Prev. Nutr. Food Sci. 2024;29(4):554-562
https://doi.org/10.3746/pnf.2024.29.4.554
ISSN 2287-8602

Property Evaluation of Noodles Substituting Wheat Flour with Drum-Dried Overripe Kepok Plantain (*Musa paradisiaca* L.) Flour to Enhance the Nutrients

Galih Kusuma Aji[1], Budiyanto[1], Hendrawan Laksono[1], Bangkit Wiguna[1], Renny Primasari Gustia Putri[1], Ambar Dwi Kusumasmarawati[1], Muhamaludin[1], Ayi Mufti[1], Anita Rutmala[2], Ahmad Khulafaur Rosyidin[3], and Achmad Sofian Nasori[1]

[1]Research Center for Agroindustry, National Research and Innovation Agency, KST Soekarno, Cibinong 16911, Indonesia
[2]Department of Food Technology, Sultan Ageng Tirtayasa University, Serang 42121, Indonesia
[3]Department of Chemistry, Udayana University, Bali 80361, Indonesia

ABSTRACT: This study investigated the potential of substituting wheat flour with drum-dried overripe Kepok plantain flour (KPF) to enhance instant the nutritional and textural properties of noodles. Noodles were prepared with varying KPF substitutions (10%, 20%, and 30%) and compared to a control (0% KPF). The results show that KPF remarkably influences the adhesiveness, springiness, cohesiveness, and hardness of noodles. Notably, 10% KPF substitution yielded noodles with moderate elasticity and good shape retention but increased their firmness. Increasing the KPF substitution resulted in less sticky noodles, with noodles with 20% KPF substitution showing improved elasticity and shape retention but a firmer texture. At 30% substitution, noodles were less sticky and slightly softer, although their shape retention somewhat decreased. Moreover, KPF substitution greatly altered the pasting properties of flour. Increasing the KPF substitution resulted in lower peak viscosity values, indicating a potential for stronger gelling of amylose in the noodles. This modification aligns with the desired characteristics of alkaline noodles, suggesting that KPF substitution, particularly at 30%, can improve the gelling properties and overall quality of the final product. Furthermore, KPF substitution improved the cooking quality, resulting in shorter cooking times and lower cooking losses than control noodles. This is attributed to the lower water uptake of KPF noodles, leading to a slimmer shape after cooking. Furthermore, KPF substitution increased the content of resistant starch and decreased oil absorption during frying. This study highlights the potential of KPF as a functional ingredient for developing more nutritious and sustainable instant noodles.

Keywords: cooking, food properties, food texture, plantain flour

INTRODUCTION

Driven by the increasing consumer focus on health and nutrition, functional foods have gained significant attention in research and development over the past few decades (Pistorio et al., 2023). Consumers are seeking food products that not only taste good but also provide health benefits (Grujić and Grujčić, 2023). One such innovation involves partially substituting wheat flour with Kepok plantain flour (KPF) in noodle production. Because of increasing consumer acceptance, the noodle market size is increasing worldwide. Noodles can be categorized into several types according to their processing techniques: fresh, dried, boiled, steamed, and instant noodles. Among them, instant noodles are unique because of their additional processing steps, which involve steaming, frying, or drying (Keeratiburana et al., 2024). Thus, it is important to evaluate the properties of instant noodles produced by replacing a portion of wheat flour with KPF.

Although similar, plantains and bananas exhibit distinct differences that influence their culinary and nutritional applications. Plantains are starchier, less sweet, and often require cooking, enabling them to be utilized in various savory dishes through frying, boiling, or baking (Kumalasari et al., 2020). They have a thicker skin and are more prominent, changing color from green to yellow and eventually black as they ripen. By contrast, bananas are typically consumed raw because of their sweeter flavor and softer texture, with their skin turning yellow and brown as they mature. Nutritionally, plan-

Received 9 September 2024; Revised 25 October 2024; Accepted 29 October 2024; Published online 31 December 2024
Correspondence to Achmad Sofian Nasori, E-mail: achm029@brin.go.id

tains provide a higher starch content and more significant amounts of vitamins A and C compared with bananas, which are richer in sugars and dietary fiber. Moreover, both fruits are highly perishable commodities because of their high moisture content, which facilitates spoilage and decay, and production of ethylene gas, which accelerates ripening. Additionally, their sensitivity to temperature fluctuations makes them prone to rapid deterioration under heat and cold conditions (Fikadu et al., 2016; Leeward et al., 2023). Their soft texture further exacerbates this issue as they are easily bruised during handling and transport, leading to accelerated spoilage. Consequently, bananas have a relatively short shelf life once they become ripe, necessitating effective management strategies to minimize waste and maintain quality.

Kepok plantain (*Musa paradisiaca* L.) is a widely available variety in Indonesia, with significant potential for processing into various food products. Drying Kepok bananas using a drum dryer can enhance their value by producing high-quality banana flour (Hidayat et al., 2021). Drum drying offers several advantages, including rapid drying, minimal nutrient loss, and extended shelf life of banana flour (Balmurugan et al., 2022). Compared with wheat flour, Kepok banana flour has a distinct nutritional profile, making it an attractive alternative for individuals with gluten intolerance or celiac disease (Tangthanantorn et al., 2022; Kabir et al., 2024).

