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Physical and Chemical Characteristics of Modified Sweet Potato Flour (*Ipomoea batatas (L.) Lam*) Based on Fermentation Duration and Yeast Concentration

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***Abstract*— The high consumption of wheat-based products in Indonesia has encouraged the development of local flour alternatives. This study aimed to modify honey sweet potato flour through fermentation using *tapai* yeast and to evaluate how fermentation duration and yeast concentration affect its physicochemical and functional characteristics. This study employed a Split-Plot Design with a Factorial Randomized Block Design as the control design. It consisted of two factors and two repetitions. The results showed that the modification significantly improved the quality of the flour: the whiteness degree increased from 73.80 to 83.72. At the same time, the moisture content decreased from 11.49% to 7.60%, aligning with the Indonesian National Standard (SNI 7622:2011). The fermentation also reduced ash content (from 2.10% to 0.58%) and pH (from 5.55 to 3.97) while enhancing amylose levels (up to 29.88%), indicating starch restructuring and improved flour purity. Morphological analysis revealed that starch granules changed from smooth and compact to porous and irregular, enhancing the water-holding capacity (276.83%) and reducing viscosity (135.00 cP). The best treatment, 36-hour fermentation with 5% *tapai* yeast, produced stable flour with desirable swelling power and functional properties, suggesting potential for bakery and noodle applications.**

***Keywords*— Fermentation duration; Honey sweet potato flour modification; *Tapai* yeast**

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I. INTRODUCTION

As the Indonesian lifestyle increasingly shifts towards consuming ready-to-eat food products such as noodles, bread, cakes, and biscuits, the national demand for wheat flour has also risen. This demand continues to increase annually, resulting in wheat imports reaching 10.287 million tons in 2022, an 8.6% increase from the previous year [1]. The Indonesian Wheat Flour Producers Association (APTINDO) reported that consumption of wheat-flour-based products reached 6.7 million tons, averaging 500,000 tons per month in 2022 [2]. Therefore, alternative local raw materials are needed as substitutes, such as honey and sweet potato.

Honey sweet potato (*Ipomoea batatas (L.) Lam*) is a local plant widely found in West Java Province, Indonesia. Its sweet taste and chewy texture make it popular among both farmers and consumers [3]. In addition to its favorable taste, this sweet potato is nutritionally rich, containing carbohydrates as the dominant macronutrient, along with significant levels of starch, protein, and dietary fibre [4]. Given its high carbohydrate and starch content, this tuber has potential as a raw material for flour production. However, flour derived from this sweet potato is reported to have limitations, including a musty odor, browning during drying, and low functional properties, such as swelling power. Recent studies show that fermentation can significantly improve the nutritional composition and sensory qualities of sweet potato-based materials. For instance, microbial fermentation has been shown to increase protein, soluble

dietary fiber, phenolics, and antioxidant activity [5], while also enhancing flavor profiles and reducing undesirable characteristics [6]. In particular, the browning that occurs during drying, whether through enzymatic oxidation of phenolic compounds or non-enzymatic Maillard reactions, has been identified as a key quality-degradation factor in sweet potato flour, affecting its visual and sensory acceptability [7]. Therefore, modification through fermentation is necessary to enhance its characteristics, making it more suitable for broader applications in the food industry.

The development of modified flours through fermentation, such as mocaf, continues to be explored to reduce reliance on wheat flour and support local food product innovation. Several studies have shown that fermentation duration and *tapai* yeast concentration influence the characteristics of the resulting flour. Bolaji et al. [8] demonstrated that fermentation alters moisture content, reduces ash and starch levels, and improves functional properties such as water absorption in cassava-based flours. Similarly, Velly et al. [9] stated that longer fermentation reduces ash content, starch, aroma, and pH while increasing swelling power. In another study, Fiqtinovri [10] found that adding 2.5% *tapai* yeast in the production of MSG flour (Mocaf Singkong Gajah) met the Indonesian National Standard (SNI) for wheat flour in terms of moisture and ash content. Based on these findings, this study aims to examine the effects of fermentation duration and *tapai* yeast concentration on the characteristics of modified honey sweet potato flour and to determine the optimal treatment using the Zeleny method and functional property analysis.

