasta from whole-grain wheat is highly nutritious but has poor sensory properties. Hence, this study prepared pasta from fractionated whole-grain wheat flour enriched with 20% Bambara groundnut. The chemical, antioxidant and sensory properties of the pasta were assessed using standard methods. The fat, protein, ash contents, lightness and antioxidant properties value of the flour and pasta increased, while carbohydrate and fibre contents decreased with a reduction in particle size from 500 μm to 112 μm. Potassium (246.50–249.00 mg/kg), calcium (223.50–254.00 mg/kg) and magnesium (184.50–192.00 mg/kg) were the major mineral element in the pasta samples, while zinc (1.00–2.00 mg/kg) and iron (3.50–13.00 mg/kg) are present in small quantities. The optimum cooking time of pasta (average 6.55 min) from the fractionated flours was shorter compared to the control pasta (pasta made from unfractionated wheat flour), but the cooking loss was not significantly affected. Pasta from flour with particle sizes of 300 and 112 μm were very similar in their sensory attributes and showed the highest ratings in overall acceptability. Fractionation of whole-grain wheat flour seems very promising in producing pasta with fairly good antioxidant potentials and high level of protein and fibre to improve the health of pasta-loving individuals.

1. Introduction

Pasta is one of the most important and popular cereal food consumed all over the world (Aranibar et al., 2018; Padalino et al., 2014; Vignola, Bustos, & Pérez, 2018a, 2018b). It is increasingly becoming popular because of its simplicity of preparation, long shelf life, low cost and sensory property (Wójtowicz & Mościcki, 2014). The increased demand for pasta products may also be associated with their low sodium and fat contents, high level of complex carbohydrate (Kaur, Sharma, Nagi, & Dar, 2012; Vignola, Bustos, & Pérez, 2018b) and low glycaemic index (Sobota, Rzedzicki, Zarzycki, & Kuzawińska, 2015).

Pasta is made mainly from durum wheat semolina (Triticum turgidum ssp. durum) because of its very good cooking quality, unique colour, flavour and high consumer acceptance (Biernacka, Dziki, Gawlik-Dziki, Różyło, & Siastała, 2017; Vignola et al., 2018a). During milling of durum wheat into semolina, the bran and germ are removed as they are regarded as contaminants (Manthey & Schorno, 2002), despite being a good source of dietary fibre, vitamins, minerals (Boroski et al., 2011) and natural antioxidants (Hirawan, Ser, Arntfield, & Beta, 2010). They are regarded as by-products and are commonly used for animal feeding or sometimes used in whole wheat bread- and pasta-making (Pasqualone et al., 2015). The consumption of pasta made from whole wheat may contribute to adequate intake of bioactive compounds, including dietary fibre and antioxidants, which are known

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to reduce the risk of several chronic diseases (Ciccoritti et al., 2017). However, the presence of bran particles has been reported to physically interfere with dough development, resulting in weak dough properties (Kaur et al., 2012), harder texture, poor cooking quality (Aravind, Sissons, Egan, & Fellows, 2012; Manthey & Schorno, 2002) and inferior sensory properties of pasta products (Steglich, Bernin, Moldi, Topgaard, & Langton, 2015; Vignola et al., 2018a). Therefore, efforts are being made through research to reach a compromise between pasta quality and the presence of bioactive components such as antioxidants in bran or fibre. Previous research reported that pasta enriched with wheat bran aqueous extracts obtained by ultrasound-assisted technology had significantly higher antioxidant activity and phenolic content as well as good sensory properties (Pasqualone et al., 2015). This seems a promising approach to the utilization of bran which is usually discarded during wheat milling. The need to balance pasta nutritional and sensory properties results from consumers demand for natural, wholesome and health-promoting foods (Vignola et al., 2018a). Because of the high level of nutrients in pasta made from whole wheat, as indicated above, and the demand for good quality pasta, it is hypothesized that fractionating the whole-grain wheat may produce pasta with better quality. This seems plausible, since variation in particle size of whole wheat makes it less homogenous compared with semolina and this variation in size may significantly affect the dough and pasta quality. Hence, fractionating the whole-grain wheat flour using sieves of different aperture size to produce flour of different particle size for the production of pasta may be an alternative method to reduce the impact of the bran on the pasta quality.

Furthermore, the enrichment of flour for improving pasta quality using different ingredients has been encouraged in recent times. For instance, wheat flour has been reportedly enriched for pasta production using different ingredients such as oregano leaves, carrot leaves (Boroski et al., 2011), legumes such as pea (Padalino et al., 2014), white bean, split yellow pea, lentil (Wójtowicz & Mościcki, 2014) and chick pea flour as well as protein isolate (El-Sohaimy, Brennan, Darwish, & Brennan, 2020). The use of legumes in enriching pasta products has been linked with their high protein content and rich source of lysine which is limiting in cereals (Padalino et al., 2014). A study by Wójtowicz and Mościcki (2014) on the influence of legume type and addition level on quality characteristics, texture and microstructure of enriched precooked pasta showed that precooked pasta products enriched with legume flour up to 30% had very good physical and sensory properties, including a firm texture, and compact internal structure. All the legumes evaluated, increased the protein, ash, fibre and fat contents of the pasta (Wójtowicz & Mościcki, 2014). The use of underutilised leguminous crops such as Bambara groundnut (*Vigna subterranea*) in the enrichment of fractionated whole-wheat flour may further enhance the nutritional profile of the various fractions. Bambara groundnut has been reportedly used in the enrichment of several foods because it is rich in protein (16.88–28.55 g/100 g) and carbohydrate (56.42–70.16 g/100 g) (Afolabi, Opara, Kareem, & Oladoyinbo, 2018; Oyeyinka, Pillay, Tesfay, & Siwela, 2017). In this study, Bambara groundnut flour was prepared using an established method and added to whole-wheat flour that was fractionated using a mechanical sieve. Each fraction was used in the production of pasta and their chemical, antioxidant and sensory properties were studied. For clarity purpose, unsieved and unfractionated were used interchangeably throughout the manuscript.

