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Enhancing Indonesian Konnyaku Quality: A Process Optimization Approach

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Abstract:

Konnyaku, a traditional Japanese food made from the porang tuber (Amorphophallus konjac), is known for its unique texture and health benefits. Despite its growing popularity, limited research has optimized the processing conditions for producing high-quality konnyaku, particularly regarding its physical and organoleptic properties. This study addresses this gap by investigating the effects of boiling temperature, boiling time, and water-to-porang (W/P) ratio on the hardness and sensory attributes (taste, color, and texture) of konnyaku. A factorial experimental design was used, and data were analyzed using Multivariate Analysis of Variance (MANOVA) and Analysis of Variance (ANOVA). The results showed that the optimal processing conditions for the highest sensory acceptance and hardness were a boiling temperature of 100°C, a boiling time of 30 minutes, and a W/P ratio of 1:4, yielding a hardness of 1788.26 g-force. All three factors significantly impacted the organoleptic properties, with distinct interactions observed between the parameters. This study provides critical insights for enhancing konnyaku production and contributes to the sustainable development of the porang industry by promoting efficient local processing techniques.

Keywords: Konnyaku, porang, boiling temperature, boiling time, W/P ratio, organoleptic properties.

Introduction:

Konjac (*Amorphophallus konjac*) is a well-known plant, particularly in Japan, and belongs to the Amorphophallus genus. This plant is widely distributed across tropical and subtropical regions, including Africa and the Pacific Islands, and has extended to temperate countries like China and Japan [1]. In Indonesia, a closely related species, *Amorphophallus onchophyllus*, commonly referred to as porang, has gained increasing attention due to its economic and agricultural potential. Porang is valued primarily for its carbohydrate content, including starch, glucomannan, crude fiber, and various sugars. It has diverse applications, both in food and non-food industries, such as adhesives, waterproof coatings, tablet fillers, thickeners, and cosmetics.

Japan has become the primary destination for porang exports, with export volumes consistently rising annually [1,2]. In Japan, porang is processed into products like flour and jelly, which are then further refined into foods such as konnyaku and shirataki. However, the Indonesian government, through the Regulation of the Minister of Trade Number 18 of 2021, has imposed a ban on the export of raw porang tubers. The government aims to encourage domestic processing of porang into semi-finished or finished products, thereby increasing added value within the country. This policy supports the sustainability of the porang industry by promoting local processing and advancing technological expertise in porang utilization.

According to the Decree of the Minister of Agriculture Number 104/KPTS/HK.140/M/2/2020, porang is classified as one of the priority commodities under the Directorate General of Food Crops, which emphasizes its importance for national development. The government's involvement, not only through regulation but also as a key stakeholder, underscores the significance of porang in the national economy.

Sustainability, which consists of three key pillars—economic, social, and environmental—plays a crucial role in the future of the porang industry [5]. In the context of sustainable agriculture, these pillars translate to maintaining ecological stability, productivity, and profitability [12]. To ensure the long-term viability of porang, its trade must provide economic benefits across the supply chain. Exporting porang in its raw tuber form often leads to price instability, causing financial losses for farmers. Therefore, value-added processing before exporting is essential to stabilize prices and improve profitability. Additionally, the environmental impact of unutilized tubers, which can rot and contribute to food loss, highlights the urgency of processing porang efficiently [23].

Porang tubers have a short shelf life due to their vulnerability to rot, necessitating prompt processing [19]. One of the notable products derived from porang is konnyaku, which is well known in Japan and resembles tofu in texture, often referred to as "porang tofu" in Indonesia [6]. The konnyaku is a highly nutritious food, containing high fiber, low calories, and no fat, as 97% of its composition is water, with the remaining 3% being glucomannan [17]. Its health benefits, especially in weight management and the prevention of obesity, have made it a popular dietary choice.

