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The Effect of Adding Bambara Groundnut (*Vigna subterranea*) on the Physical Quality, Nutritional Composition and Consumer Acceptability of a Provitamin A-Biofortified Maize Complementary Instant Porridge

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Abstract: Undernutrition is prevalent in developing regions, particularly sub-Saharan Africa (SSA), especially among children under five. Biofortification of staple crops and using indigenous and traditional crops could be an affordable and sustainable strategy together with other existing strategies to reduce undernutrition. This study aimed to determine the effect of adding bambara groundnut (BGN) on the physical quality, nutritional composition and consumer acceptability of a provitamin A-biofortified maize (PVABM) complementary instant porridge. The PVABM flour was substituted with flour of either red or brown BGN variety at 0, 10, 20 and 30% (*w*/*w*) levels. The composite flours were used to make an instantized complementary porridge. The physical quality (texture, color, water absorption capacity (WAC), solubility index (SI) and swelling volume (SV)) of the grains and the composite complementary instant porridges were assessed. Nutritional analysis was conducted using standard AOAC methods. A 55-member consumer panel evaluated the acceptability of the porridge samples using a nine-point hedonic scale. The firmness, WAC, SI and SV decreased with increasing concentration of flour of either of the BGN varieties. The decrease in SV would positively affect the porridge quality as nutrient density and viscosity decreased. The protein, fat, fiber and total mineral (ash) content of the porridges increased with an increase in either BGN variety. There was no significant difference ($p > 0.05$) in the overall acceptability of the BGN–PVABM composite porridge samples and the porridge without BGN (control). The improved nutritional composition and positive consumer acceptability of BGN–PVABM are encouraging as consumption could contribute to the alleviation of nutrient deficiencies, including protein-energy malnutrition and mineral deficiencies, especially in SSA.

Keywords: food-based approach; legumes; maize porridge; plant protein; undernutrition; underutilized crop; vitamin A deficiency; yellow maize; weaning

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1. Introduction

The concept of cereal-legume complementation has been particularly applied to the development of complementary infant foods with high protein quality [1]. Nutritionally, the high protein content of legumes increases the protein content of cereal-based complementary foods and supplements the deficient amino acids [2]. Apart from health significance, convenience foods are also a recent trend in the food market [3,4]. Due to the demand for these foods, there is a need to develop convenient yet healthy cereal-legume-based complementary instant foods. Due to several factors, including convenience, instant or ready-to-eat (RTE) cereal-legume-based porridges are increasingly gaining acceptance in most countries in the sub-Saharan African region and gradually replacing most non-instant traditional porridges [5]. The processing of instant porridges from cereal and legume grains involves the instantiation of flours, which involves key grain processing techniques, such as soaking, heat treatment (i.e., boiling, drying and roasting) and milling [6]. Before consumption, instant porridges may also need to be reconstituted with hot water or cold or hot milk, depending on the availability of resources and habits [5].

In sub-Saharan Africa (SSA), infants from impoverished communities are usually weaned on unfortified starchy staple foods, such as white maize porridge. These foods contain poor-quality proteins and do not provide all the essential nutrients needed for a growing infant. Consequently, most children suffer from undernutrition in the form of protein-energy malnutrition (PEM) and vitamin A deficiency (VAD), especially at the weaning stage [7]. A complementary composite porridge containing provitamin A-biofortified maize (PVABM) and bambara groundnut (BGN) could contribute significantly to addressing PEM and VAD as BGN is high in protein and biofortified maize in provitamin A. Further, the protein quality of the PVABM-BGN complementary food would be likely enhanced due to the fact that BGN is high in the essential amino acids lysine and tryptophan, which are generally limiting in maize, while maize is generally high in the essential amino acid methionine, which is generally limiting in legumes [2].

Although PVABM has more nutritional and health benefits when compared with white maize, consumer studies conducted in several countries in SSA have found a low acceptance of PVABM compared to white maize, e.g., in Mozambique [8] and South Africa [9]. These findings have been attributed to undesirable sensory attributes of the PVABM [8,10–12], especially the yellow/orange color and the unfamiliar, strong flavor and aroma, which are all largely due to carotenoid pigments, including PVA carotenoid pigments. The known carotenoid-derived volatiles responsible for strong flavor and aroma include α-ionone, β-ionone, β-cyclocitral and β-damascenone [13]. On the other hand, BGN grain has been reported to have desirable sensory attributes, particularly flavor [14]. The application of advanced techniques in developing a BGN-based food was found to improve consumer acceptability of BGN, e.g., in Ghana [15] and Nigeria [16].

Therefore, adding BGN meal (flour) to PVABM meal (flour) may enhance the nutritional and sensory quality of a complementary instant porridge. The undesirable sensory characteristics of the PVABM could be masked by the desirable sensory characteristics of the BGN. However, there seems to be limited information on the nutritional and consumer acceptability of a BGN–PVABM complementary instant porridge. Therefore, the current investigation aims to determine the effect of BGN on the physical quality, nutritional composition and consumer acceptability of a PVABM complementary instant porridge.

2. Materials and Methods

2.1. Bambara Groundnut and Maize Grain Varieties

The BGN grain varieties (landraces) used in this study were brown and red, and the maize varieties were white (PAN 67) and yellow PVABM (PVAH 94). The BGN grains used in the study were landraces (grain from the previous harvest used as seed for the next planting season), but the subsistence farmers did not know the original, specific variety names. The white maize (PAN 67) was used as a reference, and the yellow PVABM (PVAH 94) was used as a control. The BGN grain varieties were obtained from Mbare Musika market, Harare, Zimbabwe, whilst the maize grains were produced as described in Section 2.2.

2.2. Production of the Yellow PVABM and White Maize Varieties

The PVABM hybrid grain (PVAH 94) (control) was produced by conventional breeding methods at Cedara Research Station, KZN, South Africa. The reference (white maize variety PAN 67) was also produced under the same conditions and location as the biofortified variety. Bulk grain of the developed maize hybrids was produced under the same environmental conditions and then harvested for use in the current study. The ears of the grain were harvested manually and then dried for 21 days at ambient temperature (±25 °C). After manual threshing, the grains were stored in a cold room (approximately 4 °C) until needed. The grains were analyzed for their physical properties and nutritional composition.

2.3. Sample Preparation

The whole grains of yellow PVABM, white maize, and brown and red BGN varieties were processed using several techniques. Each grain variety was cleaned by hand to remove extraneous material and damaged grains. After that, about 3 kg of each cleaned grain was separately soaked in tap water in the ratio of 1:2 (*w*/*v*) at 25 °C overnight. After an overnight soaking, water was decanted off and each grain was washed separately thrice in tap water. Each grain was cooked separately in distilled water in the ratio of 1:3 (*w*/*v*) in a stainless-steel heavy-bottom pot on a Defy Thermofan Stove (Model 731 MF) on high heat (plate control 6) until tender. Water was then decanted. Each cooked grain was dried separately in a hot air oven drier (UL 453B, The GS Blodgett Co., Inc., Burlington, VT, USA) at 43 °C [17] to 14% moisture content. This was followed by cooling for a period of 1–2 h at 25 °C. Each oven-dried grain was separately milled into flour of particle size of 200 µm using a pilot plant roller mill (GB 12350, Leshan Dongchuan Machinery Co., Ltd., Leshan, Sichuan Province, China).

