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Optimization Of Proximate Compositions, Mineral Profiles, Physico-Chemical And Anti-Nutritional Properties Of Wheat, Pigeon-Pea And Cassava-Cortex Flour Blends For Snack Production

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Abstract

This study aimed at investigating the influence of varying proportions of wheat, pigeon pea and cassava cortex flours on proximate composition, anti-nutritional, functional and pasting properties and mineral profiles of their blends as potential ingredients for snack production. Blends were optimized for protein (10-20%) and fibre (3-5%), using Design Expert Version 6.0.8. and variables wheat flour (55-65%), pigeon-pea flour (16-25%) and cassava-cortex flour (11-20%). Blends generated were evaluated for protein and crude fibre contents and three blends with highest protein and fibre contents were evaluated for proximate and anti-nutrition compositions, functional and pasting properties and phytate/oxalate-mineral molar ratios and mineral profiles including mineral safety index of selected minerals. Protein and fibre contents of blends increased as proportions of pigeon pea and cassava cortex increased, with sample WPC-1 having highest protein content (16.30%) and sample WPC-3 having the highest fibre content (4.05%). Samples with higher proportion of pigeon pea flour (WPC-1 and WPC-3) had significantly ($p<0.05$) higher water and oil absorption and breakdown viscosities, significantly ($p<0.05$) lower swelling and water solubility and setback viscosities. There was significant difference ($p<0.05$) among samples for Oxa:Ca, and between Phy:Zn and [Ca]:[Phy]/[Zn] molar ratios, between which there was also strong positive correlation ($r = 0.99$), but no significant difference for Phy:Zn, while values for both parameters and phytate and oxalate contents for all samples were within safe thresholds. There was significant ($p<0.05$) differences between the mean calculated and standard MSI values for all the minerals, except Na, while sample WPC-3 had the highest calculated MSI values for all minerals measured. Varying proportions of wheat, pigeon pea and cassava cortex flours had significant ($p<0.05$) effects on proximate composition, physico-chemical properties and mineral profiles of their blends.

Keywords: Cassava-cortex flour; flour blends; mineral profiles; physico-chemical properties; snack; wheat flour

Introduction

Snacks constitute a group of convenience foods, which are often smaller than a regular meal and generally eaten between meals (Lasekan and Akintola, 2000). In addition to their convenience, snack foods also offer certain advantages including wide consumption, relatively long shelf life, good eating quality, high palatability and wide acceptability by most consumers (Osundahunsi *et al.*, 2010). Conventional snack foods are produced exclusive from cereal-based flours, especially wheat, which contains mainly carbohydrate with little amounts of important nutrients like protein, fibre and minerals (Olagunju, 2017). This is because, white flour from milling of wheat, is deficient in useful nutrients like fibre, vitamins and minerals contained in the germ, bran and aleurone parts of the wheat grain which are normally removed during milling. Such flour is also generally low in protein (Akinjayeju, 2015). Despite this, snacking has become so popular that snacks are now taken as major meals for a large number of people, especially those who eat on the go (Olagunju, 2017). It therefore becomes necessary to improve the nutritional value of such products by incorporating other plant materials high in protein, fibre and minerals in their formulations. High protein, high fibre diets are associated with fewer digestive disorders, reduced rate of colon cancer, better blood-sugar control, and lower blood-cholesterol levels (Lairon *et al.*, 2005). Many efforts have been made by researchers to improve the nutritional value of bakery products including snacks by incorporating protein and fibre-rich plant sources into wheat flour (Awolu et al., 2015; Ogunmodimu et al., 2015; Akinjayeju and Adekoya, 2018).

Legumes constitute excellent addition to cereal flours in the production of bakery products due to their high dietary proteins, minerals, the B-vitamins and lysine and tryptophan, the two limiting essential amino acids in cereal grains, including wheat (Okoye and Okaka, 2009). Pigeon pea *(Cajanus cajan)* is considered the fifth ranked legume grain in terms of food uses, as well its nutritional, economical and medicinal importance in different parts of the world including Nigeria

(Rachie and Wurster, 2007). It is credited with high protein and fibre contents and good source of minerals including calcium, phosphorus, magnesium, iron, and essential amino acid lysine (Amarteifio et al., 2002, Akubor, 2017). Despite its high nutritional and economic importance, pigeon pea could be considered an under-utilized legume in Nigeria, in terms of food and industrial uses. Its use as extender of cereal flours for bakery products could be explored in view of its potential benefits. Cassava cortex, commonly called the peel, is the whitish thick layer underneath the thin brown bark or periderm, and consists of about 10-12% of the root weight (Alves, 2002). Cassava cortex is reported to contain 5–15% of crude fibre (Wheatley and Chizel, 1993), which makes it a potential excellent source of dietary fibre for humans. The objective of this study was to evaluate the effects of varying proportions of wheat, pigeon pea and cassava cortex flours on some physico-chemical properties, proximate and anti-nutritional compositions, as well as mineral bio-availability and profiles of their blends, as potential ingredient for snack production, using response surface methodology.

