Journal of Food and Nutrition Sciences
2025, Vol. 13, No. 5, pp. 224-236
https://doi.org/10.11648/j.jfns.20251305.11

Research Article

Optimizing Wheat Gluten Levels to Improve Textural Integrity and Sensory Appeal in Pigeon Pea Enriched Noodles

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Abstract

Noodles made exclusively from pigeon pea flour often display undesirable textural characteristics, such as brittleness, poor mouthfeel and a lack of the chewiness typically associated with traditional wheat-based noodles. These shortcomings can significantly impact consumer acceptability and overall eating quality. Incorporating vital wheat gluten, a protein known for its viscoelastic properties, offers a promising strategy to improve the structural integrity, elasticity and sensory appeal of pigeon pea-based noodle formulations. This study aimed to evaluate the influence of varying levels of vital wheat gluten (VWG) on the textural and sensory qualities of pigeon pea-based noodles (PPBN). Two optimized experimental samples PPBN 718 and PPBN 193 designed to meet adult dietary protein and mineral requirements were prepared with three concentrations of VWG (2%, 4% and 6%). Texture Profile Analysis (TPA), Quantitative Descriptive Analysis (QDA), Consumer Preference Analysis (n=75) and Principal Component Analysis (PCA) were conducted to assess product quality. Results indicated that formulation B193 consistently outperformed formulation A718 across all quality parameters, exhibiting significantly higher hardness, elasticity and overall consumer acceptability (P <0.05). Notably, PPBN193-2 achieved the highest overall acceptability score (7.41 ±0.59). In contrast, formulation PPBN 718-3 showed diminished performance. PCA results revealed that color was a dominant driver of sensory variation, while aroma, taste and mouthfeel clustered together, suggesting a potential trade-off between visual appeal and other sensory attributes. The superior performance of PPBN193-2 was attributed to the synergistic interaction between its unique flour composition including orange-fleshed sweet potato flour and VWG, which together, formed a more cohesive protein-starch matrix. These findings suggest that incorporating VWG at an optimal concentration of 4% can significantly enhance the textural integrity and sensory quality of legume-based noodles, particularly when used in well-optimized formulations like PPBN 193. This research supports the development of nutritionally enriched and consumer acceptable legume-based noodle products for broader market adoption.

Keywords

Pigeon-Pea Based Noodles, Vital Wheat Gluten, Structural-Integrity, Sensory-Quality, Consumer Acceptability

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Received: 31 July 2025; **Accepted:** 14 August 2025; **Published:** 25 September 2025

1. Introduction

Noodles are a significant global food staple, widely consumed and economically important across diverse cultures [1]. Their popularity can be attributed to their conveniences, ease of preparation, availability, and long shelf life [2]. In 2020, approximately 116.6 billion servings of instant noodles were consumed worldwide [2]. By 2021, global pasta production reached approximately 16.9 million tons, clearly indicating the widespread acceptance and global reach of noodles [2]. Traditionally, noodles are made from processed wheat flour, which contains gluten proteins. These proteins form a viscoelastic network during the dough preparation, acting as the skeleton framework for both the dough and the final product [3]. While wheat flour contributes desirable textural qualities, it lacks essential micronutrients such as vitamins A, C, E, K, as well as minerals like potassium, magnesium, and iron, unless it is fortified with other nutrient rich flours [4]. Moreover, wheat-based noodles are often deficient in essential amino acids, particularly lysine, threonine, and tryptophan. This nutritional shortfall has raised increasing health concerns, especially in populations that depend heavily on instant noodles as a primary food source [5].

Recognizing the nutritional gap in conventional noodles, and the growing demand for healthier, functional foods, researchers have shown increasing interest in enhancing the nutritional profile of noodles by incorporating non-traditional flours derived from legumes, cereals, and vegetables [6]. Legumes such as pigeon peas (*Cajanus cajan*) are rich in protein, dietary fiber, essential amino acids, and minerals, making them a promising ingredient for improving the nutritional quality of noodle products [7, 8]. Similarly, orange-fleshed sweet potatoes are an excellent source of provitamin A- carotenoids and dietary-antioxidants, which can help address micronutrient deficiencies when blended with wheat flour [9]. This incorporation of such nutrient-dense ingredients holds significant potential for developing wholesome and nutritionally enhanced noodle products.

Numerous studies have explored the formulation of composite flours using blended wheat with nutrient-rich flour sources such as legumes, root, vegetables and cereals. These efforts aim not only to modify and increase the quality of noodles but also to enhance their health benefits [3, 10-14]. However, the inclusion of non-wheat flour has often led to negative effects on noodle quality, particularly in terms physico-chemical properties, sensory appeal, and textural attributes. Texture in particular, is a critical factor influencing consumer acceptance [15-17].

According to Bangar et al. [18], the use of non-wheat cereals in breadmaking has resulted in products with reduced loaf volume, crumb or dense texture, poor gas retention, altered color, and shorter shelf-life challenges that are similarly observed in noodles production. These issues are primarily due to the dilution or absence of gluten, which is essential for forming the viscoelastic network in dough. Additionally, competition for water between gluten and fiber. As well as sensory performance, further contribute to lower consumer acceptability. This is particularly evident in legume-based noodles, where the lack of gluten leads to a weak dough structure and poor overall integrity.