Incorporating KPF promotes food diversification, offering a healthier and more sustainable alternative for noodle products. Oguntoyinbo et al. (2023) used banana peel flour to develop functional noodles. Banana peel flour was substituted for 11%, 13%, and 15% wheat flour in the noodle-making process. The results showed that composite noodles containing banana peel flour had a higher water content (10.25%–11.25%) and cooking loss (6.28%–7.59%), with a shorter optimum cooking time (4.19–3.65 min) compared with noodles made solely with wheat flour (Oguntoyinbo et al., 2023). Choo et al. (2010) found that replacing 30% of wheat flour with green banana flour in noodle formulations significantly increased the total dietary fiber, total starch, and resistant starch of noodles while decreasing their carbohydrate digestibility rate and glycemic index (Choudhury et al., 2023). Consequently, incorporating green banana flour into foods, such as cookies, could be an innovative strategy for promoting slow digestion (Amini Khoozani et al., 2020) and enhancing fiber content (Hung et al., 2013). Green banana flour is notably rich in fiber and resistant starch, making it a valuable addition to various food products. However, the potential use of KPF dried in a drum drier for noodle-making has not been considered.

Therefore, the present study aims to investigate the use of KPF as a partial substitute for wheat flour in noodle production, focusing on its impact on nutritional quality (Zhang and Ma, 2016; Choudhury et al., 2023; Islam et al., 2024). The noodle properties, including mechanical, pasting, and cooking characteristics, will be evaluated to determine whether noodles with KPF substitution exhibit superior or comparable qualities to those made with wheat flour. The findings from this research are expected to greatly contribute to the development of healthier and more sustainable local flour-based food products.

MATERIALS AND METHODS

Materials and equipment

Ripe yellow Kepok plantain was sourced from Serpong, South Tangerang. Commercial wheat flour was obtained from Cakra Kembar, Indonesia. Sulfuric acid, sodium hydroxide, methyl red indicator, and ethanol (pure grade analysis) were acquired from Sigma Aldrich. A drum dryer (Armfield Technology); an industrial-scale noodle sheeter (Shenyang Technology); a universal laboratory oven (UN30, Memmert); a muffle furnace (Nabertherm); an analytical balance (OHAUS Pioneer); and testing equipment, including a rapid visco analyzer (RVA 4500, Perkin Elmer), Kjeldahl apparatus (behr Labor-Technik), Soxhlet apparatus (behr Labor-Technik), and texture analyzer (TA-XT Plus, Stable Micro Systems), were used in noodle production. Details of the equipment are shown in Table 1.

Table 1. Equipment settings

Equipment	Purpose	Settings
Kjeldahl apparatus	Protein content analysis	Sample size: 1 g, digestion temperature: 380°C, distillation time: 10 min
Oven (for moisture measurement)	Moisture content determination	Temperature: 105°C, time: 24 h
Muffle furnace	Ash content determination	Temperature: 550°C, time: 4 h
Soxhlet apparatus	Fat content determination	Solvent: petroleum ether, extraction time: 6–8 h
Texture analyzer (TA-XT Plus, Stable Micro Systems)	Texture analysis of noodles	Probe: P/36R, speed: 1 mm/s, compression: 75%
Rapid visco analyzer (RVA 4500)	Pasting property analysis	Sample weight: 3.5 g, rotation speed: 160 rpm, time: 70 min, temperature: 80°C to 20°C
Drum dryer	Plantain flour production	Pressure: 3.5 bar, rotation speed: 8 rpm

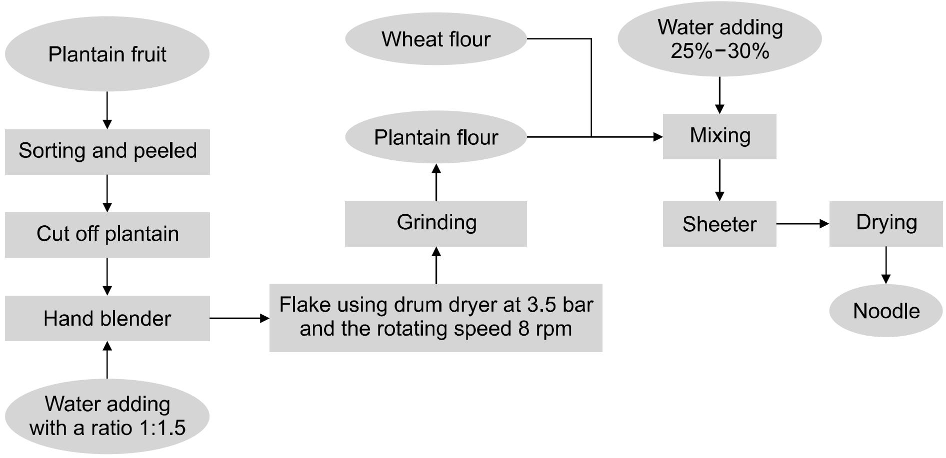

Fig. 1. Flow diagram showing the preparation of plantain flour and noodles with plantain flour substitution.