Materials And Methods

Materials and sources

The materials used for this research study were wheat flour (*Triticum spp)*, pigeon pea (*Cajanus cajan*) and cassava (*Manihot spp*) cortex. Wheat flour and pigeon pea were purchased from Oyingbo Retail Market on Lagos Mainland, while the cassava cortex was purchased from a local cassava processing market, Abule Ijesha, on the outskirt of Lagos, Nigeria.

Preparation of samples

Wheat flour was sieved using a sieve of mesh size 212µm and packaged in a high-density polyethylene bag and stored in a cool, moisture-free environment for further use.

Pigeon pea was produced using a slightly modified method of Akubor (2017). The pigeon pea seeds were hydrated in cold water (30±1.5°C) for 60mins, de-hulled manually, dried in a cabinet dryer (Carlisle CA2 5DU, Mitchel Dryers Ltd, England, 3695-010), followed by milling into flour using a grinding hammer mill (Type S/03 7.5HP, Petrel Limited, Birmingham England, 2121A). The flour was sieved in a sieve of mesh size 212µm, packaged in a high-density polyethylene bag and stored in a cool dry environment until used.

Fresh cassava peels were sorted to remove dirt and the white cortex was seperated from the brown outer covering. The cortex was washed and soaked in cold water and allowed to ferment for 72 hours, followed by drying an oven (Macadams Deck Oven, MM02 - 01023- 07/15, MB805) at 65°C for 8 hours. The dried cortex was milled in a locally-fabricated attrition mill. The flour obtained was packaged in a high-polyethylene bag and stored in a cool, dry place for further use.

The flour blends were obtained using D-Optimal model of Mixture Design of Design Expert Version 6.0.8. The design was based on the optimization of protein from pigeon pea flour and fibre from cassava cortex flour. The variables used were; wheat flour (55-65%), pigeon pea flour (16-25%) and cassava cortex flour (11-20%), which targeted protein and fibre contents of 10-20% and 3-5% in the final product respectively. The 14 blends were generated were evaluated for protein and fibre contents and three blends with the highest protein and fibre contents were selected and for further studies.

Determination of protein and fibre contents of blends and proximate compositions of selected samples

Protein and fibre contents of blends generated by Design Expert and proximate composition of selected blends were determined using standard AOAC (2005). Carbohydrate content was obtained by difference and results expressed on dry weight basis, except for moisture.

Determination of functional properties of samples

Loose bulk density was determined as described by Arisa et al. (2013). Water absorption capacity, swelling power and solubility index of each flour sample were determined using the methods described by (Falade and Okafor, 2015), while reconstitution index was determined by the method of Egounlety and Syarief (1992).

Determination of pasting properties of samples

Pasting properties of the flour samples were determined using the Rapid Visco Analyzer (RVA), and the curves obtained were used to obtain the peak viscosity, trough viscosity, final viscosity, breakdown, setback viscosity, peak time and pasting temperature (Newport Scientific, 1998).

Determination of anti-nutritional factors, selected minerals and molar ratios

Phytate and protease inhibitor were determined using the standard AOAC (2005) methods, while total phenols, oxalate and hydrogen cyanide were determined using methods of Onwuka (2005). Oxalate-calcium and Phytate-mineral molar ratios for calcium, iron and zinc for each flour sample were determined using the method of Norhaizan and Nor Faizadatul Ain (2009). The amount of phytate and each mineral was divided by their respective atomic weight, (phytate = 660g/mol, Oxalate = 88, Fe = 56g/mol, Zn = 65g/mol, Ca = 40g/mol) and the phytate-mineral molar ratio obtained by dividing the mole of phytate with the mole of the respective minerals, while mineral-mineral, [Ca] [Phy]/[Zn] and [K:Ca + Mg)] milli-equivalent ratios were calculated according to Adeyeye et al. (2012)

Calculation of Mineral Safety Index

Mineral safety index (MSI) of samples for Fe, Ca, P, Mg, Zn and Na were calculated using the method described by Watts (2010), (equation 2). The standard MSI values for the elements are, Na (4.8), Mg (15), P (10), Ca (10), Fe (6.7) and Zn (Adeyeye et al., 2012).

Statistical Analysis

Data were collected in triplicates and analyzed using the IBM SPSS version 23 (SPSS, 2015) Fand results expressed as mean ± s.d. Significant difference between means was determined using the one-way analysis of Variance (ANOVA),

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while means were separated using the New Duncan Multiple Range Test (NDMRT) at 0.05.

Results And Discussion

Protein and fibre contents of blends and proximate compositions and energy values of samples

Protein and crude fibre contents of the blends obtained through optimization by response surface methodology are presented in Table 1, while Table 2 shows the proximate compositions of the selected flour samples. These results showed increased protein and fibre contents in blends with higher proportions of pigeon pea and cassava cortex flours, due to the high protein content of pigeon pea (Okparah and Mammah, 2001, Akubor, 2017), and high fibre content in cassava cortex (Ojediran et al, 2015, Idugboe et al., 2017) respectively. Pigeon pea flour have been used to enhance the protein content of composite of unripe cooking banana, pigeon pea, and sweet potato flours (Ohizua et al., 2017).