The samples were then processed into instant porridges. Each flour type (white maize, yellow PVABM, brown BGN (BBGN) and red BGN flour (RBGN)) was roasted separately in a stainless-steel pan on a Defy Thermofan Stove (Model 731 MF) on low heat for approximately 8–10 min until a golden brown. Thereafter, they were cooled for a period of 1–2 h at 25 °C. The different weight-to-weight (*w*/*w*) ratios used to composite BGN instant flour with PVABM instant flour are presented in Table 1. The instant composite flours made with BGN and PVABM were reconstituted with boiling water (96 °C). The Reconstitution ratio (RR) [weight-to-volume (*w*/*v*)] of each instant composite flour was determined experimentally according to the serving suggestions of a commercial cereal-based instant porridge (brand Morvite, South Africa). This was completed by trial and error until the acceptable reconstitution consistency of each sample was achieved.

Table 1. The weight-to-weight (*w*/*w*) ratios of the BGN–PVABM composite instant flours.

Composite Flour	Ratio
Reference	0 BGN:100 white maize
PVABM (control)	0:100
Brown BGN: PVABM	10:90
brown BGN: PVABM	20:80
Brown BGN: PVABM	30:70
Red BGN: PVABM	10:90
Red BGN: PVABM	20:80
Red BGN: PVABM	30:70

2.4. Physical Quality

2.4.1. Color

The CIE color values (Hunter L*, a* and b*) of the cleaned whole grains, oven-dried grains and flours of the grain varieties were determined using the pre-calibrated HunterLab colorflex spectrophotometer (Hunter Associate Laboratories, Reston, VA, USA). Before measuring the color of the samples, the instrument was standardized by placing black and white standard plates, and L*, a* and b* color values were recorded. The deviation of the color of the samples to the standard was observed and recorded in the computed interface. L* values correspond to lightness/darkness and extend from 0 (black) to 100 (white), with higher values corresponding to more lightness. a* and b* values correspond to an object's color dimensions, with a* values describing a sample's redness (+a) to greenness (−a), while b* values describe a sample's yellowness (+b) to blueness (−b). Higher a* values indicate more redness, and higher b* values indicate more yellowness. The samples (3 g in a sample cup) were measured in triplicate.

2.4.2. Texture

The texture of the cleaned whole grains was determined at 20, 30 and 40% moisture content using a TA-XT Plus Texture Analyzer. The samples were brought to the desired moisture content using the procedure described by Coşkuner (2007) [18] with some modifications. Each sample was placed in a polythene bag, tightly sealed and kept in the cold room at 4 °C for five days. The amount of water (Q) that was added to the grains before sealing was calculated using the following equation:

$$Q = \frac{Wi(Mf - Mi)}{(100 - Mf)} \quad (1)$$

where *Wi* is the initial mass of seed (g), *Mi* is the initial moisture content of grains (%, db) and *Mf* is the final moisture content (%, dry basis).

The texture of the grains was then determined using the procedure described by Afoakwa and Yenyi [19] with some modifications. Three grains were placed longitudinally across the groove of the platform, and the force required by the TA-XT Plus Texture Analyzer probe, the Warner-Bratzler Blade, to cut perpendicularly through the grains was measured at a crosshead speed of 1.5 mm/s. The Warner–Bratzler probe was used to determine the texture of the grains instead of a specific probe for the assessment of several seeds, such as an Ottawa cell or a Kramer shear cell, because the authors did not have the specific probes in the laboratory. Grain texture was assessed in terms of firmness and toughness. A tough grain resists rough handling, which would otherwise cause physical damage like cracks and bruises. A firm grain is hard—it resists being cut through. This measurement was repeated five times for each sample. The following parameters were set on the texture analyzer: penetration speed 2.0 mm/s, penetration distance 30 mm, return speed 10 mm and trigger level 5.099N. Higher readings of force corresponded to harder grains and vice versa.

2.4.3. Water Absorption Capacity (WAC)

The WAC of the composite instant flours made with BGN and PVABM was determined in triplicates according to the method of Yamazaki (1953) [20] as modified by Medcalf and Gilles (1965) [21]. About 2 g of each flour sample was weighed into a pre-weighed centrifuge tube, and 20 mL of distilled water was added. Samples were vortexed with a vortex mixer (Model hs501, digital, Janke 7 Kinkel GMBH &Co. KG, Tambach-Dietharz, Germany) and allowed to stand for 30 min at 25 °C before being centrifuged at 2200 rpm with a centrifuge (Mistral 3000i, Buckinghamshire, England for 15 min. Excess water was decanted off by inverting the tubes over an absorbent paper, and samples were allowed to drain. The weights of the water samples were determined by the difference.

2.4.4. Swelling Volume (SV) and Solubility Index (SI)

The SV and SI of the flours were determined in triplicates according to the modified method of Leach, McCowen and Scotch (1959) [22]. One gram of each flour sample was transferred into a weighed graduated 50 mL centrifuge tube. Distilled water was added to give a total volume of 40 mL. The suspension was stirred uniformly, avoiding excessive speed, in order not to cause fragmentation of the starch granules. The samples were heated at 85 °C in a thermostatically regulated temperature water bath (Grant instruments Ltd., Shepreth, Cambridge, England) for 30 min with constant stirring. The tube was removed, wiped dry on the outside and cooled to 25 °C. It was then centrifuged for 15 min at 2200 rpm (Mistral 3000i, Buckinghamshire, England). The SI was determined by evaporating the supernatant in a hot air oven (BS Gallenkamp, England), and the residue was weighed.

The SV was obtained by directly reading the volume of the swollen sediment in the tube. The sediment paste was weighed. The % *solubility* was then calculated as follows:

$$\%\ Solubility = \frac{Weight\ of\ soluble\ sample}{Weight\ of\ sample\ on\ dry\ basis} \times 100 \quad (2)$$

2.5. Nutritional Analysis

The whole grains were analyzed for their nutritional composition using standard methods. Each experiment was replicated twice, and each of the replicates was analyzed in duplicate. Therefore, for each sample, four determinations were subjected to statistical analysis.

2.5.1. Sample Preparation

For analysis, the cleaned grain samples were packed into airtight containers and sent to Soil Science and Analytical Services, KZN Department of Agriculture in Cedara.

2.5.2. Moisture

The moisture content of the samples was measured according to the AOAC Official Method 934.01 [23]. The samples were dried at 95 °C for 72 h in an air-circulated oven. The weight loss of the samples was used to calculate the moisture content.

