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Local Cassava Resources for Noodle Production : Physicochemical Characterization and Principal Component Analysis (PCA)

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***ABSTRACT**: Addressing the national food security challenge requires diversifying carbohydrate sources beyond imported wheat. Using local plants, particularly cassava, is a highly strategic approach to developing gluten-free products. Therefore, this study aims to analyse the physicochemical properties and texture of noodles formulated from two different regional cassava cultivars, specifically Manggu (West Java) and Pacar (South Kalimantan). The experimental framework used a completely randomised factorial design, testing various proportions of cassava flour to tapioca (1:0, 2:1, and 0:1). Laboratory evaluation analysed the estimated composition, cooking loss, and texture profile analysis. To identify the main variables driving product quality, the dataset was analysed using Principal Component Analysis. The results show that the addition of tapioca generally increases hardness, chewiness, and elasticity in the samples. However, its influence on cohesiveness, elasticity, and cooking loss varies significantly depending on the genetic properties of the cassava used. It should be noted that the 'Pacar' cultivar produces a denser structural matrix, showing better resilience and very low cooking loss between 6.69% and 7.87%. In contrast, the Manggu noodles experience high moisture levels and greater cooking loss reaching up to 12.48%, indicating a weaker internal gel network during boiling. From a nutritional perspective, although all the tested formulations meet the mandatory moisture limit for dry noodles, their protein content remains a significant limiting factor, below the standard requirements. Additionally, multivariate analysis captured 71.48% of the total variance, successfully distinguishing two cassava varieties based on their unique physicochemical behaviours. Ultimately, these findings highlight that the optimal production of gluten-free noodles heavily relies on the selection of the right cassava genotypes and the careful adjustment of tapioca blend proportions, thereby establishing a viable path for the advancement of the local agro-industry.*

***Keywords:** Cassava noodles, Food diversification, Local food product, Physicochemical properties, PCA.*

1. INTRODUCTION

Exceeding 11 million metric tons in 2023, Indonesia's massive wheat imports continually threaten the stability of its domestic food industry by exposing it to global supply volatility (BPS, 2023). Championing indigenous crops such as cassava (Manihot esculenta Crantz) offers a

strategic diversification pathway to counter this dependency (Pandin et al., 2022). The prospect of integrating cassava is exceptionally promising in the noodle market, driven by a domestic demand that reached 14.54 billion servings in 2023, the second highest globally ([WINA] World Instan Noodles Assosiation, 2023). Despite this clear market opportunity, the technical execution of purely cassava-based noodles remains problematic. Inherently devoid of a gluten network, cassava flour yields a structurally compromised dough. As a result, the finished noodles typically display flawed physicochemical characteristics, frequently suffering from excessive stickiness, physical brittleness, and substantial matter loss during cooking (Rahmawati et al., 2022).

The structural defects often found in gluten-free noodles are primarily dictated by the inherent traits of the cassava starch, namely its amylose-to-amylopectin ratio, swelling capacity, and gelatinisation behaviour. Such attributes do not occur in a vacuum; they depend heavily on the plant's genetic makeup and its specific growing environment (Charles et al., 2005; Copeland et al., 2009). Recognising this environmental and genetic influence, our research focuses on two distinct, high-yielding cultivars sourced from contrasting geographic zones. We selected the Manggu variety from Bogor (West Java) to represent a high-starch crop cultivated in a rain-abundant region. Alongside it, we examined the Pacar variety, a prominent local commodity naturally acclimatised to the distinct soil and climatic stresses of South Kalimantan.

Our decision to utilise these particular cultivars, along with their designated drying techniques, stems directly from empirical data gathered in our preliminary trials. During that initial phase, we discovered that oven drying the Manggu tubers and sun-drying the Pacar tubers produced the highest physical quality for the resulting flour. We observed that these targeted processing methods generated exceptional paste-forming capabilities and superior starch granule morphology. Specifically, the sun-dried Pacar flour exhibited an ideal peak viscosity coupled with minimal granular breakdown, whereas the oven-dried Manggu flour retained excellent whiteness and a highly stable final viscosity. Consequently, we utilised these two optimised flour preparations as the baseline materials to accurately assess how they influence the final noodle's physicochemical profile.

Despite the undeniable commercial promise of cassava, existing literature falls short of solving the structural hurdles inherent in cassava noodles. The bulk of prior investigations restricts the scope to using modified cassava flour (Mocaf) merely as a fractional wheat substitute (Cahyani & Apriliyanto, 2024; Ernaningtyas et al., 2020). Other efforts prioritise nutritional or sensory enhancements via legume fortification, largely overlooking the core structural mechanics (Astuti et al., 2023). This narrow focus leaves a critical blind spot in current food science: researchers have yet to thoroughly compare the physicochemical variations of optimised cassava flours drawn from diverse agroclimates, nor have they mapped the definitive parameters governing gluten-free noodle quality.