Recent study by Majili et al. [7] in Tanzania found that increasing the proportional of pigeon peas flour in wheat-base noddle improved nutritional content but significantly compromised textural qualities, limiting consumer acceptance. To address this, the incorporation of vital wheat gluten, a protein concentrate containing gluten and gliadin has been proposed as a structuring agent. It forms a viscoelastic network that binds water, traps starch granules and air cells, and enhances dough elasticity and strength. When address to legume-based flours, vital gluten not only boosts protein content but also improves textural attributes such as firmness, chewiness and structural integrity, closely mimicking the properties of wheat gluten [7-21].

Therefore, this study was conducted with the objective to investigate the effects of incorporating vital wheat gluten on the textural, cooking, and sensory qualities of pigeon pea-based noodles (PPBN), building up on the findings of Majili et al. [7]. The goal was to improve the quality of PPBN without significantly compromising the enhanced nutritional profile, thereby supporting the development of nutritionally enriched, consumer-acceptable legume-based noodles suitable for wider consumption.

2. Methodology

2.1. Source of Experimental Materials and Preparation

The key ingredients used in noodle production were pigeon pea flour, wheat flour, orange-fleshed sweet potato (OFSP) flour, and vital wheat gluten, which served as a functional binder. Approximately 50 kg of pigeon pea grains (of a white colored local variety) were purchased from farmers in Mbure and Mitumbati villages in the Lindi region of southern Tanzania. The grains were transported to the Food Quality Laboratory in the Department of Food Science and Agro-processing at Sokoine University of Agriculture (SUA), Morogoro for further processing.

In the laboratory, 10 kg of the pigeon pea grains were manually cleaned to remove foreign materials and then soaked in water using a stainless-steel saucepan for 8 hours at 28 ℃. This soaking process enabled the complete removal of seed coats and aimed to improve protein digestibility by reducing anti-nutritional factors such as phytates [22].

The dehulled grains were then dried in a hot air oven at 60 ℃ until they reached a constant weight, corresponding to a moisture content of approximately 10% on a dry basis [23]. The dried and hulled grains were milled twice, first using a stainless-steel electric grain mill grinder (Model F67A, MXBAOHENGus Instrument Co. storefront), followed by a heavy-duty food blender (STRONGER-TECH-PMC) to obtain a fine flour. The flour was then sieved through a 250 µm sieve (Tokyo Screen Co. Ltd., Japan) to achieve uniform particle size. After processing, the pigeon pea flour was packed in airtight zip-lock bags to prevent moisture absorption from the environment, which could compromise its quality during storage and further use [24].

Wheat flour was produced from a local shop near SUA. Orange-fleshed sweet potato (OFSP) flour was sourced from the Sokoine University Graduate Entrepreneurs Cooperative (SUGECO), located within the SUA premises in Morogoro. Vital wheat gluten (Anthony's Premium Vital Wheat Gluten, California, United States) was imported from the USA, specifically from Anthony's supplier.

2.2. Sample Formulation

Majili et al. [7] developed eight distinct formulations of PPBN by combining pigeon pea flour with other ingredients such as wheat flour and OFSPF. These formulations exhibited protein contents ranging from 41.0 to 58.2 g/100 g dry matter, along with varying levels of iron, zinc, and pro-vitamin A. Among the eight formulations developed, two namely PPBN 718 and PPBN 193 were selected for further analysis based on their superior nutritional profiles and higher consumer preference, as reported by Majili et al [7]. However, both formulations demonstrated poor textural quality. To address this limitation, the present study supplemented each formulation with vital wheat gluten (VWG) at three different concentrations: 2%, 4% and 6%, resulting in a total of six experimental samples, as summarized in Table 1. The blending proportions for each formulation were adopted from the study by Majili et al. [7] and are detailed as follows:

PPBN 718; PPF (180g):WF (290g): OFSPF (0g)

PPBN 193; PPF (190g):WF (430g): OFSPF (55g)

Where PPBN = Pigeon Pea Based Noodles, WF =Wheat Flour and OFSPF = Orange-Fleshed Sweet potato Flour and PPF = Pigeon Pea Flour.

Table 1. *Sample formulations of noodles and corresponding proportions of pigeon pea flour, wheat flour, orange-fleshed sweet potato flour, and vital wheat gluten (VWG) used in the present study.*

Formulation	Experimental Sample	PPF content (g)	WF content (g)	OFSPF content (g)	Amount of VWG added	
					%	Weight (g)
PPBN 718	PPBN 718-1	180	290	0	2	9.4
	PPBN 718-2	180	290	0	4	18.8
	PPBN 718-3	180	290	0	6	28.2
PPBN 193	PPBN 193-1	190	430	55	2	13.5
	PPBN 193-2	190	430	55	4	27.0
	PPBN 193-3	190	430	55	6	40.5

*Percentages represent the ratio of ingredients in the total formulation.