However, challenges remain in the safe processing of porang, particularly concerning chemical contaminants. Porang tubers contain oxalate compounds, specifically oxalic acid and calcium oxalate, which can cause skin irritation, itching, and even more severe health issues such as kidney problems and reduced calcium absorption if consumed without proper processing [4]. Several studies have explored methods to reduce oxalate content in porang. For example, Widari and Rasmito [20] reported a 90.9% reduction in calcium oxalate levels after boiling porang tubers at 80°C for 25 minutes in a solution containing 8% NaCl. Similarly, Widjanarko and Khairunnisa [21] found that soaking tubers in a 15% salt solution for 89.2 minutes effectively lowered oxalate levels to 0.097.

Research on porang processing continues to evolve, with studies investigating its use in various food products. For instance, Anwar et al. [7] used porang flour as a stabilizer in oil-in-water emulsions and as a coating agent for fish oil microcapsules. Wahyuni et al. [18] explored porang's potential in chip production, while Lufiana et al. [9] examined its use as a binding agent in processed meatballs. Additionally, Nuhriawangsa et al. [10] utilized porang flour in sausage production, and Wilianto et al. [22] developed a porang-based rice substitute for blood sugar control .

Despite extensive research on porang, there is a notable gap regarding the optimization of porang processing into konnyaku. As konnyaku is a highly regarded traditional Japanese health food, further investigation into the factors influencing its production is crucial. This research aims to identify the optimal combination of factors—specifically temperature, boiling time, and water composition—that affect the physical and sensory properties of konnyaku. Previous studies suggest that these factors significantly influence the characteristics of porang flour [17, 18, 19]. In this study, the Multivariate Analysis of Variance (MANOVA) method will be used to determine the most appropriate factors and their levels in the konnyaku-making process, with a focus on physical and sensory properties [8].

Methods:

1. Pre-experiment Procedure

The study began with a pre-experiment phase aimed at standardizing the ingredients and the production process of konnyaku. This research used Indonesian Konjac (porang) as the sample. The production process of konnyaku begins with cleaning, peeling, and slicing the porang tuber into pieces with a thickness of 0.5 - 1 cm. Next, the boiled porang is ground with water in proportions according to the experimental conditions. The ground mixture is then cooled before being combined with calcium hydroxide and water. The resulting dough is then molded and boiled again at the temperature and duration specified by the experimental conditions.

The pre-experiment helped identify key parameters, such as the amount of porang tuber required, boiling time, grinding time, and water ratio during grinding. Additionally, it assisted in determining the factors and levels to be used in the main experiment, while also minimizing potential experimental errors. A crucial outcome of the pre-experiment was the assessment of oxalic acid content in the konnyaku produced, to prevent potential adverse effects associated with oxalic acid consumption. Fig. 1 shows the conceptual model of this study based on the pre-experiment.