Table 1: Protein and fibre contents of blends of wheat, pigeon pea and cassava cortex flours

Experimental Runs	Wheat Flour	Pigeon Pea Flour	Cassava Cortex Four	Protein Content	Crude fibre content
1	59.50	25.00	15.50	13.22	3.05
2	63.55	18.60	17.85	12.36	2.66
3	64.00	25.00	11.00	13.53	2.39
4	58.80	23.10	18.10	12.93	3.14
5	63.55	22.85	13.60	13.12	2.63
6	59.50	20.50	20.00	12.42	3.29
7	65.00	20.00	15.00	12.71	2.72
8	55.00	25.00	20.00	13.12	3.40
9	64.00	16.00	20.00	11.94	3.19
10	62.60	21.20	16.20	12.76	2.88
11	55.00	25.00	20.00	13.05	3.40
12	59.50	20.50	20.00	12.45	3.30
13	64.00	16.00	20.00	11.90	3.21
14	64.00	25.00	11.00	13.53	2.42

Table 2: Proximate composition of flour blends from wheat, pigeon pea and cassava cortex

Parameters/Samples	WCP-1	WPC-2	WPC-3	WHT
Moisture content (%)	9.25 ± 0.01[d]	9.76 ± 0.39[c]	11.30 ± 0.62[a]	10.16 ± 0.12[b]
Crude protein (%)	16.30 ± 0.03[a]	14.65 ± 0.03[c]	15.09± 0.02[b]	13.47 ± 0.02[d]
Crude fat (%)	1.50 ± 0.03[ab]	1.65 ± 0.05[a]	1.55 ± 0.03[a]	1.38 ± 0.03[c]
Total ash (%)	2.63± 0.05[c]	2.95 ± 0.03[b]	2.89 ± 0.02[a]	1.00 ± 0.02[d]
Crude fibre (%)	3.48± 0.03[c]	3.32 ± 0.05[b]	4.05 ± 0.07[a]	1.36 ±0.07[d]
Carbohydrate (%)	76.09 ± 0.03[c]	77.43 ± 0.14[b]	76.42 ± 0.08[d]	82.79 ± 0.28[a]
Energy value (kJ)	1626.13 ± 0.20[b]	1619.31 ± 0.15[c]	1602.14 ± 0.24[b]	1687.48 ± 0.35[a]

Values are Means ± s.d. of triplicate determinations expressed on dry-weight basis except moisture Means of similar superscripts along rows are not significantly different (p > 0.05)
WPC-1: = 59.50 WHF, 25.00 PPF, 15.50 CCF
WPC-2: = 58.80 WHF, 23.10 PPF, 18.10 CCF
WPC-3: = 55.00 WHF, 25.00 PPF, 20.00 CCF
WHT = 100% Wheat flour
WHF= Wheat flour, PPF= Pigeon pea flour, CCF= Cassava cortex flour.

As Table 1 shows, the three blends selected for further studies are those with the highest protein and fibre contents, which are RUNS 1(59.50:25.00:15.50), RUN 4 (58.80:23.10:18.10) and RUN 8 (55.00:25.00:20.00) wheat:pigeon pea:cassava cortex flours, and are coded WPC-1, WPC-2 and WPC-3 respectively. The high protein and fibre contents of the blends will be beneficial to the consumers. Protein is an important nutrient for the human body, where it performs many functions like tissue repairs, body building (Akinjayeju 2015), while pigeon pea protein has been reported to contain all essential amino acids for adult humans (Anuonye et al., 2012, Akubor, 2017). Regular consumption of high-fibre diets have been reported to reduce constipation, blood glucose level and certain degenerative diseases (Anderson et al., 2009, Akinjayeju, 2019). There were significant differences ($p<0.05$) in the proximate compositions of the flour samples. The moisture contents are low enough for good storage to confer microbiological stability on the flours, especially from moldiness (Elleuch et al. 2011). The low fat contents of the flour blends are in agreement with low fat contents previously reported for most cereals and legumes, including wheat and pigeon pea (Kavitha and Parimalavalli, 2014, Talari and Devindra, 2018, Akubor, 2017, Ocheme et al., 2018). These low fat contents will neither pre-dispose the flour samples to fat oxidation and rancid conditions during storage (Awolu et al., 2015), nor contribute to the energy density of the flour samples (Kavitha and Parimalavalli, 2014). Carbohydrate contents of the flour samples reduced slightly but significantly ($p<0.05$) as proportion of wheat flour reduced relative to other two components in the blends, namely pigeon pea and cassava cortex flours, but particularly pigeon pea. The slightly but significantly ($p< 0.05$) higher carbohydrate content of sample WPC-3 (55% wheat flour) compared to sample WPC-1 (59.5% wheat flour) is most probably due to its higher proportion of cassava cortex flour (20%) compared to that of sample WPC-1 (15.5%), due to high carbohydrate content of cassava peels of which the cortex is a high proportion of (Ojediran et al., 2015, Otache et al., 2017). The high carbohydrate contents of the flour samples enhanced their energy density, which is in agreement with the observation of Awolu et al. (2015) that carbohydrate content and energy content of a food product are directly proportional.