2.3. Development and Preparation of Improved PPBN

Improved dried PPBN were prepared following the method described by Zula et al. [25], as illustrated in Figure 1. PPF, WF, and OFSPF were mixed in proportions guided by recommended dietary intake values, as established in the previous study by Majili et al. [7]. These flours were then blended with varying concentrations of vital wheat gluten (VWG) at 2%, 4%, and 6% to enhance dough texture. The blending ratios were calculated as percentages of the total formulation weight, resulting in the following sample compositions: Sample PPBN 718-1 (36% PPF, 58% WF, 0% OFSPF, 6% VWG); Sample PPBN 718-2 (36.8% PPF, 59.2% WF, 0% OFSPF, 4% VWG); Sample PPBN 718-3 (37.5% PPF, 60% WF, 0% OFSPF, 2% VWG), Sample PPBN 193-1 (26.2% PPF, 60% WF, 7.7% OFSPF, 6% VWG); Sample PPBN 193-2: (27% PPF, 61.2% WF, 7.8% OFSPF, 4% VWG) and Sample PPBN 193-3 (27.6% PPF, 62.5% WF, 7.9% OFSPF, 2% VWG). All ingredient quantities were precisely measured using a BOECO Germany analytical balance (Boeckel + Co. BBL31, Serial No. 21505716, Model XX43-0035) prior to processing. The specified proportions of composite flour were then mixed for 5 minutes using an Amasadora Spiral Mixer Heavy Duty 3 Speed Dough Mixer (model number SC-B30). Subsequently, 250mls of water, 2% sunflower cooking oil, and 2.5 g of sodium carbonate (baking powder) were added and thoroughly mixed to achieve a uniform and consistent dough. The prepared dough was then transferred to a laboratory-scale extruder (China pasta Making Machine, Model IT IPM60) for cold extrusion into the desired noodle shape. The, extruded noodles were cut into uniform lengths and arranged on trays for drying at room temperature for 72 hours (3 days). After drying, the noodles were packed in airtight bags and stored at room temperature (approximately 20-25◦C) for subsequent analysis and sensory evaluation.

Figure 1. *A flow diagram showing preparation of improved PPBN, adapted from [25].*

2.4. Cooking of Pigeon Pea-Based Noodles

Noodles were cooked following the method described by Liang et al. [26]. The samples were boiled in water containing 2% salt for 10-15 minutes using a stainless-steel source pan. During cooking, the noodles were gently stirred with a stainless-steel kitchen spoon to prevent sticking. After cooking, the noodles were drained and rinsed with cold water to halt further cooking. The prepared noodles were then ready for texture and sensory evaluation.

2.5. Texture Profile Analysis

The textural profile analysis of noodles was conducted according to the method described by Shams et al. [27], with minor modifications. A 30 g sample of dried noodles was cooked in 250 ml of boiling water for 15 minutes using a Kjeldahl apparatus, then rinsed with in cold water and set aside for 10 minutes to remove excess moisture. For texture profile analysis, noodles measuring 1.5 mm in thickness and 28 mm in length were arranged on plates according to their respective blending formulations. The measurements were carried out using a CT3^{TM} Texture Analyzer (Model no. CT3 10K, Serial number 855028g). A single noodle strand was placed on the machine and compressed using a stainless-steel cylindrical probe (TA9 needle, 1.0mm in diameter and 43mm in length). Textural parameters including hardness, cohesiveness, elasticity and adhesiveness were recorded for each formulation, with each performed in triplicates.

2.6. Sensory Evaluation

2.6.1. Quantitative Description Analysis

Quantitative Descriptive Analysis (QDA) was conducted at the Department of Food Science and Agro-Processing, Sokoine University of Agriculture, using 15 semi-trained panelists. The selection process for the panelists, comprising both male and female aged between 20 and 26 years, is illustrated in Figure 2. The QDA followed a structured procedure as outlined by Lawless and Heymann [29]. Panelists underwent two days of training focused on assessing product performance, discrimination ability, and reproducibility. During training they collaboratively developed and defined key sensory descriptors. As a result, four sensory attributes were agreed upon: color, aroma, taste and mouthfeel (Table 2). Panelists were trained to evaluate each attribute using a 7-point hedonic scale, where 1 represented the lowest intensity and 7 represented the highest intensity. Cooked noodle samples were labelled with randomly assigned three-digit codes and presented to panelists in a random order. Panelists evaluated each sample independently, and their responses were recorded for further analysis.

