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Development and Profiling of Affordable and Nutritionally Optimal Pigeon Pea-Based Products for Improved Recipes Diversification in Rural Communities in Tanzania

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Abstract

Pigeon pea is an affordable source of protein, vitamins and minerals. Despite its nutritional importance, the legume has not been adequately utilized for human consumption in Tanzania due to limited recipes. Therefore, the study aimed to develop and profile quantitative attributes of value-added pigeon pea-based noodles (PPBN) and instant porridge (PPIP) flour for diversification of recipes in rural Tanzania communities. The computation on the amount of ingredients, the cost of the product mix and optimization was done using Linear programming, simplex method. PPBN and PPIP were developed and Quantitative Descriptive Analysis (QDA) was done by trained panelists. Data were analysed using R and XLSTAT software. Eight and four samples of PPBN and PPIP respectively were formulated and developed. Major ingredients for PPBN was pigeon pea, wheat and orange flesh sweet potatoes flour and for PPIP was pigeon pea, maize, orange flesh sweet potatoes flour (or pumpkin flour). The protein content for PPBN ranged from 41.0 to 58.2 g. The highest amount of iron content was observed in sample PPBN193 (26.4 mg), followed by PPBN1718 (21.0 mg), PPBN267 (19.3 mg) and PPBN136 (18.3mg). The highest value of zinc and pro-vitamin A was observed in sample PPBN136. For instant porridge the highest value of protein (17.1 g), iron (7.9 g), zinc (5.4 mg) and pro-vitamin A (308.5 µg) was observed in sample $PPIP_{ofsp}{}^{r}$. The highest mean intensity score for colour, aroma and mouthfeel was observed in samples PPBN718, PPBN193 and PPBN136. For sample $PPIP_{ofsp}{}^{r}$, colour (8.7) Aroma (7.7), mouthfeel (7.8), sweetness (7.1) and viscosity (7.9) had the highest mean intensity score. There was a significant increase in protein, iron, zinc and pro-vitamin A with an increase in the amount of pigeon pea and/or orange flesh sweet potato flour. Sample PPBN718, PPBN193, PPBN136 and $PPIP_{ofsp}{}^{r}$ had better nutritional and sensory qualities that make them suitable for consumption.

Keywords: *Pigeon pea-based noodles, Pigeon pea-based instant porridge, Linear programming, Descriptive profiling*

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Introduction

Food product development involves converting raw materials into a product to maintain the quality, freshness and organoleptic properties of food (Earle *et al.*, 2001). It also involves processing and preservation to provide a safe nutritious diet and increase the shelf life (Habwe & Walingo, 2008). Pigeon pea is among the raw materials used for making various food products (Ashaye *et al*., 2015; Fasoyiro *et al*., 2012; Silim *et al*., 2001). Pigeon peas has been documented to contain protein ranging from 17.9 to 26.3 g (Akubor, 2017; Adepeju *et al*., 2015). It is rich in amino acids such as lysine (but deficient in methionine and cysteine) (Akubor, 2017; Saxena *et al*., 2010), iron (24.52 – 31.98 mg); and zinc (23-54 mg) (Abebe, 2022). Household meals in rural Tanzania communities are characterised by limited portions of vegetables, fruits and legumes, which cannot provide adequate amounts of micronutrients and protein. Therefore, pigeon peas can be mixed with other ingredients to optimize nutrient content and improve organoleptic properties. It has been used in different blends in making various foods including biscuits, cookies (Ashaye *et al*., 2015; Karri & Nalluri, 2017; Okpala & Chinyelu, 2011), bread (Olanipekun *et al*., 2018) and complementary food (Liomba *et al*., 2018; Nwaoha & Obetta, 2016). Despite the nutritional importance of pigeon peas, the legume has not been adequately utilized for human consumption in Tanzania due to limited recipes (Majili *et al*., 2020). This creates an opportunity to develop value-added pigeon pea-based products for recipe diversification that can lead to increased consumption and market opportunities.

Noodle is an extruded product, traditionally made from wheat mixed with water and salt to form a dough (Okpala *et al*., 2016). Noodles are consumed in different parts of the world in various forms such as vermicelli, spaghetti, pasta or macaroni (Lande *et al*., 2017; Kaushal & Sharma, 2014; Mogra & Midha, 2013; Torres *et al*., 2006). Worldwide, it is consumed as a snack, meal and iftar during fasting months (Ramadan) for Muslims'. Based on experience, the consumption of noodles in Tanzania is very limited, especially in rural households. It is mainly consumed during Ramadan as iftar. The surface appearance, texture and minimal cooking time make wheat flour suitable for making noodles. Wheat is used in the production of noodles due to the presence of gluten that contributes to the dough rheology. Gluten level determines the appearance and the structure of cereal-based products. In addition, wheat is a good source of pyridoxine, niacin, thiamine, riboflavin, pantothenic acid manganese, phosphorus, magnesium, selenium, zinc, copper, iron, and potassium but is deficient in lysine (Lande *et al*., 2017; Mogra & Midha, 2013). Noodle flour with less gluten has poor texture and is more brittle due to weaker formation of protein linkage (Li *et al*., 2017; Barak *et al*., 2014). Pigeon peas have fewer viscoelastic properties (Olanipekun *et al*., 2018) compared to wheat flour. Therefore, blending wheat flour and pigeon pea to make noodles will improve the physical and sensory quality of the developed PPBN. It will also optimize the nutrient content of the noodles.

Traditionally, porridge is made from different cereal and root flours such as maize, sorghum, millet and cassava flour. In Tanzania, porridge flour is mainly made from cereal-based flour such as maize and finger millet (Mollay *et al*., 2021; Muhimbula *et al*., 2011; Martin *et al*., 2010). These flours are low in protein, lysine and tryptophan (Muhimbula *et al*., 2011). Currently, it is common practice among farmers and informal small-scale food processors to mix several types of cereal flours, and oilseed or legume. Although it is common knowledge that oilseeds such as groundnuts and legumes such as soybean improves the protein content, the basis of mixing the ingredients and amounts of ingredients are however not known to the processors. The use of soybean is limited among rural households due to cost and difficulties in processing to reduce anti-nutritional factors such as phytates, tannins, trypsin inhibitors and oligosaccharides. It is also considered to take long time to cook to reduce off beany flavour (Kalumbi *et al*., 2019). The use of pigeon peas in flour blend and extrusion cooking methods can be an alternative approach offering the potential to reduce processing difficulties and reduce cooking time as well as providing required nutrients for growth and development.

In this study, Linear Programming was used to determine the amount of pigeon pea that can be mixed with wheat and orange flesh sweet potato flour to meet recommended daily nutrient intakes of protein, iron, zinc and pro-vitamin A for adults. Linear programming has also been used to formulate complementary porridge for infants and young children. Linear programming has been used in previous studies as a useful tool to formulate affordable, cost-effective, nutrient-dense, and culturally acceptable products (Sheibani *et al*., 2018; Briend *et al*., 2003; Briend *et al*., 2001).