2.5.3. Fat

The fat content of the samples was determined according to the Soxhlet procedure, using a Büchi 810 Soxhlet Fat extractor (Büchi, Flawil, Switzerland) according to the AOAC Official Method 920.39 [23]. Petroleum ether was used for extraction. The percentage of crude fat was calculated using the following equation.

$$\% \; crude \; fat \; = \frac{Beaker + fat - Beaker}{sample \; mass} \times 100 \tag{3}$$

2.5.4. Protein

The protein content of the samples was measured with a LECO Truspec Nitrogen Analyzer (LECO Corporation, St. Joseph, Michigan, MI, USA) using the AOAC official method 990.03 [23]. Controls and samples were measured in duplicate and placed into a combustion chamber at 950 °C with an autoloader. The following equation was used to calculate the percentage of protein:

$$\% \; crude \; protein = \% \; N \times 6.25 \tag{4}$$

2.5.5. Total Mineral Content (Ash)

The total mineral content of the samples was determined as ash according to the AOAC Official method 942.05 [23]. The samples were weighed and placed in a furnace at 550 °C overnight. The minerals remained as a residue of ash in the crucibles after the volatilization of the organic matter from the samples. The following equation was used to determine the percentage of ash that was found in the sample:

$$\% \; ash = \frac{(mass \; of \; sample + crucible \; after \; ashing) - (mass \; of \; pre\text{-}dried \; crucible) \times 100}{(mass \; of \; sample + crucible) - (mass \; of \; pre\text{-}dried \; crucible)} \tag{5}$$

2.5.6. Fiber

Fiber was determined as neutral detergent fiber (NDF). The NDF of the samples was analyzed using a Dosi-Fiber machine (JP Selecta, Abrera, Barcelona, Spain), according to the AOAC Official Method 2002.04 [23].

2.5.7. Individual Mineral Elements

Selected individual mineral elements (calcium, magnesium, potassium, sodium, phosphorus, zinc, copper, manganese and iron) were analyzed using the Agricultural Laboratory Association of Southern Africa (ALASA) Method 6.5.1. Samples were freeze-dried (Edwards, High Vacuum International, Sussex, England) and were ashed overnight at 550 °C in a furnace. The samples were dissolved in HCl, and then HNO^3 was added. The samples were analyzed using an atomic absorption spectrophotometer. Calcium and phosphorus were determined using the Analytik Jena Spekol 1300 spectrophotometer (Analytik Jena AG, Achtung, Germany). Iron was determined with the Varian Spectr AA atomic absorption spectrophotometer (Varian Australia Pty Ltd., Mulgrave, Victoria, Australia) and the zinc with the GBC 905AA spectrophotometer (GBC Scientific Equipment Pty Ltd., Dandenong, Victoria, Australia).

2.6. Sensory Evaluation of the Composite Complementary Instant Porridges Made with BGN and PVABM

2.6.1. Pilot Study

A pilot study of the sensory evaluation was conducted before the main evaluation. This was completed to determine whether or not the approach utilized was feasible for use on a larger scale and to detect and correct methodological problems [24].

Pilot study participants were recruited from Rabie Saunders building, School of Agricultural, Earth and Environmental Sciences (SAEES), University of KwaZulu-Natal (UKZN), Pietermaritzburg (PMB), South Africa. Participation was voluntary. Pilot study participants were not permitted to participate in the main study. To ensure this, the researcher selected a different day and week to conduct the main study.

The following changes were made after the pilot study. The BGN–PVABM porridge ratio and recipes were standardized, and the processing method of the BGN–PVABM complementary instant porridge was modified by adding sugar to the porridge so that it would be more acceptable to the consumers. Additionally, the porridge samples were reconstituted with hot water before being evaluated so that the porridge did not dry out and become stiff. Furthermore, this allowed the porridge to be hot when tasted by the participants. The main study participants were recruited earlier in the day to ensure that the minimum number of participants was recruited. All the panelists were allocated a number to assist with identification.

2.6.2. Main Study

Recruitment of Panelists

Fifty-five staff and students working at or studying at SAEES, UKZN, PMB, South Africa were recruited to participate in the main study. This was an acceptable sample size, as 50 or more subjects are required for consumer acceptance studies [25]. This was a cross-sectional study design and was conducted at one point in time. The inclusion criteria were staff and students from SAEES, UKZN, PMB, South Africa who were not allergic to maize or BGN and were regular consumers of maize. Participants were recruited verbally and by invitation letters posted on the notice boards in the Rabie Saunders building. Subjects who had participated in the pilot study a week before the main study were not allowed to participate in the main study. The potential study participants were informed that participation in the study was voluntary and that there was no payment for participation. Participants were also required to abstain from eating food for 15 min before the evaluation. Participants who had smoked 30 min before the study and had flu, mouth sores or other taste or smell abnormalities were excluded from participating.

Sample Coding, Serving Order and Sensory Evaluation Set-Up

The sensory evaluation was conducted at the Dietetics and Human Nutrition Department of the UKZN, PMB, South Africa. A total of 11 panelists participated in each sensory evaluation session. Before participants could start the study, they had to sign a consent form. The contents of the consent form were explained to them by the research assistants. The participants were asked if they understood everything on the consent form before signing it. If anything was not clear, it was explained before the participant signed. If participants did not complete the consent form, they were not allowed to participate in the study. The consent form was available in English and isiZulu.

Panelists were seated in cubicles and asked not to communicate with each other to prevent them from influencing each other during the sensory evaluation of the samples.

All the panelists were given a questionnaire in English or isiZulu, depending on their preference. English and isiZulu are the most common languages spoken at UKZN. A proficient translator translated the English version of the sensory evaluation questionnaire and consent form into isiZulu. The panelists were given a pen, eight porridge samples, a polystyrene cup of water to rinse their palate between tasting the samples, a plastic spoon and a serviette. The eight porridge samples were assigned a unique three-digit code obtained from a Table of Random Numbers [26]. The serving order of the porridge samples was also determined by a Table of Random Permutations of Nine [26].

Panelists used a 9-point hedonic scale (1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much and 9 = like extremely) to rate each of the porridges. The hedonic scale is a popular sensory evaluation tool that indicates the degree of liking (or disliking) of the food sample [27,28]. All the sensory attributes (taste, color, aroma, texture and overall acceptability) were explained to the participants. If the explanation for a sensory attribute was not clear, the research assistant repeated the explanation.

Reduction of Bias

The sensory evaluation questionnaire was developed using simple language and translated into the local language (isiZulu), which isiZulu-speaking panelists could understand. Standardized equipment and apparatus were used to prepare the instant porridge. The pots in which the samples were cooked were also of the same brand, type and size. All the solid ingredients were measured using a calibrated balance, and the liquid ingredients were measured using a standardized measuring jug. The physical qualities were determined in triplicates using standard, referenced methods, whereas the nutritional analysis was replicated twice and was analyzed in duplicate.