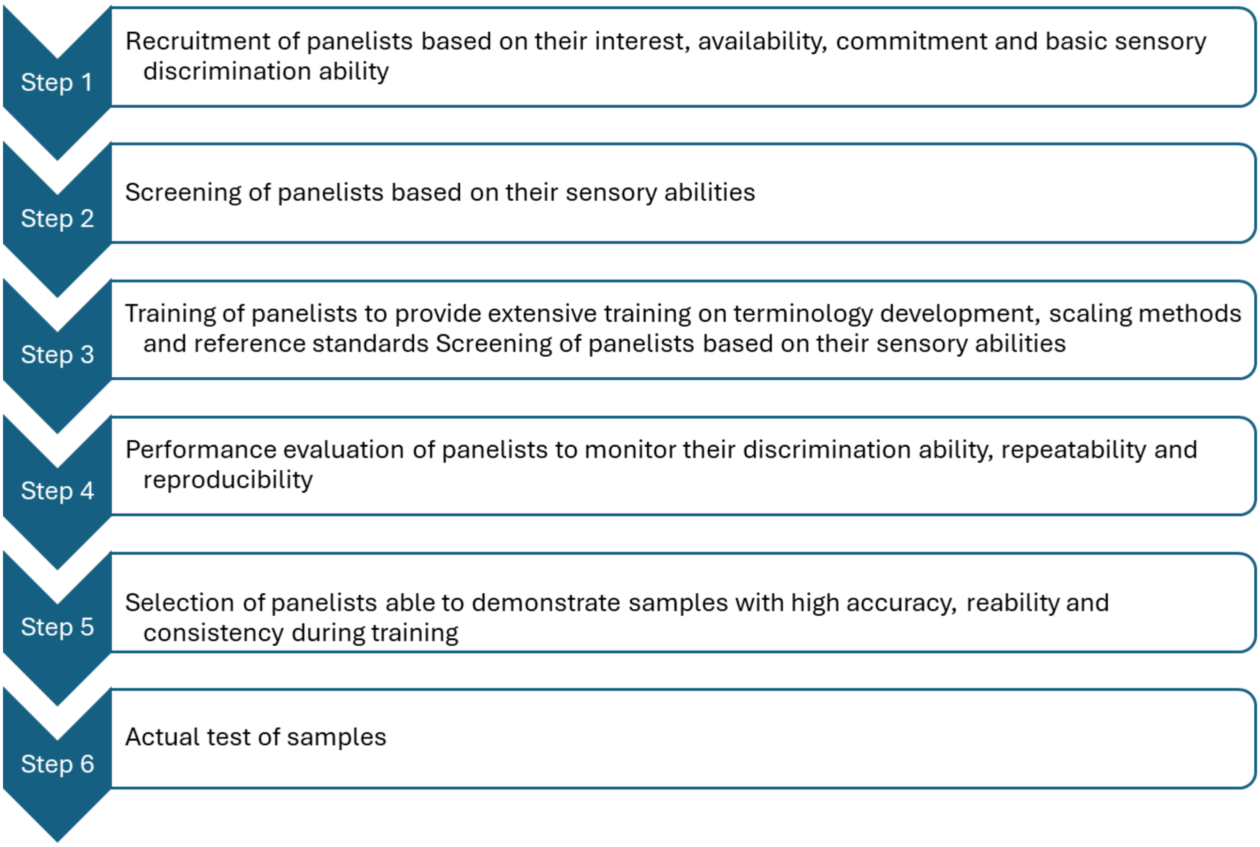

Figure 2. *Steps followed to select panelists for Quantitative Descriptive analysis.*

Table 2. *Attributes, references and scales developed in quantitative descriptive analysis panel training.*

Attributes	Descriptors	References	Scale ranges
Color	The visual appearance of food	Commercial noodle Santa Lucia	1-Not perceivable 7-Extremly colorful
Aroma	The smell of food perceived through the nose	Commercial noodle Santa Lucia	1-No perceivable smell 7-Extremly aromatic
Taste	The sensations perceived by the tongue when food chemicals interact with taste buds.	Commercial noodle Santa Lucia	1-No perceivable taste 7-Extremly tasteful
Mouthfeel	The overall physical sensations a food produces in the mouth	Commercial noodle Santa Lucia	1-No perceivable mouthfeel 7-Extremly intense in mouthfeel

2.6.2. Hedonic Test

The hedonic test was conducted in Magadu Ward in Morogoro Municipality. involving 75 untrained panelists aged between 23 and 27 years. A 9-point hedonic scale was used to assess consumers preference, offering a broad range of response options that allowed participants to express their degree of liking or disliking more precisely where 1 = “dislike extremely” and 9= like extremely [29, 7]. Noodle samples were coded with three-digit random numbers and presented to panelists in a randomized order. Pure water was provided for mouth cleansing between samples to avoid cross-flavor interference. Panelists were asked to evaluate and score each noodles samples on the hedonic scale based on their preferences for specific attribute, including color, aroma, taste, mouthfeel and overall acceptability.

2.7. Statistical Data Analysis

Statistical data analysis was carried out using the R programming software (version 4.2.3) for both descriptive and inferential analysis. A t-test was conducted to compare the mean values between the two-noodle samples. One-way Analysis of Variance (ANOVA) was conducted to determine significant differences among the sample formulations at a significant level of $P < 0.05$. The Critical Difference (CD) was used to identify the smallest significant difference between treatment means at the 5% probability level, enabling a clearer interpretation of post-hoc comparisons. The Coefficient of Variation (CV), expressed as a percentage, was calculated to assess the relative variability in the data, with lower values indicating higher experimental precision. The Standard Error of the Mean (SEm) was reported to reflect the precision of the sample means and to aid in the accurate interpretation of differences across treatments. Principal Component Analysis (PCA) was also employed to examine the association between sensory attributes and consumer acceptability of pigeon pea-based noodles. All results were reported as mean values ± standard deviation (SD), alongside CD, CV, and SEm where applicable.