II. Material and Methods

A. Material

This study utilized various equipment, materials, and chemicals to conduct the research effectively. The equipment used in this study included a cabinet dryer, slicing machine, blender (Philips), 100-mesh sieve, ColorFlex EZ colorimeter (HunterLab), furnace, pH meter, binocular microscope, oven model UN55 (Memmert), UV-Vis spectrophotometer, aluminium crucibles, and a set of glassware. Meanwhile, the primary materials included five-month-old honey sweet potatoes gathered from Cilembu Village, Pamulihan District, Sumedang Regency, West Java Province, and NKL (Na Kok Liong) *tapai* yeast. The chemicals used included water, distilled water, NaOH, HCl, pH 4 and pH 5 buffer solutions, 95% ethanol, CH_3COOH, and potassium iodide (KI).

B. Methods

This study employed a Split-Plot Factorial Randomized Block Design with two factors: fermentation duration (12, 24, 36 h) as the main plot and *tapai* yeast concentration (1.25%, 2.5%, 3.75%, 5%) as the sub-plot. Each treatment combination was replicated twice, resulting in 24 experimental units. An unfermented honey sweet potato flour sample was used as the control. Data were analyzed using two-way ANOVA (α = 5% and 1%) to assess main and interaction effects, followed by Tukey's HSD test (α = 5%) for mean separation.

C. Research Procedures

The modified honey-sweet potato flour was produced according to the study by Fatmah et al. [11], with adjustments to the fermentation mixture and sieve size. Fresh honey sweet potatoes were washed under running water, peeled, and sliced into approximately 2 mm thick pieces. The slices were then fermented for three different durations of 12, 24, and 36 hours. Before fermentation, *tapai* yeast was dissolved in warm water maintained at 35 ± 2 °C to activate the yeast culture and enhance enzymatic activity during the soaking process. The slices were then soaked in the yeast solution at concentrations of 1.25%, 2.5%, 3.75%, and 5%. Fermentation was carried out at ambient room temperature (27 ± 2 °C) without external temperature regulation, reflecting the natural *tapai* fermentation conditions commonly applied in small-scale food processing. After fermentation, the slices were washed twice, manually pressed, and soaked in a 5% NaCl solution. Finally, they were dried in a cabinet dryer at 60 °C for 6 hours, ground in a blender, and sieved through a 100-mesh sieve to obtain fine flour.

D. Observation Parameters

Physical characterization of the modified honey sweet potato flour was carried out through several parameters, such as yield [12], whiteness degree [13], pH [14], viscosity [15], starch granule morphology [15], moisture content [15], ash content [15], starch content [15], amylose content [16] and amylopectin content [17].

The best sample was selected using the multiple-attribute Zeleny (compromise programming) method [18], based on test parameters that influenced the final results and prioritizing treatments with the lowest L_1, L_2, and $L\infty$ metric distances from the ideal solution. This method evaluated the sample's functional properties, including syneresis using the freeze-thaw method [19], solubility by comparing the dry sediment weight to the sample weight [20], water holding capacity (WHC) by calculating the percentage of absorbed water relative to the sample weight % [21], swelling power by comparing the paste weight to the sample weight, and oil holding capacity (OHC) following the method of Diniyah et al. [22].

III. Result and Discussion

E. Yield

The first parameter reported in this study is yield. Yield was determined by measuring the weight of the raw material (peeled fresh sweet potatoes and chips) and the final weight of the resulting flour. In this study, the analysis of variance (ANOVA) showed that fermentation duration, *tapai* yeast concentration, and their interaction significantly affected the yield of modified honey sweet potato flour ($P<0.05$). As shown in **Table 1**, the average yield obtained ranged from 18.04% to 23.71%, which is lower than the 28.80% yield reported in a previous study on fermented sweet potato flour supplemented with fishmeal [23]. This difference is likely due to the softer texture of honey sweet

potatoes, making them more prone to loss during washing. Belkacemi [24] emphasized that blanching and peeling significantly influence flour properties due to the leaching of water-soluble components. Likewise, Ezeoha et al. [25] demonstrated that thinner chip slices result in greater nutrient loss and reduced moisture, ultimately decreasing the final flour yield.