Preparation of plantain four with drum dryer

Plantain flour production using a drum dryer involved several steps to obtain a high-quality product. The process began with the selection of ripe Kepok plantain. The plantain was carefully peeled to remove the outer skin. Once peeled, it was cut into smaller pieces to facilitate further processing. Then, the cut pieces were combined with water at a ratio of 1:1.5 (plantain to water). The mixture was homogenized to create a smooth plantain juice. Homogenization is important as it ensures uniform consistency, which is essential for even drying in the drum dryer. Next, the homogenized plantain mixture was fed into the drum dryer. The drum dryer was operated under specific conditions, with a pressure setting of 3.5 bar, a steam table temperature of 147.2°C to 148.84°C, and a rotational speed of 8 rpm. These parameters are important to achieve optimal drying (Chia and Chong, 2015). The moisture content from the plantain mixture was rapidly evaporated by the drum dryer's heated surfaces. As the drum rotated, the plantain mixture was spread into a thin film, facilitating efficient heat transfer and moisture removal. Upon completion of the drying process, the now-dried plantain material was collected. Subsequently, this material was milled to produce fine plantain flour. Fig. 1 shows the method of creating the plantain flour. The milling process ensures that the flour has a consistent texture and is suitable for various food applications, including as a wheat flour substitute in noodle production.

Production of noodles with plantain flour substitution

The production of noodles incorporating plantain flour substitution was carefully designed to evaluate the potential of drum-dried yellow KPF as a viable ingredient. The process began with the preparation of the noodle dough, which involved kneading a mixture of flour and water. For each batch, 210 g of flour was combined with 90 g of water to achieve the desired dough consistency. The flour mixtures were formulated according to the compositions shown in Table 2, with varying plantain and wheat flour proportions. For each formulation, the specific amounts of plantain and wheat flour were accurately weighed and then thoroughly mixed to ensure uniform distribution. The mixture was gradually hydrated by adding 90 g of water and then kneaded until a cohesive dough was formed. Kneading is essential to develop the gluten network in the dough, which is crucial for the texture and elasticity of the final noodle product. Once the dough reached the desired consistency, it was processed using a noodle sheeter. To achieve uniform thickness and texture, the dough was repeatedly passed through the sheeter.

Gluten plays a similar role in noodle production to that in bread-making but with a focus on the texture and elasticity required for the final noodle product. When kneading noodle dough, glutenin and gliadin proteins interact to form a network that provides the dough strength and elasticity, which is important for shaping and stretching the dough into thin sheets. During the kneading process, glutenin provides elasticity, allowing the dough to stretch without tearing, whereas gliadin contributes to extensibility, giving the dough a smooth and pliable texture. This balance is essential for producing noodles that are firm, yet flexible, with a chewy texture. Similar to bread, disulfide bridges (covalent bonds between cysteine residues), hydrogen bonds, and hydrophobic interactions help stabilize the gluten network, ensuring that the dough maintains its shape when processed.

Alternative ingredients (e.g., plantain flour, rice flour, cornstarch, or tapioca) are used for gluten-free noodles. As these ingredients do not form a gluten network, other hydrocolloids (e.g., xanthan gum or guar gum) are of-

Table 2. Flour formulation for plantain noodle production

Formula	Plantain flour (%)	Wheat flour (%)
F1	10	90
F2	20	80
F3	30	70
Control	0	100

ten added to replicate the elasticity and chewiness of gluten-based noodles. Gluten-free noodles typically have a less robust structure, and they can be more prone to breaking during preparation without the support of the gluten network.

In summary, traditional noodles have a gluten network that ensures their elasticity and chewiness, whereas gluten-free noodles rely on alternative binders to achieve similar textures. An illustration comparing these two processes would show the differences in the dough's molecular structure and texture. Fig. 1 shows the process of making noodles with plantain flour.

Cooking quality of noodles

The cooking quality of noodles was evaluated in accordance with the method of Farzana et al. (2023) with slight modifications.

Water uptake percentage

For optimal cooking time, 10 g of noodles was cooked in 150 mL of water. After cooking, the noodles were chilled in a cold water bath for 5 min. The excess water was drained for 30 s, and the water uptake percentage (WUP) was calculated using the following formula:

$$\text{WUP (\%)} = \frac{\text{cooked noodles weight} - \text{fresh noodle weight}}{\text{weight of fresh noodles}} \times 100$$

Cooking time

The cooking duration was measured when the water in the test tube reached the boiling point. Several strips were extracted and compressed between two glass slides at 30-s intervals to inspect for a white core, which would signify incomplete cooking. The cooking process was sustained until a white core was not confirmed between the slides.

Cooking loss

Twenty grams of noodles was added to 200 mL of boiling water in a beaker and cooked for 5 min. The cooking water was transferred to a pre-weighed beaker and evaporated at 105°C in an oven. The cooking loss was determined using the following formula:

$$\text{Cooking loss (\%)} = \frac{\text{weight of remaining solids after drying}}{\text{weight of fresh noodles}} \times 100$$

Proximate analysis

Proximate analysis is essential for evaluating the composition of noodle products. It is typically used to determine the moisture, ash, protein, fat, and carbohydrate content. The following procedure outlines the steps required for accurate and reliable analysis, as quantified by the Association of Official Analytical Chemists procedure.

***Sample preparation*:** Noodle samples were ground to a fine powder using a laboratory mill. The powdered samples were then stored in airtight containers to maintain their integrity until analysis.