3. Results

3.1. Textural Quality of Pigeon Pea-Based Noodles

Table 3 presents the textural performance of pigeon pea-based noodles as influenced by varying levels of vital wheat gluten. The results revealed clear trends in certain textural attributes, particularly in hardness and elasticity, while others such as cohesiveness and adhesiveness remained relatively stable or showed inconsistent patterns across gluten levels. There was no statistically significant difference ($P > 0.05$) in textural attributes between the two sample formulations with the addition of different concentration of vital wheat gluten. However, variations were evident in the mean values. Specifically, formulation PPBN193-1 exhibited higher mean values for hardness 23.33 and elasticity (1.07) indicating a firmer and more elastic noodle matrix. In contrast, sample PPBN7183 showed a decline in both hardness and elasticity with mean values 11.33 and 0.46 respectively. Adhesiveness increased in both samplePPBN718-3 and PPBN193-3, although the difference was not statistically significant.

Table 3. *Textural quality of cooked pigeon pea-based noodles.*

Sample	Hardness		Cohesiveness		Elasticity		Adhesion	
	Mean*	SD	Mean	SD	Mean	SD	Mean	SD
PPBN718-1	14.00	4.58	0.59	0.32	0.53	0.15	0.23	0.15
PPBN718-2	16.00	6.93	0.57	0.12	0.60	0.10	0.10	0.00
PPBN718-3	11.33	2.31	0.68	0.62	0.40	0.46	0.40	0.36
PPBN193-1	23.33	2.08	0.83	0.43	1.07	0.12	0.10	0.10
PPBN193-2	21.67	11.72	0.52	0.09	0.73	0.15	0.10	0.00
PPBN193-3	20.33	9.71	0.67	0.10	0.73	0.15	0.13	0.06

*Mean and standard deviation of pigeon pea-based noodle formulations.

3.2. Quantitative Descriptive Analysis of Improved Pigeon Pea-Based Noodles

The results of the Quantitative Descriptive Analysis (QDA), as presented in Table 4, show the panelists evaluations of sensory attributes, color, aroma, taste and mouthfeel for the two sample formulations PPBN718 and PPBN193 with varying concentrations of vital wheat gluten. A statistically significant different ($P < 0.05$) was observed between the two samples formulation, Sample PPBN193 revealed significant higher scores for taste, aroma and mouthfeel, while sample formulation PPBN718 was rated significantly higher for color.

Table 4. Quantitative descriptive analysis of pigeon -pea based noodles at varying vital wheat gluten levels.

Sample	Color		Taste		Aroma		Mouthfeel	
	Mean*	**SD**	**Mean**	**SD**	**mean**	**SD**	**mean**	**SD**
PPBN718-1	5.800	0.676	4.400	0.986	4.600	0.737	4.667	0.724
PPBN718-2	5.733	0.594	4.133	0.640	4.133	0.834	5.000	0.756
PPBN718-3	6.067	0.704	4.267	0.799	4.800	0.676	5.400	0.632
PPBN193-1	4.733	1.280	5.133	0.743	5.200	0.561	5.200	1.207
PPBN193-2	5.467	0.990	6.067	0.704	5.667	0.900	5.867	0.743
PPBN193-3	5.933	1.033	5.467	0.834	5.400	0.910	5.667	0.900

*Mean and standard deviation of pigeon pea-based noodle formulations.

3.3. Consumer Preference of Developed Pigeon Pea-Based Noodles

Table 5 presents consumer acceptability scores for pigeon pea-based noodles formulated with varying levels of vital wheat gluten. The results indicated sample PPBN193 consistently outperformed sample PPBN718 across all gluten levels, with statistically significant differences observed (P<0.05). Notably PPBN193-2 achieved the highest overall acceptability score (7.267± 0.980), reflecting strong consumer acceptable of the product. In contrast, sample PPBN718-3 recorded its lower acceptability scores (3.16±0.986), suggesting reduced consumer appeal at higher gluten concentrations. These findings highlight that sample PPBN193-2 delivered a sensory profile that was significantly more favored by consumers compared to all tested variations of sample A718.

Table 5. Consumer acceptability of pigeon-pea based noodles at varying vital wheat gluten levels.