2.6.3. Statistical Analysis

Data were statistically analyzed using a general linear model procedure of the SPSS program (Statistical Package for Social Science version 22, SPSS Inc., Chicago, IL, USA). Each experiment was replicated twice, and each of the replicates was analyzed in duplicate. Therefore, for each sample, four determinations were subjected to statistical analysis. Mean values and standard errors of means were reported. The data were analyzed using appropriate statistical techniques, including One-Way Analysis of Variance (ANOVA) to analyze for the effect of one variable, Multivariant Analysis to analyze for the effect of more than one variable and the Pearson Correlation Analysis to determine whether variables were significantly related. The HSD Tukey test was used to determine whether more than two sample means were significantly different. Statistical significance was set at $p < 0.05$.

3. Results and Discussion

3.1. Physical Quality

3.1.1. Grain Physical Properties

Color

CIE color values (Hunter L*, a* and b*) of the whole grain, oven-dried grains and flours of each grain variety are presented in Table 2.

There was a significant difference ($p < 0.05$) between the L*, a* and b* of the whole grains, the oven-dried grains and the flours of each grain variety, respectively. Confirming the visual appearance of the whole and oven-dried grains, the reference sample (white maize) had the highest L* values, followed by the control sample (yellow PVABM), brown BGN and red BGN grains, although the L* values of the oven-dried grains were slightly lower than those of the whole grains. However, in terms of a* values, the red BGN variety had the highest a* values, whereas the reference sample grain had the lowest a* values. The whole and oven-dried grains of the control had the highest b* values, followed by the reference c, brown BGN and red BGN. When compared with whole and oven-dried grains, the L* values of the flours were higher. In general, all the flours had higher L* values and lower a* values, which is desirable in developing instant porridges.

Table 2. The CIE color values (Hunter L*, a* and b*) of the whole grains, oven-dried grains and flours of white maize, PABM, brown and red BGN varieties.

Sample	Mean ± SD		
	L*	a*	b*
Whole grains			
White maize (reference)	70.58 ± 0.19 [a]	3.19 ± 0.02 [a]	25.98 ± 0.17 [a]
Yellow PABM (control)	65.68 ± 0.21 [b]	13.86 ± 0.17 [b]	38.42 ± 0.47 [b]
Brown BGN	44.34 ± 0.18 [c]	13.33 ± 0.08 [c]	23.65 ± 0.10 [c]
Red BGN	28.62 ± 0.11 [d]	20.33 ± 0.05 [d]	15.02 ± 0.26 [d]
Oven-dried grains			
White maize (reference)	68.91 ± 0.12 [a]	1.67 ± 0.05 [a]	33.70 ± 0.02 [a]
Yellow PVABM (control)	62.78 ± 0.05 [b]	10.11 ± 0.09 [b]	46.61 ± 0.30 [b]
Brown BGN	30.85 ± 0.12 [c]	10.60 ± 0.06 [c]	14.14 ± 0.14 [c]
Red BGN	23.95 ± 0.14 [d]	11.04 ± 0.08 [d]	7.11 ± 0.24 [d]
Flours			
White maize (reference)	75.11 ± 0.01 [a]	4.11 ± 0.01 [a]	12.80 ± 0.01 [a]
Yellow PVABM (control)	67.25 ± 0.02 [b]	6.17 ± 0.01 [b]	15.33 ± 0.01 [b]
Brown BGN	65.26 ± 0.01 [c]	6.22 ± 0.02 [c]	12.65 ± 0.00 [c]
Red BGN	75.10 ± 0.01 [d]	4.11 ± 0.01 [d]	12.80 ± 0.01 [d]

L* Measure of lightness (0 = black to 100 = white); a* Measure of redness and (+a = redness; −a = greenness); b* Measure of yellowness (+b = yellowness; −b = blueness); [a, b, c, d] denotes that there was a significant difference ($p < 0.05$) among the means in the same column, for whole grains (not dried), oven-dried grains and flours, respectively.

The L*, a* and b* values of the yellow PVABM of the current study were slightly higher than the values reported by Pillay et al. [9] and Beswa et al. [29]. However, the L* and b* values of the white maize in this study were higher, whereas a* values were lower than those reported by Beswa et al. [29]. The L*, a* and b*color values of the PVABM grain studied by Pillay et al. [9] ranged from 53.6 to 57.0; 16.5 to 25.7 and 29.3 to 37.5 whereas those studied by Beswa et al. (2015) ranged from 36.4 to 42.3, 11.5 to 19.8 and 24.0 to 33.6, respectively. The L*, a* and b* values of the white maize studied by Beswa et al. [29] were 46.3, 6.3 and 24.6, respectively. There was nothing found in the literature on the L*, a* and b* values for the whole grains, oven-dried grains and flours of the BGN varieties and that of the oven-dried grains and flours of both of the maize varieties.

The lower L* and a* values of the oven-dried grains compared to those of the whole grains could have been attributed to the reactions that took place during drying, such as evaporation and Maillard reactions, which cause changes in the color (i.e., browning) of the grains. The high L*, a* and b* of the control, red BGN and yellow PVABM are expected since the grains are white, red and yellow, respectively—hence the high degree of lightness, redness and yellowness in the respective grains. The yellow color of the biofortified maize is due to PVA carotenoids. The high L* values of the flours in this study could have been attributed to milling, which reduces the darker outer layers of the grain. The smaller particles of the flours cause low light absorption and more spectral response contributing to the whiteness L* attenuation [30]. Hence, the flours in this study are suitable for developing instant porridges since they generally have high L* and low a* values, which is generally desirable in cereal grain porridges, especially in SSA. In SSA, white maize is generally the grain of choice for making porridges and gruels; thus, consumers are accustomed to and generally prefer light porridges.

Grain Texture

The results for the texture of the whole grains of white maize, yellow PVABM, and brown and red BGN varieties determined at 20, 30 and 40% moisture content are shown in Table 3.

Table 3. The texture of the whole grains of white maize, yellow PVABM, brown and red BGN grain varieties [Newtons (N)].