Moisture content determination

One gram of sample was weighed and placed in a pre-weighed moisture dish. The sample was then dried in an oven at 105°C until constant weight was achieved. A continual weight was determined when the sample weight remained unchanged over two consecutive measurements taken at least 2 h apart. The moisture content was calculated based on the weight loss after drying:

$$\text{Moisture content determination (\%)} = \frac{\text{weight of remaining solids after drying}}{\text{weight of remaining solids before drying}} \times 100$$

Ash content determination

A 1-g portion of the dried sample was ash in a muffle furnace at 550°C for 4 h. The ash was weighed after cooling. The ash content was determined as a percentage of the sample weight:

$$\text{Ash content determination (\%)} = \frac{\text{weight of remaining ash after drying}}{\text{weight of remaining ash before drying}} \times 100$$

Protein and fat content

The protein content was assessed using the Kjeldahl method. The sample (1 g) was digested with sulfuric acid and a catalyst and then neutralized with sodium hydroxide. Ammonia was distilled and titrated with a standard acid. The protein content was calculated using a nitrogen-to-protein conversion factor (typically 6.25):

$$\text{Nitrogen content (\%)} = \frac{\text{volume of titrant (mL)} \times \text{normality of titrant (mL)} \times \text{factor}}{\text{weight of sample (g)}} \times 100$$

$$\text{Protein content (\%)} = \text{nitrogen content (\%)} \times \text{protein conversion factor (6.25)}$$

The fat content was determined using the Soxhlet extraction method. The sample (1 g) was extracted with petroleum ether for 6 to 8 h. The solvent was evaporated, and the fat content was calculated based on the weight of the extracted fat:

$$\text{Fat content (\%)} = \frac{\text{weight of extracted fat (g)}}{\text{weight of sample (g)}} \times 100$$

Texture analysis of noodles

The noodle texture was measured using the TA-XT Plus Texture Analyzer (Stable Micro Systems) in accordance with the method of Wiguna et al. (2023) with slight modifications. Default settings for noodles were applied using the P/36R probe. The analysis determined the adhesiveness, springiness, cohesiveness, and hardness values of noodles.

Analysis of the pasting properties of noodles

The pasting properties of noodles were evaluated using a RVA (RVA 4500, Perten Instrument) in accordance with the method of Laksono et al. (2022). This method adhered to the standard noodle testing procedures. The samples comprised a plantain flour and wheat blend, as specified in Table 2. For the test, 3.5 g of each sample formula with 14% moisture content and 25 mL of distilled water (1% w/w aqueous solution) were placed into the sample can. The viscosity measurements using the general pasting method were recorded as the temperature decreased from 80°C to 20°C for over 70 min at a rotation speed of 160 rpm.

Statistical analysis

The data obtained from the proximate, cooking quality, and texture analyses were statistically evaluated to determine significant differences between various formulations. Analysis of variance was performed to assess the impact of plantain flour substitution on the measured parameters. A post hoc Tukey's test was performed to further analyze differences between samples, which was when a significant effect was identified. This statistical approach helps to determine which specific groups differ from each other. Statistical analyses were conducted using PAST 4.0 software, and statistical significance was considered at $P<0.05$.

RESULTS AND DISCUSSION

Cooking quality of noodles

The cooking quality of noodles is determined by assessing parameters such as cooking loss and cooking time, which provide insights into the texture and overall performance of noodles during the cooking process. These key metrics are essential for evaluating the suitability of noodle formulations for consumer preferences and industrial applications. The specific values of these parameters are shown in Table 3.

Noodles supplemented with plantain flour displayed different cooking characteristics compared with the control noodles made with 100% wheat flour. The control noodles had the longest cooking time (15 min) and the lowest cooking loss (5.17 min), which is often desirable in noodle formulations. By contrast, noodles with plantain flour substitution exhibited shorter cooking times, decreasing from 9 min at 10% substitution to 5 min at 30% substitution. This finding indicates that incorporating plantain flour can significantly reduce cooking times, likely because of the flour's different water uptake dynamics.

Cooking loss, an important indicator of noodle quality, also decreased with higher plantain flour substitution. Noodles with 30% plantain flour substitution had the lowest cooking loss (8.36 min), suggesting that the substitution helped retain the noodles' structure and integrity during the cooking process. This is further supported by the fact that plantain flour provides more robust water retention properties because of the high number of hydrophilic groups within the starch molecules, enhancing the noodles' stability.

Water uptake is influenced by plantain flour substitution in noodle formulations. The control noodles, made entirely with wheat flour, exhibited a water absorption of 123.97%. This value is not significantly different from that of noodles with plantain flour substitution, indicating that the inclusion of plantain flour does not substantially affect the noodles' water absorption properties. Consequently, plantain flour substitution has minimal impact on the texture and appearance characteristics related to water uptake.

Noodles produced with whole wheat flour exhibited the highest water absorption capacity. This is attributed to the structure of wheat starch, which has a high swelling ability. By contrast, plantain flour provides more robust water retention properties because of the high number of hydrophilic groups within the starch molecules. Consequently, noodles with plantain flour substitution

Table 3. Cooking quality parameters of noodles with varying plantain flour substitution

Kepok plantain flour substitution	Water uptake (%)	Cooking time (min)	Cooking loss (min)
10%	151.10±6.66^{a}	9.00±0.00^{b}	19.15±1.34^{a}
20%	111.79±10.30^{a}	6.00±0.00^{c}	9.52±0.76^{b}
30%	130.94±28.00^{a}	5.00±0.00^{c}	8.36±1.27^{b}
Control	123.97±2.70^{a}	12.00±0.00^{a}	2.06±1.06^{c}
P-value	0.07	<0.001	<0.001

Values are presented as mean±SD (n=3).
Different letters (a-c) within the same column denote significant differences among the treatments at $P<0.05$.

demonstrated lower water uptake and retained a slimmer shape after cooking (Thongkaew and Singthong, 2020). In summary, introducing plantain flour into noodle formulations positively influenced the cooking quality by reducing cooking times and losses without changing water uptake. These modifications contribute to creating a unique product that retains its shape and integrity after cooking while potentially offering a more efficient cooking process in home and industrial settings.