Disentangling the intricate web of these physicochemical variables, for instance, tracing how a starch's gelatinisation profile dictates a noodle's stickiness and firmness requires more than basic statistical observation. In this context, Principal Component Analysis (PCA) serves as an essential methodological tool rather than a supplementary metric. By reducing complex multivariate data into interpretable dimensions, PCA effectively isolates the underlying patterns driving the behaviour of starch-based matrices (Gyau Akyereko et al., 2020; Jolliffe & Cadima, 2016). Deploying this technique allows for a highly accurate identification of the exact variables controlling the end-product's structural integrity.

Driven by the need to resolve these limitations, the present study establishes three primary objectives. First, it aims to evaluate and contrast the physicochemical

traits of noodles formulated entirely from the optimised Manggu (Bogor) and Pacar (South Kalimantan) cassava preparations. Second, the research utilises PCA to map the correlations among various physicochemical markers, isolating the dominant factors that shape noodle texture. Finally, we seek to translate these findings into actionable, location-specific technical guidelines, empowering local food manufacturers to commercialise high-grade, purely cassava-based noodles.

2. MATERIALS AND METHODS

Materials

The main ingredient is 9-month-old cassava (Manihot esculenta) of the Manggu variety, sourced from farmers in Carang Pulang Village, Bogor. Nine-month-old cassava of the Pacar variety was obtained from farmers in South Kalimantan, specifically in Hamparaya Village, Batumandi Sub-district, Balangan Regency; Pak Tani brand tapioca flour was purchased in Cihideung Ilir Sub-district, Cibanteng Setu Sub-district, Bogor Regency; chicken eggs, glucomannan (porang flour), and xanthan gum were obtained from online shops. The chemicals used, including distilled water, 95% ethanol, 70% ethanol, acetone, phosphate buffer, protease enzyme solution, amyloglucosidase enzyme solution, HCl, HgO, H_2SO_4, K_2SO_4, NaOH, methyl blue indicator, RVA canister, methylene red indicator, phenolphthalein indicator, hexane solvent, Thermamyl, borax solution, filter paper, and H_3BO_3 solution, were obtained from the stockroom of the ITP Department at IPB.

The equipment used in this study comprised a rough-use balance (Excellent, Indonesia) with a capacity of 10 kg, baking trays, a mixing bowl, a slicer, a noodle maker, a knife, a measuring jug, a drying oven (Cascade TEK, USA), a disc mill, a fan, a 100-mesh sieve, a Texture Analyzer TA-XT2i (Stable Micro Systems Ltd, UK), a water bath, a Ravid Visco Analyzer Tecmaster (Newport Scientific), aluminum dishes, a desiccator, a rice spoon, glassware, saucepans, plastic pouches, Kjeldahl flasks, fat flasks, a gas hob, LPG gas, large jars, filter paper, an electric furnace, a polarizing microscope, and a C-100 whiteness meter.

Methods

The experimental design used to determine the properties of cassava noodles was a Completely Randomized Factorial Design (CRFD) with two variables and two repetitions. The first factor was the refined preparation of cassava flour, selected based on the best results from our preliminary research. This factor had two levels: oven-dried Manggu variety (from Bogor) and sun-dried Pacar variety (from South Kalimantan). These specific combinations of cultivar and drying technique were deliberately chosen because our previous study showed that they produced better flour quality in terms of starch granule structure, gelatinization characteristics, and visual color. The second variable was the ratio of cassava flour to tapioca flour at three ratios (1:0, 2:1, and 0:1), as shown in Table 1.

Table 1. Research design for the production of cassava noodles

Type of cassava	Test	Cassava flour formulation (A) : tapioca flour (D)		
		1 : 0	2 : 1	0 : 1
Manggu Cassava Flour (A_1)	1	$A_{11}D_1$	$A_{11}D_2$	$A_{11}D_3$
	2	$A_{12}D_1$	$A_{12}D_2$	$A_{12}D_3$
Pacar Cassava Flour (A_2)	1	$A_{21}D_1$	$A_{21}D_2$	$A_{21}D_3$
	2	$A_{22}D_1$	$A_{22}D_2$	$A_{22}D_3$

The mathematical model for the factorial completely randomised design (CRD) experiment in this study is as follows:

$$Yijk = \mu + \alpha i + \beta j + (\alpha\beta ij) + \varepsilon ijk \qquad (1)$$

Where Yij = Observation value for factor A at level i, factor B at level j, and replicate k, μ = Overall mean , αi = Main effect of factor A (optimized cassava flour preparation), βj = Main effect of factor B (rasio of cassava flour to tapioca flour), $(\alpha\beta)_{ij}$ = interaction effect between factor A at level i and factor B at level j, εijk = random error associated with observation ijk.