Grain Variety	Moisture Content	Firmness		Toughness	
		Mean ± SD	*p* Value	Mean ± SD	*p* Value
White maize (reference)	20%	19,805.9 ± 3474.9 [a]	0.401	19,406.9 ± 5686.8 [a]	0.107
	30%	17,688.7 ± 7035.3 [a]		25,095.3 ± 3030.1 [a]	
	40%	15,327.3 ± 3830.4 [a]		19,759.1 ± 3838.3 [a]	
Yellow PVABM (Control)	20%	29,101.2 ± 6708.9 [a]	0.027	25,529.1 ± 7055.8 [a]	0.564
	30%	19,883.4 ± 7296.6 [a]		26,945.7 ± 3072.8 [a]	
	40%	17,227.7 ± 4461.4 [b]		23,037.0 ± 6203.2 [a]	
Brown BGN	20%	21,908.2 ± 2567.8 [a]	0.139	70,148.9 ± 14,884.0 [a]	0.097
	30%	15,278.1 ± 1654.0 [a]		52,430.9 ± 9447.5 [a]	
	40%	16,589.0 ± 8362.8 [a]		66,382.7 ± 12,105.2 [a]	
Red BGN	20%	19,931.4 ± 4123.2 [a]	0.078	64,408.8 ± 18,205.9 [a]	0.042
	30%	15,605.8 ± 2266.0 [a]		60,208.0 ± 6197.9 [a]	
	40%	14,306.3 ± 4320.1 [a]		42,003.2 ± 11,788.0 [a]	

[a, b] Means marked with different letters in the same column are significantly different ($p < 0.05$).

The results in Table 3 show that at 40% grain moisture content, the yellow PVABM (control) was significantly firmer than the other grains, i.e., the white maize (reference) and both the brown and red BGN ($p < 0.05$). The firmness of the white maize (reference), yellow PVABM and red BGN decreased with an increase in the moisture content of the grains from 20 to 40%. There was no clear-cut trend in the mean values for the firmness of the brown BGN grains with respect to an increase in moisture content from 20 to 40%. However, the toughness of the red BGN grain decreased with an increase in moisture content, whereas there was no clear-cut trend in the toughness of the reference, control and brown BGN as the moisture content of the grain increased.

The findings of this study are different from those reported by Zhang et al. [31], where there was a significant difference ($p < 0.05$) in the texture of the grains. The variations in the texture of the grains in this study could be mainly due to genetic factors and different environmental conditions to which the grains were exposed, such as growth conditions, soil type and storage conditions. Grain size could have also contributed to the variations in texture as small grains tend to be harder in texture than large-sized grains [32]. Grain texture is an important quality attribute as it is related to grain processing properties (e.g., milling) and storage. For example, harder grains tend to mill better and are more resistant to mold infection than softer grains. The correlation between grain color and grain texture is shown in Table 4.

As shown in Table 4, Hunter L* is significantly ($p < 0.01$) and negatively correlated to Hunter a*, positively correlated to Hunter b* and negatively correlated to toughness. Hunter a* is significantly ($p < 0.05$) and positively correlated to toughness, whereas Hunter b* is significantly ($p < 0.05$) and negatively correlated to toughness. There were no previous studies reporting on the correlation between grain color and grain texture to compare with. The correlation between grain texture and color observed in the current study suggests that grain texture, which is tedious to measure, can be predicted by measuring grain color, which is simple and rapid to assess. However, the sample size (n = 2) of the BGN varieties is too small to make a firm conclusion.

Table 4. The correlation between color and texture of the whole grains of white maize, yellow PVABM, red and brown BGN varieties.

		Hunter L*	a*	b*	Firmness	Toughness
L*	Pearson Correlation	1.00	−0.836 **	0.786 **	0.357	−0.873 **
a*	Pearson Correlation		1.00	−0.344	−0.015	0.619 *
b*	Pearson Correlation			1.00	0.526	−0.632 *
Firmness	Pearson Correlation				1.00	−0.134
Toughness	Pearson Correlation					1.00

L* Measure of lightness (0 = black to 100 = white); a* Measure of redness and (+a = redness; −a = greenness); b* Measure of yellowness (+b = yellowness; −b = blueness); **. Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). Whole grains adjusted to 20% moisture were used for correlation analysis.

3.1.2. Water Absorption Capacity, Solubility Index (SI) and Swelling Volume (SV)

The results of the WAC, SI and SV are presented in Table 5. Table 5 shows that there was a gradual decrease in WAC, SI and SV mean values as the concentration of either of the BGN flour increased. Significant differences ($p < 0.05$) in WAC and SI were also observed among the composite flours. The highest WAC, S1 and SV values were found in flours without added BGN flour. Amongst the two samples with no fortification (BGN addition), the control sample (100% yellow flour) PVABM had the highest WAC and SI mean values as compared to the reference sample (100% white maize flour) whereas the reference sample had the highest SV value than the control sample. Although the WAC, SI and SV mean values of the samples with either of the BGN flour increased with an increase in BGN concentration, the samples with brown BGN flour had higher mean values than the samples with red BGN flour.

Table 5. The WAC, SI and SV of the BGN-PABM composite flours compared to white maize flour (reference) and PVABM (control).

Variable		Treatment				*p* Value		
	Variety	0% (Control) Yellow PVABM	10%	20%	30%	V	T	V × T
WAC (mlg)	BBGNF	57.86 ± 0.18	52.12 ± 0.02	50.03 ± 0.58	47.10 ± 0.12	0.000	0.000	0.000
	RBGNF	57.86 ± 0.18	49.13 ± 1.00	49.91 ± 0.36	41.50 ± 0.05			
	Reference	54.05 ± 0.32						
SI (%)	BBGNF	50.03 ± 0.07	40.06 ± 0.23	30.58 ± 0.75	23.02 ± 0.37	0.000	0.000	0.000
	RBGNF	50.03 ± 0.07	37.19 ± 0.20	27.96 ± 0.58	20.98 ± 0.06			
	Reference	49.54 ± 0.22						
SV	BBGNF	7.67 ± 0.58	7.00 ± 0.00	5.67 ± 0.58	5.00 ± 0.00	0.048	0.000	0.000
	RBGNF	7.67 ± 0.58	6.00 ± 1.00	5.33 ± 0.36	4.33 ± 0.58			
	Reference	9.67 ± 0.58						

V = variety; BBGNF = Brown bambara groundnut flour; RBGNF = Red bambara groundnut flour. T= Treatment; 0% (control) = PABM flour; V × T, variety and treatment interaction. $p < 0.05$ is significant.

The findings of this investigation compare quite well with the result obtained by Mbata et al. (2009) when substituting ogi with BGN flour, whereby the WAC and SI values of the BGN–ogi decrease with an increase in BGN concentration [33]. The results of this investigation are also in line with the report of Mbofung et al. (2002), which showed that most uncomposited flours had higher WAC and SI compared to composite flours [34]. The mean values of the WAC of the composite instant flours containing 30% (w/w) of red BGN are similar to that of Mbata et al. (2009) [33].