All these calls for the use of pigeon peas in different blends for nutrient optimization of different food products. The objectives of this study were therefore to (i) determine the best combinations of ingredients to formulate pigeon pea-based noodles and instant porridge flour using Linear programming, (ii) develop pigeon pea-based noodles and instant porridge flour, (iii) test whether the developed products meet the consumer needs

Materials and Methods

Sample Procurement and Collection

Maize grains and pumpkin were bought at local markets around Morogoro municipality, Tanzania. Wheat flour was bought at the nearby shops around Sokoine University of Agriculture. Orange flesh sweet potatoes flour (OFSP) was bought at Sokoine University Graduate Entrepreneurs Cooperative (SUGECO) premises located at the Sokoine University of Agriculture, Morogoro. Pigeon peas were bought from farmers in the study site described earlier (Majili *et al*., 2020) and transported to Sokoine University of Agriculture, Department of Food Science and Agro-processing. Ingredients for producing noodles were pigeon peas, wheat and orange flesh sweet potatoes flour (or pumpkin flour).

Sample Preparation and Processing

Maize Flour (MF)

Maize was sorted to remove all dirt and damaged one. The maize sample was then washed and dried in the direct sunlight. The samples were then milled to get fine flour. After milling, the maize flour was stored on a well-tight bag and labelled.

Pumpkin Flour (PF)

The pumpkins were cleaned with distilled water and peeled to remove the skin. The seeds were removed and manually chopped into small pieces of about 3 to 4 cm in length and 1 to 1.5 cm in width for easy drying. The chopped pieces were then dried on the oven dryer at 60°C for 24hrs to a moisture content of 10%. The dried pumpkin sliced were milled, packed and labelled.

Pigeon Pea-Based Flour (PPBF)

Soaking, dehulling and cooking of pigeon peas were used as processing practices to increase the nutritional quality and organoleptic properties and reduce anti-nutritional factors (e.g. phytates) (Prodanor *et al*., 2004). Before processing the pigeon peas were sorted to remove all dirty and damage grains. The pigeon pea was then divided into two portions. One portion was immersed in boiled water at 100^{o}C for 30 minutes to allow the testa to swell. The boiled water was then discarded and cold water was added to cool the grains for easing the removal of the seed coat/testa. The cooled grains were rubbed by clean hands to remove the seed coat/testa, and later dried on the direct solar dryers. The second portion of PP was roasted in an oven at the temperature of 180^{o}C for 20 minutes. The roasted grain was then soaked in cold water overnight and manually rubbed to remove the seed coat. Thereafter, the grains were dried on the direct solar dryers and milled twice using stainless steel electric grain mill grinder (model F67A, MXBAOHENGus Instrument Co. Storefront) and a heavy-duty food blender (STRONGERTECH-PMC) to get fine flour. The flour was sieved through a 250µg testing sieve (Tokyo Screen. Co. Ltd Japan) and packed well for further processes. The flour made from boiled pigeon pea was used on noodle production (PPBN) whereas the flour made from both boiled and roasted pigeon pea was used on the production of porridge flour (PPIP)

Formulation

Formulation of the product was done using Linear programming (LP) in Microsoft excel software version 2020. The LP model was developed using the objective function, decision variables and constraints. The cost of ingredients used, nutrient composition of each ingredient and Recommended Nutrient Intake (RNI) for protein, iron, vitamin A and zinc were considered as the objective function, decision variables and constraints, respectively. The objective functions were formulated to minimize the cost as well as maximizing the nutrient content of developed products.

The objective function of noodles formulations is

1. $Z1_{nd} = 10^{-3}(C_{pp} + C_{wf})$ .... (Equation 1a)
2. $Z2_{nd} = 10^{-3}(C_{pp} + C_{wf} + C_{ofspf})$ .... (Equation 1b)

The objective function for instant porridge formulation is

3. $Z1_{ip} = 10^{-3}(C_{pp} + C_{mf} + C_{pf})$ ....(Equation 2a)
4. $Z2_{ip} = 10^{-3}(C_{pp} + C_{mf} + C_{ofspf})$ ....(Equation 2b)

Where Z1 and Z2 = total cost of 100g of the product mix for formulations 1 and 2 respectively, nd = noodles, ip = instant porridge, 10^{-3} = Conversion factor from kg to grams, pp = pigeon pea, wf = wheat flour, ofsp = orange flesh sweet potatoes flour, pf = pumpkin flour, mf =maize flour.

The decision variables used in the LP model were the nutrient composition of each ingredient in the formulation (Table 1). The LP constraints were RNI based on the World Health Organization and USA Institute of Medicine recommendations (FAO and WHO, 2004; IOM, 2002). The RNI for adults aged above 18 years were used as LP constraints for noodles and for the instant porridge, the RNI for children aged 12 to 36 months were used (Table 1). In terms of gender differences in nutrient requirements, the highest value was used in the computation to accommodate those with the highest and lowest requirements. The equation for calculating the amount of each nutrient in 100g of the product mix for noodles and instant porridge to meet the nutritional requirements for protein, iron, vitamin A and zinc (constraints) is as follows:

Table 1:
Decision variables and constraints used in the formulation

Nutrients	Decision variables						Constraints	
	PP_r	PP_b	wf	ofspf	pf	mf	RNI/day (1 - 3 years)	RNI/day (19 - 55 years)
Protein (g)	17[b]	15[b]	11.2[h]	2.48[i]	0.12[a]	8.1[c]	13[d]	56[d]
Iron (mg)	6.8[b]	3.5[b]	5.6[h]	11.5[i]	1.47[j]	3.5[c]	11[f]	18[f]
Pro-vitamin A* (µg)-RE	23.3[e]	23.3[e]	93[h]	1467[c]	575[g]	0[c]	300[f]	900[f]
Zinc (mg)	6.1[b]	4.3[b]	0.87[h]	0.93[i]	3.1[a]	1.8[c]	8.3[f]	14[f]

*the RNIs is for vitamin A not for pro-vitamin. PP_r roasted pigeon pea, PP_b blanched pigeon pea, *wf* refined and fortified wheat flour; [a] Ivanova *et al.*, 2016; [b] (Liomba *et al.*, 2018), [c] (Lukmanji *et al.*, 2008); [d] (IOM, 2002), [e] (Adepoju *et al.*, 2019), [f] (FAO and WHO, 2004), [g] (Pereira *et al.*, 2020), [h] (FAO/GOK, 2018), [i] (Dako *et al.*, 2016), [j] (Usha *et al.*, 2010)

The minimum amount of nutrient X in 100g of noodle mix was calculated as

F1 $10^{-3}(X_{ppf} + X_{wf}) \geq m_X$ .... (Equation 3a)

F2 $10^{-3}(X_{ppf} + X_{wf} + X_{ofspf}) \geq m_X$ ....(Equation 3b)

The minimum amount of nutrient X in the instant porridge flour mix was calculated as

F3 $10^{-3}(X_{ppf} + X_{mf} + X_{ofspf}) \geq m_X$ .... (Equation 4a)

F4 $10^{-3}(X_{ppf} + X_{mf} + X_{pf}) \geq m_X$ .... (Equation 4b)

Where
X = nutrient of interest (protein/iron/pro-vitamin A/zinc),
m = minimum amount of nutrients of interest in 100g of the product mix for formulation F1…F4,
ppf = pigeon pea flour, wf = wheat flour,
ofspf = orange flesh sweet potatoes flour,
pf = pumpkin flour.