The Process of Making Cassava Noodles

Table 2. Ingredients used in the production of cassava noodles

Formulation	Composition				
	Cassava Flour	Tapioca Flour	Egg	Xanthan gum	Glucomanan
1 : 0	60	0	1	2.5	5
2 : 1	40	20	1	2.5	5
0 : 1	0	60	1	2.5	5

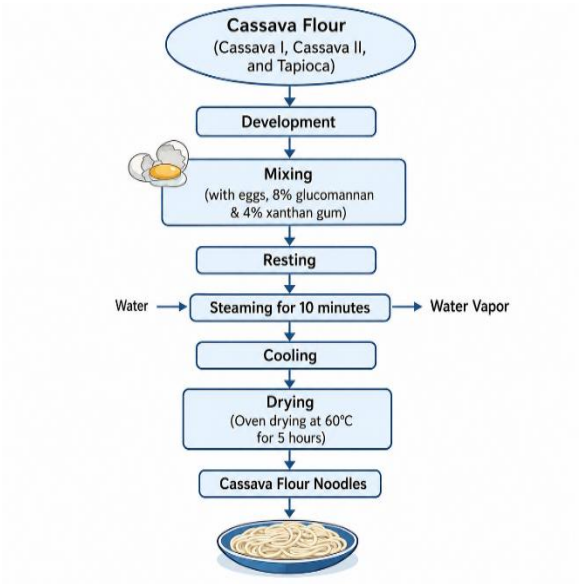


Figure 1. The process of making cassava noodle

Methods of Analysis

The analyses carried out comprised physical analyses (cooking loss and RVA) and chemical analyses (moisture content, ash, fat, protein, carbohydrates, and dietary fiber).

3. RESULTS AND DISCUSSION

3.1. Interpretation of Result

Cooking loss is one of the crucial parameters in the quality assessment of starch-based noodles. This parameter represents the extent to which the starch polymer matrix is able to maintain the integrity of its constituent components when exposed to high temperatures during boiling. According to Indrianti et al. (2013) in a previous study, the release of a portion of the starch fraction into the boiling water not only causes the water to become cloudy but also has a direct impact on the weakening of the noodles' texture, making them less slippery and prone to breaking. This phenomenon is closely linked to the stability of the gel network formed during gelatinisation. A high cooking loss figure indicates that the gelatinised starch matrix is not yet strong and cohesive enough to bind the non-gelatinised starch molecules. Consequently, the hydrophilic components are more prone to diffusion (leaching) into the cooking medium, which ultimately reduces yield and compromises the textural quality of the final product (Chisenga et al., 2019; J. Wang et al., 2021).

When using Manggu variety cassava flour, the trend observed was that an increasing proportion of tapioca actually exacerbated the solid loss. The cooking loss figure increased gradually from 9.62 ± 0.06 % when using pure cassava flour (1:0), rising to 10.00 ± 0.08 % when mixed with tapioca (2:1), and surging sharply to 12.48 ± 0.18 % when using tapioca exclusively (0:1). This increase suggests that the dominance of tapioca in the Manggu variety dough system is unable to form a stable gel network. Given that tapioca flour is essentially 100 % cassava starch, its addition in large quantities risks increasing the cooking loss if the primary binding matrix lacks adequate binding capacity. Although tapioca excels in the speed and high swelling capacity of its granules, excessive granule expansion unsupported by a robust polymeric framework will actually damage the matrix walls, facilitating the release of soluble starch

fractions into the cooking water (J. Wang et al., 2021). The opposite was observed with cassava flour of the 'Pacar' variety, which exhibited an excellent synergistic effect. Adding tapioca to this variety was effective in reducing cooking loss. The figures were recorded as 7.77 ± 0.09 % in the formulation without tapioca (1:0), remained at around 7.87 ± 0.71 % at a mixing ratio of 2:1, and reached the lowest cooking loss and best yield of 6.69 ± 0.25 % when using a full proportion of tapioca (0:1). This finding provides strong evidence that tapioca starch, when interacting with the starch system of the 'Pacar' variety, is capable of forming a very dense network to lock in solids, thereby significantly reducing the water permeability of the gel structure.

Table 3. Physical characteristics of cassava noodles based on an analysis of cooking loss and TPA

Types of Cassava	Formulation	Parameter					
		Cooking loss	*Elasticity*	*Cohesiveness*	*Chewiness*	*Stickiness*	*Hardness*
Manggu Cassava Flour	1	9.62 ± 0.06^{Aa}	0.34 ± 0.01	0.39 ± 0.02 ^{Aa}	636.37 ± 45.45 ^{Aa}	1858.39 ± 75.46 ^{Aa}	4724.60 ± 172.01 ^{Aa}
	2	10.00 ± 0.08^{Ab}	0.45 ± 0.06	0.52 ± 0.02 ^{Ab}	1548.76 ± 297.38 ^{Aa}	3458.40 ± 809.21 ^{Aa}	6724.90 ± 1780.18 ^{Aa}
	3	12.48 ± 0,18^{Ac}	0.15 ± 0.26	0.50 ± 0.02 ^{Ab}	447.72 ± 772.16 ^{Aa}	3777.35 ± 744.82 ^{Ab}	7623.40 ± 1795.01 ^{Ab}
Pacar Cassava Flour	1	7.77 ± 0.09^{Ba}	0.45 ± 0.01	0.50 ± 0.06 ^{Ba}	1779.88 ± 97.02 ^{Ba}	39883.0 ± 280.10 ^{Ba}	7996.77 ± 430.35 ^{Ba}
	2	7.87 ± 0.71^{Bb}	0.37 ± 0.04	0.51 ± 0.02 ^{Bb}	1093.70 ± 143.42 ^{Ba}	2985.12 ± 203.18 ^{Ba}	5898.13 ± 363.79 ^{Ba}
	3	6.69 ± 0.25^{Bc}	0.51 ± 0.07	0.47 ± 0.03 ^{Bb}	2276.42 ± 849.14 ^{Ba}	4339.56 ± 1030.13 ^{Bb}	9154.73 ± 1450.75 ^{Bb}

