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Enhancing the Nutritional Profile of Noodles With Bambara Groundnut (*Vigna subterranea*) and Moringa (*Moringa oleifera*): A Food System Approach

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Bambara groundnut (BG, *Vigna subterranea)* and moringa (*Moringa oleifera*) are underutilized crops that improve nutritional quality of diets locally. The objectives of this study were to measure the performance of both crops on a marginal soil, analyze the harvested plant parts and noodles produced from them, and to undertake taste testing and survey consumer reactions. The noodles contained either 100% wheat flour or wheat with either BG flour (20%) or moringa powder (6%). BG yielded 0.70 t ha^{-1} of dry nuts and moringa 1.54 t ha^{-1} of dry leaflets. Both plant products were high in nutrients (especially K, and Ca in moringa) and some amino acids. Inclusion in noodles significantly enhanced their nutritional composition particularly energy content, crude fat, crude fiber and carbohydrate. Significant increases ($p < 0.05$) of Mg, Mn, P, K, and Zn occurred. Total essential amino acid concentration increased from 34.1% in the pure wheat noodles to 38.2% in BG and 34.8% in moringa noodles. Sensory analysis showed acceptability of all three noodle types was above the "Neither like nor dislike" category leaning toward the liking end for almost all the attributes tested. A consumer reaction survey showed there were internal and external factors motivating respondents to choose both products. Weak correlations were found between some of these factors and respondents' willingness to pay more for the BG and moringa noodles. We conclude that adopting a comprehensive research approach from plant to plate can assist transfer of underutilized crops from field studies to acceptable consumer products with enhanced nutritional profiles.

Keywords: bambara groundnut, moringa, proximate analysis, minerals, amino acids, sensory perception

INTRODUCTION

Improved food and nutritional security for humans requires an approach that spans the food system from plant to plate (GLOPAN, 2016). Ericksen (2008) combined ideas from the food production, chain and security literatures to develop a food systems framework that has proven useful in a variety of analyzes including the improvement of nutritional well-being and assessing adaptations to changing climate (Ingram, 2011). The ways in which crops are grown, stored, and then processed into food, packaged, marketed and prepared in kitchens all influence the nutritional quality of the food consumed (for a UK example see Ingram et al., 2013). Consumption of a diverse range of plants and plant products is generally regarded as beneficial to human health with fruits, vegetables and nuts enhancing vitamin and mineral intake of cereal-based diets (Boedecker et al., 2014; GLOPAN, 2016).

Several currently underutilized crops have the potential to improve agricultural diversity and the nutritional quality of diets through either consumption of the plants alone or incorporated into processed food products. Bambara groundnut (BG, *Vigna subterranea)* is a drought-tolerant legume that is native to West Africa and grown in regions of Thailand, Malaysia, and Indonesia. BG consists typically of 49–63.5% carbohydrate, 15–25% protein, 4.5–7.4% fat, 5.2–6.4% fiber, 3.2–4.4% ash, and 2% minerals (Mazahib et al., 2013; Murevanhema and Jideani, 2013) with reported micronutrient concentrations of Ca 95.5–99.0 mg/100 g, Fe 5.1–9.0 mg/100 g, K 11.45–14.36 mg/100 g, and Na 2.9–10.6 mg/100 g (Karikari and Lavoe, 1977). It has also been reported that BG is rich in essential amino acids such as leucine, isoleucine, lysine, methionine, phenylalanine, threonine, and valine (Ihekoronye and Ngoddy, 1985; Olaleke et al., 2006; Yao et al., 2015). Despite these favorable nutritional properties, BG consumption is limited because it is regarded as hard to cook with water and firewood scarcity serious problems in many regions (e.g., Mubaiwa et al., 2018).

Moringa, a drought-resistant tree that is found growing wild in the foothills of the Himalayas in northwestern India (Olson, 2017) but now grows in many countries of the dry and lowland tropics, has been used as an alternative food source to combat malnutrition (Anwar et al., 2007; Gopalakrishnan et al., 2016). The leaves contain high concentrations of protein and micronutrients such as calcium, potassium, magnesium, iron, manganese, copper, together with vitamin A, B, C, and E and phenols (Aslam et al., 2005; Thurber and Fahey, 2009; Olson et al., 2016). Growing conditions are known to influence the nutritional composition of crops (especially mineral composition) with protein concentration of moringa leaves ranging from 19 to 35% and Ca and K concentrations varying 2- to 3-fold (Aslam et al., 2005; Moyo et al., 2011; Olson et al., 2016). Fuglie (2002) and Yang et al. (2006) reported that seasonality also influenced composition with vitamin A found abundantly in the hot, wet season, while vitamin C and iron were richer in the cool, dry season.

These studies suggest that both BG and moringa might be good sources of macro- and micro- nutrients, making them good supplements of staple foods such as noodles. Noodles are a popular food in much of South East and East Asia, due to their convenience, availability, accessibility and versatility. Cereal-based noodles are often enhanced with additives (e.g., protein supplements, emulsifiers and edible gums, antioxidants, and preservatives) to enhance flavor, taste, appearance and nutritional profile of the product.

The aim of the study reported here was to adopt a food systems approach to follow the nutritional composition of BG and moringa crops from harvest through the drying and storage processes to their incorporation into wheat-based noodles. The objectives of the work were to: (i) develop a system of tracking from planting to final food (ii) evaluate the performance of crops on a marginal soil; (iii) undertake proximate, mineral, and amino acid analysis of the harvested plant parts and the noodles containing them; and (iv) undertake taste testing and survey consumer reactions to the noodles. Large parts of objective (i) have already been published (Nur Marahaini et al., 2019) so here we focus on objectives (ii), (iii), and (iv).