A low WAC and SI of the composite flours can be explained by their respective contents of hydrophilic constituents, such as carbohydrates, which bind more water than protein and lipids. Therefore, an increase in the concentration of either of the BGN flour led to an increase in protein content and a decrease in carbohydrate content thereby reducing the WAC and SI. The lower WAC and SI values of the composited flours of this investigation could also have been attributed to the small particle size of the composite flours as well as the heat treatment. Heat treatment by roasting flours causes the starch molecules to tighten/shrink there by reducing their ability to absorb water. With regard to milling, Enwere (1998) [35] confirmed that starch quality in terms of particle size plays an important role in the absorption of water, as larger particle sizes have higher WAC than smaller particles. In the present investigation, the flour fraction used was 200 µm in size obtained from conventional roller milling, hence the low WAC and SI mean values. The differences in mean WAC and SI values of the composite flours made with either of the BGN flours suggests that variety and treatment had a negative effect on the WACs and SI of the composite instant flours. However, a low mean SV value is desirable in a complementary food as it reduces the viscosity of the food thereby increasing its nutrient density and ability to be handled by the digestive tract of the child.

3.2. The Nutritional Composition of the BGN–PVABM Instant Porridges

The results of the nutritional analysis of the composite complementary instant porridges made with BGN and PVABM are presented in Tables 6 and 7.

Table 6. The moisture, protein, fat, fiber and ash content of the BGN–PVABM composite complementary instant porridges [dry basis (db)].

	BGN Variety	Mean ± SD				*p* Value		
Variable		**Yellow PVABM 0% (Control)**	**10% BGN**	**20% BGN**	**30% BGN**	**V**	**T**	**V × T**
Moisture (g/100 g)	BBGNF	1.56 * ± 0.06	1.61 ± 0.01	1.71 ± 0.04	1.79 ± 0.02	0.000	0.029	0.017
	RBGNF	1.56 ± 0.06	1.56 ± 0.05	1.55 ± 0.04	1.55 ± 0.02			
Ash (g/100 g)	BBGNF	1.28 ± 0.16	1.44 ± 0.14	1.61 ± 0.13	1.77 ± 0.11	0.970	0.004	1.000
	RBGNF	1.28 ± 0.16	1.45 ± 0.13	1.60 ± 0.11	1.77 ± 0.09			
Fat (g/100 g)	BBGNF	3.58 ± 0.00	4.07 ± 0.01	4.55 ± 0.01	5.03 ± 0.02	0.060	0.000	0.472
	RBGF	3.58 ± 0.00	3.94 ± 0.13	4.29 ± 0.25	4.65 ± 0.38			
ADF (g/100 g)	BBGF	9.60 ± 0.08	11.34 ± 0.04	13.10 ± 0.16	14.84 ± 0.28	0.000	0.000	0.057
	RBGNF	9.60 ± 0.08	11.54 ± 0.06	13.48 ± 0.06	15.42 ± 0.04			
NDF (g/100 g)	BBGNF	21.68 ± 0.82	23.77 ± 0.70	25.86 ± 0.59	27.94 ± 0.47	0.630	0.000	0.986
	RBGNF	21.68 ± 0.82	23.66 ± 0.76	25.62 ± 0.69	27.60 ± 0.63			
Crude Protein (g/100 g)	BBGNF	8.32 ± 1.27	9.57 ± 1.15	10.82 ± 1.02	12.07 ± 0.91	0.710	0.005	0.993
	RBGNF	8.32 ± 1.27	9.71 ± 1.13	11.10 ± 1.00	12.50 ± 0.87			

* Mean of four determinations; NDF: Neutral detergent fiber; ADF: Acid detergent fiber; V = variety; BBGNF: Brown bambara groundnut flour; RBGNF: Red bambara groundnut flour; T = treatment; V × T, variety and treatment interaction; $p < 0.05$ is significant.

Table 7. The mineral element content of the BGN-PABM composite complementary instant porridges [dry basis (db)].

Variable		**Yellow PVABM 0% (Control)**	**10% BGN**	**20% BGN**	**30% BGN**	***p* Value V**	**T**	**V × T**
Calcium (mg/100 g)	BBGNF	0.01 * ± 0.00	0.01 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.000	0.000	0.124
	RBGNF	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	0.02 ± 0.00			
Magnesium (mg/100 g)	BBGNF	0.11 ± 0.01	0.11 ± 0.01	0.12 ± 0.01	0.12 ± 0.00	0.720	0.053	0.931
	RBGNF	0.11 ± 0.01	0.11 ± 0.01	0.12 ± 0.01	0.12 ± 0.01			
Potassium (mg/100 g)	BBGNF	0.21 ± 0.00	0.28 ± 0.00	0.36 ± 0.00	0.43 ± 0.00	0.213	0.142	0.452
	RBGNF	0.21 ± 0.00	0.29 ± 0.00	0.37 ± 0.00	0.45 ± 0.00			
Sodium (mg/100 g)	BBGNF	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.01	0.01 ± 0.00	0.010	0.023	0.025
	RBGNF	0.00 ± 0.00	0.03 ± 0.01	0.06 ± 0.03	0.01 ± 0.00			
Phosphorus (mg/100 g)	BBGNF	0.22 ± 0.01	0.22 ± 0.00	0.23 ± 0.01	0.23 ± 0.00	0.440	0.023	0.878
	RBGNF	0.22 ± 0.01	0.23 ± 0.01	0.23 ± 0.01	0.24 ± 0.01			
Zinc (mg/100 g)	BBGNF	2.90 ± 1.41	2.90 ± 1.41	2.80 ± 1.41	2.80 ± 1.41	0.030	0.855	0.290
	RBGNF	2.90 ± 1.41	3.00 ± 1.41	3.05 ± 0.71	3.15 ± 0.71			
Copper (mg/kg)	BBGNF	3.50 ± 0.71	3.50 ± 0.71	4.00 ± 0.00	4.50 ± 0.71	0.720	0.140	0.931
	RBGNF	3.50 ± 0.71	3.50 ± 0.71	4.50 ± 0.71	4.50 ± 0.71			
Manganese (mg/kg)	BBGNF	4.00 ± 0.00	5.00 ± 0.00	6.00 ± 0.00	7.00 ± 0.00	0.301	0.093	0.619
	RBGNF	4.00 ± 0.00	5.00 ± 0.00	6.00 ± 0.00	6.00 ± 0.00			
Iron (mg/100 g)	BBGNF	3.00 ± 2.83	2.85 ± 2.12	2.75 ± 2.12	2.55 ± 2.12	0.240	0.502	0.819
	RBGNF	3.00 ± 2.83	3.00 ± 2.83	2.90 ± 2.83	2.90 ± 2.83			

* Mean of four determinations. V = variety; BBGNF: Brown bambara groundnut flour; RBGNF: Red bambara groundnut flour; T = treatment. V × T, variety and treatment interaction. $p < 0.05$ is significant.

From the results in Table 6, it can be seen that there was a significant difference ($p < 0.05$) in moisture, crude protein, fat, fiber and total mineral (ash) content of the BGN–PVABM composite complementary instant porridges. The mean moisture content of the samples containing brown BGN increased with an increase in BGN concentration, whereas those containing red BGN flour decreased with an increase in BGN concentration. However, the crude protein, fat, fiber and total mineral (ash) content of the BGN–PVABM composite complementary instant porridges increased with an increase in either of the BGN flours (Table 6).