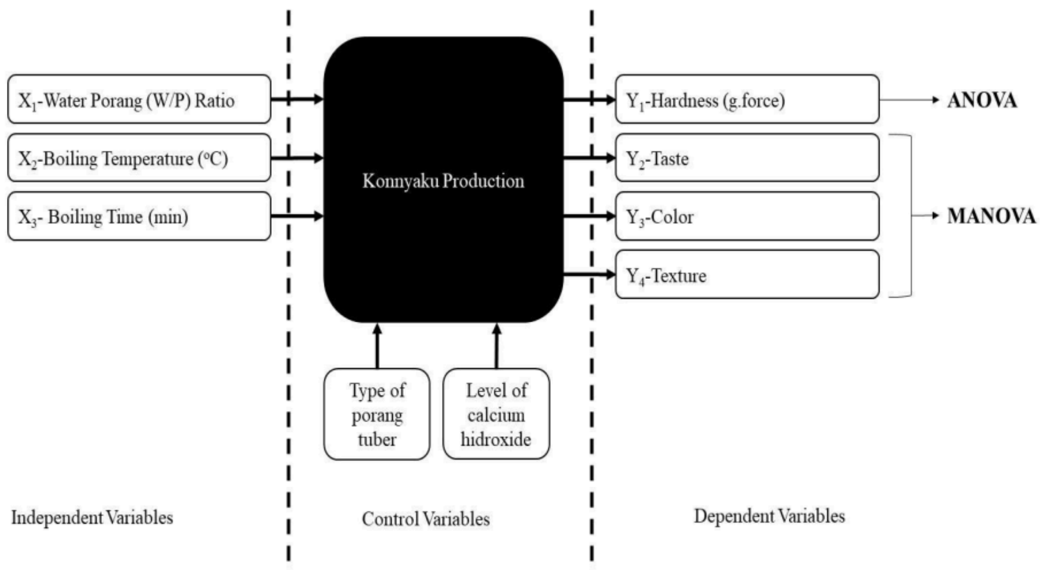

Fig. 1 The Conceptual Model

2. Experimental Design

The main experiment was designed as a factorial experiment, which allowed for the examination of the interaction between multiple factors. Factorial designs are useful in simultaneously investigating the effects of different experimental variables. The factors and their respective levels used in this experiment are presented in Table 1. Each treatment was replicated three times for the independent variable Y_1 (hardness). Data obtained were analyzed using analysis of variance (ANOVA).

Table 1. The Design Experiment

Factor	Level
X_1-W/P Ratio (by mass)	1:4
	1:8
X_2-Boiling Temperature	80°C
	100°C
X_3-Boiling Time	10min
	30min

3. Hardness Measurement

The hardness of the konnyaku samples was measured using a texture analyzer model TA.TX plus Texture Analyzer. Konnyaku samples were cut into 1 cm thick pieces for testing. The texture analyzer was set to the following parameters:

- Pre-test speed: 1 mm/s
- Test speed: 2 mm/s
- Post-test speed: 10 mm/s
- Target mode: distance
- Distance: 8 mm
- Trigger force: 25 g
- Probe: P 25

The results from the texture analyzer were then analyzed using ANOVA in Software Minitab 19 to evaluate the effects of the different treatments on konnyaku hardness.

4. Organoleptic Testing

To assess Y_2 (taste), Y_3 (color), and Y_4 (texture), organoleptic tests were conducted. Organoleptic evaluation is a sensory analysis method, where human senses are used as primary tools for product quality assessment. In this study, 30 non-expert panelists participated in the organoleptic tests. The panelists were selected based on general preference criteria, and inclusion requirements included good health, no color blindness, and no allergies to the test product. The test followed these steps:

1. Panelists were asked about their willingness to participate and their health condition.
2. Each panelist was given a questionnaire and instructions on how to fill it out.
3. Eight coded samples of equal size (minimum 2x2 cm) and quality were presented to avoid bias in the assessments.
4. Panelists were asked to evaluate the color, taste, and texture of the samples and record their preferences on a scale of 1 (lowest) to 9 (highest) on the provided questionnaire.
5. Between tasting each sample, panelists drank water to cleanse their palate.
6. After completing the sensory evaluation, the panelists submitted their questionnaires.

5. Data Analysis

The experimental data were analyzed using Multivariate Analysis of Variance (MANOVA) to identify significant factors and interactions that influenced the physical and sensory properties of konnyaku. The results were then interpreted and discussed based on statistical outcomes.

Results:

Texture Analyzer

Table 2 demonstrates the effects of varying water-to-porang (W/P) ratios, boiling temperatures, and boiling times on hardness, measured in g-force. Results indicate that higher boiling temperatures (100°C) generally reduce hardness, particularly with shorter boiling times (10 minutes). Additionally, samples with a W/P ratio of 1:8 and longer boiling times (30 minutes) tend to show higher hardness values, as seen in treatment 6, which yielded the highest hardness of 2569.878 g-force.