MATERIALS AND METHODS

Crop Cultivation and Harvest

BG and moringa were planted at the Crops For the Future Research Centre (CFFRC) field research center at Semenyih, Selangor, Malaysia (2°55′54.42″N 101°52′43.33″E). The soil is free-draining Rengam series derived from coarse-grained, acidic, igneous rocks. The soil at the BG site was predominantly sandy clay and sandy clay loam in texture whereas at the moringa site it ranged from clay, sandy clay, to sandy clay loam. Both sites were acidic (<5.0 pH) and contained low organic carbon (<1%), total nitrogen (0.05–0.15%), and CEC (<6.0 cmol/100 g). The amount of available P was the same (21.00 mg/kg) for both sites while exchangeable K was higher at the moringa site than the BG site (0.81 cmol/100 g and 0.31 cmol/100 g, respectively). A weather station (Campbell Scientific CR1000 Automated Weather Station, USA) recorded the weather during the cropping period. In summary, the site received 868.4 mm of rain with an average air temperature of 26.6°C (March–July 2017). An overhead sprinkler irrigation system supplied supplementary water during dry periods.

BG landrace (Ex-Sokoto; cream colored seed) was sown on 24 March 2017 in a single 0.22 ha plot consisting of thirty 1 m wide ridges of 0.3–0.4 m height spaced 1.6–1.7 m apart. Ground magnesium limestone (2 t ha^{-1}) was applied to the ridges and 15 kg ha^{-1} of nitrogen (urea), 50 kg ha^{-1} of phosphorus (Christmas island rock phosphate), and 50 kg ha^{-1} of potassium (muriate of potash) broadcast and incorporated. Seeds were soaked overnight in 1.5% sodium hypochlorite then sown singly in a 5 cm deep hole in three rows per ridge at a spacing of 0.3 m between rows and 0.4 m between plants (46,875 plants ha^{-1}). Pests and diseases were controlled chemically, and weeds controlled by hand and pre- and post-emergence herbicides; the plants were earthed up at the podding stage.

Ten-month old moringa trees were used for this study. Seeds were collected from local markets in July 2016, sown in the CFFRC nursery and transplanted to the field 1 month after sowing. Triplicate moringa plots each of 144 m^2 (18 m × 8 m) were established with a spacing of 1 m within rows and 2 m between rows, resulting in 96 plants per plot and a planting density of 5,000 plants ha^{-1}. On 3 April 2017, trees were cut at 1 m above soil level then allowed to regrow for 3 months prior to subsequent cutting. Weeds, pests, and diseases were controlled by chemical and manual means.

BG growth was measured at 30, 60, and 90 days after sowing (DAS). At 108 DAS, 5 BG plants were harvested from each of six sub-plots by pulling them from the soil and yield measured. For moringa, 10 plants were sampled randomly by cutting branches from the trees in each of the three plots and the fresh weight of compound leaves, leaflets, and fresh biomass measured. Fresh BG pods and the compound leaves of moringa were then transported to the laboratory for post-harvest handling and processing.

Preparation of BG Flour, Moringa Leaf Powder, and Noodles

BG pods were thoroughly washed, damaged pods removed, dried at 60°C for 24 h, or until constant weight was achieved, and deshelled with an in-house 1st Generation Prototype Desheller. The extracted seeds were rinsed with tap water, air dried for 30 min and roasted at 150°C for 20 min. The roasted seeds were ground using a blender (Super Mixer Grinder MX-AC400W, Panasonic, Malaysia), sieved through a 1 mm mesh sieve (No. 18) and the flour (BGF) vacuum packed with a Vacuum Sealer Professional VS188 (Quiware, Malaysia) and stored at 25°C, 65–70% relative humidity.

Moringa leaflets up to 90 days old were manually stripped from the compound leaves and washed with tap water and 1% salt solution. After draining excess water, the leaflets were spread thinly on trays and dried at 45°C for 10 h, or until constant weight was achieved. The dried leaves were then milled into moringa leaf powder (MLP), sieved, vacuum packed and stored in a similar way to the BGF.

BGF and MLP were used to make three types of noodles—plain noodles (PN, 100% unbleached wheat flour), bambara groundnut noodles (BN, 80% wheat and 20% BGF), and moringa noodles (MN, 94% wheat flour and 6% MLP). The dry ingredients were sifted into the mixing bowl of a tabletop mixer (SPAR SP-800 Tabletop Mixer, Taiwan) and, using the dough hook attachment, mixed at 132 rpm for 30 s. The same amounts of egg and water for each type of noodle were stirred together in a separate bowl, added to the dry mixture, and mixed at 132 rpm for 3 min until a dough formed. The dough was placed in a covered container and left at room temperature (25 ± 1°C) for 30 min. The rested dough was made into 3 mm thick pasta sheets using a Shule Pasta Machine followed by a single-fold. This step was repeated twice, to obtain a smooth dough sheet that was then rested at room temperature in a covered container for 10 min. The dough was again made into sheets and its thickness progressively reduced to 1 mm when it was cut into 1 mm wide strips. These noodles were cooked in boiling water for 1.5 min, then immediately plunged in iced water at 10°C for 20 s to halt the cooking process. Finally, the noodles were left on a strainer for 2 min to drain off excess water. For sensory analysis, the noodles were served immediately but for nutritional analysis they were vacuum packed and stored at 4°C. On serving the PN were a faint yellow, almost creamy color while the BN had a slightly darker tone with black specks and the MN were a bright, vibrant green.

Chemical Analysis

Plant materials and noodles were analyzed for moisture (moisture analyser), protein (semi-automated Kjeldhal), crude fat (manual Soxhlet), crude fiber (Fiberbag), and total ash (furnace) using standard methods (National Technical Working Group of Malaysian Food Composition Database, 2011). Carbohydrate content was determined by difference and caloric value estimated by summing the multiplied values for crude protein, fat and carbohydrate by their respective factors (4,9,4).

Mineral content was determined at the University of Nottingham, UK. Samples were microwave-digested then analyzed using inductively coupled plasma mass spectrometry. Amino acids were determined in accordance with AOAC 994.12 by an ISO 17025 accredited laboratory, ALS Bangkok Laboratory, Thailand.