Functional properties of selected blends

The functional properties of the flour blends are presented in Table 3, which showed significant differences ($p<0.05$) among the flour samples for most parameters. Functional properties are those physico-chemical characteristics which often affect how food systems function especially during processing and storage (Akubor et al., 2000). The bulk densities of the flour samples, which measures how dense a flour sample is, ranged between 0.78g.cm3 for samples PWC-1 and PWC-2 to 0.86g/cm3 for sampleWPC-3. The slightly higher bulk density of sample WPC-3 was most probably due to its slightly higher moisture content and higher composition of cassava cortex flour, which resulted in higher fibre content. The bulk densities are higher that values obtained for blends of quality protein maize, soy cake and whole millet flours reported by Akinjayeju et al. (2019), but are within the range of bulk densities for blends of rice, cassava and kersting's groundnut flours (Awolu et al. 2015). The high bulk densities of the flour samples may be an advantage since it may allow for ease of dispensability reduced paste thickness during reconstitution (Amadinkwa, 2012), but may enhance packaging, storage and transportation costs (Akubor, 2017) The water and oil absorption capacities showed significant difference among the flour samples, ranging from 118.45 to 128.65% for water absorption and 86.24 and 96.43% for oil absorption, with sample WPC-1 having the highest value and sample WPC-3 having the lowest value for both parameters.

Table 3: Functional Properties of flour blends from wheat, pigeon pea and cassava cortex flours

Parameters/ Samles	WPC-1	WPC-2	WPC-3
Packed bulk density (g/ cm^3)	0.78 ± 0.01^b	0.78 ± 0.02^b	0.86 ± 0.05^a
Water Absorption Capacity (%)	128.65 ± 0.02^a	118.45 ± 0.02^c	123.87 ± 0.01^b
Oil Absorption Capacity (%)	96.43 ± 0.15^a	86.24 ± 0.20^c	94.10 ± 0.12^b
Swelling capacity (%)	2.13 ± 0.02^b	2.59 ± 0.02^a	2.08 ± 0.01^c
Water solubility index (%)	5.62 ± 0.03^b	4.84 ± 0.06^c	6.00 ± 0.04^a
Reconstitution index (ml)	7.80 ± 0.02^a	6.60 ± 0.01^b	7.74 ± 0.15^a
Foaming capacity (%)	21.00 ± 0.10^a	15.02 ± 0.73^c	19.25 ± 0.15^b

Values are Means ± s.d. of triplicate determinations Means of similar superscripts along rows are not significantly different (p > 0.05)
WPC-1: = 59.50 WHF, 25.00 PPF, 15.50 CCF
WPC-2: = 58.80 WHF, 23.10 PPF, 18.10 CCF
WPC-3: = 55.00 WHF, 25.00 PPF, 20.00 CCF
WHT = 100% Wheat flour
WHF= Wheat flour, PPF= Pigeon pea flour, CCF= Cassava cortex flour.

The significantly (p<0.05) lower water and oil absorption values for sample WPC-2 was most probably due its lower protein and fibre contents, brought about by relatively lower proportion of pigeon pea flour compared to samples WPC-1 and WPC-3, and slightly lower cassava cortex flour compared to sample WPC-3. High water absorption values of flours have been associated with high protein, fibre and carbohydrate contents, due to their high hydration properties (Oluwalana et al. (2011, Adegunwa et al., 2017). Increased water absorption values of legume-fortified composite flours with increasing proportion of legume flours have been previously reported (Ocheme et al., 2018, Akinjayeju et al., 2019). Oil absorption of the flours also showed similar trend as water absorption with WPC-2(86%) < WPC-3(94%) < WPC-1(96%). The slightly higher oil absorption values for samples WPC-1 and WPC-3 compared to WPC-2 is most probably due to their slightly higher protein content brought about by higher proportion of pigeon pea flour. This result is similar to the observations of Kiin-Kabari et al. (2015) for wheat-plantain flours enriched with bambara nut protein, as well as Awolu et al. (2015) for rice-cassava-Kersting's ground nut composite flours as the proportion of protein sources increased. High oil absorption capacity of foods has been observed to enhance flavour, mouth feel and palatability (Blundell and MacDiarmid, 1997, Akubor, 2017), as well as promote satiety in foods due to release of satiety hormones in the body (Feinle-Bisset et al., 2005). These sensory properties are particularly important for snacks for which the flour samples were formulated.

The swelling capacity and water solubility index values ranged from 2.08 to 2.59% and 4.84 to 6.00% respectively, with sample having higher proportions of pigeon pea flour (WPC-1 and WPC-3) having lower swelling capacity but higher water solubility values compared to sample with lower pigeon pea flour. The slightly lower swelling capacity of samples with higher proportion of pigeon pea is most probably due to its restricted swelling which has been observed to characterize legume flours (Akinjayeju and Francis, 2008, Akinjayeju and Ajayi, 2011). These results are similar to the observations of Akinjayeju et al. (2019) who reported lower swelling capacity values for blends of quality protein maize, soy cake flour and whole millet with higher proportions of soy cake flour. The high water solubility index for samples with higher proportions of pigeon pea flour could be due to high concentration of soluble protein in most legumes (Garba and Kaur, 2014). These results are in agreement with the observations of Awolu et al. (2015) for blends of rice, cassava, and Kersting's ground nut, and Ocheme et al. (2018) for composite of wheat and ground nut protein concentrate. Water absorption capacity showed a strong negative correlation with swelling index (r = -0.84), but positive correlation with (r = 0.69), while swelling had very strong negative correlation with solubility (r = -0.97). Reconstitution index, a measure of dispersibility of flours in water, ranged from 6.60mls for sample WPC-2 to 7.80mls for sample WPC-1, with sample WPC-2 significantly (p<0.05) lower than other two samples, among which there was no significant (p>0.05) difference. The relatively lower reconstitution index of sample WPC-2 could be attributed to its lower proportion of pigeon pea flour compared to other two samples.