2. Materials and methods

2.1. Materials

Whole-grain wheat (*Triticum turgidum* ssp. durum) and cream coat Bambara groundnut (*Vigna subterranea*) were purchased from a local market in Ilorin, Nigeria. The grains were cleaned to remove foreign matter, kept in Ziploc bags and stored at 4 °C for 2 wk until needed for production.

2.2. Production of Bambara groundnut flour

Flour was prepared as previously reported except that the grains were not dehulled (Oyeyinka, Singh, Adebola, Gerrano, & Amonsou, 2015). Briefly, cleaned grains were dried at 50 °C in a hot air oven (D-37520, Thermo Fischer Scientific, South Africa) for 12 h to reduce the moisture content of the grains. The grains were milled into flour using a Warring blender (HGBTWTS3, Torrington USA) and packaged in Ziploc bags and stored at 4 °C until needed for compositing with the wheat flour.

2.3. Fractionation of whole-wheat flour and compositing with Bambara flour

Cleaned wheat grains were milled using a Warring blender (HGBTWTS3, Torrington USA) and sieved using a mechanical sieve shaker with varying aperture size (112, 250, 300, 350, and 500 μm). Flour (100 g) was weighed and sifted on the five-stacked screens for 10 min. After completely shaken, the material on each sieve was taken off and kept in Ziploc bags. The step was repeated until all the flours were screened. Each fraction was composited with 20% Bambara groundnut flour. This level was chosen based on a previous study where moderately acceptable cooking and sensory quality was reported for pasta enriched with different flours (Krishnan & Prabhasankar, 2010). The amount of whole-wheat flour on the sieve with aperture size of 250 μm was too small and therefore not used in the experiment.

2.4. Pasta preparation and drying

Pasta (short spaghetti), was prepared according to the modified method of Aranibar et al. (2018). Briefly, each formulation was made with flour, water, and salt (50 g, 22.5 g, and 1.0 g, respectively) and mixed in a bench top mixer until the dough had an adequate consistency. Dough was divided by hand and extruded using a metal clay extruder (YG-21, China) with a diameter of 1.3 mm into trays laid with aluminium foils. Pasta was dried at 80 ± 5 °C for 2 h in a hot air oven (D-37520, Thermo Fischer Scientific, South Africa). Dried pasta was packaged in Ziploc bags and stored at room temperature (25 ± 2 °C) until needed for further analyses. All the flours used in pasta production had 20% Bambara groundnut, but the control pasta was made from whole-wheat grain flour that was not fractionated.

2.5. Proximate composition of flours and pasta

The proximate composition (ash, fat, fibre and moisture contents) of the grains were determined using standard methods (AOAC, 2000). Protein content was measured using the Kjeldahl method (6.25 × N), while the total carbohydrate was calculated by difference.

2.6. Functional properties of flour

The swelling index, bulk densities, water absorption and oil absorption capacities of the whole wheat flour, Bambara groundnut flour, unsieved composite flour and the fractionated flours were determined according to methods described earlier (Falade & Nwajei, 2015).

2.7. Colour of flour and pasta

The colour of flour and raw pasta in terms of lightness (L*) and colour values (+a: red; -a: green; +b: yellow; -b: blue) were measured using a Colorflex-EZ bench top spectrophotometer (A60-1014-593, Hunter Associates, Reston, VA, USA). Total colour difference (ΔE) was calculated according to equation given below (Falade & Oyeyinka, 2015).

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

2.8. Total phenolic content and antioxidant properties of pasta

Total phenolic content of the dried pasta was determined as previously reported (Ahmed, Khan, & Saeed, 2015; Klompong & Benjakul, 2015) while the antioxidant properties using DPPH and FRAP assays were determined according to the method of Klompong and Benjakul (2015) at absorbances of 517 and 593 nm, respectively using a spectrophotometer (Jenway 7305 Bibby Scientific, London, UK).

2.9. Mineral composition of pasta

Pasta samples were analyzed for calcium, magnesium, potassium, zinc and iron using a Flame Atomic Absorption Spectrometer (Unicam 939 spectrometer, Burladingen, Germany) as previously described (Tazrart, Lamacchia, Zaidi, Haros, & Analysis, 2016). Briefly, samples were placed in a Teflon perfluoroalkoxy (PFA) vessels and treated with 4 mL of 14 M HNO_3 and 1 mL of H_2O_2, 30% (v/v). The Teflon PFA vessels were irradiated at 800 W (15 min at 180 °C) in a microwave accelerated reaction system (MARS). At the end of the digestion, the digests were placed in polypropylene tubes and made up to final volume with 5% HCl. Measurements were done in duplicates and average values reported.

2.10. Cooking properties of pasta

The disappearance of the white central core of the pasta samples squeezed between two plates of glass was used to ascertain the optimum cooking time (OCT) (Zarzycki et al., 2020). The OCT was determined by the method of Sobota et al. (2015). Briefly, 100 g of pasta was placed in 1000 mL of boiling distilled water. Samples were taken every 15 s to determine the OCT, until the white core could no longer be seen. The cooking time was done in triplicate and was used to prepare samples for sensory evaluation.

The swelling index and water absorption index of the pasta were determined using the method described by Padalino et al. (2014), while weight increase and cooking loss were done according to the procedure of Özyurt et al. (2015).

2.11. Sensory properties

A 9-point hedonic scale was used to evaluate the acceptability of the pasta, where 1 and 9 represent 'dislike extremely' and 'like extremely', respectively. The pasta samples were evaluated by a consumer panel consisting of 57 members who are regular consumers of pasta. Pasta samples were cooked in distilled water to optimum cooking time as described above and thereafter drained for 2 min and served in coded plates. Participants were instructed to rinse their mouth with water before they began testing and between samples. Pasta samples were evaluated for colour, taste, aroma, texture (mouth feel), and overall acceptability. In order to prevent bias, each panellist received samples in a randomized order, which was done using a table of permutation. The study proposal was presented within the Departmental Research and Ethical Committee and was approved by the Ethical Committee of the Department of Home Economics and Food Science, University of Ilorin, Nigeria. All participants used in the study were duly informed of the implication of participating in the investigation and gave their consent.