Sensory Acceptability and Consumer Reaction

The three types of noodle were tested on untrained volunteers from CFFRC and the University of Nottingham Malaysia Campus in CFFRC's Sensory Suite. A total of 86 respondents, aged 18 and above with no allergies to any of the ingredients, were tested in two groups: on 1 August and 14 November 2017. In both sessions, consumer acceptance of the appearance, odor, texture, taste and overall attributes of the noodles were evaluated using a 9 Point Hedonic Scale with 1 being "Extremely Dislike," 5 being "Neither Like Nor Dislike" and 9 being "Extremely Like." The samples were served one at a time on transparent containers labeled with 3-digit codes. Respondents were provided with a cup of drinking water and instructed to rinse their mouth before starting and between sample tasting. After the tasting, the respondents were directed to a different room where they were briefed on underutilized crops and their products prior to answering a survey on their perceptions of the tasted samples. The survey was conducted using an electronic self-administered questionnaire on laptops.

Data Analysis

Quantitative data were analyzed using analysis of variance (ANOVA) with SPSS Version 25.0 software. Comparison of means was carried out using Tukey HSD on variables with homogenous variances and Games-Howell used for variables with non-homogenous variances. A value of $p < 0.05$ was considered statistically significant. Data on consumer reactions was analyzed using Spearman Correlation and Factor Analysis. In factor analysis, Principal Component Analysis (PCA) and orthogonal varimax were chosen as analysis technique and rotation method.

RESULTS

Growth and Yield

The height and number of leaves of BG increased to 90 DAS reaching 20.3 cm and 86.4 leaves per plant but diameter (28.3 cm) decreased after 60 DAS as pods filled. At harvest, the average number of pods/plant was 27.3 with some pods containing two seeds. Fresh and dry weight of pods and dry weight of seeds were 47.5, 21.2, and 14.9 g/plant respectively, equating to a fresh pod yield of 2.23 t ha^{-1} and a seed yield of 0.70 t ha^{-1} (**Table 1**).

Moringa produced a fresh biomass of 1211.1 g/plant of which 432.4 g/plant was compound leaves; this produced 307.4

TABLE 1 | Yield (with standard error) of BG and moringa plants.

Yield assessment	BG	Moringa
Fresh weight of pods plant^{-1} (g)	47.50 ± 13.86	–
Dry weight of pods plant^{-1} (g)	21.17 ± 4.96	–
No of pods plant^{-1}	27.33 ± 5.78	–
No of seeds plant^{-1}	27.73 ± 5.67	–
Dry weight of seeds plant^{-1} (g)	14.94 ± 3.43	–
Fresh biomass plant^{-1} (g)	–	1211.12 ± 330.96
Fresh weight of compound leaves plant^{-1} (g)	–	432.38 ± 104.41
Fresh weight of leaflets plant^{-1} (g)	–	307.38 ± 76.02

g/plant of leaflets (**Table 1**). These equate to 2.16 t ha^{-1} of fresh compound leaves and 1.54 t ha^{-1} of leaflets.

Nutritional Composition of Plant Products

BGF consisted of 62.1% crude carbohydrate, 19% crude protein, 8.2% moisture, 6.8% crude fat, 5.9% crude fiber, and 3.9% total ash whereas the MLP was 45.2% crude carbohydrate, 33.1% crude protein, 10.3% moisture, 8.4% crude fiber, 7.8% total ash, and 3.6% crude fat (**Table 2**). Each 100 g dry weight of BGF contained about 385 kcal and MLP 340 kcal.

Among the essential macro minerals, K concentration was highest, and present in similar concentrations in both moringa (16.96 g/kg) and BG (16.13 g/kg; **Table 2**). Moringa had higher concentrations of Ca (13.93 g/kg), Mg (5.75 g/kg), and P (3.80 g/kg) than BG, which were 0.31, 1.27, and 3.31 g/kg, respectively. The essential trace elements in BGF comprised 27.66 mg/kg Zn, 20.35 mg/kg Fe, 70.75 mg/kg, 6.55 mg/kg Cu, 0.25 mg/kg Mo, and 0.06 mg/kg Se. Concentrations in moringa were similar except for iron which was higher at 86.01 mg/kg (70.75 mg /kg Mn, 28.56 mg /kg Zn, 8.09 mg /kg Cu, 0.61 mg /kg Mo, and 0.07 mg /kg Se). The largest difference in concentration recorded between the plant products was for Ca which was about 44 times greater in moringa than BG. Na, Mg, and Fe concentrations were up to 6 times higher in moringa compared to BGF. Some non-essential trace elements were also higher in moringa including Sr which was 50 times more in MLP (19.23 mg/kg).

The two most abundant amino acids in BGF protein were the non-essential glutamate (14.03%) and aspartate (13.68%). Total essential amino acids (TEAA) were 42.6% of crude protein in BGF, mainly composed of lysine (10.13%) and histidine (9.75%) with low levels of methionine (0.5%). The protein profile of moringa was similar that of BG being also dominated by aspartate (13.77%) and glutamate (10.99%) with TEAA 43.87% of crude protein and histidine (8.25%) and lysine (7.49%) the principal essential amino acids.

Nutritional Composition of Noodles

Substitution of wheat flour by BGF and MLP significantly affected the nutritional composition of the noodles (**Table 2**). Moringa reduced the energy content (172 kcal/100 g) compared to both PN and BN. BGF increased crude fat by 22% whereas moringa reduced it by 27% and there was a non-significant trend for increased crude protein with both substitutions. Both BG and moringa increased crude fiber and ash but reduced the carbohydrate concentration of the noodles.

Differences were also observed in the mineral concentrations of the noodles. Compared to PN, both BG and moringa significantly ($p < 0.05$) increased the concentrations of most essential minerals; Mg (by 46 and 82%, respectively), Mn (by 30 and 47%), P (by 19 and 14%), K (by 123 and 58%), and Zn (by 31 and 8%). Some non-essential elements including Ar, B, and Ru were also increased by the substitutions. Moringa substitution increased the concentrations of Ca by more than 200%, Se by 6%, and Ag, Sr, and Ti by up to 100% compared to PN and BN.