Table 2 The effect of varying level and factors in hardness measurement

Treatment			Replication	Hardness (g-force)
1	X_1-W/P Ratio	1:4	1	1345.093
	X_2-Boiling Temperature	80°C	2	1328.585
	X_3-Boiling Time	30min	3	1333.447
2	X_1-W/P Ratio	1:4	1	2060.38
	X_2-Boiling Temperature	80°C	2	2163.614
	X_3-Boiling Time	10min	3	2213.818
3	X_1-W/P Ratio	1:4	1	1573.383
	X_2-Boiling Temperature	100°C	2	1522.841
	X_3-Boiling Time	10min	3	1294.776
4	X_1-W/P Ratio	1:4	1	1807.214
	X_2-Boiling Temperature	100°C	2	1891.905
	X_3-Boiling Time	30 minutes	3	1665.649
5	X_1-W/P Ratio	1:8	1	1068.069
	X_2-Boiling Temperature	80°C	2	1129.467
	X_3-Boiling Time	10 minutes	3	1186.454
6	X_1-W/P Ratio	1:8	1	2138.173
	X_2-Boiling Temperature	80°C	2	2505.202
	X_3-Boiling Time	30 minutes	3	2569.878
7	X_1-W/P Ratio	1:8	1	1432.61
	X_2-Boiling Temperature	100°C	2	1300.882
	X_3-Boiling Time	10 minutes	3	1391.452
8	X_1-W/P Ratio	1:8	1	1391.452
	X_2-Boiling Temperature	100°C	2	1328.585
	X_3-Boiling Time	30 minutes	3	1478.404

Table 3 ANOVA Results for Hardness Measurement

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		1634.4	23.3	70.25	0.000	
X_1-W/P Ratio	-255.5	-127.8	23.3	-5.49	0.000	1.00
X_3-Boiling Time	195.2	97.6	23.3	4.20	0.001	1.00
X_1-W/P Ratio	115.3	57.6	23.3	2.48	0.025	1.00
X_2-Boiling Temperature * X_3-Boiling Time	-20.7	-10.3	23.3	-0.44	0.663	1.00
X_2-Boiling Temperature * X_1-W/P Ratio	123.5	61.7	23.3	2.65	0.017	1.00
X_3-Boiling Time * X_1-W/P Ratio	-455.2	-227.6	23.3	-9.78	0.000	1.00
X_2-Boiling Temperature * X_3-Boiling Time * X_1-W/P Ratio	605.3	302.6	23.3	13.01	0.000	1.00

The ANOVA results presented in Table 3 indicate that the P-values for X_1-W/P Ratio (both instances), X_3-Boiling Time, X_2-Boiling Temperature * X_1-W/P Ratio, X_3-Boiling Time * X_1-W/P Ratio, and the three-way interaction are all less than 0.05, indicating significant effects on konnyaku hardness. This is supported by the high t-values (e.g., 13.01, -9.78), which reflect strong and practically significant effects, likely corresponding to large effect sizes in terms of explaining variance in the dependent variable. Conversely, the interaction between X_2-Boiling Temperature and X_3-Boiling Time (p-value = 0.663) was not significant. The t-value of -0.44, which is very small (close to 0), confirm that it is not a meaningful relationship. This is further supported by the interaction plot in Fig. 3, where the parallel lines between boiling temperature and boiling time indicate no interaction. While, the non-parallel lines between W/P ratio and the other factors suggest significant interactions.