Sample	color		Taste		Aroma		Mouthfeel		Overall acceptability	
	Mean*	**SD**	**mean**	**SD**	**mean**	**SD**	**mean**	**SD**	**mean**	**SD**
PPBN718-1	3.900	0.885	4.367	0.718	4.300	0.952	4.100	0.885	4.100	0.803
PPBN718-2	3.467	0.937	3.900	0.885	3.767	1.135	3.467	1.106	3.667	0.959
PPBN718-3	3.200	0.805	3.467	0.860	3.200	1.064	3.300	0.988	3.167	0.986
PPBN193-1	6.200	0.805	6.533	1.196	6.567	0.817	6.567	0.774	6.500	0.820
PPBN193-2	7.100	0.712	7.333	1.061	7.300	1.179	6.900	0.995	7.267	0.980
PPBN193-3	6.533	0.973	6.633	0.850	6.567	0.935	6.367	0.890	6.367	0.809

*Mean and standard deviation of pigeon pea-based noodle formulation.

3.4. PCA Bi-Plot

Figure 3 (biplot (correlation circle) illustrates the relationships among sensory attributes of pigeon pea-based noodles as represented by the first two principal components (PC1 and PC2), which together account for 60.8% of the total variance, 45.9% by PC1 and 14.9% by PC2. The plot shows that color is strongly and positively associated with PC1, as indicated by its long vector aligned closely with the horizontal axis. In contrast aroma, taste and mouthfeel are clustered together, oriented along the negative side of PC1 and spanning both the positive and negative directions of PC2. These attributes are presented by shorter vectors suggesting they are closely interrelated and may be jointly perceived by panelists during evaluation. The opposing orientation of color relative to aroma, taste and mouthfeel suggests a potential trade-off between visual appeal and flavor-related qualities.

In other words formulations that score highly on color may tend to receive lower scores for aroma, taste, and mouthfeel, or vice versa. This biplot highlights the dominant influence of color in driving variation along PC1, while aroma, taste, and mouthfeel form a cohesive sensory dimension contributing to variation along PC2.

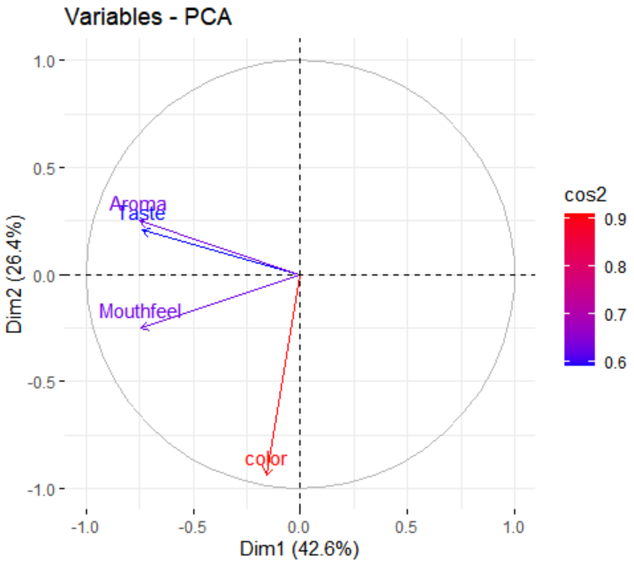

Figure 3. *PCA Biplot showing correlations between sensory texture attributes in pigeon pea-based noodles.*

4. Discussion

4.1. Hardness

This refers to food resistance to deformation when subjected to force. The observed increase in noodle hardness for samples formulated under PPNB193 is likely attributable to enhanced protein–starch interactions. The incorporation of wheat gluten improves the dough's water absorption capacity during hydration, facilitating the development of a robust protein matrix that encapsulates starch granules. This network restricts starch swelling during cooking, thereby yielding a denser, more rigid structure that contributes to the increased hardness of the final product. These findings align with prior studies, which have demonstrated that the addition of wheat gluten at optimal concentrations (2.5–4.7%) to composite flours significantly enhances noodle quality attributes [16]. Similarly, the judicious use of hydrocolloids in non-wheat-based formulations has been shown to improve the functional and textural properties of noodles, leading to better cooking stability, reduced breakage, and increased consumer acceptability [30, 31].

In contrast, samples formulated under PPBN 718-3, which incorporated a higher gluten level, exhibited reduced hardness. This decrease may be attributed to excessive water absorption by the surplus gluten, resulting in heterogeneous hydration and weakening of the dough matrix. Such a disruption in structural integrity can produce a crumbly and less cohesive noodle texture. This observation is consistent with the findings of Zhao et al. [31], who reported that gluten levels exceeding the optimal threshold can detrimentally affect noodle firmness and overall structural stability.

4.2. Elasticity

Elasticity in food technology refers to a material's ability to return to its original shape after deformation. The increased elasticity observed in samples of PPBN 193 formulation suggests that the addition of an optimal concentration of vital wheat gluten effectively restores the structural integrity of the noodle matrix. This is likely due to the formation of viscoelastic network that binds to and surrounds starch granules, allowing the noodle strands to deform and recover, thereby enhancing both extensibility and elasticity. Similar findings were reported by Nisa [30], who attributed improvement in noodle elasticity to the w development.

In Contrast samples from formulation PPBN 718 exhibited decreased elasticity with increasing gluten concentration, which may be due to higher starch content dominating the dough matrix and disrupting the protein network. Supporting this Gul et al. [32] observed a reduction in elasticity and springiness in gluten-free noodles up on Xanthan gum addition, which they attributed to competition for water between starch and protein. This competition resulted in insufficient starch hydration and suboptimal gelatinization leading to a crumby texture.