Overall, the TEAA increased from 34.1% in PN to 34.82% in MN and 38.22% in BN whereas the total of conditional essential amino acids (arginine, cystine, glycine, proline, and tyrosine) remained at 23–24% for all noodle types. Substitution of both BG and moringa significantly increased the concentrations of aspartic acid and lysine in the noodles compared to PN. BG increased histidine, arginine, and tyrosine but reduced glutamate levels compared to PN. Substitution of moringa increased alanine and glycine concentrations while reducing tryptophan concentrations compared to PN.

Sensory Analysis

Because there was no significant difference between them, data from the two groups of sensory evaluations were pooled (**Table 3**). Overall, acceptability of all three noodle types was above the "Neither like nor dislike" hedonic scale, skewing toward the liking end for almost all the attributes tested, but both BN and MN scored lower values for all attributes compared to PN. There were no significant differences between PN and BN but MN recorded significantly lower for appearance ($p = 0.012$), taste ($p = 0.001$), odor ($p = 0.000$), and overall acceptability ($p = 0.001$) compared to PN. The overall, taste and odor acceptability of MN were also notably lower compared to BN. The texture of all noodle types was similarly favorable, scoring between 6.0 and 6.4. Appearance was the most liked attribute while odor was least liked in all noodles.

Consumer Reactions

Factor analysis showed that there were two latent variables, accounting for 72.9% of total variance and 1.558 eigenvalues (**Table 4**). Although the factors were assigned to two different groups, both were equally important as the difference for average factor loading was only 0.003. In the first group there were four sub-variables. Firstly, the respondents were motivated to choose BN and MN if they were available in the market (0.875). Secondly, respondents were interested in BN and MN because they perceived both noodles as attractive and innovative products (0.860). Thirdly, respondents voted both BN and MN as tasty and appetizing food products (0.814). Finally, the respondents were motivated to choose both products because they fulfilled their needs and wants (0.790). All the sub-variables generated were closely related to marketing strategy and product positioning. They can therefore be categorized as external motivation factors.

TABLE 2 | Nutritional composition of BGF, MLP, PN, BN and MN.