2.12. Statistical analysis

Samples were prepared in duplicate and analyses done in triplicate. All the data obtained were analyzed using one-way analysis of variance (ANOVA) and the means were compared using the Fisher's Least Significant Difference (LSD) test ($p \leq 0.05$) using the Statistical Package for the Social Sciences (SPSS) Version 16.0 for Windows (SPSS Inc., Chicago, IL, USA).

3. Results and discussion

3.1. Proximate composition of fractionated flours

Whole wheat flour had significantly ($p < 0.05$) different proximate composition from the Bambara groundnut flour (Table 1). This was expected, since wheat is a cereal, and Bambara groundnut is a leguminous crop. Protein and carbohydrate were the major components of the two flours, while the ash, fibre, fat and moisture contents were generally low. The protein content (24.56 g/100 g) of Bambara groundnut flour was higher (almost double) than that of whole wheat flour. Legumes generally have higher protein than cereals and tubers, and are also excellent sources of carbohydrate. The proximate composition data in this study is in agreement with previous studies on Bambara groundnut (Falade & Nwajei, 2015; Oyeyinka et al., 2017) and wheat flour (Aranibar et al., 2018; Ocheme, Adedeji, Chinma, Yakubu, & Ajibo, 2018).

The protein content of whole-wheat flour increased by approximately 37% when 20% Bambara groundnut flour was added to it. Fractionation significantly ($p < 0.05$) influenced the composition of the composite flours (Table 1). Generally, fat, protein and ash contents increased, while carbohydrate and fibre contents decreased with a reduction in particle size from 500 μm to 112 μm. The nutrients were randomly distributed among the different fractions and indicate their suitability for various applications. The trend observed in this study with regards to the ash, fat and protein contents after fractionation, is similar to previous reports (Ahmed, Thomas, & Arfat, 2019; Dhen et al., 2016; Sullivan, Engebretson, & Anderson, 1960). However, some authors found the opposite, with protein content decreasing with a reduction in particle size (Ahmed, Al-Attar, & Arfat, 2016; Bressiani et al., 2017; Memon et al., 2020). Differences noted in the effect of particle size on the proximate composition of flours may be attributed to several factors. Firstly, change in composition after fractionation has been suggested to depend on the structure of the endosperm (hard/soft), and type of endosperm cells (peripheral, prismatic or central) (Sullivan et al., 1960). Secondly, variation in the composition of the fractionated flours could be due to the different aperture size of the sieves used in the respective studies. Another plausible reason could be attributed to the milling efficiency with regards to the initial size of the flour and compositional differences in terms of the type of flour may also influence the variation observed. For instance, in this study, the flour used was a composite of whole-wheat (80%) and Bambara groundnut flour (20%) while majority of the studies where protein fractions decreased with a reduction in particle size used only whole-grain wheat flour (Ahmed et al., 2016; Bressiani et al., 2017; Memon et al., 2020).

3.2. Functional properties of flours

Presented in Table 1 are the functional properties of wheat flour, Bambara flour, their composite (unsieved) and the fractionated flours. Wheat flour showed significantly ($p < 0.05$) higher bulk density (BD), swelling index (SI), water absorption capacity (WAC) and oil absorption capacity (OAC) than Bambara groundnut flour. The higher WAC of wheat flour may be due to its higher carbohydrate and fibre contents compared to Bambara groundnut flour (Table 1). Differences in amylose content (Oyeyinka et al., 2015), starch content and granule structure may also explain the variation in the WAC of the flours (Falade and Oyeyinka, 2015). Fractionation did not significantly influence ($p \geq 0.05$) the SI of the flours, but influenced their BD, WAC and OAC. Finer particles were more compact as shown in their high BD. The BD increased with a reduction in particle size, while the SI, WAC and OAC decreased. Ideally, small-sized particles should show an increase in WAC due to an increase in surface area. However, the opposite was the case in this study. It is possible that the higher fibre content of the samples with bigger particles enhanced their water absorption compared to the smaller ones.

Table 1
Proximate composition ((g/100 g) and functional properties fractionated whole-grain wheat flour enriched with Bambara groundnut.