Prolonged fermentation duration and increased *tapai* yeast concentration enhance microbial and enzymatic activity, which, in turn, promote the leaching of soluble solids and the degradation of cell-wall polysaccharides—ultimately reducing the final flour yield. A similar trend was observed by Nainggolan [26], who reported that extended *Rhizopus oryzae* fermentation led to lower flour recovery due to starch granule degradation and the release of intracellular contents into the soaking medium. Furthermore, Sama et al. [27] emphasized that fermentation methods significantly influence fufu yield from cassava, noting that prolonged fermentation promotes enzymatic hydrolysis and structural softening, which causes dry matter loss. Their study demonstrates that enzymatic activity during lactic acid fermentation disrupts starch–fibre complexes, thereby reducing extraction efficiency. Likewise, Yuliana et al. [28] observed that spontaneous fermentation of orange-fleshed sweet potato flour altered its functional and physical characteristics through microbial modification, including polysaccharide degradation and solubilization. These biochemical processes, driven by endogenous and microbial enzymes such as amylases and cellulases, perforate starch granules and compromise cell wall integrity, explaining the observed decline in flour yield over time.

TABLE 1
YIELD (%) OF MODIFIED HONEY SWEET POTATO FLOUR BASED ON FERMENTATION DURATION AND *TAPAI* YEAST CONCENTRATION

Fermentation Duration (S)	***Tapai* Yeast Concentration (T)**				**Average**
	1.25% (T1)	**2.5% (T2)**	**3.75% (T3)**	**5% (T4)**	
12 hours (S1)	20.60 ± 0.56^{abc}	20.90 ± 1.55^{abc}	23.71 ± 0.42^{a}	22.28 ± 0.23^{ab}	21.87^{C}
24 hours (S2)	22.15 ± 0.77^{ab}	22.09 ± 0.22^{ab}	20.69 ± 0.18^{abc}	18.04 ± 0.82^{c}	20.74^{B}
36 hours (S3)	19.40 ± 0.53^{bc}	18.80 ± 0.37^{c}	18.29 ± 0.61^{c}	17.91 ± 1.52^{c}	18.60^{A}
Average	20.72^{PQ}	20.59^{PQ}	20.90^{Q}	19.41^{P}	20.40

Note: Numbers followed by different letters in the same column or row indicate a significant difference based on the Tukey HSD test at a 5% significance level.

Similarly, an increase in *tapai* yeast concentration also contributes to a decline in the yield of modified honey sweet potato flour. This decreasing trend is evident in the T4 treatment, which had the lowest yield. Meanwhile, the T1 treatment produced the highest yield. The yield reduction (from 20.72 % to 19.41 %) is attributed to intensified microbial metabolism and acidogenesis at higher yeast concentrations, leading to greater starch hydrolysis and the diffusion of soluble carbohydrates into the fermenting medium [29]. Comparable enzymatic and acid-driven hydrolysis has been reported in cassava and yam fermentations, reinforcing that the honey sweet potato exhibits a similar physiological response under prolonged fermentation stress

F. Whiteness Degree

The following parameter evaluated was the whiteness degree, measured using a chromameter based on the Hunter L*, a*, and b* color systems. This parameter was analyzed to identify changes in the brightness of modified honey sweet potato flour during fermentation. In this study, the average whiteness degree ranged from 73.80 to 83.72 (see **Table 2**). This result does not meet the SNI 7622-2011 standard for mocaf flour, which requires a minimum whiteness degree of 87 [30]. The whiteness degree in this study was also lower than that reported by Putri et al. [14], which ranged from 80.60 to 84.00. Variations in the whiteness degree of fermented flour are mainly attributed to natural pigment content, fermentation-induced acidification, and enzymatic activity of microbes that degrade phenolic and carotenoid compounds [31]. In the present study, the increase in whiteness degree was significantly affected by fermentation duration and *tapai* yeast concentration, which promoted pigment degradation and reduced browning precursors associated with chlorogenic acid. Heat- and acid-mediated oxidation reactions can further destabilize chromophore structures in carotenoids and phenolics, leading to lighter flour color [32]. This behavior aligns with Kourouma et al. [33], who observed that degradation of β-carotene and related pigments in orange-fleshed sweet potato during thermal and enzymatic treatment produced lighter hues due to oxidative cleavage of conjugated double bonds. Similarly, Menon et al. [34] reported that structural changes in sweet potato starch matrices during processing enhance pigment solubilization and diffusion, thereby reducing overall color intensity in the resulting flour.