Database Setting and Optimization
MS excel software 2020 was used to create a database for the composition of the ingredients. Number of nutrients in 100g, cost per 1000g of each ingredient, and RNI for each selected nutrient (Table 1) were included in the database. Nutrient composition of pigeon pea, pumpkin, all-purpose wheat flour and maize was extracted from different food composition databases (FAO/GOK, 2018; Lukmanji *et al.*, 2008). Kenya food composition table was used for the nutrient content of wheat flour used in the formulation and Tanzania food composition table was used to obtain information on pro-vitamin A content of orange flesh sweet potatoes. Also, different literature was used to obtain information of protein, iron, zinc and pro-vitamin A for pigeon pea flour, orange flesh sweet potatoes flour, pumpkin and maize flour (Table 1) (Adepoju *et al.*, 2019; Dako *et al.*, 2016; Liomba *et al.*, 2018; Pereira *et al.*, 2020; Usha *et al.*, 2010). The changing variable cells (proportion/amount of each ingredient to be added to the product mix) and cell reference (amount of nutrient in the product mix) were introduced in the software. The computation of the amount of each ingredient and the cost of the product mix was done using the simplex method. The optimization was done using Solver add-in Microsoft Excel 2010 (Microsoft, Inc., Redmond, WA, USA). A solver command was used to minimize the cost of the pigeon pea-based food product mix while optimizing the nutrient content of the product mix.

Amount of Ingredients in Each Formulation
Figure 1 and 2 presents the amount of each ingredient used in different formulations. A total of 12 samples were formulated, eight samples of noodles (designated as PPBN) and four samples of instant porridge (designated as PPIP). The assumption for the formulation is to meet at least 75% of RNI for protein and 50% of RNI for iron, zinc and vitamin A. Another objective was to change the amount of ingredients to check for sensory attributes that will be acceptable. For pigeon pea-based instant porridge flour, the objective function was to maximize the protein, iron, zinc and vitamin A content of the product mix. An equal amount of ingredients was used in all formulations with the difference in the type of ingredients used and processing methods. Sample $PPIP_{pf}^{r}$ and $PPIP_{ofsp}^{r}$ were mixed with roasted pigeon pea and samples $PPIP_{pf}^{b}$ and $PPIP_{ofsp}^{b}$ were mixed with pigeon pea that has been blanched before being processed into flour (Fig. 2). The reason for the variation is to increase the chances of acceptance.

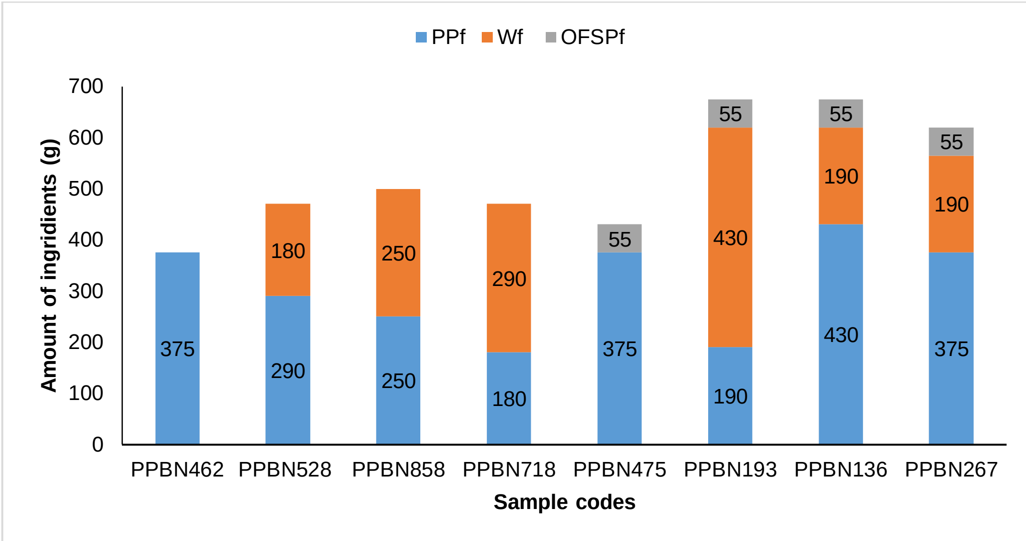

Figure 1:
Amount of ingredients used in the different formulations of pigeon pea-based noodles

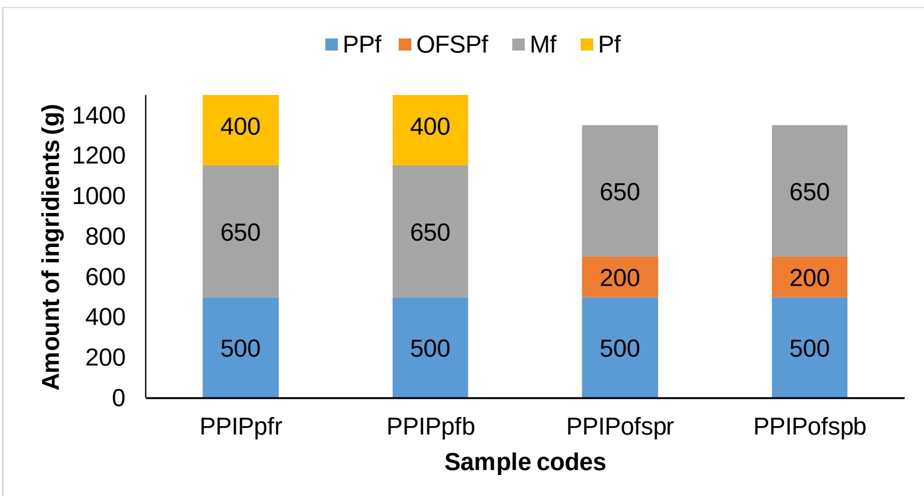

Figure 2:
Amount of ingredients used in the different formulations of pigeon pea-based noodles