In terms of individual mineral elements assessed, it is clear in Table 7 that there was a significant difference ($p < 0.05$) in the calcium, sodium and phosphorus content of the BGN–PVABM composite complementary instant porridges as the concentration of either of the BGN flours was increased. There was no significant difference ($p > 0.05$) in the magnesium, potassium, zinc, copper, manganese and iron content of the BGN–PVABM composite complementary instant porridges as the concentration of either of the BGN flour was increased (Table 7).

The literature on the nutritional composition of instant BGN–PVABM based complementary foods was not found. However, the literature on other ingredients as well as on non-instant BGN maize-based complementary foods was found. The mean moisture values in this investigation are lower than those of Prapluettrakul et al. [36], where the moisture content of the complementary instant rice was 5%; however, they are within the acceptable value for instant flours [36]. The moisture, protein and fat content of the BGN–PVABM in this investigation are lower than those of complementary foods developed from BGN-fortified fermented raw or boiled BGN flour and white maize at 10 and 20% (w/w) BGN concentration by Mbata et al. [37]. The total mineral (ash) content of this investigation is lower at 10% (w/w) and higher at 20% (w/w) concentration of either of the BGN as compared to that of Mbata et al. [33]. The moisture, protein, fat and ash content of the BGN–maize complementary food produced from raw fermented flour ranged from 50.6 to 51.9, 12.5 to 16.2, 5.1 to 6.3 and 1.5 to 2.4%, respectively. In contrast, those produced from boiled fermented flours ranged from 52.7 to 52.9, 12.6 to 16.4, 5.1 to 6.5 and 1.5 to 2.4%, respectively. The higher moisture content of the fermented BGN–maize complementary foods of Mbata et al. [37] compared to this study's moisture content was expected since the product was not instantized. The copper, zinc, magnesium, calcium and iron contents of the BGN–PVABM composite complementary instant porridges of this study at 30% (w/w) concentration of either of the BGN varieties are lower than those of (30/70) BGN–maize complementary food by Mbata et al. which were 24.6, 78.20, 475.20, 128.40 and 50.80 mg/100 g, respectively [33]. The fiber, zinc, and iron contents of this study are higher, whereas the moisture, crude protein, fat, ash and calcium are lower than those of the maize–BGN complementary foods fortified with foods rich in calcium (beef bones), iron (Roselle calyces) and zinc (potash) by Uvere et al. [38]. The fat, ash and fiber of the composite complementary instant porridge with 20% (w/w) of either of the BGN flours in this study are higher, whereas the protein content was lower than those of an (80/20) yellow PVABM–cream BGN composite complementary food by Oluwatofunmi et al. [39].

The low moisture content of the composite flours in this investigation can be attributed to the roasting of the flours, which caused some water to evaporate from the flour. Low moisture content in instant porridges is desirable as it increases the shelf stability of the product. An increase in protein, fat, fiber and total mineral (ash) of the BGN–PVABM composite complementary instant porridges was due to incorporating the BGN into the PVABM complementary instant porridge; the two BGN grain varieties were higher in these nutrients as compared to the yellow PVABM grain variety. The results of this investigation indicate that the BGN–PVABM complementary instant porridges are nutritious since the products provide about one-third of the Recommended Dietary Allowance with respect to crude protein (10–12%) as recommended by FAO/WHO/UNU [40] for combating protein deficiency in children living in poor rural parts of SSA. The high-fat content of the BGN–PVABM complementary instant porridges would result in an increase in the children's energy intake and thereby contribute to addressing energy deficiency which is prevalent among children in SSA. Vitamin A deficiency has been declared a public nutritional health problem affecting children in SSA whose diets depend solely on maize. Therefore, there is a need to select PVABM grain types that contain desired levels of PVA for use in the composite porridges so that the complementary instant porridges also make a significant contribution to addressing VAD among the children of low economic-status communities in SSA.

The three major mineral deficiencies in infants identified by WHO are iron, zinc and calcium, and these micronutrient deficiencies are important contributors to the burden of disease [41,42]. Therefore, there is a need to improve the levels of these minerals in the BGN–PVABM composite complementary instant porridges in order to reduce the incidence of calcium, iron and zinc deficiencies among children in SSA, including South Africa.

3.3. Consumer Acceptability of the BGN–PVABM Composite Complementary Instant Porridges

The consumer acceptability ratings of the composite complementary instant porridges made with different ratios of BGN and PVABM are presented in Tables 8 and 9.

Table 8. Sensory acceptability of BGN–PVABM composite complementary instant porridges.

		Treatment							
		White Maize (Reference)	Yellow PVABM 0% (Control)	10%	20%	30%	*p* Value		
Attribute	**Variety**			**Mean**			**V**	**T**	**V × T**
Taste	BBGN		3.95 ± 2.31	4.96 ± 2.50	4.93 ± 2.46	4.59 ± 2.53	0.420	0.090	0.790
	RBGN		3.95 ± 2.31	4.30 ± 2.54	4.63 ± 2.65	4.65 ± 2.77			
	Reference	3.44 ± 2.21							
Color	BBGN		4.95 ± 2.16	4.91 ± 2.09	4.78 ± 2.13	5.00 ± 2.32	0.245	0.741	0.840
	RBGN		4.92 ± 2.16	4.30 ± 2.38	4.56 ± 2.65	4.65 ± 2.46			
	Reference	4.75 ± 2.20							
Aroma	BBGN		4.36 ± 2.05	4.85 ± 2.16	5.07 ± 2.26	5.07 ± 2.32	0.461	0.271	0.902
	RBGN		4.36 ± 2.05	4.81 ± 2.42	4.59 ± 2.55	4.85 ± 2.49			
	Reference	4.49 ± 2.18							
Texture	BBGN		4.36 ± 2.52	4.67 ± 2.40	4.64 ± 2.67	4.78 ± 2.59	0.212	0.987	0.876
	RBGN		4.36 ± 2.52	4.15 ± 2.74	4.26 ± 2.74	4.23 ± 2.49			
	Reference	4.16 ± 2.52							
Appearance	BBGN		4.13 ± 2.41	4.71 ± 2.51	4.64 ± 2.30	4.61 ± 2.29	0.475	0.582	0.924
	RBGN		4.13 ± 2.41	4.22 ± 2.36	4.41 ± 2.98	4.54 ± 2.50			
	Reference	4.27 ± 2.35							
Overall acceptability	BBGN		4.24 ± 2.18	4.95 ± 2.27	5.02 ± 2.30	4.83 ± 2.27	0.551	0.167	0.909
	RBGN		4.24 ± 2.18	4.52 ± 2.14	4.78 ± 2.64	4.88 ± 2.53			
	Reference	4.05 ± 2.33							

BBGN = Brown Bambara groundnut; RBGN = Red Bambara groundnut; V = variety; T = treatment. V × T, variety and treatment interaction. $p < 0.05$ is significant.