Pasting properties of selected blends

The pasting properties of the flour samples are presented in Table 4, which showed significant (p<0.05) differences among the samples for almost all parameters. The peak, trough and final viscosities (RVU) varied from 115 (WPC-

2) to 124 (WPC-3), 61 (WPC-1) to 69 (WPC-3) and 145 (WPC-1) to 153 (WPC-2) respectively, with sample WPC-3 having highest values for peak and trough viscosities, while sample WPC-2 had significantly ($p<0.05$) lowest trough and final viscosities. Peak viscosity of starch granules indicates maximum swelling before undergoing disintegration (Liu et al., 2006), and high peak viscosities have been associated with weak granular forces and high degree of disintegration (Newport Scientific, 1998).

Table 4: Pasting Characteristics of flour blends from wheat, pigeon pea and cassava

Parameters/ Samples	WPC-1	WPC-2	WPC-3
Peak Viscosity(RVU)(a)	116.13 ± 1.13^{b}	115.14 ± 0.47^{b}	124.49 ± 1.07^{a}
Trough Viscosity(RVU) (b)	61.29 ± 0.46^{c}	67.04 ± 0.54^{b}	69.08 ± 0.41^{a}
Final viscosity(RVU)(c)	145.24 ± 0.44^{c}	153.54 ± 1.37^{a}	152.11 ± 0.94^{b}
Breakdown (RVU)(a – b)	54.84 ± 1.17^{b}	48.10 ± 0.98^{c}	55.41 ± 0.10^{a}
Setback (RVU)(c – a)	29.11 ± 0.69^{b}	38.40 ± 0.85^{a}	27.62 ± 0.05^{c}
Consistency (RVU)(c – b)	83.95 ± 0.30^{b}	86.50 ± 0.80^{a}	83.03 ± 0.55^{c}
Pasting temp (°C)	89.50 ± 0.10^{a}	89.80 ± 0.20^{a}	87.25 ± 0.00^{b}
Pasting time (mins)	5.56 ± 0.90^{b}	5.80 ± 0.00^{a}	5.74 ± 0.01^{a}

Values are Means ± s.d. of triplicate determinations Means of similar superscripts along rows are not significantly different ($p > 0.05$)
WPC-1: = 59.50 WHF, 25.00 PPF, 15.50 CCF
WPC-2: = 58.80 WHF, 23.10 PPF, 18.10 CCF
WPC-3: = 55.00 WHF, 25.00 PPF, 20.00 CCF
WHT = 100% Wheat flour
WHF= Wheat flour, PPF= Pigeon pea flour, CCF= Cassava cortex flour.

Trough, or hot paste viscosity, is the minimum viscosity attained during the constant heating phase and gives a measure of the ability of a starch paste to resist breakdown during the cooling phase (Newport Scientific, 1998), while final viscosity measures the ability of flours to form viscous pastes or gels after cooking and cooling and their resistance to shearing during stirring (Adebowale et al., 2005). Peak viscosity showed strong positive correlation with trough viscosity ($r = 0.63$), but weak correlation with both final viscosity ($r = 0.23$) and water absorption ($r = 0.13$). Breakdown, setback and consistency viscosities (RVU) for the flour samples varied significantly ($p<0.05$) from 48 for sample WPC-2 to 55 for WPC-3, 28 for WPC-3 to 38 for WPC-2 and 83 for WPC-3 and 86.50 for WPC-2 respectively and showed similar trends for both setback and consistency. Breakdown gives indication of susceptibility of cooked starch granules to disintegrate during continued stirring and heating, which illustrates the stability or consistency of the paste during cooking (Koh and Singh, 2009). Samples WPC-1 and WPC-3 with slightly higher proportion of pigeon pea had higher breakdown viscosities compared with sample WPC-2, with lower breakdown viscosity. These results are in contrast to the results of Akinjayeju et al. (2019) who reported lower breakdown viscosity for blends of quality protein maize, soy cake and whole millet flours containing higher proportions of soy cake flour.