4.3. Cohesiveness

Cohesiveness refers to the internal structural strength of a food product, reflecting its ability to maintain integrity under stress. In noodles, cohesiveness is primarily influenced by the protein network formed during processing, which sustains the internal structural regardless of gluten concentration. This effect is largely attributed to the main protein present in wheat flour and vital wheat gluten, which plays a critical role in developing a continuous matrix. This matrix enables them to retain their shape and resist breaking during handling and consumption [28]. These findings are consistent with those by Zang et al. [16], who reported advances in understanding the role of wheat protein and other food components in shaping the gluten network and noodles properties, noting a decrease in cohesiveness under certain conditions. Similarly, Wang et al. [33], in a comprehensive review on the impact of starch on the quality of wheat-based noodles and pasta, observed that starch content can reduce cohesiveness. Furthermore,Khatkar & Kaur [34], investigated the effects of protein incorporation on the functional, thermal, textural and overall quality of instant noodles, finding a decrease in cohesiveness. Their results suggest that cohesiveness may be less sensitive to change in specific pulse-based formulations with added wheat gluten due to the relatively inactive role of starch within the flour matrix.

4.4. Adhesiveness

Adhesiveness refers to the tendency of a food's surface to adhere to other surfaces, such as the tongue, palate, teeth, or packaging materials. The absence of a significant effect of varying gluten levels on adhesiveness suggests that this attribute is predominantly influenced by starch gelatinization within the composite flour blend rather than the gluten network. Specifically, the high starch content from orange-fleshed sweet potato flour, likely plays a major in contributing to surface stickiness. Additionally, the unique starch and protein composition of pigeon pea flour may interact synergistically to modulate the influence of gluten on the adhesive properties of noodles. These findings align with those by Huang et al. [35], who observed no significant differences in adhesiveness following the addition of wheat gluten to frozen cooked noodles with protein incorporation, indicating that the effect of protein adhesiveness may vary depending on the type of noodle product, despite changes in texture. Conversely, Khatkar & Kaur [34] reported increased adhesiveness in instant cooked noodles with protein incorporation, indicating that the effect of protein on adhesiveness may vary depending on the type of noodle product and processing conditions.

4.5. Color

Color is a key visual attribute of food products and is primarily influenced by the composition of the raw materials. The initial color difference observed between the two noodle samples can be attributed to their district flour compositions. Sample PPBN193 contained OFSPF, which is rich in carotenoid, impacting a characteristic yellow-orange hue [9]. This natural pigmentation clearly differentiates PPBN193 from sample PPBN718, which was formulated exclusively with pigeon pea and wheat flours, lacking the intense coloration provided by OFSP. The observed increase in perceived color intensity in both samples with higher levels of vital wheat gluten can be explained by the formation of a more uniform and compact protein-starch matrix. While vital wheat gluten itself does not contribute pigment, its capacity to create a denser and more organized structure affects light reflection and absorption within the noodle matrix. This enhances the visual uniformly and intensity of the inherent pigments present in the composite flour [16, 37]. Similar results were reported by Jaka et al. [37], who noted decreased consumer preference for color as the proportion of pigeon pea flour increased in noodle formulation, likely due to color changes associated with the flour composition.

4.6. Taste and Aroma

The significant higher taste and aroma observed for sample PPBN193-2 suggested its unique formulation, due to incorporating OFSPF and a higher wheat flour content, that positively influenced these sensory attributes. Wheat flour, a primary ingredient in traditional noodles, is well-known for contributing desirable taste and aroma profiles. A study by Effiong et al. [38] noted that the addition of OFSPF may introduce subtle, pleasant flavors and aromas that complemented the pigeon pea and wheat base, potentially masking any undesirable "beany" notes associated with pigeon pea flour, which are often linked to volatile compounds such as aldehydes, alcohols and ketones. These findings align with those of Bayomy & Alamri [39] and Lawrence et al. [40], who demonstrated that the strategic incorporation of non-traditional flour, such as soy flour into gluten-free rice bread, significantly enhanced taste and overall acceptability. This highlights the potential for composite flours to improve sensory qualities in various food products. Additionally, the improved structural integrity and textural properties of noodles often influenced by gluten content affect the release kinetics of flavor compounds during mastication, indirectly enhancing the perception of taste intensity.

4.7. Mouthfeel

The superior mouthfeel of sample PPBN193, along with the overall improvement in mouthfeel for both samples as gluten content increased, was attributable to the role of vital wheat gluten as a functional binder. Gluten forms a viscoelastic network that traps air and water, enhancing texture, elasticity and chewiness in noodle products. The higher overall sensory scores for sample PPBN193 may also be linked to its specific flour proportions, which may have interacted more synergistically with added gluten to produce a more desirable textural profile. Previous studies by Rahimi et al. [17] and Zang et al. [16] have reported that the inclusion of non-wheat flours can negatively impact textural attributes, making gluten supplementation essential for quality improvement. Similar findings by Tan et al. [20] and Rejeki et al. [21] support the conclusion that vital wheat gluten functions as a hydrocolloid, enhancing dough elasticity, firmness, structure and chewiness by reinforcing the protein, an effect consistent with the improved mouthfeel observed in this study.