Pigeon Pea-Based Noodles Development

Noodles ingredients included pigeon pea, wheat, and orange flesh sweet potatoes (or pumpkin flour) in different formulations. The amount of water to be added to the mixture was also measured (ranging from 200 to 300 ml) and boiled to reach the temperature of 30°C. Water was added to the dry flour blend and mixed well using a pasta mixer (Model: MSM-15, Henan Alchemy machine, Zhengzhou, China). The pasta mixer was run for 5 to 7 minutes depending on the flour blend formulation to allow the ingredients to mix well. The mixture was then left to rest for 15 minutes to allow the spreading of water and improvement of gluten properties. Thereafter, little amount of the flour blends at a time was added to the hopper for the extrusion process using a single screw extruder pasta machine (model MST-30, Henan Alchemy machine, Zhengzhou, China). The noodles were then dried outdoor in solar driers at a temperature between 27 to 37°C. The weight of each sample was recorded before being taken to the drier and each day around 2 pm until the weight remains constant. After drying the noodles were packed well in a zip bag and labelled.

Pigeon Pea-Based Instant Porridge Development

Four pigeon pea based instant porridge samples were developed using extrusion technology as one of the modern food processing technologies used to improve functionality, physical state and shelf stability of food products. The main ingredient was pigeon pea flour mixed with maize flour and OFSP (or pumpkin) flour. Each ingredient was measured and put into a basin for mixing and labelled as samples 1(a), 1(b), 2(a), and 2(b). Distilled water was added to the mixture of each sample to raise the moisture content of the flour to 14%. Then each sample was extruded using a twin-screw extruder (Model JS 60 D, Qitong Chemical Industry Equipment Co. Ltd, Yantai, China). Sample 1(a) and 1(b) was extruder at a motor speed rate of 30.23rpm, feeder speed rate of 06.2rpm, and temperature of 135 ^{o}C at zone I and 89 ^{o}C at zone II. For samples 2(a) and 2(b) the motor speed rate of 28.83rpm, feeder speed rate of 06.2rpm, and temperature of 123 ^{o}C at zone I and 107^{o}C at zone II. After extrusion, the samples were left to cool and dry at room temperature. The samples were then milled using a commercial hammer mill (Intermech, Tanzania) to get fine flour. The flour was packed in a clean and well-labelled tight container.

Quantitative Descriptive Analysis of Pigeon Pea-Based Noodles (PPBN) and Instant Porridge (PPIP)

Quantitative Descriptive Analysis (QDA) was conducted at the Department of Human Nutrition and Consumer Sciences, Sokoine University of Agriculture. The conduct of QDA involved several steps as summarized in the flow chart (Figure 3).

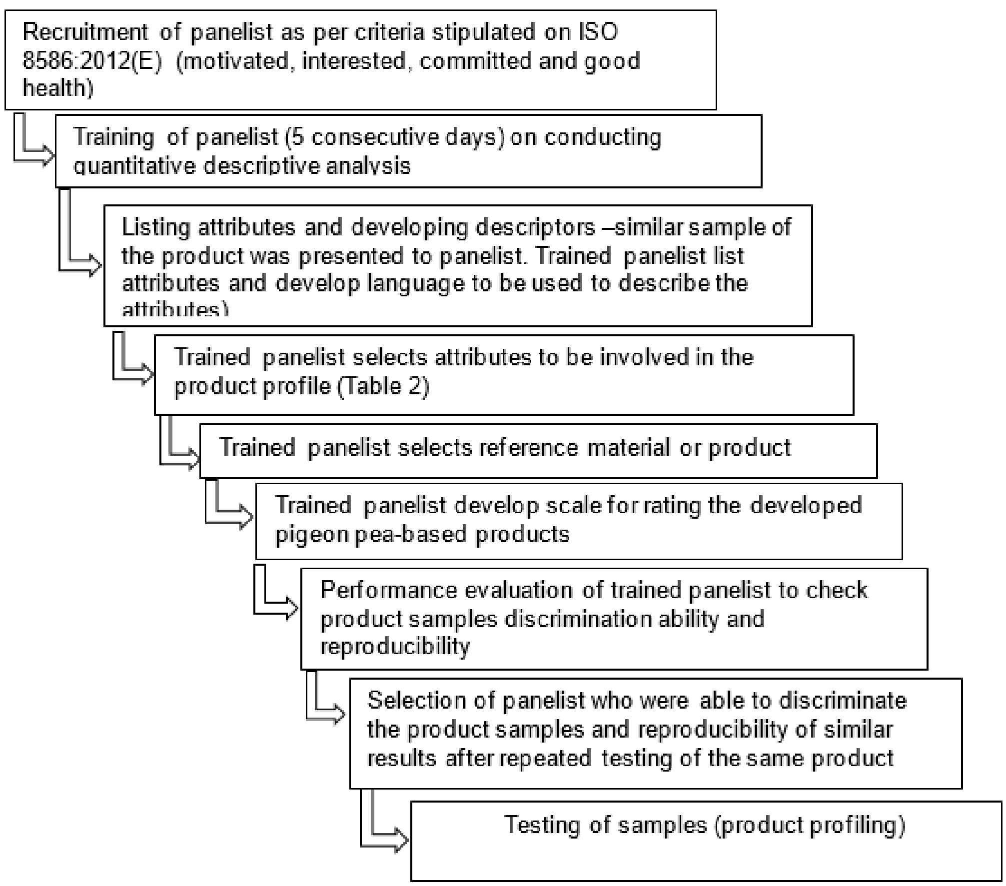

Figure 3:

A flow chart showing QDA steps for developed pigeon pea-based products

A total of 26 panellists were recruited and trained to conduct QDA. Fifteen product attributes were identified and listed for QDA, after a similar sample of product was presented to the panellist for testing and developing a common language to be used. Only 5 attributes for PPBN and PPIP were selected for inclusion in final product testing (Table 2). Trained panellist developed a 9-point scales (1 = not noticeable, 2 = trace, 3 =not sure, 4 = faint, 5 = slight, 6 = mild, 7 = moderate, 8 = definite strong, 9 =very strong) for the 5 attributes. Performance evaluation of trained panellist was done to check the product samples discrimination ability and reproducibility. One of the panellists was disqualified after performance evaluations and remained with 25 panellists to conduct QDA. Among them, 14 panellists were involved in the QDA of pigeon pea-based noodles and 11 panellists were involved in the QDA of instant porridge.