Samples	Moisture	Fat	Protein	Fibre	Ash	[a]CHO	BD (g/mL)	SI	WAC (mL/g)	OAC (mL/g)
Wheat flour	$6.54^{a}\pm0.01$	$2.69^{e}\pm0.01$	$13.67^{g}\pm0.02$	$5.85^{a}\pm0.01$	$1.86^{g}\pm0.01$	$69.39^{a}\pm0.02$	$0.49^{d}\pm0.01$	$0.97^{ab}\pm0.01$	$1.99^{bc}\pm0.01$	$1.30^{a}\pm0.09$
Bambara flour	$5.74^{c}\pm0.02$	$7.93^{a}\pm0.01$	$24.56^{a}\pm0.03$	$2.59^{g}\pm0.07$	$5.04^{a}\pm0.00$	$54.15^{f}\pm0.00$	$0.48^{d}\pm0.00$	$0.94^{c}\pm0.01$	$1.88^{d}\pm0.05$	$1.01^{bc}\pm0.01$
[b]Unsieved	$6.14^{b}\pm0.01$	$3.95^{d}\pm0.02$	$18.66^{e}\pm0.00$	$5.36^{c}\pm0.01$	$4.74^{c}\pm0.01$	$61.15^{e}\pm0.05$	$0.48^{d}\pm0.01$	$0.98^{a}\pm0.00$	$2.02^{b}\pm0.04$	$1.08^{b}\pm0.07$
500 μm	$5.67^{d}\pm0.02$	$4.01^{c}\pm0.00$	$16.75^{f}\pm0.00$	$5.61^{b}\pm0.01$	$3.88^{f}\pm0.00$	$64.09^{b}\pm0.01$	$0.40^{e}\pm0.00$	$0.98^{a}\pm0.01$	$2.25^{a}\pm0.09$	$1.29^{a}\pm0.08$
350 μm	$5.72^{c}\pm0.02$	$3.93^{d}\pm0.04$	$18.97^{d}\pm0.00$	$3.47^{e}\pm0.02$	$4.60^{e}\pm0.00$	$63.31^{c}\pm0.01$	$0.50^{c}\pm0.00$	$0.97^{ab}\pm0.00$	$1.90^{cd}\pm0.10$	$1.03^{bc}\pm0.02$
300 μm	$5.77^{c}\pm0.03$	$4.44^{b}\pm0.02$	$20.06^{c}\pm0.02$	$3.87^{d}\pm0.01$	$4.67^{d}\pm0.00$	$61.19^{de}\pm0.08$	$0.51^{b}\pm0.01$	$0.97^{ab}\pm0.03$	$2.03^{b}\pm0.03$	$0.93^{c}\pm0.08$
112 μm	$5.66^{d}\pm0.03$	$4.47^{b}\pm0.02$	$20.57^{b}\pm0.01$	$3.16^{f}\pm0.00$	$4.87^{b}\pm0.01$	$61.27^{d}\pm0.04$	$0.52^{a}\pm0.00$	$0.96^{b}\pm0.01$	$1.80^{d}\pm0.03$	$1.02^{bc}\pm0.02$

Mean ± S.D. Means with different superscript within the same column are significantly ($p < 0.05$) different.
[a] CHO: Carbohydrate; BD: Bulk density; SI: Swelling index; WAC: Water absorption capacity; OAC: Oil absorption capacity.
[b] Composite of whole wheat (80%) and Bambara groundnut flour (20%).

3.3. Colour of flour and pasta

Bambara groundnut flour ($L^* = 81.67$) was lighter than whole-grain wheat flour ($L^* = 77.85$) and the unsieved ($L^* = 74.13$) composite flour (Table 2). Fractionation of the unsieved flour resulted in flour samples with varying colour attributes (Table 2). Except for the flour from 500 μm sieve aperture size, all the fractionated flours had higher lightness (75.99–83.24) values compared to the unsieved flour (74.13). The higher L* values suggest the presence of fewer amounts of bran or fibre in the flour samples. This is the thrust of the current study, which was to fractionate flours in order to have varying levels of bran or fibre in the flours and to produce pasta of different composition that could be appealing to consumers and also provide the desired level of nutrients.

The colour parameters of the pasta were not significantly ($p \geq 0.05$) affected by flour fractionation as revealed by their L*, a* and b* values, but the L* value increased with a reduction in particle size. The observed increase in L* with reduction in particle size has been previously reported (Ahmed & Al-Attar, 2015; Ahmed et al., 2016) and is suggested to be associated with an increase in surface area that allows more reflection of light (Ahmed & Al-Attar, 2015). Pasta from fractionated flours were lighter, less red and yellower, with a reduction in particle size. Previous studies reported that pasta with a bright yellow colour was the most acceptable by consumers (Biernacka et al., 2017).

The calculated total colour difference (ΔE) values of the pasta samples ranged between 1.33 and 4.71 for pasta prepared from fractionated flour with particle sizes of 350 and 300 μm, respectively (Table 2). Although the ΔE values did not increase progressively with a reduction in particle size, pasta from flour with smaller particle size (112 and 300 μm) showed significantly ($p < 0.05$) higher ΔE than pasta from bigger particle size (350 and 500 μm). The ΔE values were calculated by comparing the colour values (L*, a* and b*) with that of the control pasta that was made without fractionating the flour. Hence, the ΔE results of the pasta indicate that fractionation significantly altered the surface characteristics of the pasta with greater effect observed in pasta made from flour with smaller particles.

3.4. Proximate composition of pasta

The proximate composition of pasta prepared from unsieved and fractionated flours enriched with Bambara groundnut flour are presented in Table 3. Regardless of fractionation, protein (16.12–20.63 g/100 g) and carbohydrate (61.15–69.59 g/100 g) were the major components of the pasta samples. Fractionation significantly influenced the composition of the pasta samples. For instance, the fat, protein and ash contents of pasta from finer particles (112–350 μm) were significantly lower than values recorded for pasta from coarse flour with a particle size of 500 μm. Among pasta from fractionated flours, the fibre content was highest for pasta produced from flour with a particle size of 500 μm. This is in agreement with the flour composition result (Table 1). Compared with pasta from the unsieved enriched flour, the protein content of the pasta samples increased by approximately 2.7, 16 and 17%, for pasta produced from fractionated flours with particle sizes of 350, 300 and 112 μm, respectively. Although the addition of Bambara groundnut flour resulted in a significant increase in the protein content of the whole-grain wheat flour (Table 1), the increase in protein in the pasta after fractionation could be due to re-distribution of the various components within the flour during fractionation. The enrichment of pasta using different legumes has earlier been reported (Padalino et al., 2014; Wójtowicz & Mościcki, 2014). The protein contents of enriched pasta in this study were higher than values reported for pasta enriched with 5–15% partially-deoiled chia flour (11.04–12.66 g/100 g) (Aranibar et al., 2018), 5–15% pea flour (15.29–16.16 g/100 g) (Padalino et al., 2014) and 1–4% parsley leaf (14.59–17.41 g/100 g) (Sęczyk, Świeca, Gawlik-Dziki, Luty, & Czyż, 2016). The variations in the amount

Table 2
Colour of flour and pasta from fractionated whole-grain wheat flour enriched with Bambara groundnut.