Proximate analysis

The results of proximate analysis of noodles with varying levels of plantain flour substitution revealed significant changes in their composition, as shown in Table 4.

The moisture content showed a noticeable increase with higher KPF substitution. KPF had a moisture content of 7.64%±0.36%, whereas control noodles (without plantain flour) exhibited the highest moisture content of 8.81%±0.07%. As the proportion of plantain flour increased, the moisture content of noodles progressively increased, from 8.61%±0.17% at 10% substitution to 10.19%±0.19% at 30% substitution. This increase in moisture content suggests that plantain flour has a higher water uptake capacity than wheat flour, potentially because of its starch properties. The additional moisture may impact the noodles' texture and cooking properties, influencing industrial production and consumer preferences.

Along with the moisture content, the ash content, which reflects mineral composition, increased with increasing plantain flour substitution. Although control noodles had an ash content of 0.51%±0.06%, KPF exhibited a much higher value of 2.70%±0.08%. This trend was mirrored in the noodles, where the ash content increased from 0.66%±0.03% at 10% substitution to 1.02% ±0.03% at 30% substitution. This increase in ash content suggests that noodles made with plantain flour have a higher mineral content, which could be beneficial for enhancing the nutritional profile of the final product.

The protein content was also affected by the level of plantain flour substitution. Control noodles, made entirely with wheat flour, had the highest protein content of 13.52%±0.09%. As plantain flour was introduced, the protein content decreased, ranging from 12.91%±0.06% at 10% substitution to 10.80%±0.28% at 30% substitution. Since KPF contains less protein (4.49%±0.24%), this reduction in protein is expected. Although the protein content decreases with higher plantain flour levels, the substitution introduces other benefits (e.g., improved fiber content), making these noodles appealing to those seeking gluten-free or more nutritionally diverse products.

The noodles' fat content showed a similar reduction pattern with increasing plantain flour substitution. Control noodles had a fat content of 0.07%±0.02%, whereas noodles with 30% plantain flour substitution had a lower fat content of 0.09%±0.01%. Interestingly, noodles with 10% and 20% plantain flour substitution had no detectable fat content, indicating that the introduction of plantain flour contributes to lowering fat levels in the final product. KPF itself had a fat content of 0.16%± 0.06%. These findings suggest that incorporating plantain flour into noodles can help develop healthier, low-fat alternatives, which may be particularly attractive for health-conscious consumers or those following specific dietary restrictions.

Overall, the results of proximate analysis show how plantain flour substitution alters the nutritional composition of noodles, providing a valuable foundation for developing healthier and more sustainable noodle products. The gradual increase in moisture and ash content, coupled with the reduction in protein and fat content, indicates the potential of KPF as an alternative ingredient in noodle production, offering unique benefits in terms of texture, nutritional value, and functionality.

Noodle texture

The texture properties of noodles modified with varying levels of plantain flour substitution were assessed, revealing significant changes in adhesiveness, springiness, cohesiveness, and hardness. As shown in Table 5, these findings demonstrate how plantain flour concentration can markedly affect the noodles' texture, providing insights into the formulation of diverse noodle products.

At 10% substitution, the noodles demonstrated low

Table 4. Proximate content determination of noodles with varying plantain flour substitution compared with control and Kepok plantain flour

Sample name	Moisture content (%)	Ash content (%)	Fat content (%)	Protein content (%)
Kepok plantain flour	7.64±0.36^{d}	2.70±0.08^{a}	0.16±0.06	4.49±0.24^{e}
Noodles (wheat)	8.81±0.07^{bc}	0.51±0.06^{d}	0.07±0.02	13.52±0.09^{a}
Noodle with 10% plantain flour	8.61±0.17^{c}	0.66±0.03^{d}	Not detected	12.91±0.06^{b}
Noodle with 20% plantain flour	9.29±0.21^{bc}	0.82±0.03^{c}	Not detected	11.86±0.38^{c}
Noodle with 30% plantain flour	10.19±0.19^{a}	1.02±0.03^{b}	0.09±0.01	10.80±0.28^{d}
P-value	<0.001	<0.001	0.06	<0.001

Values are presented as mean±SD (n=3).
Different letters (a-e) denote significant differences among the treatments at $P<0.05$.

Table 5. Texture test results for modified plantain noodles

Plantain flour substitution	Adhesiveness (g.s)	Springiness	Cohesiveness	Hardness (kgf)
10%	−48.87±4.08[b]	0.65±0.02[a]	0.54±0.01[c]	767.39±98.78[a]
20%	−41.42±4.95[b]	0.64±0.02[a]	0.59±0.01[a]	926.12±117.40[a]
30%	−36.34±9.82[b]	0.59±0.02[b]	0.57±0.01[ab]	804.79±41.44[a]
Control	−3.28±1.61[a]	0.63±0.03[ab]	0.55±0.01[bc]	879.07±106.13[a]
P-value	<0.001	0.03	0.01	0.25

Values are presented as mean±SD (n=3).
Different letters (a-c) within the same column denote significant differences among the treatments at $P<0.05$.

adhesiveness (−48.87 g.s), indicating that they were less sticky than other formulations. The springiness value was moderate (0.65), reflecting an average elasticity level, whereas the cohesiveness value of 0.54 showed that the noodles maintained their shape reasonably well. The hardness value of 767.39 kgf indicated that the noodles were relatively firm.