*Within the same row, numbers followed by different capital letters indicate that the simple effects of the different cassava flour varieties were significantly different at the 0.05 significance level; and within the same column, numbers followed by different lower-case letters indicate that the simple effects of the different formulation treatments were significantly different at the 0.05 significance level, as determined by Duncan's Multiple Range Test.

The results of data analysis using two-way analysis of variance (ANOVA), presented in Table 4, clearly show that cooking loss is not only significantly influenced by the individual factors of cassava flour variety ($p < 0.001$) and the ratio of cassava flour to tapioca in the formulation ($p < 0.001$), but also by a strong interaction between these two factors ($p < 0.001$). The significance of this variety × formulation interaction reveals an important finding: the effect of adding tapioca on the release of solids is not linear and cannot be generalised to all cassava raw materials. This confirms that the behaviour of cooking loss is highly dependent on the inherent characteristics of the starch in each variety. Further DMRT analysis revealed a significant effect of differences in cassava flour variety and formulation ratio on the cooking loss of the noodles. Amylose released during heating forms a strong network of hydrogen bonds that bind the molecules together, thereby preventing the starch granules from leaching into the boiling water. In the Manggu variety, the internal gel structure is less effective at binding free starch components; consequently, increasing the tapioca ratio actually exacerbates solid loss (cooking loss rising to 12.48 %). Overall, these DMRT data confirm that selecting specific cassava varieties (such as the Pacar variety from Kalimantan) is far more effective in producing gluten-free noodles with good solid retention.

The superior performance demonstrated by the 'Pacar' variety is consistent with the crucial role of amylose in modifying the texture profile. According to data from (Moorthy SN, 2004), tapioca flour contributes a relatively high amount of amylose, ranging from 20–27 %. This view is supported by Kong X et al. (2009) who state that the strength of the gel structure is largely determined by a high amylose content. Within the Pacar dough matrix, amylose functions optimally to form a three-dimensional network through interactions between linear chains and post-gelatinisation hydrogen bonds, whilst amylopectin also plays a role in determining the viscoelastic properties of the gel (Ai & Jane, 2024; J. Wang et al., 2021). The combination of the characteristics of Pacar's endogenous starch (which is low in protein) with those of tapioca (which is rich in amylose) results in the formation of structural cross-links that are far more compact and continuous. It is this structural integrity that effectively slows the rate at which dissolved components diffuse out of the noodles.

Table 4 Two-way ANOVA summary (*F*-values and *p*-values) for the physical characteristics of cassava noodles

Parameter	Variety (V)	Formulation (F)	Interaction (VxF)
Cooking Loss	$p < 0.001$	$p < 0.001$	$p < 0.001$
Elasticity	$F = 5.74$; $p = 0.034$	$F = 0.82$; $p = 0.461$	$F = 6.11$; $p = 0.015$
Cohesiveness	$F = 3.99$; $p = 0.069$	$F = 12.38$; $p = 0.001$	$F = 14.84$; $p = 0.001$
Chewiness	$F = 13.22$; $p = 0.003$	$F = 0.15$; $p = 0.855$	$F = 8.59$; $p = 0.005$
Stickiness	$F = 6.16$; $p = 0.029$	$F = 5.20$; $p = 0.024$	$F = 6.45$; $p = 0.013$
Hardness	$F = 5.36$; $p = 0.039$	$F = 5.72$; $p = 0.018$	$F = 4.30$; $p = 0.039$

Elasticity, or flexibility, refers to the ability of noodles to return to their original shape after being deformed or subjected to pressure. A higher flexibility value indicates better shape recovery after the sample has been compressed (Bourne, 2002). The results of the analysis of variance confirmed that tapioca substitution did not result in a uniform increase in elasticity across all cassava varieties, but rather depended heavily on the interaction between the type of raw material and the mixing ratio ($p = 0.015$). In the noodle test using Manggu cassava flour as the raw material, the elasticity value of 0.34 ± 0.01 in the formulation without substitution (1:0) increased to 0.45 ± 0.06 when tapioca was substituted at a ratio of 2:1. Conversely, the addition of tapioca at the same ratio (2:1) to the Pacar variety actually reduced elasticity from 0.45 ± 0.01 to 0.37 ± 0.04. The greatest increase in elasticity for Pacar cassava flour was only observed when pure tapioca was used (0.51 ± 0.07). These differences in physical response are related to starch structural characteristics, the amylose–amylopectin ratio, swelling capacity, as well as gelatinisation and paste-forming properties, all of which can influence the final texture of the noodles (J. Wang et al., 2024a). Variations in the properties of starch between cassava genotypes may also explain the differences in response between Manggu cassava and Pacar cassava (Ribeiro et al., 2024).