TABLE 2
THE WHITENESS DEGREE OF MODIFIED HONEY SWEET POTATO FLOUR BASED ON FERMENTATION DURATION AND *TAPAI* YEAST CONCENTRATION

Fermentation Duration (S)	*Tapai* Yeast Concentration (T)				Average
	1.25% (T1)	2.5% (T2)	3.75% (T3)	5% (T4)	
12 hours (S1)	73.80±1.07	74.39±1.36	75.37±0.31	74.94±0.17	74.63^{C}
24 hours (S2)	81.99±0.05	81.11±0.45	81.74±0.12	82.29±0.32	81.79^{B}
36 hours (S3)	82.67±0.09	82.34±0.48	83.37±0.85	83.72±0.51	83.03^{A}
Average	79.49^{PQ}	79.28^{P}	80.16^{PQ}	80.32^{P}	79.81

Note: Numbers followed by different letters in the same column or row indicate a significant difference based on the Tukey HSD test at a 5% significance level.

The significant increase in whiteness degree ($P < 0.05$) with longer fermentation and higher yeast levels (**Figure 1**) is attributed to progressive acidification and release of pigments from cell matrices, followed by their hydrolysis and oxidative bleaching in aqueous conditions [34][35]. Carotenoids and phenolics are particularly unstable in acidic environments, where microbial enzymes, such as oxidoreductases from *Lactobacillus plantarum* and *Saccharomyces cerevisiae,* accelerate chromophore degradation [31]. A comparable oxidative mechanism was described by Zhang et al. [32] who found that heat-induced oxidation disrupted the conjugated structures of lignin chromophores, resulting in visible discoloration—a process that parallels microbial acid-enzyme bleaching during fermentation.

Fig 1. Whiteness degree of modified honey sweet potato flour (Personal documentation, 2024)

Legend:
S1 = Fermentation duration (12 hours)
S2 = Fermentation duration (24 hours)
S3 = Fermentation duration (36 hours)
T1 = Tapai yeast concentration (1.25%)
T2 = Tapai yeast concentration (2.5%)
T3 = Tapai yeast concentration (3.75%)
T4 = Tapai yeast concentration (5%)

G. Acidity Level (pH)

Acidity level (pH) serves as an important indicator of the biochemical changes occurring during fermentation and plays a key role in controlling microbial growth and sensory stability [36]. The average pH values obtained in this study ranged from 3.97 to 5.52 (**Table 3**), which is lower than the values reported in previous studies, where mocaf flour processed using the dry milling method had an acidic pH ranging from 4.75 to 6.41 [14]. Fermentation duration and *tapai* yeast concentration significantly influenced pH variation ($P < 0.05$), while the interaction between these two factors was not significant ($P > 0.05$). The gradual decrease in pH is attributed to the metabolic activity of lactic acid bacteria and yeasts that convert available carbohydrates into organic acids such as lactic, acetic, and succinic acids, thereby increasing the acidity of the flour matrix. This acid accumulation reflects the progress of glycolytic and fermentative pathways, in which microbial enzymes hydrolyze starch into simpler sugars that serve as substrates for acidogenesis [37].

The lowest pH value was found in the S3T4 treatment, with a recorded pH of 3.97, while the highest pH was observed in the S1T1 treatment, reaching 5.50 (**Table 3**). This trend indicates that longer fermentation and higher yeast concentration promote stronger acid production. Similar findings were reported by Martínez et al. [36], who observed that cassava flour fermented with Lactobacillus sp. exhibited reduced pH and enhanced sensory stability, attributed to lactic and acetic acid accumulation. Likewise, Jayanegara et al. [37] demonstrated, through a meta-analysis, that lactic acid fermentation effectively reduces cyanogenic compounds while lowering pH in fermented cassava, highlighting the detoxifying and acidifying effects of LAB metabolism. The decrease in pH during fermentation is also associated with the activity of *Lactobacillus plantarum*, *Leuconostoc mesenteroides*, *Pediococcus sp.*, and *Saccharomyces cerevisiae*, naturally present in *tapai* yeast, which produce lactic, acetic, and succinic acids that accumulate in the substrate, lowering its pH [38] [39]**.** Aryee et al. [40] further explained that during fermentation, these microbial consortia generate volatile acids and aroma precursors through carbohydrate catabolism and acidogenesis, which not only decrease pH but also enhance the flour's flavor profile and microbiological stability. Collectively, this

microbial synergy drives both biochemical and sensory transformations in the fermented flour, linking carbohydrate hydrolysis with acid production and stabilization of functional quality [34].