For setback viscosity, which indicates reduced dough digestibility when high (Shittu et al., 2001) and reduced tendency for retrogradation when low (Sandhu et al., 2007), samples with high proportion of pigeon pea (WPC-1 and WPC-3), had significantly ($p<0.05$) lower values compared to sample WPC-2. This means that these samples will give dough meal which will not undergo too much starch retrogradation when cooled. Breakdown viscosity showed very strong negative correlation with consistency ($r = -0.98$) and swelling ($r = -1.00$), which are in agreement with previous observations that lower breakdown viscosity indicates greater resistance to disintegration (Koh and Singh, 2009, Falade and Okafor, 2015). Pasting temperatures, which determine the rate starch granules absorb water, swell and form a paste when heated, varied significantly ($p<0.05$) among the samples, showing very strong negative correlation with peak viscosity ($r = -1.00$), which agreed with the results of Falade and Okafor, 2013, 2015). Pasting or peak time, which measures cooking time, was not significantly different ($p>0.05$) among the flour samples, which agrees with the observation of Akinjayeju et al. (2019) for blends of quality protein maize, soy cake, whole millet flours and cassava starch.

Anti-nutritional factors, mineral contents, phytate/oxalate-mineral molar ratios of selected minerals

The phytate, oxalate and mineral contents of the flour samples and their molar ratios with some selected minerals are presented in Table 5, which showed that there were significant differences ($p<0.05$) among the samples for most parameters determined. Sample WPC-3 has slightly but significantly ($p<0.05$) higher phytate and oxalate contents (15.29 and 35.64mg/100g) compared to samples WPC-1 and WPC-2 with values of 14.81, 35.40mg/100 and 14.75, 33.69mg/100g respectively. There was no significant difference ($p>0.05$) between samples WPC-1 and WPC-2 for phytate and between samples WPC-1 and WPC-3 for oxalate. The relatively higher contents of phytate and oxalate in sample WPC-3 could be attributed to its relatively high proportions of pigeon pea and cassava cortex flours both of which have been reported to have high anti-nutritional contents (Jain et al., 2009, Otache et al., 2017). The similar oxalate contents of samples WPC-1 and WPC-3 could be due to their equal proportion of pigeon pea flour in the blends (25%), while the differences in their cassava cortex flour (15.5 and 20%) most probably did not have too much effect on the oxalate content, most probably an indication of low oxalate content in cassava cortex.

The phytate and oxalate contents of the flour samples are within safety thresholds of 2-5g/kg for oxalate and 50-60mg/100g for phytate (Nwosu, 2011), which indicates that consumers will not be subjected to any risk from the consumption of snack produced for the flour samples. Results showed significant differences ($p<0.05$) in the mineral contents of the flour samples, with samples WPC-3 having the highest mineral contents compared to other two samples. The higher contents of most minerals in sample WPC-3 could be due to its higher proportions of pigeon pea and cassava cortex flours, both of which have been previously reported to have high contents of dietary minerals especially Mg, Ca and K (Akubor, 2017, Otache et al., 2017, Nwanekezi et al., 2017). These high mineral contents of the flour samples will be beneficial to consumers as they will enhance their nutritional status. The low levels of Fe and Zn in the flour samples are consistent with the low contents of these minerals previously reported for wheat, pigeon pea and cassava peel (Akubor, 2017, Otache et al., 2017, Anon et al., 2018). There was no significant difference (p>0.05) in Fe:Zn and Oxa:Ca molar and [K : (Ca + Mg)] milli-equivalent ratios of the flour samples, which indicated that varying proportions of pigeon pea and cassava cortex flours had no effect on these parameters. Fe and Zn are often assessed together in view of the effects on the absorption of one over the other. Absorption of Zn will be adversely affected when the Fe:Zn molar ratio is more than 2 (Lim et al., 2013). The Fe:Zn values of the flour samples ranged between 1.35 for sample WPC-3 and 1.39 for sample WPC-1, and are therefore lower than the maximum value of 2, which means that Zn absorption in the snack produced from the flour samples will not impaired by Fe.

The [K : (Ca + Mg)] ratio is considered more useful than Ca:Mg molar ratio in assessing magnesium absorption (Ademola and Abioye, 2017. A milli-equivalent value of 2.2 is considered as maximum level at which magnesium absorption will not be impaired. The milli-equivalent values of the flour samples are 0.38. 0.38 and 0.40 for samples WPC-1, WPC-2 and WPC-3 respectively which are lower than the maximum value of 2.2 allowed. This indicates that consumers of snack produced from the flour samples will not suffer from acute hypomagnesaemia, a condition of abnormal low blood magnesium level (Ademola and Abioye, 2017; Adetuyi, 2019). Results for Oxa:Ca and Phy:Zn molar ratios showed that while there is significant difference (p<0.05) among the flour samples for Phy:Zn, there is no significant difference (p>0.05) for Oxa:Ca. The Oxa:Ca and Phy:Zn values for the flour samples are 0.26, 0.25, 0.25 and 0.66, 0.62 and 0.61 for samples WPC-1, WPC-2 and WPC-3 respectively. These values are much lower than the maximum values of not more than 1 and < 2.5 proposed for Oxa:Ca (Frontela et al., 2009 and Haliu and Addis, 2016) and < 18 suggested for Phy:Zn (Rosalind et al., 2010). This means that the bio-availability of these minerals will not be impaired by these anti-nutritional factors. The [Ca]:[Phy]/[Zn] molar ratio is considered to be a more appropriate parameter for assessing the bioavailability of zinc than Phy:Zn molar ratio, because calcium intake has been observed to effect on critical Phy:Zn molar ratio at which zinc bioavailability will be affected (Haliu and Addis, 2016). The values for this parameter are 1.03, 0.94 and 0.99 for samples WPC-1, WPC-2 and WPC-3 respectively, which are a little higher than the critical value of 0.5mol/kg recommended by Haliu and Addis (2016) and Adetuyi (2019). The slightly higher [Ca]:[Phy]/[Zn] molar ratio of sample WPC-1 compared to other two samples is most probably due to its lower zinc content of 2.22. There was strong positive correlation (r = 0.70) between the Phy:Zn and [Ca]:[Phy]/[Zn] molar ratios