	Plant materials		Noodles			
	BGF (Mean ± SD)	**MLP (Mean ± SD)**	**PN (Mean ± SD)**	**BN (Mean ± SD)**	**MN (Mean ± SD)**	**RNI**
Energy (kCal)	384.43 ± 0.46p	345.67 ± 1.96q	187.78 ± 1.80a	184.73 ± 3.15a	172.41 ± 2.90b	2412
Proximate (g)						
Carbohydrate*	62.06 ± 0.35p	45.22 ± 0.38q	33.04 ± 0.50a	29.94 ± 0.56b	30.91 ± 1.15b	130
Crude Fat*	6.76 ± 0.27p	3.59 ± 0.31q	3.40 ± 0.18a	4.15 ± 0.06b	2.47 ± 0.26c	–
Crude Fiber*	5.87 ± 0.07p	8.38 ± 0.13q	0.31 ± 0.08a	1.16 ± 0.18b	0.80 ± 0.08c	25.00
Crude Protein*	19.00 ± 0.08p	33.12 ± 0.18q	6.26 ± 0.31a	6.89 ± 0.40a	6.64 ± 0.49a	46.20
Moisture*	8.23 ± 0.03p	10.31 ± 0.11q	56.98 ± 0.50a	58.36 ± 0.79ab	59.16 ± 0.61b	–
Total Ash*	3.94 ± 0.07p	7.77 ± 0.04q	0.32 ± 0.04a	0.66 ± 0.01b	0.82 ± 0.02c	–
Macro-minerals (g)						
Calcium (Ca)*	0.03 ± 0.02p	1.39 ± 0.25q	0.04 ± 0.001a	0.04 ± 0.001a	0.12 ± 0.000b	1.00
Magnesium (Mg)*	0.13 ± 0.01p	0.58 ± 0.10q	0.04 ± 0.000a	0.05 ± 0.000b	0.07 ± 0.01c	0.31
Phosphorus (P)*	0.33 ± 0.03p	0.38 ± 0.09q	0.16 ± 0.001a	0.20 ± 0.001b	0.19 ± 0.03c	0.70
Potassium (K)*	1.61 ± 0.02p	1.70 ± 0.36p	0.09 ± 0.001a	0.20 ± 0.001b	0.14 ± 0.023c	4.70
Sodium (Na)*	0.03 ± 0.00p	0.18 ± 0.02q	0.20 ± 0.001a	0.22 ± 0.001b	0.23 ± 0.04b	1.50
Sulfur (S)	0.34 ± 0.01p	0.96 ± 0.20q	0.18 ± 0.003a	0.21 ± 0.000b	0.23 ± 0.09b	–
Trace-minerals (mg)						
Aluminum (Al)	LD	23.12 ± 0.88	6.93 ± 0.000a	6.39 ± 0.000a	8.46 ± 0.001a	–
Arsenic (Ar)	0.01 ± 0.00p	0.11 ± 0.00q	LD	0.003 ± 0.000a	0.006 ± 0.000b	–
Barium (Ba)	0.73 ± 0.03p	2.14 ± 0.03q	1.60 ± 0.000a	1.56 ± 0.000a	1.82 ± 0.000a	–
Beryllium (Be)	0.003 ± 0.01p	0.002 ± 0.00p	0.002 ± 0.000a	0.003 ± 0.000a	0.004 ± 0.000a	–
Boron (B)	9.51 ± 0.44p	27.68 ± 2.05q	LD	1.15 ± 0.000a	1.60 ± 0.001a	<20
Cadmium (Cd)	0.05 ± 0.00p	0.01 ± 0.01q	0.01 ± 0.000a	0.05 ± 0.000a	0.01 ± 0.000a	–
Caesium (Cs)	0.17 ± 0.00p	0.04 ± 0.00q	LD	0.012 ± 0.000	LD	–
Chromium (Cr)*	LD	1.11 ± 0.18	LD	LD	LD	0.03
Cobalt (Co)	0.02 ± 0.01p	0.01 ± 0.00p	0.01 ± 0.000a	0.01 ± 0.000a	0.01 ± 0.000a	–
Copper (Cu)*	6.55 ± 1.86p	8.09 ± 1.38p	2.55 ± 0.000a	3.63 ± 0.000a	2.62 ± 0.000a	0.90
Iron (Fe)*	20.35 ± 2.75p	86.01 ± 2.46q	23.71 ± 0.000a	23.90 ± 0.000a	27.67 ± 0.000a	18.00
Lead (Pb)	0.02 ± 0.01p	0.22 ± 0.02q	0.03 ± 0.000a	0.05 ± 0.000a	0.06 ± 0.000a	–
Lithium (Li)	LD	0.02 ± 0.01	LD	LD	LD	–
Manganese (Mn)*	18.66 ± 0.29p	70.75 ± 1.05q	8.98 ± 0.000a	11.69 ± 0.000b	13.25 ± 0.000c	1.80
Molybdenum (Mo)*	0.25 ± 0.11p	0.61 ± 0.67p	0.63 ± 0.000a	0.41 ± 0.000a	0.86 ± 0.000a	0.05
Nickel (Ni)	0.51 ± 0.20p	0.29 ± 0.07p	0.65 ± 0.000a	0.43 ± 0.000ab	0.34 ± 0.000b	1.00
Rubidium (Ru)	54.09 ± 0.34	11.62 ± 0.23	0.69 ± 0.000a	5.05 ± 0.000b	1.03 ± 0.000c	–
Selenium (Se)*	0.06 ± 0.00p	0.07 ± 0.00p	0.18 ± 0.000a	0.18 ± 0.000a	0.19 ± 0.000b	0.06
Silver (Ag)	0.004 ± 0.00	LD	LD	LD	0.001 ± 0.000	–
Strontium (Sr)	0.38 ± 0.03p	19.23 ± 0.33q	1.42 ± 0.000a	1.32 ± 0.000a	2.63 ± 0.000b	–
Thallium (Tl)	LD	0.11 ± 0.00	LD	LD	LD	–
Titanium (Ti)	0.14 ± 0.03p	2.94 ± 0.11q	0.18 ± 0.000a	0.18 ± 0.000a	0.35 ± 0.000b	–
Uranium (U)	LD	LD	LD	LD	LD	–
Vanadium (V)	0.003 ± 0.00p	0.03 ± 0.00q	0.01 ± 0.000a	0.01 ± 0.000a	0.01 ± 0.000a	<1.80
Zinc (Zn)*	27.66 ± 0.52p	28.56 ± 1.85p	12.16 ± 0.000a	15.87 ± 0.000b	13.13 ± 0.000c	8.00
Amino Acids (g) of CP						
Alanine	4.22 ± 0.20p	7.47 ± 0.21q	4.03 ± 0.31a	4.15 ± 0.06ab	4.55 ± 0.11b	–
Arginine^	7.94 ± 0.21p	6.11 ± 0.25q	5.47 ± 0.28a	6.37 ± 0.15b	5.84 ± 0.16a	–
Aspartic Acid	13.68 ± 0.30p	13.77 ± 0.27p	6.56 ± 0.50a	8.42 ± 0.38b	7.82 ± 0.29b	–
Cysteine^	1.30 ± 0.06p	1.66 ± 0.09q	1.78 ± 0.07a	1.65 ± 0.30a	1.77 ± 0.15a	–
Glutamic Acid	14.03 ± 0.77p	10.99 ± 0.48q	26.11 ± 0.55a	20.34 ± 3.21b	23.76 ± 1.11ab	–

(Continued)

TABLE 2 | Continued

	Plant materials		Noodles			RNI
	BGF (Mean ± SD)	MLP (Mean ± SD)	PN (Mean ± SD)	BN (Mean ± SD)	MN (Mean ± SD)	
Glycine^	3.75 ± 0.03p	4.47 ± 0.04q	4.41 ± 0.21ab	4.15 ± 0.11a	4.73 ± 0.05b	–
Histidine*	9.75 ± 0.62p	8.25 ± 0.16q	4.73 ± 0.34a	6.86 ± 0.51b	5.39 ± 0.41a	0.70
Hydroxylysine	LD	LD	LD	LD	LD	–
Hydroxyproline	0.46 ± 0.02p	0.32 ± 0.04q	0.00	0.00	0.00	–
Isoleucine*	2.55 ± 0.08p	3.14 ± 0.13q	2.70 ± 0.16a	2.91 ± 0.22a	2.82 ± 0.08a	1.40
Leucine*	5.59 ± 0.27p	6.56 ± 0.62p	5.98 ± 0.60a	6.48 ± 0.90a	5.91 ± 0.61a	2.73
Lysine*	10.13 ± 0.35p	7.49 ± 0.21q	4.48 ± 0.28a	6.37 ± 0.39b	5.23 ± 0.08c	2.10
Methionine*	0.51 ± 0.25p	1.59 ± 0.09q	1.18 ± 0.19a	1.15 ± 0.16a	1.19 ± 0.27a	0.70
Phenylalanine*	5.37 ± 0.12p	5.64 ± 0.13p	5.14 ± 0.32a	5.15 ± 0.18a	5.47 ± 0.10a	–
Proline^	3.82 ± 0.20p	3.83 ± 0.62p	9.80 ± 1.09a	8.41 ± 0.79a	8.70 ± 0.602a	–
Serine	5.54 ± 0.17p	4.65 ± 0.32q	5.32 ± 0.12a	5.58 ± 0.31a	5.35 ± 0.26a	–
Threonine*	4.05 ± 0.08p	5.45 ± 0.20q	3.85 ± 0.24a	3.89 ± 0.28a	4.22 ± 0.19a	1.05
Tryptophan*	1.28 ± 0.35p	0.86 ± 0.23p	2.37 ± 0.59a	1.63± 0.08ab	0.90 ± 0.09b	0.28
Tyrosine^	2.64 ± 0.13p	2.86 ± 0.10p	2.44 ± 0.15a	2.71 ± 0.07b	2.65 ± 0.03ab	–
Valine*	3.38 ± 0.13p	4.89 ± 0.40q	3.65 ± 0.10a	3.78 ± 0.53a	3.69 ± 0.53a	1.82