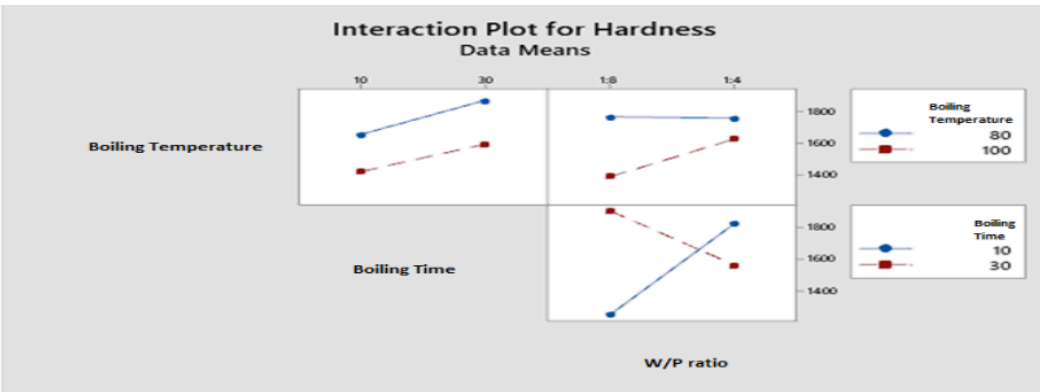

Fig. 3. Interaction Plot for Hardness

Organoleptic Test

The organoleptic tests were conducted using a preference test method, where panelists rated their liking of the tested material. The panelists, categorized as untrained/non-standard, provided their assessments on a scale from one (lowest) to nine (highest) using an evaluation sheet. A total of 30 panelists participated, in accordance with SNI standards for organoleptic testing. The dependent variables for the konnyaku tested included taste, color, and texture.

The results showed that the average taste preference scores ranged from 4.47 to 6.77. indicating a range between slightly dislike and like. The color preference scores averaged between 4.97 and 6.13, corresponding to somewhat dislike to somewhat like, while the texture preference scores ranged from 4.87 to 6.77, also between somewhat dislike and like. The graphical representation of these average preference scores across treatments is presented in Fig. 4.

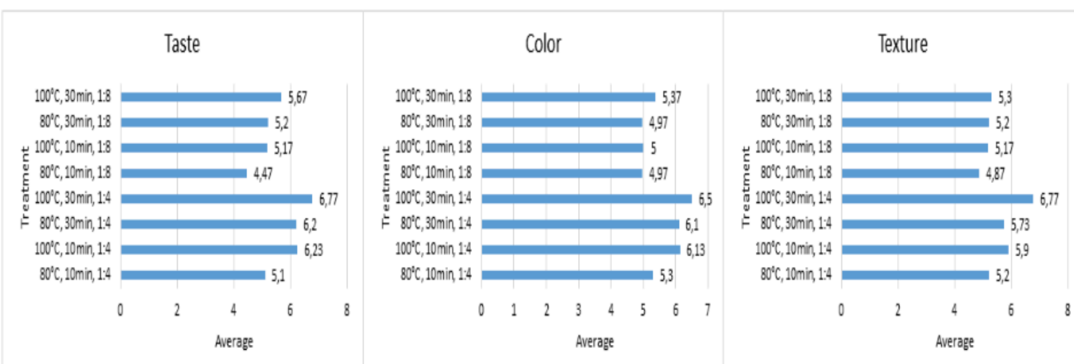

Fig. 4 The Average Preference Scores of Organoleptic Test for Taste. Color. and Texture of Konnyaku

Table 5 MANOVA Results of Organoleptic Test

MANOVA Tests for	Criterion	P-value
X_1-W/P Ratio	Wilks'	0.000
	Lawley-Hotelling	0.000
	Pillai's	0.000
X_2-Boiling Temperature	Wilks'	0.000
	Lawley-Hotelling	0.000
	Pillai's	0.000
X_3-Boiling Time	Wilks'	0.000
	Lawley-Hotelling	0.000
	Pillai's	0.000

The MANOVA results from the Wilks', Lawley-Hotteling, and Pillai's tests consistently indicated that the P-value was less than the α threshold (0.05). Therefore, it can be concluded that X_2-Boiling Temperature, X_3-Boiling Time, and X_1-W/P Ratio significantly affect the preference scores for Y_2-Taste, Y_3-Color, and Y_4-Texture of konnyaku. The p-value that is extremely close to zero could be the result of rounding in the software, but it also suggests strong effects in the model.