Cohesiveness is a parameter in texture profile analysis that indicates the strength of internal bonds within the noodle matrix when the sample undergoes repeated deformation or compression. A higher cohesiveness value indicates that the internal structure of the noodles is better able to maintain its integrity after the first compression, but does not directly reflect the loss of solids during the cooking process (Hernawan et al., 2026; Rosenthal & Thompson, 2021). Table 4 confirms the presence of a highly significant interaction effect between variety and formulation on the noodle cohesiveness parameter ($p=0.001$). The pure Manggu cassava dough (1:0) exhibited a relatively low level of internal cohesion, namely 0.39 ± 0.02. Nevertheless, this structural weakness

could be optimally compensated for by mixing in tapioca at a ratio of 2:1, which was shown to significantly increase cohesiveness to 0.52 ± 0.02. On the other hand, the Pacar variety naturally possesses a more robust functional matrix. This is evidenced by the relatively stable cohesiveness values obtained, ranging from 0.47 to 0.51 across all formulation levels. The structural stability of the Pacar variety suggests that its starch macromolecules are capable of forming strong cross-links without the need for external binding agents, in line with the concept that the addition of modified starch is not always essential if the main ingredient already possesses a stable gelatinisation profile (Matita et al., 2024; Pedcharat et al., 2023; J. Wang et al., 2024b).

The chewiness parameter measures how firm or elastic the noodles are when chewed. Further evaluation of this parameter (chewiness) also revealed fluctuations in values that were sensitive to the interaction between the two treatment factors ($p = 0.005$). Under conditions using pure cassava flour (1:0), noodles produced from Pacar cassava flour required significantly higher masticatory energy, namely 1,779.88 ± 97.02, compared to those made from the Manggu variety, which tended to be softer with a value of 636.37 ± 45.45. However, the partial tapioca substitution treatment (2:1) produced the opposite effect. The chewiness value of Manggu cassava flour increased dramatically to 1,548.76 ± 297.38, whilst the chewiness of noodles made from Pacar cassava flour actually decreased to 1,093.70 ± 143.42. The peak elasticity in the Pacar cassava flour-starch system was only achieved when the formulation was completely replaced by tapioca, with a value of 2,276.42 ± 849.14. Based on these findings, efforts to engineer the texture of non-wheat noodles have proven to be highly complex. The level of compatibility between the added hydrocolloid and the endogenous starch components is the dominant factor determining the success of forming a noodle structure with an ideal level of elasticity (Hernawan et al., 2026).

Stickiness is a textural attribute that represents the magnitude of the adhesive force between noodle strands. According to the statistical test results, this stickiness profile is not influenced solely by the proportion of tapioca, but is strongly governed by a significant interaction between the cassava genotype and the formulation composition ($p = 0.013$). In noodles made using Manggu cassava flour, the addition of tapioca consistently triggered an upward trend in stickiness; the value rose from 1,858.39 ± 75.46 gf in the unblended formulation (1:0), to 3,458.40 ± 809.21 gf at a 2:1 ratio, and peaking at 3,777.35 ± 744.82 gf when the formulation was entirely replaced by tapioca (0:1). Interestingly, structural anomalies actually occurred in noodles made with 'Pacar' variety cassava flour. The use of the pure formulation (1:0) and full tapioca (0:1) did indeed result in extremely high stickiness, at 3,988.30 ± 280.10 gf and 4,339.56 ± 1,030.13 gf, respectively. Nevertheless, the intervention of blending the two types of starch at a 2:1 ratio proved effective in significantly reducing this stickiness to 2,985.12 ± 203.18 gf. This reduction in stickiness at this specific ratio can be attributed to the degree of intermolecular gelatinisation. When the blended starch matrix reaches the ideal gelatinisation phase, the exudation of amylose forms a stable surface layer through tight hydrogen bonding. A 2:1 ratio of this Pacar variety appears to be the most effective in preventing the loss of the free starch fraction, which generally acts as a binding agent after cooking (Marti et al., 2010).