Table 2:

Description of product attributes and scale for PPBN and PPIP

Attribute	Descriptor	Reference	Rating scale (1 to 9 point)
Colour (PPBN & PPIP)	Ivory colour	Santa Lucia pasta	Light to deep ivory
Aroma (PPBN &PPIP)	Aroma of cooked dried pigeon pea	Cooked pigeon pea	Less to very strong aromatic
Mouthfeel (PPBN &PPIP)	Slippery feel when chewing products	Ripen banana (PPBN) Instant finger millet porridge (PPIP)	Less slippery Course to very strong fine particles
Saltiness (PPBN)	1g of $NacCl_2$ in 1000mls of water	Solution of Table salt	Less to too much salt
Softness (PPBN)	Easy chewiness associated with normally cooked noodles	Cooked noodles (Santa Lucia Pasta)	slightly to very soft
Viscosity (PPIP)	Resistance to flow (Thickness/thinness)	ASAS yoghurt	Low (watery) to high viscosity
Sweetness (PPIP)	1g of sugar in 1000mls of water	Solution of sugar	Slightly to very sweet

Sample Preparation for QDA

Noodle samples were cooked in boiling water, a pinch of salt was added and letting them boil for 5 minutes. The remained water was drained and cold water was poured on it to stop further cooking that can affect the appearance and texture of the sample. Sugar and cardamom were then added to drained noodle and mixed well. The noodle was then partially fried. During cooking equal amount of salt, sugar, cardamom and cooking oil were added to each sample. The cooked noodles were then removed from the cooker and served in identical containers. Each container was labelled with 3- digit random numbers (e.g. 462, 571 etc.); that vary from one sample to another on each test session. The samples were stored in hot flask to maintain the temperature ready for serving.

Porridge samples were prepared by mixing 750 ml of hot water and 100g of PPIP flour. The PPIP flour was poured in the bowl and little amount of hot water was added at a time while continuous stirring the porridge until all water has been added and the porridge is free from lumps. The mixed porridge was then taken to the cooker and boiled for 5 minutes to make it hot and reduce any contamination made during mixing. The porridge was then stored in the hot flask to keep it hot during testing.

Design and Procedures for Testing Developed PPBN and PPIP

Balanced incomplete block design (BIBD) was used during PPBN sample testing (Lawless & Hildegarde, 2010). The BIBD was used because the samples to be tested were many and could not be served to panellists all at a time. However, all PPBN samples were served in an equal number of times into each experimental unit. The experimental unit (blocks) for this was trained panellist and developed pigeon pea-based products were set as the treatments. The statistical model used is

$Y_{ijo} = \mu + t_i + p_j + r_k + e_{ijo}$ .... (Equation 5)

Where Y_{ijo} = the observed response (o) to the i^{th} treatment in the j^{th} block (panellist), μ = total mean, t_i = the effect of i^{th} treatment, P_j = random effect of the j^{th} panellists, r_k = random effect of the k^{th} replicate and e_{ijo} = random error associated to ijo. It is assumed that e_{ijo} is normally distributed with mean zero and variance σ_e^2.

Four samples of PPBN were simultaneously served at a time, followed by 3 hours of resting before testing another 4 samples. Testing was conducted around 9 am for the morning session and 3 pm for the evening session to avoid physiological biases that may be caused by being hungry or full. Panellists were instructed to test each sample served and evaluate it independently by indicating the intensity of each specified attributes by rating it in a 9-point scale where 1 = not noticeable, 2 = trace, 3 = not sure, 4 = faint, 5 = slight, 6 = mild, 7 = moderate, 8 = definite strong, 9 = very strong. The ratings were filled in the respective column in the provided questionnaire (Appendix 2). The testing was done in triplicate for each sample. During testing, panellists were provided with water for mouth rinse before testing another sample.

A complete randomized block design (CRBD) was used in testing PPIP samples as there were few (four) samples. The treatments were PPIP samples, and the blocks were panellists. The statistical model used is as follows:

$Yij = \mu + ti + ei$ .... (Equation 6)

Where Yij= the observed response for the i^{th} treatment in the j^{th} block (panellist), μ = total mean, t_i=the effect of i^{th} treatment, e_i=random effect of the j^{th} panellists

Four PPIP samples were served at once in random order. Ten millilitres of porridge were served in labelled disposable glass coded with 3 unique digit numbers in random order. Each panellist was requested to test the porridge and rate it against each PPIP attribute (Table 2). The samples were served in triplicates.

Data Analysis

Data were analysed using R software (3.6.2 version) for quantitative descriptive analysis of developed pigeon pea-based noodles and instant porridge. Mean and standard deviation was computed. Two-way ANOVA was computed to determine the mean differences among formulations. A post hoc pairwise test (Tukey test) was used to determine differences between the samples at a p-value < 0.05. Sensory attributes were treated as dependent variables against sample formulations and panellists. The Principal Component Analysis (PCA) was done to determine the multidimensional and possible relations of the samples against sensory attributes using XLSTAT (Addinsoft, New York, USA).

Results

Nutrient Content of Developed PPBN and PPIP Flour

The protein content of PPBN ranged from 41.0 to 58.2 g (Table 3). Iron content in samples PPBN193 was 26.4 mg and PPBN136 was 18.3 mg. Pro-vitamin A, content for sample PPBN136 was 867.4 µgRE. Sample PPBN462 had a zinc content of 12 mg. For PPIP samples protein content was between 13.8 and 17.1 g and pro-vitamin A content of 245.1 - 308.5 µgRE was observed. Sample $PPIP_{ofsp}{}^{r}$ had an iron content of 7.9 mg and 5.4 mg of zinc (Table 3).

Table 3

Amount of nutrients in 100g of the optimized PPBN and PPIP and percent contribution to the nutrient requirement of the study population

Product	Sample code	Protein g(%)	Iron mg (%)	Zinc mg (%)	Pro-vitamin A μg(%)
PPBN	RNI/day-adults	56	18	14	900*
	PPBN462	41 (74)	10(53)	12.0(84)	64(7)
	PPBN528	44 (79)	16(87)	8.0(60)	37(4)
	PPBN858	45.9 (82)	15.9(88)	9.0(65)	40.8(5)
	PPBN718	56.0(100)	21.0(116)	10.0(71)	42.0(5)
	PPBN475	42.6 (76)	15.9(89)	12.3(88)	870.9(97)
	PPBN193	54.5(97)	26.4(147)	9.6(69)	844.1(94)
	PPBN267	49.3(88)	19.3(107)	12.8(92)	870.9(92)
	PPBN136	58.2(104)	18.3(102)	12.7(91)	867.4(96)
PPIP	RNI children	13	11	7	300*
	$PPIP_{pf}{}^{r}$	17.1(131)	6.2(56.7)	5.3 (76)	245.1(82)
	$PPIP_{pf}{}^{b}$	13.8(106)	4.6(42)	3.8(53.9)	245.1(82)
	$PPIP_{ofsp}{}^{r}$	17.5(134)	7.9(72)	5.4 (77)	308.5(102)
	$PPIP_{ofsp}{}^{b}$	14.2(109)	6.3(57)	3.8(55)	308.5(102)

* the value presented is for RNI of vitamin A

Panellists' Characteristics

A total of 14 panellists were involved: 57% males and 43% females. Their mean age was 22.78 ± 0.57 (SD) years ranging from 22 to 24 years. For PPIP panellists the mean age was 23.54 ± 1.21(SD) years ranging from 22 to 25 years, among them 6 (55%) were male and 5 (45%) were female.