4.8. Overall Acceptability

Overall acceptability highlights a key determinant of product success: formulations that achieve a well-balanced combination of color, taste, aroma and mouthfeel are more likely to gain consumer preferences. The synergistic interaction between various flour components such as the complementary flavors of OFSP flour from orange-fleshed sweet potato flour and the structural support provided by wheat flour and vital wheat gluten can result in a highly palatable product with broad consumer appeals [40]. In contrast, formulations that lack this sensory balance are less likely to succeed. This underscores the importance of optimizing the entire sensory profile, especially in novel food products that incorporate non-wheat flour to enhance nutritional value. For such products, achieving sensory harmony is essential for widespread adoption and sustained consumption [8].

4.9. PCA Bi-Plot

The contrasting sensory profile where color emerges as a dominant attribute while aroma, taste and mouthfeel cluster oppositely can be attributed to differences in sample formulations, particularly the inclusion levels of vital wheat gluten and its consequential impact on texture. Variations in pigeon pea- flour content across the noodle's formulations may influence the inherent legume color, as previously reported by Majili et al. [7]. Consequently, the addition of vital wheat gluten is intended to improve noodle texture by enhancing chewiness and elasticity, qualities often lacking in gluten free legume-based noodles [41]. While vital wheat gluten improves key textural properties such a s hardness and elasticity, which are critical for consumer acceptance, this enhancement may induce trade-offs in other sensory attributes. Specifically, the formation of a stronger gluten network, though beneficial for mouthfeel, can restrict the release of volatile aroma compounds, thereby diminishing perceived aroma and taste intensity. Conversely, formulations with lower or no gluten content may exhibit more pronounced color, aroma and taste attributes but often at the expense of textural quality. This inverse relationship between sensory attributes has been observed in similar studies by Bayomy & Alamri [41] and Majili et al. [42]. These findings underscore the complex interplay between ingredients composition and processing conditions in shaping the multisensory perception of composite noodle products, highlighting the challenge of balancing texture with flavor and aroma in product development.

5. Conclusion

This study demonstrated that the incorporating vital wheat gluten at optimum percentages 2 to 4% as a binder in non-wheat flours blend significantly improved the sensory and textural qualities of pigeon pea-based noodles. Sample B193 formulated with optimal gluten concentration and the inclusion of OFSPF exhibited superior hardness, elasticity and overall consumer acceptability. These enhancements are largely attributed to the synergistic interactions between gluten, starch, and legume proteins, which contribute critically to the structural integrity and desirable texture of the noodles.

The results also highlighted that while increasing gluten content generally improved texture and mouthfeel, excessive gluten addition above 4% could negatively affect hardness and elasticity due to uneven water distribution and weakening of the dough matrix. Moreover, sensory attributes such as color, taste, and aroma were influenced not only by gluten but also by the specific composite flour formulations, underscoring the complexity of ingredient interactions.

Overall, the findings emphasize the importance of optimizing both flour composition and gluten concentration to achieve a balanced product that addresses nutritional gaps without compromising sensory appeal. This balance is essential for enhancing the nutritional profile of pigeon pea-based noodles and promoting their wider acceptance among consumers. The study provides valuable insights for developing novel, nutrition, and appealing legume-based noodle products that can support food diversification and improved dietary quality.

Abbreviations

VWG	Vital Wheat Gluten
PPBN	Pigeon Pea Based Noodles
TPA	Texture Profile Analysis
QDA	Quantitative Descriptive Analysis
PCA	Principal Component Analysis
OFSPF	Orange Fleshed Sweet Potato Flour
SUA	Sokoine University of Agriculture
IITA	International Institute of Tropical Agriculture
COSTECH	Tanzania Commission for Science and Technology

Acknowledgments

This work was part of the Msc studies of the first author. The research was made possible through the generous support of the LEG4DEV program, the financial supporters for this work under the International Institute of Tropical Agriculture (IITA) their financial and institutional backing throughout the study is highly appreciated. Engineer Isack Gerald Barongereje, a laboratory technician in the food quality laboratory of the food science and Agro-processing, School of Engineering and Technology of Sokoine University of Agriculture is acknowledged for his technical assistance during the laboratory analysis of the samples.

Author Contributions

Shakira Rashid Dotto: Data Curation, Formal Analysis, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing

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Ethical Consideration

An ethical concern addressed in this research pertained to obtaining proper permissions for data collection. An ethical approval was provided by Sokoine University of Agriculture (SUA) on behalf of Tanzania Commission for Science and Technology (COSTECH). Confidential and informed consent were maintained throughout the research process reflecting the commitment to upholding ethical standards and conducting a responsible study.

Conflicts of Interest

The authors declare no conflicts of interest.

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