The hardness parameters, which evaluate the resistance of the dough to mechanical deformation, also showed a significant dependence on the interaction between the two factors ($p = 0.039$). The response patterns recorded in Table 3 further confirm that the hardening effect of adding tapioca is not uniform across all raw materials. In the Manggu variety, tapioca acts linearly as a matrix hardening agent; the hardness value increased from 4,724.60 ± 172.01 gf (1:0) to 6,724.90 ± 1,780.18 gf (2:1), and exceeded

7,623.40 ± 1,795.01 gf at the maximum tapioca usage ratio (0:1). In contrast, the Pacar variety responded to this hydrocolloid modification with a highly fluctuating trend. The hardness level in the pure formulation (7,996.77 ± 430.35 gf) was recorded as having dropped sharply when tapioca was substituted at a 2:1 ratio (5,898.13 ± 363.79 gf), before eventually surging dramatically in the 0:1 formulation (9,154.73 ± 1,450.75 gf). These differing response patterns across genotypes reflect the inherent complexity of each starch, including its internal amylose-amylopectin ratio, polymer interactions during heating, and specific retrogradation behaviour, which collectively dictate the compactness of the myo-cavity walls during the drying process (Hernawan et al., 2026; Ribeiro et al., 2024). However, the effect of tapioca on hardness may vary depending on the starch source, raw material composition, and processing conditions (Pokharel et al., 2023).

3.2 Chemical Characteristics of Cassava Noodles

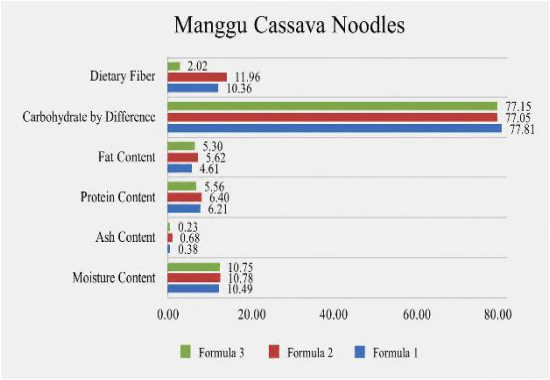
The moisture content of cassava noodles affects the product's storage stability and textural characteristics. Analysing the data distribution in Figure 2, each variety exhibits a highly specific water-holding capacity. The group of noodles made from Manggu cassava recorded a relatively low and uniform moisture content, ranging from 10.49% to 10.78%. Statistical analysis using Duncan's Multiple Range Test (DMRT) confirmed that the variation between formulations within this cluster was very narrow (differing by only 0.29 %), with the pure formulation without substitution (1:0) achieving the lowest moisture content of 10.49%. Conversely, the starch matrix of the Pacar variety appeared to have a much stronger affinity for binding residual water. The final moisture content remained at a higher level, ranging from 12.03 % (1:0 formulation) to 13.98 % with a 2:1 tapioca substitution. Although disparities in water retention arose due to inherent differences in the physicochemical properties between genotypes, the results of all these treatments are worthy of recognition, as they fully comply with the quality regulations of SNI 01-3551-2000, which sets the maximum tolerance limit for the moisture content of dry instant noodles at 14.5 %(BSN, 2000) .

The success in reducing the percentage of free water, which appears to be predominant in the cassava flour matrix of the Manggu variety, provides crucial technical assurance regarding product shelf life. The reduction in water volume through thermal heating not only reduces weight but also, in parallel, lowers the water activity (Aw) value. A reduction in Aw within the matrix disrupts the ideal ecosystem required for the proliferation of pathogenic microbes and spore-forming spoilage agents. This dehydrated environment provides highly robust microbiological protection, meaning that formulations with the lowest moisture content are projected to have a significantly longer shelf life than products that still trap large numbers of water molecules within their structural conformation (Z. Wang et al., 2025).

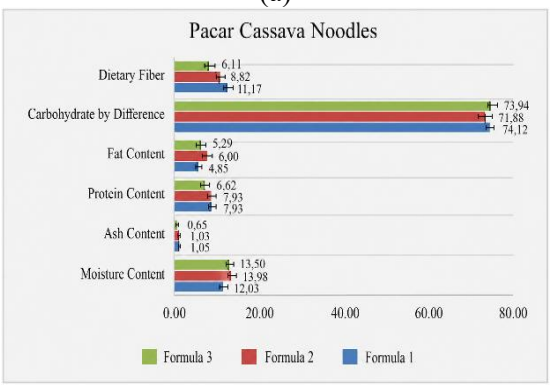
More than just a preservation parameter, the transition of water molecules directly dictates the evolution of the rheological properties of muscle tissue during the production stage. Within the wet dough, active water molecules act as an internal plasticiser, imparting mechanical flexibility to the long starch polymer chains. When these plasticising compounds are forced to evaporate from the interpolymer spaces during the baking process, the macromolecular structure undergoes physical stress and is driven to transition from an elastic, rubber-like state to a rigid, glass-like state. It is this thermodynamic phase shift that forms the mechanistic basis for why the rate of moisture loss is always directly proportional to the increase in the noodles' rigidity and mechanical toughness. This physical stability is essential for protecting the noodle strands from the risk of breaking, cracking or crumbling throughout the supply chain until the product is ready to be boiled by the consumer (Cai et al., 2024).