As the plantain flour concentration increased to 20%, the noodles exhibited slight improvements in adhesiveness (−3.28 g.s), suggesting better adherence. The springiness value also slightly improved to 0.64, indicating enhanced elasticity, whereas the cohesiveness value increased to 0.59, implying better shape retention. However, the hardness value dramatically increased to 926.12 kgf, indicating a firmer texture.

At 30% substitution, the adhesiveness further decreased to −36.34 g.s, showing that the noodles became even less sticky. The springiness remained relatively stable (0.59), whereas the cohesiveness value decreased slightly to 0.57, indicating a marginal reduction in shape retention compared with that at 20% substitution. The hardness value also decreased to 804.79 kgf, suggesting a softer texture than noodles with 20% plantain flour substitution, although the noodles were still firmer than control noodles.

For comparison, control noodles (with 0% plantain flour) showed an adhesiveness of −3.28 g.s, a springiness value of 0.63, a cohesiveness value of 0.55, and a hardness value of 879.07 kgf (Jonkers et al., 2022) These results indicate that the inclusion of plantain flour modifies the texture, making the noodles less sticky, more elastic, and either softer or firmer depending on the concentration.

Substituting wheat flour with up to 30% KPF resulted in softer noodles with reduced shape retention. This is likely because of the absence of gluten in plantain flour, which weakens the gluten network in the dough, leading to a softer texture. The differences in starch properties between plantain and wheat flour, including lower gelatinization and retrogradation tendencies in plantain starch, also contribute to the reduction in shape retention. Furthermore, the higher fiber content of plantain flour might disrupt the cohesion and structure of the dough.

In previous studies, the lower firmness and less rigid texture in noodles with 30% banana flour incorporation were partly because of the dilution of gluten proteins (Zang et al., 2022), changes in water uptake behavior (Jia et al., 2022), impaired gluten network integrity (Liu et al., 2021), and changes in starch-water interactions (Shang et al., 2023). These factors affect the chemical and structural properties of the noodle matrix, causing these textural and stability differences.

These findings suggest that modifying noodles with plantain flour can significantly influence their texture, particularly in terms of elasticity, stickiness, and hardness. Therefore, balancing these properties is essential for optimizing the quality of noodles. Incorporating plantain flour into noodle formulations offers promising opportunities for creating new noodle products with enhanced textures, providing valuable insights for product development.

Pasting properties of flour

Fig. 2 shows the test results of the RVA for raw noodles with wheat flour (control) and noodles with plantain flour substitution. This figure shows a significant difference between the control and experimental samples, indicating that adding plantain flour can substantially alter the quality of noodles.

According to Panozzo and McCormick (1993), the RVA value, particularly the peak viscosity (PV), can determine the quality of flour used for making noodles. A PV value

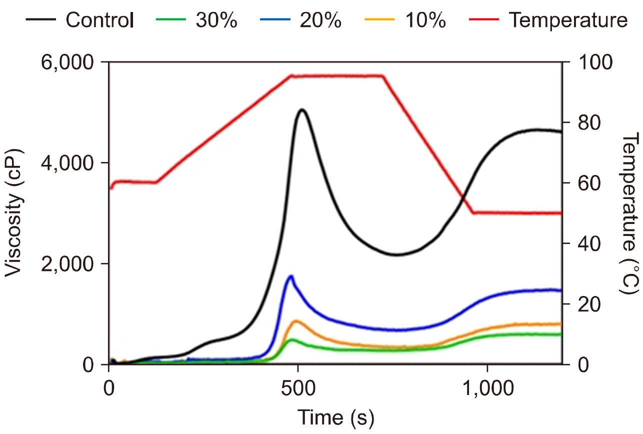

Fig. 2. Test results of the rapid viscosity analyzer.

Table 6. Pasting properties of noodles with plantain flour substitution

Plantain flour substitution	Peak viscosity (cP)	Peak time (s)	Breakdown (cP)	Final viscosity (cP)
10%	860±2.00[c]	496±1.00[b]	340±2.00[c]	802±2.52[c]
20%	1,745±3.00[b]	484±1.00[c]	678±1.53[b]	1,474±2.00[b]
30%	494±2.00[d]	484±1.00[c]	279±1.00[d]	595±2.00[d]
Control	5,032±3.51[a]	512±1.00[a]	2,167±1.53[a]	4,597±2.00[a]
P-value	<0.001	<0.001	<0.001	<0.001

Values are presented as mean±SD (n=3).
Different letters (a-c) within the same column denote significant differences among the treatments at $P<0.05$.

above 2,400 cP is considered to indicate superior-grade flour. From the data obtained, only the control sample had a PV above 2,400 cP, with a value of 5,032 cP. By contrast, the addition of plantain flour significantly reduced the PV value in all experimental samples, with none exceeding 1,745 cP.