Sample	Flour				Pasta			
	L[a]	a[a]	b[a]	ΔE	L[a]	a[a]	b[a]	ΔE
Wheat flour	$77.85^{c}\pm1.55$	$-1.45^{a}\pm0.15$	$18.72^{cd}\pm0.88$	$4.24^{cd}\pm1.41$	_	_	_	_
Bambara flour	$81.67^{ab}\pm0.85$	$-2.89^{b}\pm0.23$	$20.26^{bc}\pm1.42$	$7.75^{b}\pm1.14$	_	_	_	_
[a]Unsieved	$74.13^{d}\pm1.66$	$-3.28^{b}\pm0.37$	$18.78^{cd}\pm0.85$	0	$51.79^{a}\pm2.01$	$-4.99^{a}\pm1.26$	$13.57^{b}\pm1.80$	0
500 μm	$68.09^{e}\pm1.12$	$-2.58^{b}\pm0.34$	$17.99^{d}\pm0.56$	$6.16^{bc}\pm1.16$	$52.11^{a}\pm1.09$	$-4.74^{a}\pm0.86$	$13.57^{b}\pm0.96$	$1.46^{b}\pm0.46$
350 μm	$75.99^{cd}\pm1.99$	$-2.81^{b}\pm0.67$	$18.99^{bcd}\pm1.66$	$2.43^{d}\pm2.04$	$52.28^{a}\pm0.58$	$-4.21^{a}\pm0.53$	$14.46^{ab}\pm0.55$	$1.33^{b}\pm0.86$
300 μm	$80.69^{b}\pm1.47$	$-3.11^{b}\pm0.30$	$20.51^{b}\pm0.74$	$6.79^{b}\pm1.58$	$54.78^{a}\pm2.61$	$-3.48^{a}\pm2.61$	$16.62^{a}\pm2.28$	$4.71^{a}\pm3.43$
112 μm	$83.24^{a}\pm0.62$	$-3.27^{b}\pm0.66$	$22.35^{a}\pm1.01$	$9.81^{a}\pm0.89$	$54.19^{ab}\pm2.82$	$-4.39^{a}\pm1.36$	$15.45^{ab}\pm2.08$	$4.02^{ab}\pm2.32$

Mean ± S.D. Means with different superscript within the same column are significantly ($p < 0.05$) different.
[a] Composite of whole wheat (80%) and Bambara groundnut flour (20%) ΔE: Total colour difference.

Table 3
Proximate (g/100 g), mineral composition (mg/kg) and total phenolic content (mg GAE/g) of pasta from fractionated whole-grain wheat flour enriched with Bambara groundnut.

Samples	[b]Unsieved	500 μm	350 μm	300 μm	112 μm
Moisture	4.26[a] ± 0.02	3.64[c] ± 0.00	3.62[c] ± 0.01	4.27[a] ± 0.03	4.02[b] ± 0.01
Fat	2.65[c] ± 0.01	2.12[e] ± 0.01	3.58[a] ± 0.01	3.23[b] ± 0.01	2.39[d] ± 0.01
Protein	17.64[d] ± 0.00	16.12[e] ± 0.03	18.13[c] ± 0.01	20.46[b] ± 0.01	20.63[a] ± 0.01
Fibre	5.51[a] ± 0.01	4.58[b] ± 0.01	3.49[d] ± 0.00	4.01[c] ± 0.01	3.21[e] ± 0.00
Ash	4.59[b] ± 0.01	3.94[d] ± 0.01	4.48[c] ± 0.01	4.60[b] ± 0.00	4.63[a] ± 0.01
[a]CHO	61.15[e] ± 0.05	69.59[a] ± 0.05	66.69[b] ± 0.02	63.42[d] ± 0.01	65.12[c] ± 0.03
Calcium	238.50[ab] ± 4.95	223.50[b] ± 3.54	230.50[b] ± 4.95	254.00[a] ± 2.83	237.50[ab] ± 13.44
Magnesium	184.50[c] ± 0.71	191.00[a] ± 0.00	192.00[a] ± 0.00	188.50[b] ± 0.71	170.00[d] ± 0.00
Potassium	248.00[a] ± 0.05	247.50[a] ± 0.71	248.50[a] ± 4.95	249.00[a] ± 0.00	246.50[a] ± 3.54
Zinc	1.00[a] ± 0.01	1.00[a] ± 0.00	1.00[a] ± 0.00	2.00[a] ± 0.00	1.00[a] ± 0.00
Fe	8.50[c] ± 0.71	3.50[e] ± 0.71	10.00[b] ± 0.00	13.00[a] ± 0.00	7.00[d] ± 0.00
TPC	0.65[c] ± 0.01	0.86[a] ± 0.01	0.73[b] ± 0.02	0.55[d] ± 0.01	0.39[e] ± 0.01

Mean ± S.D. Means with different superscript within the same column are significantly ($p < 0.05$) different.
[a] CHO: Carbohydrate; GAE: Gallic acid equivalents; TPC: Total phenolic content.
[b] Composite of whole wheat (80%) and Bambara groundnut flour (20%).

of protein is due to the varying levels of the ingredient added in the respective studies. In the current study, the flour used in pasta production was enriched with 20% Bambara groundnut flour, which is higher than the levels used by other authors.

3.5. Mineral composition

Potassium (246.50–249.00 mg/kg), calcium (223.50–254.00 mg/kg) and magnesium (184.50–192.00 mg/kg) were the major mineral element in the whole-grain wheat pasta and pasta made from fractionated-enriched flours, while zinc (1.00–2.00 mg/kg) and iron (3.50–13.00 mg/kg) are present in relatively small quantities (Table 3). High levels of potassium in human diet is well-known to protect against life-threatening diseases cardiac dysfunctions and osteoporosis (Lewu, Adebola, & Afolayan, 2010). Previous studies also found potassium, calcium and magnesium as major minerals in pasta enriched with potato peel autohydrolysis extract (Fradinho et al., 2020), whole grain pasta (Vignola et al., 2018b) and pasta containing buckwheat bran flour (Manthey and Hall, 2007).