Quantitative Descriptive Profiling of Developed PPBN and PPIP Flour

Table 4 presents the mean intensity scores of the PPBN sample. The highest mean intensity score for colour was 7.1 ± 0.66 (SD) found in sample PPBN718, followed by PPBN193 (7.0 ± 1.02 (SD)) and PPBN136 (7.0 ± 0.74 (SD)). The lowest mean intensity score was 5.1 ± 0.83 (SD) observed in sample PPBN462. Similarly, the highest mean intensity scores for aroma and mouthfeel were observed in samples PPBN718, PPBN193 and PPBN136. There were significant differences ($p< 0.05$) in mean intensity scores in terms of colour and aroma between samples PPBN718, PPBN193 and the remaining formulations. In terms of mouthfeel there was no significant difference between sample PPBN193 and PPBN136; sample PPBN528 and PPBN858 at p-value < 0.05. The means values with different superscript letters within a column are significantly different at ($p< .05$). The multivariate analysis for noodle samples against sensory attributes indicated 91% of the total variation in sensory attributes for different PPBN samples. The F1 axis which was also a principle component 1 explained 71% of the variability between samples on the right of the Y-axis (PPBN718, PPBN193, PPBN136) and those on the left of the Y-axis (PPBN462, PPBN528, PPBN267, PPBN475, PPBN858) (Fig. 4).

Table 4

Mean intensity scores of sensory attributes for PPBN samples

Sample code	Colour Mean ± SE	Aroma Mean ± SE	Mouthfeel Mean ± SE	Saltiness Mean ± SE	Softness Mean ± SE
PPBN462	5.1 ± 0.83 c	5.9 ± 0.94 b	4.0 ± 1.52 e	5.3 ± 1.75a b	5.1 ± 2.55 a
PPBN528	6.0 ± 0.72 b	6.0 ± 1.16 a b	6.1 ± 0.88 c d	5.8 ± 1.74a	5.1 ± 1.94 a
PPBN858	5.9 ± 1.53 b c	6.1 ± 1.47 a b	5.8 ± 1.55 c d	5.1 ± 1.42 a b c	4.7 ± 1.98 a
PPBN718	7.1 ± 0.66 a	7.1 ± 0.83a	7.2 ± 0.87 a	4.7 ± 1.91 b c	5.3 ± 1.99 a
PPBN475	5.4 ± 1.73 b c	6.0 ± 1.04 a b	5.5 ± 1.29 d	4.9 ± 1.86 b c	4.6 ± 2.22a
PPBN193	7.0 ± 1.02 a	7.1 ± 1.06a	7.0 ± 0.76 a b	5.1 ± 1.62 a b c	5.5 ± 1.96 a
PPBN136	7.0 ± 0.74 a	7.1 ± 0.98 a b	7.0 ± 1.00 a b	4.4 ± 1.45 c	5.2 ± 1.93 a
PPBN267	5.7 ± 1.53 b c	6.6 ± 1.81 a b	6.3 ± 1.06 b c	4.9 ± 1.72 a b c	4.8 ± 2.42a

The F1 was also associated with high intensity in aroma, mouthfeel, colour and softness for samples PPBN718, PPBN193 and PPBN136 while sample PPBN528 and PPBN462 had higher saltiness intensity. Looking at F2 which accounts for 20% of variability, samples PPBN528 and PPBN462 were associated with saltiness while sample PPBN193 was associated with softness and sample PBN718 was associated with colour, aroma and mouthfeel.

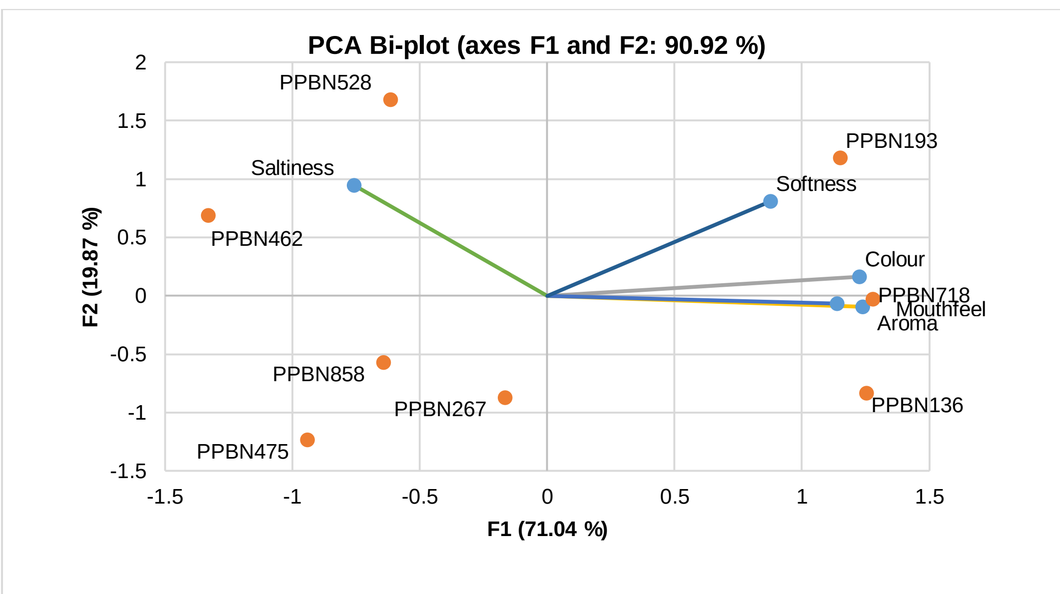

Figure 4

PCA Bi-Plots for PPBN

The highest mean intensity scores for colour (8.7) aroma (7.7), mouthfeel (7.8), sweetness (7.1) and viscosity (7.9) were observed in sample $PPIP_{ofsp}{}^{r}$ (Table 5). The lowest mean intensity scores for colour (5.3) and mouthfeel (5.8) were observed in sample $PPIP_{pf}^{r}$. Sample $PPIP_{ofsp}^{r}$ and $PPIP_{ofsp}^{b}$, were significantly different in colour, mouthfeel and sweetness with sample $PPIP_{pf}^{r}$ and $PPIP_{pf}^{b}$ at p-value < 0.05 (Table 5). There were no significant differences in the aroma for all samples.