The viscosity values obtained are shown in Table 6. The sample with 10% plantain flour substitution had a PV of 860 cP, whereas that with 20% plantain flour substitution had a PV of 1,745 cP. The sample with 30% plantain flour substitution exhibited the lowest PV of 494 cP. These values indicate that increasing the plantain flour substitution level results in lower PV values.

According to Ross et al. (1997), noodles with a low pasting peak have stronger gelling properties of amylose in the continuous phase of the noodle. This suggests that plantain flour substitution affects the gelling properties of the noodles. Moreover, the protein content and quality are important determinants of alkaline noodle quality. Fan et al. (2018) indicated that alkaline noodles typically have low PV, breakdown, and final viscosity values. Therefore, substituting wheat flour with plantain flour modifies its properties, making it suitable for alkaline noodles. Specifically, replacing 30% of wheat flour with plantain flour produces noodles with the lowest viscosity values, aligning with the desired characteristics for alkaline noodles. This modification can improve the gelling properties and overall quality of alkaline noodles, providing valuable insights for developing noodle products using plantain flour as a key ingredient.

Incorporating plantain flour decreases the PV because of the changes in starch composition and interaction within the noodle matrix. Such a shift in starch composition can have a significant impact on the final noodle quality because of insufficient structural support from the weakened gluten network combined with altered starch behavior, such as making a softer texture (Heo et al., 2012), shorter cooking time (Zhang et al., 2022), lower viscosity that decreases chewability (Zang et al., 2022), and more prone to breaking during cooking (Li et al., 2024).

Substituting wheat flour with up to 30% KPF resulted in noodles with favorable gelling properties, optimal cooking quality, and acceptable texture characteristics. This study provides important insights for developing healthier and more sustainable noodle products using KPF. Such innovations offer a valuable gluten-free alternative, catering to consumers with specific dietary needs and preferences. These findings contribute to the broader field of food diversification, promoting the use of locally sourced ingredients to enhance the nutritional profile and sustainability of food products.

FUNDING

None.

AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Concept and design: HL, BW, ASN. Experimental: BB, AR, AKR. Writing the articles HL, GKA, ASN. Analysis and interpretation: RPGP, ADK, MM, AM. Critical revision of the article: ASN, BW, HL, GKA. Final approval, and overall responsibility: all authors.

REFERENCES

Amini Khoozani A, Kebede B, Birch J, Bekhit AEA. The effect of bread fortification with whole green banana flour on its physicochemical, nutritional and in vitro digestibility. Foods. 2020. 9:152. https://doi.org/10.3390/foods9020152
Balmurugan M, Saravanakumar R, Kanchana S, Vellaikumar S, Mini M, Haripriya S. Development of noodles using unripe banana flour and evaluation of its cooking characteristics and nutritional profile. Pharma Innov. 2022. 11:954-959.
Chia SL, Chong GH. Effect of rotation speed and steam pressure on physico-chemical properties of drum dried pitaya (*Hylocereus polyrhizus*) peel. Int Food Res J. 2015. 22:372-376.
Choo CL, Aziz NAA. Effects of banana flour and β-glucan on the nutritional and sensory evaluation of noodles. Food Chem.