Except for magnesium and iron contents, which were affected by fractionation, the potassium, zinc and calcium contents of the pasta were very similar. Pasta from flour with finer particle size (112–350 μm) showed significantly ($p < 0.05$) higher iron contents (7.00–13.00 mg/kg) compared to pasta (3.50 mg/kg) from flour with a larger particle size (500 μm). Of the pasta samples prepared in this study, pasta made from finer particles seems to provide the recommended dietary allowance (RDA) for all age groups of men and postmenopausal women, which is 8 mg/d and may also supply the needed iron of 12 mg/d for women (FNB, 2001). The added Bambara groundnut flour may have contributed to the mineral content of the pasta since the Bambara flour showed higher (3 times) ash than the whole-grain wheat flour (Table 1).

3.6. Total phenolic content and antioxidant properties of pasta

The total phenolic content (TPC) of the pasta samples expressed as milligrams of gallic acid equivalent per gram varied between 0.39 and 0.86 mg GAE/g for pasta made from fractionated flour with a particle size of 112 μm and 500 μm, respectively (Table 3). Pasta from unfractionated flour showed a TPC value of 0.65 mg GAE/g, which is significantly ($p < 0.05$) higher than pastas made from 112 μm to 300 μm flours, but significantly lower than those of 350 μm and 500 μm. The TPC of the pasta from fractionated flours decreased with a reduction in particle size, indicating that the fractionation process significantly influenced the TPC of the pasta samples. The higher TPC of pastas with larger particle size were expected since the flours from which they were prepared (Table 1) and pasta (Table 3) had higher fibre contents. Grain outer membranes, especially the bran fraction are reportedly richer in phenolic acids than the endosperm (Vignola et al., 2018a) and may also contain carotenoids which contributes significantly to the final antioxidant activities (Lv et al., 2012). Memon et al. (2020) studied the impact of flour particle size on nutrient and phenolic acid composition of commercial wheat varieties and found that flour samples with the smallest particle size fractions showed the lowest quantity of total phenolic acids. Hirawan et al. (2010) reported varying TPC values (0.773–1.529 mg ferulic acid/g) for commercial and regular whole-wheat pasta.

Antioxidant properties of the pasta samples were assessed using FRAP (Fig. 2A) and DPPH assays (Fig. 2B). Generally, the FRAP and DPPH activities of the pasta samples increase with increasing concentration of the extracts. Fractionation significantly ($p < 0.05$) affected the FRAP and DPPH radical scavenging activities of the pasta samples. The FRAP and DPPH activities of the pasta samples significantly ($p < 0.05$) increased with a reduction in particle size. Among the pasta produced from fractionated flour samples, pasta prepared from flour with a particle size of 112 μm displayed the highest antioxidant activities (FRAP = 58.10%; DPPH = 92.43%), while pasta prepared from flour with a particle size of 500 μm had the lowest (FRAP = 13.87%; DPPH = 41.51%). The antioxidant activities of the pasta followed the order 112 μm > 350 μm > 300 μm > 500 μm for both FRAP and DPPH assays. Ahmed et al. (2019) reported that finer particles with increased surface area enhances the release of phenolic compounds embedded in the fibrous matrix due to a higher mass transfer rate. The FRAP and DPPH assay data were not in agreement with the TPC since pasta from flour with smaller particle size showed lower TPC value. The observed trend suggests that not all the phenolics are contributing to the antioxidant activities of the pasta. Hirawan et al. (2010) also did not find any correlation between the TPC and the overall antioxidant activity (DPPH radical scavenging activity and ORAC values) of the regular and whole wheat spaghetti. According to these authors, the variation may be due to the underlying mechanisms of the assays employed and also to the varying degrees of reactivity of several components in the extracts. Furthermore, the inclusion of Bambara groundnut flour at 20% level to whole-wheat flour may also have contributed to the variation in the TPC of the fractionated flours. Whole Bambara grains are rich sources of antioxidants (Abdualrahman et al., 2019; Ademiluyi & Oboh, 2011; Oyeyinka et al., 2017) including their protein hydrolysates and membrane ultrafiltration fractions (Arise et al., 2016).

3.7. Cooking properties

Fractionation of the composite flour generally altered the cooking properties of the pasta (Table 4). There was a significant ($p < 0.05$) reduction in the OCT of pasta (average 6.55 min) from the fractionated flours compared to the control pasta made from unfractionated flour (unsieved), indicating less preparation time. Fractionated flours with bigger particle size seemed to have lower OCT, suggesting the influence of bigger particles such as fibres and germ in providing a path for ease of water absorption. Previous research associated reduced cooking time to

Table 4
Cooking properties of pasta from fractionated whole-grain wheat flour enriched with Bambara groundnut.

Samples	Optimum cooking time (min)	Swelling index (g water/g dry pasta)	Water absorption index (g/100 g)	Cooking loss (g/100 g)	Weight increase index (g/100 g)
[a]Unsieved	8:23^{a} ± 00:01	1.89^{b} ± 0.06	138.50^{bc} ± 6.36	6.95^{ab} ± 1.34	243.00^{b} ± 0.00
500 μm	5:02^{e} ± 00:03	2.56^{a} ± 0.09	208.00^{a} ± 0.00	6.50^{ab} ± 2.12	308.00^{a} ± 0.00
350 μm	6:23^{d} ± 00:00	1.56^{c} ± 0.08	125.50^{c} ± 0.70	8.45^{a} ± 0.64	226.00^{c} ± 1.41
300 μm	7:33^{c} ± 00:02	1.82^{b} ± 0.12	150.00^{b} ± 2.83	7.90^{ab} ± 1.41	250.00^{b} ± 2.83
112 μm	7:45^{b} ± 00:00	1.57^{c} ± 0.39	139.50^{bc} ± 10.61	4.50^{b} ± 0.71	239.50^{b} ± 10.61