Following this, ANOVA was conducted to further analyze the specific impact of each independent variable on the dependent variables. A summary of these results is presented in Table 6, showing that X_1-W/P Ratio, X_2-Boiling Temperature, and X_3-Boiling Time individually influence Y_2-Taste, Y_3-Color, and Y_4-Texture. However, interactions between variables do not show significant effects, except for the interaction between X_2-Boiling Temperature and X_1-W/P Ratio, which significantly influences Y_4-Texture.

Table 6 ANOVA Results for Organoleptic Test

Source	P-Value					
	Y_2-Taste	Remarks	Y_3-Colour	Remarks	Y_4-Texture	Remarks
X_1-W/P Ratio	0.000	Significant	0.000	Significant	0.000	Significant
X_2-Boiling Temperature	0.000	Significant	0.004	Significant	0.000	Significant
X_3-Boiling Time	0.000	Significant	0.008	Significant	0.001	Significant
X_2-Boiling Temperature * X_3-Boiling Time	0.132	Insignificant	0.908	Insignificant	0.819	Insignificant
X_2-Boiling Temperature * X_1-W/P Ratio	0.314	Insignificant	0.166	Insignificant	0.023	Significant
X_3-Boiling Time * X_1-W/P Ratio	0.450	Insignificant	0.166	Insignificant	0.109	Insignificant
X_2-Boiling Temperature * X_3-Boiling Time * X_1-W/P Ratio	0.529	Insignificant	0.166	Insignificant	0.359	Insignificant

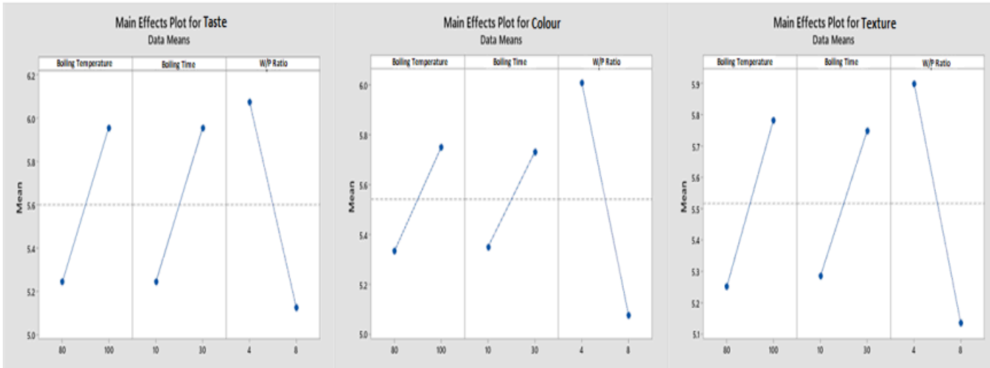

Fig. 5 Graph of the Effects of Boiling Temperature. Time. and W/P Ratio on Taste Preference Scores

Fig. 5 highlights that the highest average taste preference score (5.95833) was recorded at the longest boiling time of 30 minutes, while the lowest (5.24167) occurred at 10 minutes. Similarly, a W/P ratio of 1:4 resulted in the highest taste preference score (6.075), with the lowest (5.125) observed at a ratio of 1:8. Regarding color preference, the highest average score (5.73333) was achieved after 30 minutes of boiling, with a lower value (5.35) recorded at 10 minutes. The W/P ratio also impacted the color preference, with a ratio of 1:4 yielding the highest value (6.00833), while a ratio of 1:8 resulted in the lowest score (5.075). Lastly, texture preference peaked at a boiling time of 30 minutes (5.75), with the lowest recorded score at 10 minutes (5.28333). The W/P ratio of 1:4 produced the highest texture preference (5.9), while the ratio of 1:8 yielded the lowest (5.13333).