TABLE 3
PH OF MODIFIED HONEY SWEET POTATO FLOUR BASED ON FERMENTATION DURATION AND *TAPAI* YEAST CONCENTRATION

Fermentation Duration (S)	*Tapai* Yeast Concentration (T)				Average
	1.25% (T1)	2.5% (T2)	3.75% (T3)	5% T4)	
12 hours (S1)	5.55±0.07	5.44±0.01	5.41±0.00	5.38±0.07	5.45^{A}
24 hours (S2)	4.40±0.00	4.31±0.04	4.25±0.01	4.21±0.01	4.29^{B}
36 hours (S3)	4.17±0.04	4.13±0.02	4.07±0.00	3.97±0.05	4.08^{C}
Average	4.70^{P}	4.63^{Q}	4.57^{QR}	4.52^{R}	4.61

Note: Numbers followed by different letters in the same column or row indicate a significant difference based on the Tukey HSD test at a 5% significance level.

H. Viscosity

Following that, the viscosity parameter results are revealed. A 2 g sample was dissolved in 400 mL of distilled water, heated, and stirred for 20 minutes on a hotplate. In this way, the viscosity was measured using a viscometer. The average viscosity obtained in this study ranged from 135.00 to 282.50 cP, as provided in **Table 4**. Among the samples, the treatment with a fermentation duration of 36 hours and a *tapai* yeast concentration of 5% (S3T4) resulted in the lowest viscosity of 135.00 cP. Meanwhile, the highest viscosity was observed in the treatment with a fermentation duration of 12 hours and a *tapai* yeast concentration of 1.25% (S1T1), reaching 282.50 cP. Viscosity requirements for mocaf flour are not specified in SNI 7622:2011. However, recent studies on modified sweet potato starch have shown that changes in the amylose and amylopectin structures significantly influence its pasting and viscosity profiles. According to Tong et al. [41], starches with higher proportions of short amylopectin chains (fa, DP 6–12) exhibit lower peak viscosity and gelatinization temperature, which supports the finding that increased fermentation duration (leading to greater amylopectin degradation) contributes to a viscosity decline. Furthermore, Lou et al. [42] demonstrated that dual modification of sweet potato starch using ultrasound-assisted nanoprecipitation and OSA esterification significantly altered starch granule morphology, reduced swelling power, and decreased paste viscosity. These findings support the notion that structural changes during fermentation and chemical modification contribute to viscosity reduction in starch-based products.

TABLE 4
VISCOSITY OF MODIFIED HONEY SWEET POTATO FLOUR BASED ON FERMENTATION DURATION AND *TAPAI* YEAST CONCENTRATION

Fermentation Duration (S)	*Tapai* Yeast Concentration (T)				Average
	1,25% (T1)	2,5% (T2)	3,75% (T3)	5% (T4)	
12 hours (S1)	282.50±3.54^{a}	240.00±0.00^{abc}	240.00±3.54^{abc}	274.00±8.84^{ab}	259.06^{C}
24 hours (S2)	246.25±8.84^{abc}	230.00±3.54^{bc}	265.00±14.14^{ab}	200.00±14.14^{c}	235.31^{B}
36 hours (S3)	150.00±0.00^{d}	225.00±21.21^{bc}	205.00±14.14^{c}	135.00±0.00^{d}	178.75^{A}
Average	226.25^{Q}	231.67^{Q}	236.67^{Q}	202.92^{P}	224.50

Note: Numbers followed by different letters in the same column or row indicate a significant difference based on the Tukey HSD test at a 5% significance level.

The viscosity analysis revealed that increasing fermentation duration and *tapai* yeast concentration consistently reduced the viscosity of modified honey sweet potato flour due to progressive starch degradation and weakening of the granule matrix. This finding aligns with the study by Tong et al. [41], which demonstrated that variations in the fine structure of sweet potato starch (particularly in amylose and amylopectin chain-length distribution) strongly influence pasting behavior, breakdown viscosity, and textural stability. Shorter amylopectin chains and a reduced fa/fb_1 ratio were associated with lower paste viscosity and enhanced stability, suggesting that fermentation-induced depolymerization produces starch with improved processability. Similarly, Lou et al. [42] reported that dual modification of sweet potato starch through nanoprecipitation and octenyl succinic anhydride (OSA) esterification substantially decreased paste viscosity while improving its thermal stability and dispersion behavior. This supports the hypothesis that both enzymatic and physicochemical alterations of starch structure—whether by microbial fermentation or chemical modification—lead to improved paste stability.