Table 5

Mean intensity scores of attributes for developed PPIP sample

Sample code	Colour Mean ± SD	Aroma Mean ± SD	Mouth feel Mean ± SD	Sweetness Mean ± SD	Viscosity Mean ± SD
$PPIP_{pf}^{r}$	7.0±0.97^{b}	7.3±0.08^{a}	6.4±2.23^{b}	5.9±2.17^{b}	6.9±1.18^{c}
$PPIP_{pf}^{b}$	5.3±1.23^{c}	7.0±1.88^{a}	5.8±1.82^{b}	6.2±1.99$^{a\,b}$	7.1±1.47$^{b\,c}$
$PPIP_{ofsp}^{r}$	8.7±0.67^{a}	7.5±1.50^{a}	7.8±0.99^{a}	7.1±0.90^{a}	7.9±1.02^{a}
$PPIP_{ofsp}^{b}$	8.7±0.49^{a}	7.3±1.02^{a}	7.7±0.84^{a}	7.1±0.76^{a}	7.8±0.73$^{a\,b}$

The means values with different superscript letters within a column are significantly different at ($p<0.05$).

The XLSTAT PCA output explained 97% of the total variation among PPIP samples. The results in Figure 5 show the relationship between sensory attributes and the PPIP sample. The F1 accounted for 87% of variability in sensory attributes. Aroma, colour, mouthfeel, viscosity and sweetness were significantly associated with samples $PPIP_{ofsp}^{r}$ and $PPIP_{ofsp}^{b}$. There was no association in sensory attributes between samples $PPIP_{pf}^{r}$ and $PPIP_{pf}^{b}$. The F2 explained 10% of the variability in aroma, colour and mouthfeel between samples $PPIP_{ofsp}^{r}$ and $PPIP_{pf}^{r}$ as well as viscosity and sweetness among samples $PPIP_{ofsp}^{b}$ and $PPIP_{pf}^{b}$.

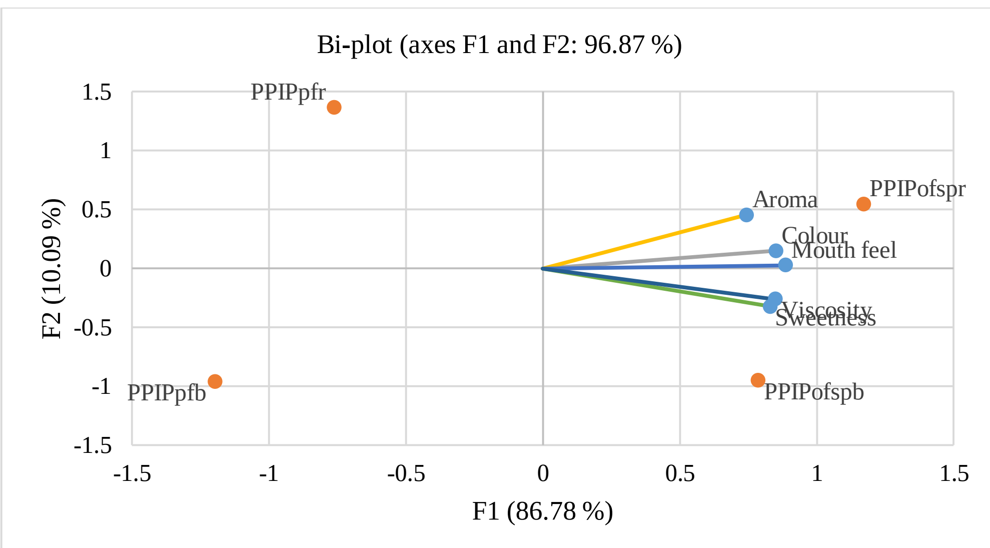

Figure 5

PCA Bi-plots for pigeon pea-based instant porridge

Discussion

Pigeon pea-based noodles and porridge were formulated to maximize protein, iron, pro-vitamin A and zinc content while minimizing the cost of producing the product using Linear programming. The amount of ingredients that will be mixed to meet nutrient requirements of protein, iron, zinc and vitamin A for children aged 7 - 36 months and adults were also determined.

Nutrient Content of the Developed Noodles (PPBN) and Instant Porridge Flour (PPIP)

Protein content of developed PPBN and PPIP flour

The protein content of all developed PPBN is 5 times higher than that of wheat-based noodles which contain only 11–15 percent of the protein requirement (Mahmoud *et al*., 2012). If 100 g of developed PPBN is consumed there is likely a person to get at least 50% of RNI for protein per day. The addition of pigeon peas in the production of noodles improves the protein content of the product.

The protein level of the developed PPIP is significantly higher than cereal-based porridge flour used by community members in the study area. This is due to the addition of pigeon peas which contained a considerable amount of protein. A similar finding was reported earlier in a study by Muhimbula *et al*. (2011) who revealed that legumes such as common beans and soybeans have been used to increase the protein content of different complementary foods (Keyata *et al*., 2021; Trehan *et al*., 2015; Martin *et al*., 2010; Lukmanji *et al*., 2008). Supplementing legumes in cereal-based foods not only raises the protein level but also complement each other. Studies show that blending cereals and legumes improve the nutritional and functional properties of food (Keyata *et al*., 2021; Martin *et al*., 2010).

Iron content of developed PPBN and PPIP flour

The iron content of developed pigeon pea-based noodles was three times higher than in traditional noodles which are composed of 4 to 4.90 mg of iron per 100g (Sunil *et al*., 2019; Thi Le *et al*., 2007). The addition of pigeon pea and orange flesh sweet potato flour increased iron content. Sample PPBN193, PPBN136, and PPBN267 have the highest amount of iron than other samples. This is due to the reported high content of iron in orange flesh sweet potatoes (Dako *et al*., 2016) than in wheat (FAO/GOK, 2018) and pigeon pea flour (Liomba *et al*., 2018). Since iron content in pigeon peas is less bioavailable due to the presence of phytates, the developed products were made from pre-treated pigeon peas to reduce these inhibitors of nutrient absorption.

Sample $PPIP_{ofsp}^{r}$ had higher iron content which contributes 72% of RNI than sample $PPIP_{ofsp}^{b}$. This is attributed to the higher iron content in roasted pigeon pea than in raw and blanched pigeon pea. Comparing the PPIP sample with pumpkin flour and orange flesh sweet potato flour, the former has less amount of iron content. This is due to the high amount of iron content in orange flesh sweat potatoes (Dako *et al*., 2016) compared to the amount available in pumpkin flour (Usha *et al*., 2010).