Mean ± S.D. Means with different superscript within the same column are significantly ($p < 0.05$) different.
[a] Composite of whole wheat (80%) and Bambara groundnut flour (20%).

the presence of bran and germ particles, which causes physical disruption of the gluten matrix and provides a path for water absorption (Kaur et al., 2012; Manthey & Schorno, 2002). Differences in the rate of water penetration to the core of the pasta due to the absence of continuity in the protein-starch network has also been suggested to influence cooking time (El-Sohaimy et al., 2020; Padalino et al., 2014). The OCT recorded in this study is much lower than values (10–11.15 min) reported for semolina spaghetti enriched with pea flours (Padalino et al., 2014), but similar to values reported for pasta enriched with flaxseed flour (6.05–7.10 min) and flaxseed cake (5.82–6.10 min) (Kowalczewski et al., 2019) as well as pasta (5.30–6.00 min) enriched with chick pea flour and protein isolate (El-Sohaimy et al., 2020).

Fractionation similarly affected the swelling index (SI), water absorption index (WAI), and weight increase index (WII). In general, pasta from finer particles (112–350 μm) had reduced SI, WAI and WII compared to pasta produced from coarse flour (500 μm). The lower SI in pasta from finer particles may be due to the presence of less amounts of fiber and carbohydrate (Table 1) including starch, which possibly resulted in the lower water absorption ability. Starch and fibre are known to absorb water to a greater extent than proteins and varied amount of these components have been shown by other researchers to influence the water absorption capacities of food (Ahmed et al., 2016; Padalino et al., 2014). Padalino et al. (2014) enriched durum wheat spaghetti with pea flour and found that the water absorption significantly decreased as the pea flour was incorporated into the pasta. According to their report the protein in the pasta matrix may link to most of the water molecules leaving less water to swell the starch phase during cooking. Thus, the high protein in the pasta (Table 3) from flours with finer particles may also explain the decreased WAI of the pasta samples.

The cooking loss (CL) values, which indicate the amount of dry matter lost into the cooking water, of the pasta samples were not significantly affected by fractionation (Table 4). Pasta made from the finest flour (112 μm) had the lowest CL value of 4.50 g/100 g, while the sample made from flour with a particle size of 300 μm had the highest CL value (8.45 g/100 g). High cooking loss is suggested to result from amylose leaching and solubilisation of some salt soluble globulins (Petitot, Barron, Marie-Morel, & Micard, 2010; Petitot, Boyer, Minier, & Micard, 2010). The lower the CL the better for pasta products, because the CL is an important parameter used to predict pasta cooking quality (Özyurt et al., 2015). The CL values (4.50–8.45 g/100 g) in this study, were within the range (4.27–13.61 g/100 g) reported for pasta enriched with legume flours (Aranibar et al., 2018; Padalino et al., 2014; Petitot et al., 2010a, 2010b). With the exception of the pasta prepared using flours with a particle size of 300 μm, all the pasta samples had CL values below the technologically acceptable limit (≤8%) previously reported (Özyurt et al., 2015).

3.8. Appearance and sensory properties of pasta

Obvious differences were observed in the appearance of the pasta before and after cooking (Fig. 1) and these differences could be due to variation in their composition (Table 1) and particle size. Furthermore, pasta appearance appears less defective with a reduction in particle size of the flour used. Pasta from finer particles showed lighter appearance indicating the influence of particles size on the colour of the pasta. Compared with pasta samples from fractionated flours, pasta from flour with a particle size of 500 μm appeared darker, and this observation, is in agreement with the objective colour result for both flour and pasta (Table 2). The darker appearance of the pasta from flour with a particle size of 500 μm was due to its high fibre content (Tables 1 and 3). Earlier studies reported that bran particles physically interfere with dough development, resulting in weak dough properties (Kaur et al., 2012) and poor sensory properties of pasta products (Steglich et al., 2015; Vignola et al., 2018a). The surface characteristics of the pasta may also have been influenced by the impact of a gluten-free Bambara groundnut flour (20%) that was added to the fractionated wheat flours.

Fractionation of the flours resulted in significant ($p < 0.05$) differences in the sensory attributes of the resulting pastas (Table 5). Pasta from flours with finer particles (112–350 μm) generally had higher ratings in colour, taste, mouthfeel and overall acceptability compared with the pasta from 500 μm flour sample. The ratings for pasta made from flour with 300 and 112 μm were very similar in all the sensory attributes assessed and both had higher ratings in overall acceptability compared to all the pasta samples. The lower ratings observed for pasta made from coarse sample (500 μm) may be attributed to its higher fibre content (Table 1), which obviously imparted its appearance before and after cooking (Fig. 1). The dark colour of pasta from coarse flour samples, especially from whole-grain wheat has been a concern for consumers over the years (Aranibar et al., 2018). Thus, improving pasta appearance while ensuring the delivery of healthier products will be a welcome development. From the result of sensory evaluation, it appears that the finer the particles, the less defective was the pasta appearance. Findings by earlier researchers noted that the particle size distribution of flour samples play an important role on its properties and determine the quality of resulting products (Bressiani et al., 2017).

4. Conclusion

This study determined the quality of pasta made from fractionated whole-grain wheat enriched with Bambara groundnut flour. The addition of Bambara groundnut to whole-wheat flour increased the protein content by approximately 37%. Pasta from finer particles are rich in fat, protein and ash, but low in carbohydrate and fibre compared to pasta made from larger particles. Pasta colour, protein, fibre and antioxidant properties improved with fractionation. The sensory results further showed that fractionation of whole-grain wheat flour can produce pasta with improved appearance and sensory properties. Fractionation is therefore a promising technique to produce pasta with fairly good antioxidant potentials and high level of protein, fibre, calcium, potassium, magnesium and iron to improve the health of pasta-loving individuals. This study has demonstrated that fractionation of enriched flour can produce pasta with different beneficial health and improved sensory properties. Future studies may be required to determine the in-vitro digestibility and storage stability as well as the impact of cooking on the nutritional properties of the pasta for the possibility of commercialization.