The decrease in viscosity observed in fermented flour can thus be explained by the combined effects of microbial and thermal modification. During fermentation, hydrolytic enzymes such as α-amylase and glucoamylase partially depolymerize starch, producing shorter-chain dextrins and reducing sugars. These smaller molecules decrease paste consistency and weaken the

intermolecular hydrogen bonding within the starch network. Additionally, the acidic pH generated by lactic acid bacteria promotes partial gelatinization and disrupts granule integrity, further lowering viscosity. Together, these enzymatic and structural transformations yield flour with a more stable and less cohesive paste, improving its suitability for bakery and noodle applications.

I. Starch Granule Morphology

The next parameter is starch granule morphology. It was measured by suspending a 0.1 g sample in 1 mL of distilled water. Subsequently, 1–2 drops were examined under a binocular microscope. **Figure 2** presents the starch granule morphology of modified honey sweet potato flour and the control flour, observed using a binocular microscope. The results indicate that the granules exhibit round, polygonal, and semi-spherical shapes. These findings corroborate those of Ngoc [43], who reported that yellow and white sweet potato starch granules are generally round and polygonal, whereas purple varieties tend to be polygonal. As seen in **Figure 2**, the morphology of honey sweet potato starch granules also resembles that of cassava and potato starch. In samples S1T1, S1T2, S1T3, S1T4, S2T1, S2T2, S2T3, and S2T4, the starch granules appear intact with smooth surfaces. On the other hand, in samples S3T1, S3T2, S3T3, and S3T4, the granules exhibit irregular shapes with rough and loosely packed surfaces (as indicated by the circles in **Figure 2**).

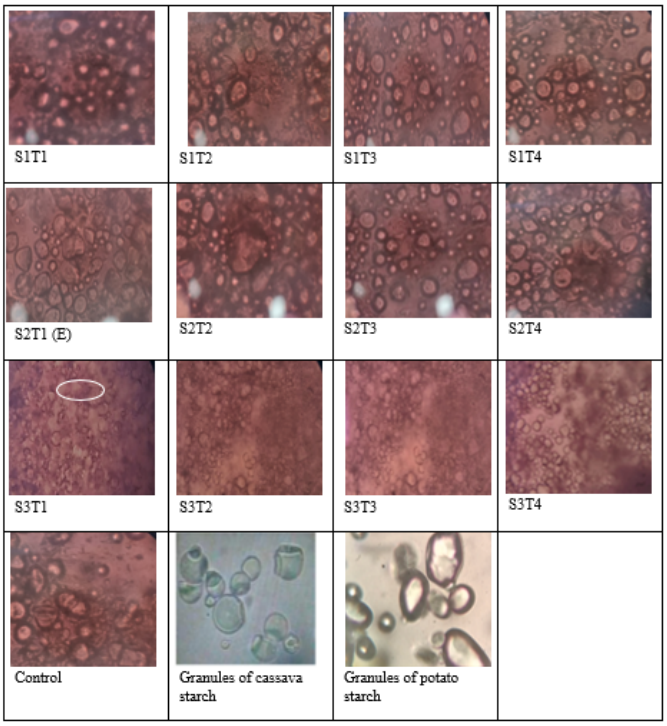

Fig 2. Morphology of Cassava Starch Granules, Potato Starch, Control, and Modified Honey Sweet Potato Flour. Sources: A-M (Personal Documentation, 2024); Cassava Starch Granules [44]; Potato Starch Granules [45].