RNI is the Recommended Nutrient Intake per day as suggested by Institute of Medicine (2001, 2005a,b, 2011), World Health Organization (2007).
*Values are expressed in indicated unit per 100 g of sample weight, except for amino acids which are presented as unit per 100 g Crude Protein (CP). SD is standard deviation; LD shows values below detection limit; *essential nutrients; ^conditional essential nutrients. The mean value followed by a different letter in the same row is significantly different at $p < 0.05$.*

TABLE 3 | Mean value of attribute scores for noodle samples in 1 Aug and 14 Nov 2017.

Noodle	Overall	Taste	Appearance	Odor	Texture
PN	6.50 ± 1.66a	6.30 ± 1.68a	6.83 ± 1.29a	6.07 ± 1.83a	6.37 ± 1.84a
BN	6.33 ± 1.81a	6.06 ± 1.99a	6.66 ± 1.39ab	5.78 ± 1.91a	6.23 ± 1.81a
MN	5.48 ± 1.99b	5.21 ± 2.25b	6.07 ± 2.06b	4.69 ± 2.25b	6.02 ± 1.99a

The mean value is based on 9 Point Hedonic Scale with 1 being "Extremely Dislike," 5 being "Neither Like Nor Dislike" and 9 being "Extremely Like." Each mean ± SD followed by the same alphabet in the same column for the same group is not significantly different ($p > 0.05$).

The second group of motivation factors, identified as internal motivation factors, had three sub-variables. BN and MN were perceived as good for their health (0.890) and nutritious products (0.874), thus driving respondents to choose them. Furthermore, consumers were motivated to choose both noodles because they perceived them as high-quality products that were safe for consumption (0.721).

A three-point price for BN and MN was investigated using an average price for a typical type of regular instant cup noodles (MYR2.00) as comparison. Respondents were willing to pay a minimum price of MYR1.50, a maximum price of MYR20.00 and an average price of MYR3.30 for both BN and MN.

Respondents' willingness to pay more for BN and MN compared to other noodles showed a linear and positive relationship for seven of the nine food choice motivation attributes (**Table 5**). The attributes: tasty and appetizing, and high quality and safe for consumption were the main reasons for respondents to pay more for both products ($p = 0.000$). The other five attributes are being able to fulfill their needs and wants ($p = 0.001$), the products' availability in the market ($p = 0.001$), good for their health ($p = 0.001$), product attractiveness and innovation ($p = 0.004$), and perception that the product is nutritious ($p = 0.006$). In terms of correlation strength, all seven food choice motivation attributes had r-values ranging from 0.295 to 0.399.

TABLE 4 | Factors motivating respondents to choose BN and MN as food.

Items	Factor loading	
	F1	F2
Factor 1: External—Marketing and promotional strategy		
BN and MN availability in the market	0.875	
BN and MN are attractive and innovative products	0.860	
BN and MN are tasty and appetizing	0.814	
BN and MN could fulfill my needs and wants	0.790	
Factor 2: Internal—Food quality		
BN and MN are good for my health		0.890
BN and MN are nutritious		0.874
BN and MN are high quality and safe for consumption		0.721
Eigenvalues	3.547	1.558
% of variance	50.7	22.3
Total of % variance	50.7	72.9

TABLE 5 | Correlation between respondents' willingness to pay more for BN and MN and their food choice motivation.

Independent variable	**Willingness to pay more for both noodles compared to the other noodles available in the market**	
Food choice motivation for BN and MN	**Spearman's rho**	***P*-Value**
Tasty and appetizing	**0.399	0.000
High quality and safe for consumption	**0.393	0.000
Fulfill needs and wants	**0.353	0.001
Availability in the market	**0.346	0.001
Good for their health	**0.344	0.001
Attractive and innovative food products	**0.311	0.004
Nutritious	**0.295	0.006
No culture restriction	0.054	0.623
Can be consumed any time	0.105	0.334

***Correlation is significant at the 0.01 level (2-tailed).*

DISCUSSION

Growth and Yield

Yield of BG varies depending on season and geographical location but it is known to be resilient and can perform well in marginal environmental conditions (Ihekoronye and Ngoddy, 1985; Begemann, 1988; Collinson et al., 2000; Sesay et al., 2008; Effa and Uko, 2017). This study showed that BG (Ex-Sokoto), which originated from arid to semi-arid Sub-Saharan Africa and typically grows on sandy soils, was able to produce a good yield in a humid tropical region on a clayey, acidic soil. A similar result was reported for BG (Ex-Sokoto) grown under similar environmental conditions when pod number/plant was the highest amongst other landraces (41 pods plant^{-1}; 3,152 kg ha^{-1}; Musa et al., 2016). The number of pods/plant obtained in this experiment was smaller than the previous finding, which is most likely due to differences in crop management practices, environmental condition, and genetic stability of seed. Substantial genetic variation exists between BG lines for many characters such as number of branches, number of nodes and internode length suggesting that seed yield can be increased by direct selection (Onwubiko et al., 2019).

Moringa produced 2.16 t ha^{-1} of fresh leaf yield per harvest on the marginal soil used in this study. It is important to note the planting density of moringa adopted in this study was not optimal for leaf biomass production. Previous studies have shown that narrow spacing offers greater yield per unit area compared to wider spacing, but cultivation practices also need to be more intensive to increase plant survivability and productivity over time (Amaglo et al., 2007; Mabapa et al., 2017; Patricio et al., 2017).