Mineral Safety Index

The mineral safety index (MSI) values of the flour samples for selected minerals, including Ca, Fe, Mg, Na, Ph, and Zn, are presented in Table 6. Mineral safety index of foods is important because it measures the possibility of minerals to cause their overload in the human body, by comparing the sample mean of calculated MSI values of all flour samples for each mineral (CV) with the standard or table value (SV). A mineral will cause its overload when its calculated MSI is higher than its standard value (Adeyeye et al., 2012, Niyi et al., 2019). For all minerals determined, sample WPC-3 had the highest MSI values compared to other two samples, due most probably to its high mineral contents, as a result of higher proportion of pigeon pea and cassava cortex flours (Table 5) (Akubor, 2017, Otache et al., 2017). In addition, results obtained showed that mean values for calculated MSI for Ca(5.25), Na(3.82) and Ph(6.65) were lower than the standard MSI values of 10, 4.8 and 10 respectively. This means that these minerals will not expose potential consumers to risk of overload or toxic conditions by these minerals. On the other hand, mean calculated MSI for Fe(14.28), Mg(32.52) and Zn(51.63) were higher than the standard values of 6.7, 15 and 33 for these minerals respectively, indicating MSI values which are far higher than their recommended adult intakes by 113, 117 and 56% for Fe, Mg and Zn respectively. Similar results of low MSI values for Ca, Na and Ph and high values for Fe, Mg and Zn have been reported by previous studies of fast foods commonly consumed in Nigeria (Adeyeye et al., 2012) and other plant products, including flours from peeled, unpeeled and blanched plantain (Ademola and Abioye, 2017; Adeyeye and Adubiaro, 2018, Akinjayeju et al., 2020).

The excessively high calculated MSI values for these minerals may be detrimental to the consumers since high intakes of these mineral may results in certain deleterious effects in the human body. The daily requirements of Zn is 3-11mg for males and 3-8 for females and too much intake of this mineral can lead to its toxicity resulting in gastrointestinal disruption and imbalance of other nutrients especially Cu and Fe (Galan, 2019). Symptoms of high Zn in the body include nausea, vomiting, decreased immunity and reduction in concentration of 'good cholesterol' or high density lipoprotein (Meixner, 2018). With respect to magnesium, a healthy body has a concentration of 1.7-2.3mg/dL and a value of above 2.6mg/dL is considered high and may result in hypermagnesemia, which is however normally rarely occurred since gastrointestinal and renal systems are capable of the amount of magnesium absorbed in the body and how much is excreted. Symptoms of hypermagnesemia include neurological impairment and abnormally low pressure, which may led to heart problems, difficulty in breathing and coma (Barrell, 2017). Symptoms of iron overload, which occur when it is at advance stage, are fatigue, weakness and high blood sugar levels, which can lead to other degenerative diseases. There was very strong positive correlation in the calculated MSI values of Fe and Zn (r = 0.99), which most probably confirms the reported similarities of these mineral elements in certain respects including sharing similar dietary sources, their absorption being enhanced or impaired by the same compounds and simultaneous occurrence of their deficiencies (Lim et al., 2013). Statistical t-test results showed significant ($p<0.05$) differences between mean calculated and standard MSI values for all the minerals, except Na for which calculated t-value (|-4.04|) is less that tabulated t-value (4.303), unlike other minerals for which calculated t-values were higher than tabulated t-values.

Table 5: Anti-nutritional factors, mineral-mineral, and phytate/oxalate-mineral molar ratios of selected minerals of blends of wheat, pigeon pea and cassava cortex flours

Parameter/Samples	WPC-1	WPC-2	WPC-3	*RAI
Phytate (mg/100g)	14.81 ± 0.08[b]	14.75 ± 0.09[b]	15.29 ± 0.06[a]	
Oxalate (mg/100g)	35.40 ± 0.15[a]	33.69 ± 0.20[b]	35.64 ± 0.02[a]	
Calcium (mg/100g)	62.88 ± 0.05[b]	60.47 ± 0.15[c]	65.58 ± 0.10[a]	1200
Iron (mg/100g)	3.08 ± 0.03[c]	3.16 ± 0.04[b]	3.35 ± 0.02[a]	15
Magnesium (mg/100g)	87.63 ± 0.13[b]	79.03 ± 0.17[c]	93.46 ± 0.16[a]	400
Phosphorus(mg/100g)	77.51 ± 0.50[c]	79.77 ± 0.25[b]	82.18 ± 0.40[a]	1200
Potassium (mg/100g)	153.93 ± 1.13[b]	142.74 ± 0.34[c]	176.13 ± 0.63[a]	400
Sodium (mg/100g)	39.93 ± 0.01[b]	35.44 ± 0.21[c]	44.10 ± 0.19[a]	500
Zinc (mg/100g)	2.22 ± 0.03[c]	2.33 ± 0.04[b]	2.49 ± 0.04[a]	15
Iron:Zinc	1.39 ± 0.02[a]	1.36 ± 0.03[a]	1.35 ± 0.01[a]	
Oxalate:Calcium	0.26 ± 0.01[a]	0.25 ± 0.00[a]	0.25 ± 0.01[a]	
Phytate:Zinc	0.66 ± 0.01[a]	0.62 ± 0.00[b]	0.61 ± 0.00[b]	
[K:Ca + Mg)] (meq.)	0.38 ± 0.00[a]	0.38 ± 0.01[a]	0.40 ± 0.02[a]	
[Ca] [Phy]/[Zn]	1.03 ± 0.02[a]	0.94 ± 0.01[c]	0.99 ± 0.03[b]	