Cassava noodles made from the Pacar variety of cassava flour, using a cassava flour:tapioca ratio of 2:1, yielded the highest ash content of 1.25 ± 0.11%. This value indicates that this sample has a relatively higher mineral content compared to the other treatments. Thus, an increase in ash content can be interpreted as an indicator of a higher mineral content in the food product. In this context, Pacar cassava flour may have a higher mineral content than Manggu, although this conclusion requires further verification. An increase in ash content is usually associated with an increase in the mineral content of food, and this phenomenon is widely accepted in the literature as an important indicator in the assessment of the nutritional quality of foodstuffs(Liu et al., 2021) .

The data in Figure 2 show that cassava noodles made from the three formulations and two varieties of cassava flour had varying moisture contents, though these still fell within the range of 10.18 ± 0.58 to 13.98 ± 0.41% (w/w). Based on Figure 2, the lowest moisture content was obtained in the treatment using the Manggu variety with the 2:1 formulation, namely 10.18 ± 0.58% (w/w), and was therefore assessed as the most optimal for the production of cassava noodles. This finding is consistent with the Duncan Multiple Range Test (DMRT), which indicated that the 2:1 formulation was the best treatment, as it produced the lowest moisture content compared to the other formulations. In accordance with SNI 01-3551-2000, the maximum moisture content for dried instant noodles is 14.5 percent; therefore, all samples shown in Figure 2 still meet the specified quality requirements.



(a)



(b)

Figure 2. Graph showing the chemical characteristics of cassava noodles from Manggu (a) and Pacar (b)

The carbohydrate content difference between Manggu and Pacar cassava noodles was relatively high across all three formulations. Manggu cassava noodles showed higher and more consistent values, ranging from 77.05% to 77.81%, with the highest value in Formulation 1. Pacar cassava noodles had lower values, ranging from 71.88% to 74.12%, with the highest value also found in Formula 1. The difference between formulas for Manggu was only 0.76%, while for Pacar it reached 2.24%, indicating greater variation in carbohydrate content for Pacar. The high carbohydrate content in both types of noodles indicates the predominance of starch from cassava flour and tapioca as the main ingredients. This finding is consistent withHernawan et al. (2026), who stated that cassava- and tapioca-based noodles have a high carbohydrate content. However, the carbohydrate value by difference is calculated from other proximate components and therefore does not directly

represent available carbohydrates or digestible starch.

The dietary fiber content in Manggu and Pacar cassava noodles showed different patterns. In Manggu, the highest content was found in Formula 2 at 11.96%, followed by Formula 1 at 10.36 % and Formula 3 at 2.02 %. In Pacar, the highest content was found in Formula 1 at 11.17%, followed by Formula 2 at 8.82% and Formula 3 at 6.11%. These data indicate that Formula 2 is more prominent in Manggu, while Formula 1 is more prominent in Pacar. These differences may be influenced by the composition of the ingredients, the characteristics of the cassava flour, the proportion of tapioca, and changes in starch during processing. Gelatinization and retrogradation can form resistant starch, which is included in total dietary fiber (Baptista et al., 2024; Fatimah et al., 2024). Higher fiber content provides added nutritional value, but its impact on carbohydrate digestion still needs to be confirmed, as the effects of fiber are influenced by the type, viscosity, quantity, and structure of the food matrix (Tsitsou et al., 2023).

3.3 Multivariate Analysis

Principal Component Analysis (PCA) was carried out to understand the complex relationships between the proximate, physical, and textural characteristics of two cassava noodle formulations, namely Manggu cassava noodles and Pacar cassava noodles. The resulting PCA biplot (Figure 3) shows successfully extracted two principal components that define the data structure: PC1, which accounts for 43.28 %, and PC2, which accounts for 28.20 %. Collectively, these two axes account for 71.48 % of the total variability in the test. This cumulative variance indicates that these two components successfully capture a very substantial proportion of the overall data variance, meaning that the two-dimensional representation in this biplot is highly adequate for explaining the diversity of the sample characteristics. Measurements such as carbohydrate content, fiber, moisture content, and rheological properties can be summarized into principal components that reveal significant relationships between these variables, thereby facilitating a deeper understanding of the characteristics of the final product(Valinger et al., 2021).

The biplot analysis shows a clear separation between the two types of cassava noodles based on the first principal component (PC1). The Manggu cassava noodle samples are concentrated in the left quadrant (negative PC1), while the Pacar cassava noodle samples tend to be positioned in the right quadrant (positive PC1). This separation pattern indicates that, along PC2, Pacar cassava noodles are more concentrated in the upper part of the graph, demonstrating different characteristics compared to Manggu cassava noodles, which are more widely distributed in the lower part. This suggests that the differences between these two types of noodles are evident in the variations in their proximate composition and the physical characteristics measured.