Nutritional Composition of Plant Products

The proximate composition of BGF fell within the previously reported range (Azam-Ali et al., 2001; Murevanhema and Jideani, 2013; Anhwange and Atoo, 2015; Ogwu et al., 2018). Its high carbohydrate content provides adequate energy to support bodily function, particularly in children and nutritionally vulnerable communities. BG carbohydrate is mainly composed of starch, similar to other legume species, e.g., lima bean, kidney bean, pigeon pea, and jack bean (Apata, 2008; Oyeleke et al., 2012) so provides complex carbohydrate with low glycemic index and long-lasting satiation (Ludwig et al., 2018). Different landraces and cultivars of BG have variable starch yields with different amylose concentrations and gelatinisation temperatures but similar glycemic index 40.1 (Oyeyinka S. A. et al., 2017). Similarly, different processing methods can produce BG starch with variable rheological properties suitable for a range of food products (Oyeyinka and Oyeyinka, 2018). Results for MLP differed from other findings. Gopalakrishnan et al. (2016) found lower values for all proximal compositions, except crude fiber (19.2%) while Mbailao et al. (2014) found lower crude fat (2.3–2.9%) and carbohydrate (13.4–14.2%) among samples collected from three regions in Chad. Ogbe and Affiku (2011) measured lower crude protein (17.0%), lipid (2.11%), moisture (3.2%), and fiber (7.1%) but higher carbohydrate (63.1%) was measured in moringa harvested from Lafia, Nigeria. Despite these differences, the proximate composition of both BG and moringa supports their utility as alternative sources of plant-based protein, especially for people with limited resources to access animal protein or because of dietary restrictions, e.g., vegans. Furthermore, their crude fiber contents, which were higher than other known laxative inducing foods e.g., papaya, banana, and guava (Madhu et al., 2017), but low enough for consumption by young children, could promote the health of digestive systems (Biel et al., 2017).

Both plant products were also rich in nutrients. Potassium was plentiful in both and up to 48 times higher in concentration in BG than in previous studies (Aremu et al., 2006; Abdulrahman et al., 2019). In moringa, potassium concentration was higher than that found in Nigeria (0.79%) but slightly lower than samples collected from Chad, Ethiopia, and Namibia (1.7–2.0%; Korsor et al., 2017). With the exception of Ca and Fe, the essential minerals were higher in concentration compared to other published values (Gopalakrishnan et al., 2016). Moringa can provide Ca equivalent to cheese and milk and Fe comparable to beef and soy flour (United States Department of Agriculture Agricultural Research Service, 2019) and its consumption can prevent negative health outcomes associated with mineral and protein deficiencies (Tshabalala et al., 2019). The BGF in the present study had the same Mn concentration, higher Cu, Mg, and Na, and lower Ca, Fe, and Zn concentrations than those reported previously by Aremu et al. (2006). Compared to chickpea, soybean, lupin and green pea flours, BGF Mg, Se, and Cu concentrations were comparable to those of chickpea and lupin, S and K concentrations were higher than all four legumes while Zn and Mn were higher than green pea (Jahreis et al., 2016). The present study used a single genotype with cream-colored flesh but Mandizvo and Odindo (2019) found that dark-colored landraces had higher concentrations of macro and micro nutrients compared to light colored seeds.

Most of the amino acid values in BGF were consistent with those of bambara groundnut seeds in Cote d'Ivoire (Yao et al., 2015) and Nigeria (Adebowale et al., 2011; Adeyeye and Olaleye, 2012) except that in this study, histidine was four times higher while leucine was well below the range reported in the three previous studies. Compared with soybean, chickpea, lupin and green pea flours, the histidine and lysine concentrations were 3.6 and 1.4 times higher, respectively, while the other amino acids were within the same range or slightly lower (Jahreis et al., 2016). The protein profile of BGF showed good complementarity with cereal-based products due to its high lysine concentration (Adebowale et al., 2011), which is important for protein synthesis in the body. Its high glutamate content, although not an essential amino acid, has good potential in the food industry, as glutamate from natural source is highly sought for its flavor enhancing properties (Jinap and Hajeb, 2010). The amino acid composition of moringa differed from other findings in which glycine had the highest value and cysteine and methionine the lowest values (Mbailao et al., 2014; Isitua et al., 2015).

Both plant products contained good profiles of essential nutrients for human consumption. The Recommended Nutrient Intake (RNI) for specific nutrients acts as reference for the estimation of percentage daily value (%DV) of nutrient provided by the foods to fulfill the daily nutrient requirement of an adult (see **Table 2**). A cup (∼140 g) of BGF could provide an excellent source of carbohydrate (>66% DV), crude fiber (>32% DV), crude protein (>57% DV), essential minerals (>48% DV of Cu, K, Mg, Mn, Mo, P, and Zn), and essential amino acids (13–133% DV) with moderate amounts of Se and Fe (>14% DV). Similarly, three tablespoons (∼30 g) of MLP could provide an excellent source of crude protein (21%), essential minerals (>26%DV of Ca, Cr, Cu, Mg, Mn, and Mo) and essential amino acids (16–57% DV) with moderate Fe, P, K, and Zn (up to 16% DV).

Nutritional Composition of Noodles

Prior to this study, substitution tests were conducted to determine what was possible. Substitution of more than 20% BG impaired the dough strength and elasticity while moringa leaf powder at 6% was the highest acceptable substitution based on an organoleptic test by 10 panelists.