Table 9. The percentage of panelists who rated the overall acceptability of composite complementary instant porridge samples containing different concentrations of either red BGN or brown BGN and yellow PVABM flours.

	Brown BGN				Red BGN			
Score	**0% (Control) Yellow PVABM**	**10%**	**20%**	**30%**	**0% (Control) Yellow PVABM**	**10%**	**20%**	**30%**
Dislike extremely	18.2%	9.1%	13.6%	11.4%	18.2%	20.5%	9.1%	0%
Dislike very much	13.8%	20.7%	13.8%	20.7%	13.8%	13.8%	3.4%	0%
Dislike moderately	26.1%	13.0%	8.7%	8.7%	26.1%	10.9%	6.5%	0%
Dislike slightly	13.5%	18.9%	16.2%	27.0%	13.5%	5.4%	5.4%	0%
Neither like nor dislike	14.8%	11.5%	16.4%	9.8%	14.8%	23.0%	9.8%	0%
Like slightly	14.5%	20.0%	18.2%	12.7%	14.5%	12.7%	7.3%	0%
Like moderately	11.6%	16.3%	16.3%	23.3%	11.6%	18.6%	2.3%	0%
Like very much	13.6%	13.6%	22.7%	18.2%	13.6%	13.6%	4.5%	0%
Like extremely	5.9%	23.5%	17.6%	11.8%	5.9%	17.6%	17.6%	0%
Total acceptable	45.6%	73.4%	74.8%	66.0%	45.6%	62.5%	31.7%	0%

The samples were rated in terms of taste, color, aroma, texture, appearance and overall acceptability using a nine-point hedonic scale [43]. The ANOVA test showed that there was no significant difference ($p > 0.05$) in the acceptability of the samples in terms of all the sensory attributes evaluated, including the overall acceptability (Table 8). The acceptability ratings were generally lower for all the different sensory attributes rated by the panelists. The ratings generally ranged from '4 = dislike slightly' to '5 = neither like nor dislike' (Table 8). The mean values for aroma acceptability of the composite complementary instant porridges containing brown BGN flour increased with an increase in the concentration of BGN. In contrast, there was no trend observed in the mean values for aroma acceptability of the samples made with red BGN with respect to increasing BGN concentration in the porridge. The reference (white maize flour alone) had a higher mean value for aroma acceptability compared to the control (100% yellow PVABM flour) but had lower aroma acceptability than the samples fortified with either of the BGN flour (Table 8).

The samples made with brown BGN flour had higher mean values for both taste and appearance acceptability compared to the samples with red BGN flour. However, the mean taste and appearance acceptability values of the samples made with brown BGN flour decreased with an increase in BGN concentration, whereas those of the samples made with red BGN flour increased with an increase in BGN concentration, with the reference sample having the lowest taste mean values and the control having the lowest appearance mean values (Table 8).

Although the samples containing brown BGN flour had higher mean values for color and texture acceptability than the samples made with red BGN flour, the mean values for color and texture acceptability did not show any clear-cut trend. The mean values for both color and texture acceptability of the samples containing red BGN flour increased with an increase in the concentration of the BGN flour. The reference samples had the lowest mean values for both color and texture acceptability (Table 8).

In terms of the overall acceptability, the reference sample had the lowest mean overall acceptability values than the composite complementary instant porridges containing either of the BGN flour. There was no trend observed in the mean values for the overall acceptability of the composite complementary instant porridges containing brown BGN flour, whereas the overall acceptability of the composite complementary instant porridges containing red BGN increased with an increase in BGN concentration (Tables 7 and 8).

Table 9 shows the percentage of the panelists who gave different ratings for the overall acceptability of the composite complementary instant porridge fortified with either of the BGN flours at 0, 10, 20 and 30% (*w*/*w*) substitution levels. It is clearly shown that as the concentration of either of the BGN flour increased, the number of panelists liking the BGN–PVABM composite complementary instant porridge decreased, although the number of panelists who liked the composite complementary instant porridge containing brown BGN was higher than those who liked the samples with red BGN. None of the panelists liked the composite complementary instant porridge containing 30% (*w*/*w*) of red BGN, and the composite complementary instant porridge containing 20% (*w*/*w*) of brown BGN was liked the most by the panelists.

The findings of this investigation compare well with those of Mbata et al., who reported that there was no significant difference ($p > 0.05$) in the mean values of the sensory attributes of ogi complementary food samples containing different concentrations of BGN [33].

The sensory evaluation results of the current study indicate that the composite complementary instant porridges prepared with different ratios of BGN and yellow PVABM flours are acceptable to consumers. Several studies have found yellow PVABM-based food products to be less acceptable to consumers when compared with the corresponding white maize products, which has been largely attributed to the undesirable sensory attributes of the PVABM. For example, Pillay et al. found that the acceptance of yellow PVABM food products, such as samp, *phutu* and thin porridge, was lower than the corresponding white maize products [9]. Incorporating BGN in the PVABM complementary instant porridge in this investigation could have contributed to the improvement in the sensory attributes of the yellow PVABM complementary instant porridge. It is possible that the presumably undesirable sensory attributes of the PVABM were masked by the desirable sensory attributes of the BGN. Bambara groundnut has been reported to have desirable sensory attributes [14];

in the current study, it seems BGN significantly contributed to the improvement in the sensory properties of the yellow PVABM porridge. The roasting of the flours led to the enhancement of the color, texture and flavor of the porridges, thereby increasing their acceptance. A desirable golden brownish color that was formed as a result of roasting made the BGN–PVABM composite complementary instant porridges more visually appealing. It is also likely that the heat treatment reduced the undesirable beany flavor associated with cereal-legume-based complementary foods, as the consumers did not report it. The texture of the porridges was improved by conventional roller milling to a particle size of 200 µm.

4. Conclusions

The current study findings indicate that adding BGN flour to PVABM flour to form a complementary instant porridge improves its nutritional composition in terms of protein, fat, fiber, and total mineral content (ash). The higher fat, protein and total mineral (ash) content of the BGN–PVABM composite complementary instant porridges would contribute to addressing the escalating levels of PEM and mineral deficiencies in most sub-Saharan African regions. However, careful steps would have to be taken before and during the processing of the complementary foods to ensure that the PVABM supplies the desired concentration of PVA in the products so that the BGN–PVABM composite complementary porridge could also address VAD.

The composite complementary porridges were also acceptable to the study population with a clear preference for BGN–PVABM composite complementary porridges over the white maize composite complementary instant porridge in terms of taste acceptability, aroma acceptability, appearance acceptability and overall acceptability. It appears that the BGN masked the presumably undesirable sensory characteristics of the PVABM. However, there is a need to conduct a sensory evaluation of the BGN–PVABM composite complementary instant porridges with the caregivers whose children have or are vulnerable to undernutrition, specifically PEM and VAD.

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