Discussion:

The analysis was conducted to assess the panelists' acceptance of the color, taste, and texture preferences from the organoleptic test of konnyaku's hardness. The spider web method was employed to identify the best treatment across the three organoleptic parameters—color, taste, and texture. This method selects the optimal hardness based on the area formed in the spider web graph, where the largest value and proximity to the outer edge of the graph indicate the best treatment. As noted by Santosa et al. [13] , the most favorable treatment is the one that creates the largest area closest to the outer edge of the spider web graph. Fig. 6 illustrates the spider web graph used in this evaluation.

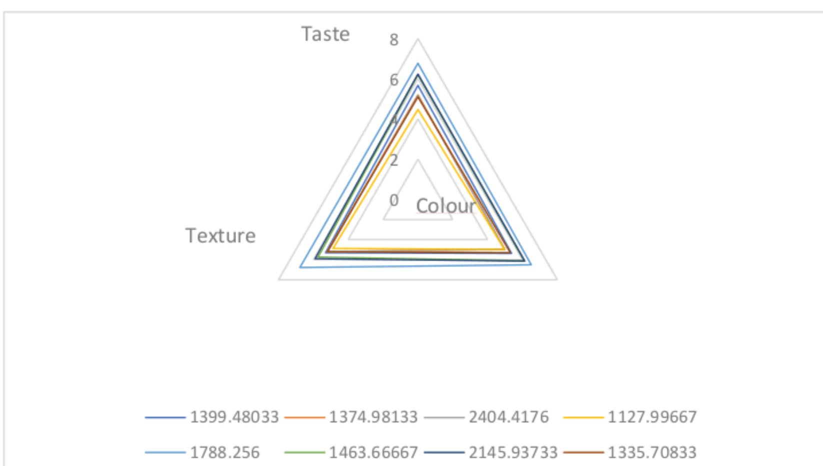

Fig. 6 Spider Web Graph of Texture Evaluation from the Organoleptic Test of Konnyaku

The area calculations presented in Table 6 show that the treatment with the best hardness, based on the panelists' acceptance, is the combination of a boiling temperature of 100°C, a boiling time of 30 minutes, and a W/P ratio of 1:4. The sample with this combination (1:4, 100°C, 30 minutes) achieved mean preference scores of 6.77 for taste. 6.5 for color. and 6.77 for texture.

Table 6 Area Calculation Results from the Spider Web Analysis

Hardness	Area
1127.997	21.9924
1335.708	26.775
1374.981	26.442
1399.48	30.24945
1463.667	36.673
1788.256	44.91895
2145.937	37.47345
2404.418	26.28945

Consumers generally prefer konnyaku with a chewy yet soft texture, which offers a balance between density and softness, providing a pleasant mouthfeel and ease of chewing. Konnyaku itself has a neutral flavor, absorbing the taste of the sauces or broths it is prepared with, making it a versatile ingredient in various dishes, especially in Japanese cuisine [15]. Additionally, consumers tend to favor bright white konnyaku over yellow varieties [16].

Conclusion:

This study aimed to investigate the effects of boiling temperature, boiling time, and water content on the hardness and organoleptic properties (taste, color, and texture) of konnyaku. The findings demonstrate that these factors significantly influence the final product's quality. Specifically, the optimal combination for achieving the best organoleptic properties and hardness was identified as a boiling temperature of 100°C, a boiling time of 30 minutes, and a water-to-porang ratio of 1:4, resulting in a hardness of 1788.26 g-force.

In line with the research objectives, the one-way analysis revealed that all three factors individually affect hardness, taste, color, and texture. The two-way interaction showed that boiling temperature and water content influenced hardness and texture, while boiling time and water content impacted hardness. Moreover, the three-way interaction of these factors also significantly affected the hardness of konnyaku. These findings provide valuable insights into optimizing the production process of konnyaku to achieve desired quality characteristics.

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