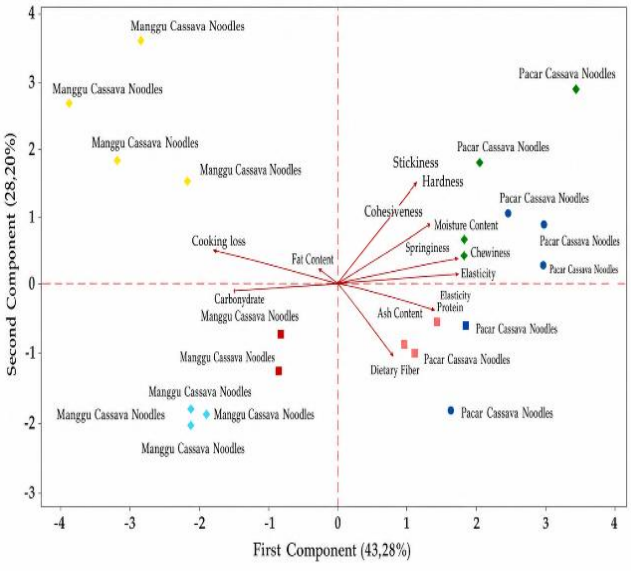


Figure 3. Biplot results for the physico-chemical characteristics of cassava noodles

The contribution of each variable to the formation of the principal components can be explicitly evaluated via the loadings. The PC1 axis is strongly influenced by the chewiness parameter, with a loading of 0.411, followed by protein content (0.358)

and elasticity (0.352) in the positive direction. Conversely, PC1 shows a fairly strong negative correlation with cooking loss (-0.428) and carbohydrate content (-0.337). Meanwhile, the PC2 axis is specifically dominated by the stickiness attribute, with the highest loading of 0.459, followed by hardness at 0.437 and 'moisture content' at 0.231 on the positive pole. The negative pole of PC2 is governed by the dietary fibre variable (-0.443) and ash content (-0.422).

The interpretation of the variable vectors on the biplot provides important information regarding the relationships between the parameters under investigation. The moisture content vectors are clearly clustered very closely together and form narrow acute angles with the elasticity, stickiness and hardness parameters. The spatial proximity between these vectors provides a mechanistic indication that water retention within the dough matrix is closely related to the formation of a dense noodle texture profile. This suggests that noodles with a high level of hardness also tend to have high levels of flexibility, stickiness and elasticity. This phenomenon can be explained by the crucial interaction between proteins and starch. Gelatinised starch forms an interwoven structure with the proteins, resulting in a final product with improved texture and elasticity (Chamorro et al., 2025).

On the opposite side (left quadrant), the vectors for cooking loss and carbohydrate content move in the same direction and are the main distinguishing features of the Manggu noodle sample group. This cooking loss vector forms an obtuse angle (approaching 180°) with the texture parameter cluster in the right quadrant, confirming the presence of an extreme negative correlation. From a physicochemical perspective, this phenomenon indicates that noodles with a high cooking loss tend to have a weak matrix density and are prone to disintegration. The high release of solids in this Manggu variety is most likely triggered by the weakening of the starch network due to excessive granule swelling during boiling, causing the amylose fraction to be released and dissolved into the cooking water (Luca et al., 2025; J. Wang et al., 2021).

This PCA analysis provides a solid basis for further product development by identifying the critical parameters that distinguish the varieties of flour used and the optimal formulation based on the ratio of cassava flour to tapioca flour. Optimization of the Manggu cassava noodles formulation can focus on reducing cooking loss through starch modification, the addition of hydrocolloids such as carrageenan, or adjustments to extrusion conditions to strengthen the starch-protein network structure. This approach is expected to result in cassava noodles with optimal textural quality and minimal cooking loss, thereby enhancing consumer acceptance and the commercial value of the product.

4. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The physicochemical properties of cassava noodles depend heavily on the specific cassava variety and the ratio in which it is blended with tapioca flour. Noodles formulated with Pacar variety cassava flour exhibit superior textural characteristics, particularly in terms of firmness, flexibility, chewiness and elasticity, which collectively result in a denser and more durable noodle matrix. Conversely, formulations using Manggu variety cassava flour exhibited greater loss during cooking and higher moisture content, indicating a less stable structure during the boiling process. From a chemical perspective, whilst all samples met the required moisture standards for dried noodles and contained dietary fibre, their protein levels consistently fell short of the quality requirements for instant noodles. Furthermore, Principal Component Analysis (PCA) clearly distinguished the samples based on these combined variables, accounting for 71.48% of the total data variance. Overall, this study confirms that cassava noodles hold promising potential as an alternative to wheat-based noodles.

Recommendations

Future research should focus on efforts to minimise nutrient loss during the cooking process and optimise the ratio of cassava to tapioca for each specific variety. Additionally, the addition of local protein sources to the formulation is essential to address the low protein content. Finally, to validate these findings for commercial application, further research should include sensory evaluation, protein digestibility assessment, and shelf-life testing on a pilot scale.

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