Overall, the significant enhancement of most essential nutrients in the noodles was similar to that found in other studies. Charles et al. (2018) reported enhanced protein, fiber, fat, and ash concentrations when the ratio of fermented BGF to wheat was increased, while Kamble et al. (2018) measured increased Ca, Mg, Fe, and Zn together with beta-carotene with addition of MLP. Both BN and MN had higher concentrations of some toxic minerals including As, B, Ag, and Ti but the amounts were too small to be a risk. For example, B concentrations in a serving of noodles amounted to <1.1% of the Tolerable Upper Intake Levels (UL) of 20 mg/day (Institute of Medicine, 2001), while As was <2.5% of the allowable 0.56 μg/kg bodyweight/day [EFSA Panel on Contaminants in the Food Chain (CONTAM), 2009].

Sensory Analysis

Appearance of the different noodles met consumer expectations and was the most favorable attribute, but odor was the least acceptable attribute most likely due to the strong aroma of egg in the PN. The beany smell of BG aggravates this unfavorable quality in BN (Mensah, 2011); this might be reduced through appropriate processing methods such as grinding at high temperature and blanching (Lv et al., 2011). The odor of MN, which was particularly unfavorable, could be a consequence of the respondents' unfamiliarity with moringa or a genuine dislike (Ntila et al., 2019). Abilgos (1996) described "Odorless" as one of the preferred characteristics of moringa-supplemented rice flat noodles apart from being light green in color and having a bland flavor. In general, the substitution of BG and moringa in the noodles gave good ratings for organoleptic properties considering the samples were not seasoned during tasting. BN were well-accepted by the panelists, similar to studies which had shown high consumer acceptability for 20% (Abidin et al., 2014), 32% (James et al., 2017), and 70% (Charles et al., 2018) BGF substitution in noodle samples. In contrast, low sensory acceptance limits the potential moringa substitution into noodles despite its potential to enhance nutritional composition. Others have also reported that sensory acceptance decreases as the moringa substitution increases, e.g., >2% in rice cracker (Manaois et al., 2013), >3% in rice noodle (Wijesiri et al., 2014), >5% in flat noodle (Abilgos, 1996), and >12% in muffin (Srinivasamurthy et al., 2017). Chan et al. (2019) found that the acceptability of moringa in fortified soup formulations was significantly increased by addition of sweetness (aspartame) that reduced bitterness.

Consumer Reactions

The external motivation factors in this study are related to 4p's and 12p's marketing mix elements, namely product availability (place, channel distribution), attractiveness and innovation (product, branding), tasty and appetizing (promotion, advertising), and fulfilled needs and wants (people, price). Product distribution, which involves transportation, packaging and delivery, is also crucial to make the product available for purchasing. Based on Ferrell and Hartline (2011) product visibility can be improved through an intensive distribution strategy, which could be applied to both BN and MN. However, adopting this strategy might result in low product prices and margins (Kotler et al., 2012). BN and MN were positioned in the present study as products to increase interest among consumers for innovative foods to diversify their diets and improve health status. The respondents were motivated to choose both products due to their tasty and appetizing attributes. These responses are similar to a study in which caregivers ranked BG puree as "very delicious" and the sensory attributes were perceived positively (Oyeyinka, A. T. et al., 2017). Lastly, respondents were motivated to choose both products because they fulfilled their needs and wants, implying the noodles might form a profitable business venture.

The internal motivation factors were related to food quality attributes where the respondents perceived BN and MN were good for their health, nutritious, high-quality and safe for consumption. Numerous studies have proven the health benefits of both BG and moringa including BG's role in preventing heart disease and moringa's anti-cancer properties (Brink and Belay, 2006; Abdull Razis et al., 2014; Jideani and Diedericks, 2014). This finding is encouraging as respondents gave positive responses despite being unfamiliar with the noodles, suggesting potential for penetration into high-end markets.

Setting a price for new products is always a difficult decision for business. The present results showed that respondents were willing to pay more than the average market price. This is encouraging as it would allow businesses to adopt a skimming price strategy in the early introduction of noodles to the market. Such a strategy is profitable to business and enables them to cover the cost in short period, particularly when the market segment is willing to pay a higher price for the value received.

Although seven food choice motivation attributes were significantly correlated with the willingness of respondents to pay more, the strength of the correlation ($r = < 0.2–0.4$) was "weak" (Dancey and Reidy, 2007). The first attribute, tasty and appetizing, was consistent with Stanton (2013) marketing study showing that taste had become the most important factor in buying food over the last 40 years, and that trend was expected to continue. Secondly, the products were viewed as high in quality and safe for consumption and were perceived to fulfill respondents' needs. According to Market Talk News (2019) consumers are willing to pay a premium price for products offering tangible health benefits especially when it meets their basic health and dietary needs. Moringa is among the potential products that sit in the premium product class being known for its medicinal properties and a nutritional profile that rivals milk and eggs (Star Tribune, 2015). Respondents also perceived BN and MN as foods that were nutritious and good for their health hence they were willing to pay more.

CONCLUSIONS

A well-developed food system can improve the human nutritional security. Cultivation practices, post-harvest processes and product development all influence the nutritional quality of the food. In this study we demonstrated that varietal selection and crop management practices could produce pilot product quantities of BG and moringa with acceptable yields (0.7 t ha^{-1} BG and 1.54 t ha^{-1} moringa leaflets) in a humid tropical region with acidic soil. Nutritional analysis showed that both BGF and MLP had good nutritional profiles that were retained through the packaging, storage, and food production processing stages to significantly enhance the macro and micronutrient profiles of noodle products. The overall taste testing and consumer reactions survey of these products produced encouraging feedback about acceptability, motivations, and willingness to pay. This study demonstrates how adopting a comprehensive research approach from plant to plate can transfer underutilized crops from field studies to acceptable consumer products with enhanced nutritional profiles.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

AUTHOR CONTRIBUTIONS

SA-A conceived the project which was managed by HH. FR grew the crops and undertook the crop measurements. AJ and XT created the noodles. GS oversaw the chemical analysis and relevant data collection. HH, AJ, and XT undertook the sensory and consumer surveys and the analysis. PG provided technical advice throughout the project and managed the writing of this manuscript.

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