Values are Means ± s.d. of triplicate determinations means of similar superscripts along rows are not significantly different ($p > 0.05$)
WPC-1: = 59.50 WHF, 25.00 PPF, 15.50 CCF
WPC-2: = 58.80 WHF, 23.10 PPF, 18.10 CCF
WPC-3: = 55.00 WHF, 25.00 PPF, 20.00 CCF
WHT = 100% Wheat flour
WHF= Wheat flour, PPF= Pigeon pea flour, CCF= Cassava cortex flour.

Table 6: Mineral safety index of selected minerals of blends of wheat, pigeon pea and cassava cortex flours

Minerals/Samples	Ca		Fe		Mg		Na		Ph		Zn	
	SV	CV	SV	CV	SV	CV	SV	CV	SV	CV	SV	CV
WPC-1	10	5.24	6.7	13.76	15	32.86	4.8	3.83	10	6.46	33	48.84
WPC-2	10	5.04	6.7	14.11	15	29.64	4.8	3.40	10	6.65	33	51.26
WPC-3	10	5.47	6.7	14.96	15	35.05	4.8	4.23	10	6.85	33	54.78
Sample mean	10	5.25	6.7	14.28	15	32.52	4.8	3.82	10	6.65	33	51.63
Sample STD		0.22		0.62		2.72		0.42		0.20		2.99
*t-test $t_{-calculated}$		|-37.40|		21.18		11.16		|-4.04|		|-29.01|		10.79

Table value for t-test ($t_{tabulated}$) at p = 0.05 = 4.303
WPC-1: = 59.50 WHF, 25.00 PPF, 15.50 CCF
WPC-2: = 58.80 WHF, 23.10 PPF, 18.10 CCF
WPC-3: = 55.00 WHF, 25.00 PPF, 20.00 CCF
WHT = 100% Wheat flour
WHF= Wheat flour, PPF= Pigeon pea flour, CCF= Cassava cortex flour.
SV = Standard (Table) value; CV = Calculated value
Ca = Calcium, Fe = Iron, Mg = Magnesium, Na = Sodium, Ph = Phosphorus, Zn = Zinc
STD = Sample standard deviation

Conclusion

This study showed that varying proportions of wheat, pigeon pea and cassava cortex flours resulted in significant ($p<0.05$) changes in proximate compositions, physico-chemical and mineral profiles of their blends. Protein and fibre contents of the blends increased with increasing proportions of pigeon pea and cassava cortex flours respectively. Most functional properties the flours increased significantly ($p<0.05$) as proportions of pigeon pea and cassava cortex increased, except swelling, which reduced with increasing proportions of pigeon pea. Peak, trough and final viscosities of the flours varied significantly ($p<0.05$) as proportions of pigeon pea and cassava cortex flours varied, while samples WPC-1 and WPC-3 with higher proportions of pigeon pea had significantly ($p<0.05$) higher breakdown viscosities, but significantly ($p<0.05$) lower setback viscosities. These samples also had similar values for oxalate (35.40 and 35.64mg/100g) respectively, but significantly ($p<0.05$) lower phytate contents, but both anti-oxidants were within safe thresholds for all the flour samples. There was no significant ($p<0.05$) difference for Fe:Zn and Oxa:Ca and [K: (Ca + Mg)] milli-equivalent ratios, while there was significant ($p<0.05$) difference and large positive correlation ($r = 0.99$) between Phy:Zn and [Ca]:[Phy]/[Zn] molar ratios. Average calculated MSI values were lower than standard table values for Ca, Na and Ph in all flour samples, which indicates that these minerals will not produce overloads in the body, unlike for Fe, Mg and Zn, for which average calculated MSI values were much higher than standard table values, which may result in their overloads. Varying proportions of wheat, pigeon pea and cassava cortex flours had significant ($p<0.05$) effects on proximate composition, physico-chemical properties and mineral profiles of their blends. It is expected that the varying proximate compositions and physico-chemical properties will also have considerable effects on other properties of the flour blends, including sensory properties of snack produced from them. Future studies will focus on other nutritional parameters, including amino acid profiles and predicted protein quality indices, as well as the glycaemic properties and toxicity of the flour blends using rat models. Sensory attributes of the snacks produced from the flour samples will also be evaluated.

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