Zinc content of developed PPBN and PPIP flour

Sample PPBN136 had a significant higher amount of zinc content attributed to a large amount of pigeon pea. Literature indicates that pigeon peas have zinc content ranging from 3 - 8.2 mg/100g dry matter (Karri & Nalluri, 2017; Amarteifio *et al*., 2002). Therefore, the addition of pigeon pea flour in the food product mix resulted in an increase in zinc content. Similarly, sample $PPIP_{ofsp}^{r}$ and sample $PPIP_{pf}^{r}$ was observed to have a significantly higher content of zinc than another sample despite of an equal amount of pigeon pea and maize flour were added in all samples. This is due to roasted pigeon pea having more zinc content than the blanched ones (Ojwang *et al*., 2021).

Pro-vitamin A content of developed PPBN and PPIP flour

Higher pro-vitamin A content was observed in all samples with OFSP flour (PPBN475, PPBN193, PPBN267, PPBN136 which contributes more than 90% of RNI. This is due to the amount of pro-vitamin A available in orange flesh sweet potatoes. Orange flesh sweet potatoes had a higher amounts of pro-vitamin A than the amount available in pumpkin (Lukmanji *et al*., 2008). Similarly, sample $PPIP_{ofsp}^{r}$ and $PPIP_{ofsp}^{b}$

had higher pro-vitamin A content due to added orange flesh sweet potatoes.

Quantitative Descriptive Profiling of Developed PPBN and PPIP Flour

Samples PPBN718, PPBN193 and PPBN136 were highly preferred samples due to higher mean intensity scores observed. This was due to the favourable composition of the ingredients that enhanced organoleptic attributes. All samples composed of pigeon pea, wheat flour and/or OFSP have higher mean intensity scores than the sample which has pigeon pea alone or the one with pigeon pea and OFSP flour. Colour change was attributed to the additional wheat flour, which is white, as a result, it reduces the deep colour of OFSP and PP. The Colour of Sample PPBN718 was mostly preferred due to the high amount of wheat flour in the sample. This makes the colour to be lighter and closer to the Pasta Santa Lucia (WILMAR Pasta Tanzania Limited) as a reference food. Saltiness is associated with samples PPBN528 and PPBN462 due to the higher amount of pigeon pea than other ingredients. Other samples had composed of OFSP flour which naturally had a sweet taste that masks the saltiness. Similar observation exists in sample PPBN475 and PPBN267 which has an equal amount of PPs with sample PPBN462 but has fewer saltiness intensities.

The Principal Component Analysis (PCA) loadings for samples PPBN193, PPBN718 and PPBN136 were positioned in a similar direction. This indicates the three samples had a similar intensity of colour, aroma and mouthfeel as the key drivers for liking the samples. Sample PPBN718 was closer to the origin, hence contributing less to the aroma, colour and mouthfeel variability. This means that almost all consumers feel the same in terms of aroma, colour and mouthfeel for sample PPBN718. Sample PPBN136 was a little bit far from origins and contributes more to variability of aroma, colour and mouth feel due to higher PCA loadings. Colour and aroma are among the quality attributes that attract consumer acceptability (Methakhup *et al*., 2005). Samples PPBN462 and PPBN528 were far and opposite directions from other samples hence contributing more to variability of colour, aroma, mouthfeel and softness. This was due to their appealing characteristics influenced by pigeon peas and less amount of wheat flour and no OFSP flour added to the mixture.

Moreover, there was a significant difference in terms of colour, mouthfeel and sweetness between the porridge flour samples composed of OFSP flour ($PPIP_{ofsp}{}^{r}$, $PPIP_{ofsp}{}^{b}$) and those with pumpkin flour ($PPIP_{pf}{}^{r}$, $PPIP_{pf}{}^{s}$). This was due to the colour differences of these samples. Sample $PPIP_{ofsp}{}^{r}$ and $PPIP_{ofsp}{}^{b}$ had colour which is closer to ivory colour as a reference food product. The colour for samples $PPIP_{pf}{}^{r}$, $PPIP_{pf}{}^{s}$ that were composed of pumpkin flour was very far from the reference sample. This was due to the deep orange or yellow colour of the pumpkin. Among samples composed with OFSP, sample $PPIP_{ofsp}{}^{r}$ had a higher mean intensity score in all attributes which may be attributed to the addition of roasted PPs flour. According to Tumuhimbise and colleagues, OFSP products have been reported to have many positive attributes (Tumuhimbise *et al.*, 2019). All samples were different in terms of viscosity; this could be due to serving temperature as all samples were served at one time while the testing was done one sample after another. As the time for testing porridge passes the temperature of the other samples decreases and makes them thicker and consequently less viscosity. Samples $PPIP_{ofsp}{}^{r}$ and $PPIP_{ofsp}{}^{b}$ had higher PCA loadings and contributed more to variability of aroma, mouthfeel, colour, sweetness and viscosity with samples $PPIP_{pf}{}^{r}$ and $PPIP_{pf}{}^{b}$. These variations were contributed by different compositions of the ingredients. Samples which were composed of pigeon pea, maize and OFSP flour were highly associated with higher intensity scores of aroma, mouthfeel, colour, sweetness and viscosity.

Conclusion and Recommendations

The protein, iron and zinc content of developed noodles and instant porridge were higher compared to wheat-based noodles. The addition of pigeon pea flour in developed noodles and instant porridge improves the protein, iron and zinc content in the developed noodles and instant porridge. Higher amount of iron and zinc in developed PPBN and PPIP is attributes to considerable amount of pigeon pea and OFSP added to the flour blend. Roasted pigeon pea flour used in the development of PPIP contributes a significant amount of iron and zinc content.

All samples which are composed of pigeon pea, wheat flour and/or OFSP have higher mean intensity scores for selected sensory attributes than sample which has pigeon pea alone or the one with pigeon pea and OFSP flour. Samples PPBN193, PPBN718 and PPBN136 have similar colour, aroma and mouthfeel intensities. Sample $PPIP_{ofsp}^{r}$ has a higher mean intensity score in aroma, mouthfeel, colour, sweetness and viscosity attributed to the addition of roasted PPs flour. Samples $PPIP_{ofsp}^{r}$ and $PPIP_{ofsp}^{r}$ have higher PCA loadings and contribute more to variability of aroma, mouthfeel, colour, sweetness and viscosity with samples $PPIP_{pf}^{r}$ and $PPIP_{pf}^{b}$. Generally, samples PPBN718 and $PPIP_{ofsp}^{r}$ are accepted due to their higher intensities in colour, aroma and mouthfeel. This study recommends that consumers should use the developed value-added pigeon pea-based products to improve their nutritional status (protein, iron, zinc and vitamin A status). Also consumers should use pigeon pea-based flour to enrich different food products in the household.

The results from this study makes an important contribution on the development of relevant interventions to mitigate macro and micronutrients problems in the country as crucial aspects to policy-making. Processing of pigeon peas increase the monetary value of the crop hence increases Market opportunities as one of the policy concerns to promote and support value addition in agricultural products consequently, improving the livelihood of community members and poverty alleviation.

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