2010. 119:34-40. https://doi.org/10.1016/j.foodchem.2009.05.004
Choudhury N, Nickhil C, Deka SC. Comprehensive review on the nutritional and therapeutic value of banana by-products and their applications in food and non-food sectors. Food Biosci. 2023. 56:103416. https://doi.org/10.1016/j.fbio.2023.103416
Fan H, Ai Z, Chen Y, Fu F, Bian K. Effect of alkaline salts on the quality characteristics of yellow alkaline noodles. J Cereal Sci. 2018. 84:159-167. https://doi.org/10.1016/j.jcs.2018.10.007
Farzana T, Abedin MJ, Abdullah ATM, Reaz AH. Exploring the impact of pumpkin and sweet potato enrichment on the nutritional profile and antioxidant capacity of noodles. J Agric Food Res. 2023. 14:100849. https://doi.org/10.1016/j.jafr.2023.100849
Fikadu T, Tekele T, Markos W. Effect of different storage facilities on ripening and post-harvest quality of banana (*Musa app*). Int J Res Innov Earth Sci. 2016. 3:65-73.
Grujić S, Grujčić M. Factors affecting consumer preference for healthy diet and functional foods. Foods Raw Mater. 2023. 11:259-271.
Heo H, Baik BK, Kang CS, Choo BK, Park CS. Influence of amylose content on cooking time and textural properties of white salted noodles. Food Sci Biotechnol. 2012. 21:345-353. https://doi.org/10.1007/s10068-012-0046-9
Hidayat DD, Sagita D, Darmajana DA, Indriati A, Rahayuningtyas A, Sudaryanto A, et al. Development and thermal evaluation of double drum dryer for ready-to-eat food products to support stunting prevention. INMATEH Agric Eng. 2021. 64:43-53. https://doi.org/10.35633/inmateh-64-04
Hung PV, Cham NTM, Truc PTT. Characterization of Vietnamese banana starch and its resistant starch improvement. Int Food Res J. 2013. 20:205-211.
Islam MF, Islam S, Miah MAS, Bhuiyan MNI, Abedin N, Mondol MMH, et al. Quality assessment and sensory evaluation of green banana starch enriched instant noodles. Appl Food Res. 2024. 4:100431. https://doi.org/10.1016/j.afres.2024.100431
Jia R, Zhang M, Yang T, Ma M, Sun Q, Li M. Evolution of the morphological, structural, and molecular properties of gluten protein in dough with different hydration levels during mixing. Food Chem X. 2022. 15:100448. https://doi.org/10.1016/j.fochx.2022.100448
Jonkers N, van Dommelen JAW, Geers MGD. Intrinsic mechanical properties of food in relation to texture parameters. Mech Time Depend Mater. 2022. 26:323-346. https://doi.org/10.1007/s11043-021-09490-4
Kabir MR, Hasan SMK, Islam MR, Ahmed M. Development of functional noodles by encapsulating mango peel powder as a source of bioactive compounds. Heliyon. 2024. 10:e24061. https://doi.org/10.1016/j.heliyon.2024.e24061
Keeratiburana T, Siangwengwang N, Somphunga W, Fu T, Blennow A. Ultrasound-assisted annealing treatment to improve physicochemical and digestive properties of banana flour. J Sci Food Agric. 2024. 104:6640-6648. https://doi.org/10.1002/jsfa.13488
Kumalasari R, Mayasti NKI, Surahman DN, Ekafitri R, Wahyuni AS, Desnilasari D. Functional properties of ripe plantain (*Musa* spp) flour from different varieties. IOP Conf Ser Earth Environ Sci. 2020. 462:012018. https://doi.org/10.1088/1755-1315/462/1/012018
Laksono H, Dyah CK, Putri RPG, Soraya M, Purwoto H. Characteristics of rapid visco analyzer carrageenan extract with enzymatic pretreatment of *Kappaphycus striatum*. ASEAN J Chem Eng. 2022. 22:326-336. https://doi.org/10.22146/ajche.76994
Leeward BO, Alemawor F, Deku G. Nutritional and sensory evaluation of yoghurt incorporated with unripe false horn plantain (*Musa paradisiaca* var. "apentu"). Int J Food Sci. 2023. 2023:2221302. https://doi.org/10.1155/2023/2221302
Li X, Wu Y, Li C, Tong S, Zhang L, Jin J. Improvement in noodle quality and changes in microstructure and disulfide bond content through the addition of pepper straw ash leachate. Foods. 2024. 13:1562. https://doi.org/10.3390/foods13101562
Liu C, Song M, Hong J, Li L, Zheng X, Bian K, et al. Effects of salt and kansui on rheological, chemical and structural properties of noodle dough during repeated sheeting process. Food Chem. 2021. 342:128365. https://doi.org/10.1016/j.foodchem.2020.128365
Oguntoyinbo OO, Olumurewa JAV, Omoba OS. Antioxidant and dietary fibre content of noodles produced from wheat and banana peel flour. IPS J Nut Food Sci. 2023. 2:46-51. https://doi.org/10.54117/ijnfs.v2i2.24
Panozzo JF, McCormick KM. The rapid viscoanalyser as a method of testing for noodle quality in a wheat breeding programme. J Cereal Sci. 1993. 17:25-32. https://doi.org/10.1006/jcrs.1993.1004
Pistorio E, Chinnici G, Zarbà C, Bellia C, Pappalardo G. The revolution of functional food: a market analysis. Proceedings of the 23rd International Multidisciplinary Scientific Geoconference SGEM. 2023. p 433-441.
Ross AS, Quail KJ, Crosbie GB. Physicochemical properties of Australian flours influencing the texture of yellow alkaline noodles. Cereal Chem. 1997. 74:814-820. https://doi.org/10.1094/CCHEM.1997.74.6.814
Shang J, Zhao B, Liu C, Li L, Hong J, Liu M, et al. Impact of wheat starch granule size on viscoelastic behaviors of noodle dough sheet and the underlying mechanism. Food Hydrocoll. 2023. 134:108111. https://doi.org/10.1016/j.foodhyd.2022.108111
Tangthanantorn J, Wichienchot S, Sirivongpaisal P. Development of fresh and dried noodle products with high resistant starch content from banana flour. Food Sci Technol. 2022. 42:e68720. https://doi.org/10.1590/fst.68720
Thongkaew C, Singthong J. Effect of partial substitution of Riceberry rice flour on rice noodles quality. Food Res. 2020. 4(Suppl 4):9-16. https://doi.org/10.26656/fr.2017.4(S4).002
Wiguna B, Kahfi J, Aji GK, Rachman D, Nasori AS, Muhamaludin, et al. The influence of virgin red palm oil on the physical and textural properties of various vegetable full-fat mayonnaise. Sains Malays. 2023. 52:2843-2854. http://doi.org/10.17576/jsm-2023-5210-09
Zang P, Gao Y, Chen P, Lv C, Zhao G. Recent advances in the study of wheat protein and other food components affecting the gluten network and the properties of noodles. Foods. 2022. 11:3824. https://doi.org/10.3390/foods11233824
Zhang J, Kong H, Ban X, Li C, Gu Z, Li Z. Rice noodle quality is structurally driven by the synergistic effect between amylose chain length and amylopectin unit-chain ratio. Carbohydr Polym. 2022. 295:119834. https://doi.org/10.1016/j.carbpol.2022.119834
Zhang N, Ma G. Noodles, traditionally and today. J Ethn Foods. 2016. 3:209-212. https://doi.org/10.1016/j.jef.2016.08.003