CRediT authorship contribution statement

Samson A. Oyeyinka: Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing, analyses of data, writing of original draft and revision of reviewed manuscript. **Adetutu A. Adepegba:** Data curation, Formal analysis, analyses of data.

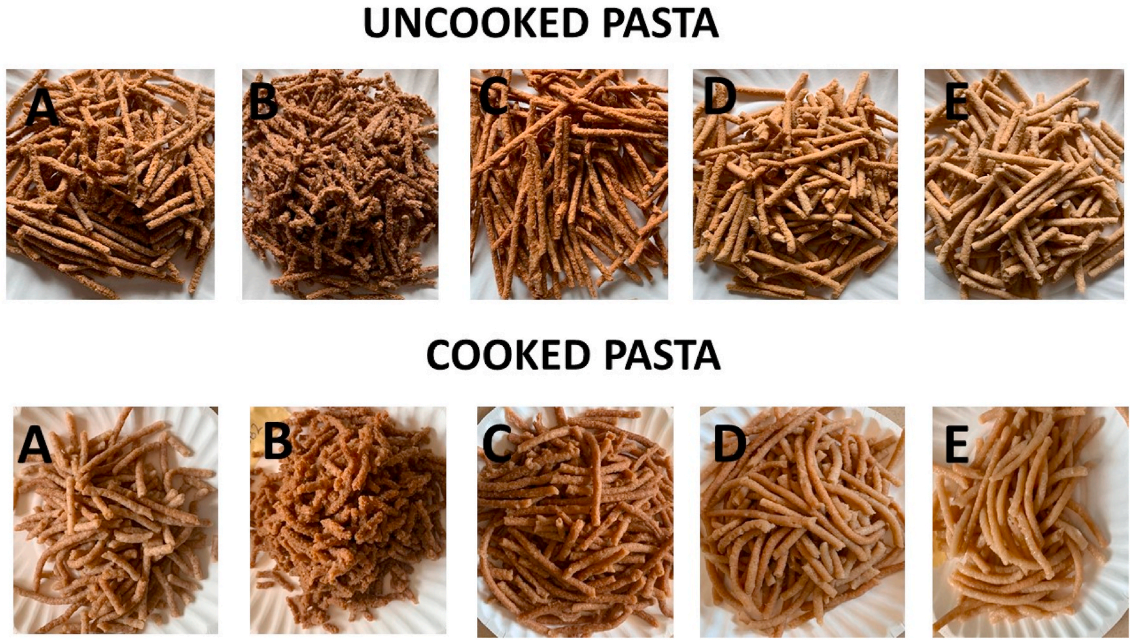

Fig. 1. Appearance of uncooked and cooked pasta from fractionated whole-grain wheat enriched with Bambara groundnut. A: Pasta from unsieved flour (control); B: Pasta from fractionated flour (500 μm); C: Pasta from fractionated flour (350 μm). D: Pasta from fractionated flour (300 μm); E: Pasta from fractionated flour (112 μm) *Composite of whole wheat (80%) and Bambara groundnut flour (20%).

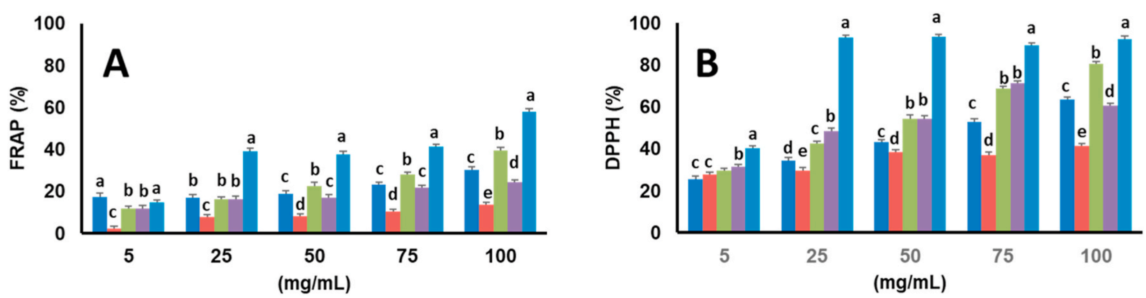

Fig. 2. Antioxidant capacities of pasta from fractionated whole-grain wheat enriched with Bambara groundnut. A: FRAP; B: DPPH.

Table 5
Mean sensory scores of pastas from fractionated whole-grain wheat flour enriched with Bambara groundnut.

samples	Colour	Aroma	Taste	Mouth feel	Overall acceptability
[a]Unsieved	$6.56^c \pm 0.89$	$6.26^a \pm 1.75$	$6.53^b \pm 1.43$	$5.42^b \pm 1.78$	$6.65^b \pm 1.51$
500 μm	$5.23^d \pm 1.86$	$6.39^a \pm 1.39$	$4.74^c \pm 1.69$	$4.28^c \pm 2.05$	$5.51^c \pm 1.73$
350 μm	$6.88^{bc} \pm 1.47$	$5.72^b \pm 1.04$	$6.05^b \pm 1.52$	$5.77^b \pm 1.97$	$6.30^b \pm 1.66$
300 μm	$7.46^a \pm 1.19$	$6.77^a \pm 0.92$	$7.33^a \pm 1.16$	$7.07^a \pm 1.24$	$7.68^a \pm 0.95$
112 μm	$7.21^{ab} \pm 1.05$	$6.65^a \pm 1.19$	$7.07^a \pm 0.96$	$7.37^a \pm 1.03$	$7.63^a \pm 0.88$

Mean ± S.D. Means with different superscript within the same column are significantly ($p < 0.05$) different.
[a] Composite of whole wheat (80%) and Bambara groundnut flour (20%).

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Declaration of competing interest

All authors declare that there are no conflicts of interest.

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