These observations are consistent with those of Ye et al. [44], who reported that spontaneous fermentation altered the molecular structure of sweet potato starch, resulting in significant changes in granule surface morphology, including fragmentation, erosion, and granule integrity collapse, as revealed by SEM imaging. Furthermore, Zhang et al. [45] demonstrated that annealing treatments led to increased compactness and decreased smoothness of granules, indicating structural rearrangement at the molecular level. Zhang et al. [46] also found that simulated gelatinization via heat-moisture treatment caused multiscale morphological changes such as granule fragmentation, fissures, and cavity formation, particularly under high-temperature moist conditions. In addition, Liu et al. [47] observed irregular granular shapes and surface damage in blended sweet potato–rice composite flours, which were attributed to the breakdown of starch crystallinity during hydration and blending.

In this study, granules from S1T1 to S2T4 appear mostly smooth and intact, while those from S3T1 to S3T4 exhibit signs of erosion, deformation, and disintegration. This indicates that extended fermentation and increased *tapai* yeast concentration likely caused enzymatic degradation and acid-induced disruption of starch structure—findings that correlate well with structural evolution observed in chemically or thermally modified starch systems [48].

J. Moisture Content

Moisture content was determined using the gravimetric method. **Table 5** presents the moisture content obtained in this study, ranging from 7.60% to 11.49%. This falls within the standard set by SNI 7622-2011, which establishes a maximum limit of 14% [30]. Comparable moisture ranges have been reported for fermented cassava and sweet potato flours, generally between 9–13%, depending on raw material characteristics, fermentation conditions, and drying parameters [49], [50].
The relatively lower moisture content observed in this study can be attributed to differences in drying temperature and fermentation-induced physicochemical changes in the starch matrix. Previous studies on sweet potato flour demonstrated that drying temperature, peeling treatment, and sulphite application significantly influence moisture reduction by enhancing evaporation efficiency and altering water starch interactions [51].

Based on **Table 5**, fermentation duration and *tapai* yeast concentration significantly affected the moisture content of the modified flour ($p<0.05$), while their interaction had no significant effect. Moisture content decreased as fermentation time increased, with significant differences observed between 12-hour (S1), 24-hour (S2), and 36-hour (S3) fermentation durations. This behavior is consistent with reports indicating that fermentation disrupts starch granule integrity, loosens the polysaccharide network, and facilitates moisture diffusion during drying [52]. Recent studies on fermented cassava flour produced using mixed cultures of lactic acid bacteria and yeasts revealed that microbial activity promotes partial starch

depolymerization and increases matrix porosity, thereby accelerating water release during pressing and drying stages [53]. Likewise, investigations on sweet potato-based bakery products showed that fermentation-induced structural changes reduce water retention and enhance drying efficiency, contributing to improved shelf stability of flour-based ingredients [49].

The reduction in moisture content is also influenced by processing steps such as soaking, pressing, and thermal drying, which convert bound water into free water that evaporates more readily. Fermentation has been shown to weaken hydrogen bonding within starch–protein complexes and promote cell wall relaxation, resulting in a more porous flour structure and enhanced moisture loss during thermal processing [52].

In line with this, the moisture content of the product tended to decrease as the concentration of *tapai* yeast increases. The average moisture content ranged from 9.09% to 10.59%. This phenomenon is attributed to intensified microbial metabolism, where yeasts and associated microorganisms utilize available substrates and water for growth, generating metabolic heat and further promoting moisture evaporation during drying. Similar trends have been reported in fermented cassava flours and gluten-free flour systems, where higher inoculum levels improved fermentation efficiency, reduced residual moisture, and enhanced flour stability for downstream food applications such as bakery and gluten-free products [53], [55].

TABLE 5
MOISTURE CONTENT OF MODIFIED HONEY SWEET POTATO FLOUR BASED ON FERMENTATION DURATION AND *TAPAI* YEAST CONCENTRATION

Fermentation Duration (S)	*Tapai* Yeast Concentration (T)				Average
	1.25% (T1)	2.5% (T2)	3.75% (T3)	5% (T4)	
12 hours (S1)	10.94±1.08	11.68±0.77	11.49±0.26	10.03±0.77	11.03^{A}
24 hours (S2)	10.47±0.49	9.77±0.16	8.95±0.73	9.39±0.28	9.65^{B}
36 hours (S3)	10.35±0.02	9.89±0.52	8.54±0.13	7.60±0.02	9.09^{C}
Average	10.59^{P}	10.45^{P}	9.59^{PQ}	9.00^{Q}	9.86

Note: Numbers followed by different letters in the same column or row indicate a significant difference based on the Tukey HSD test at a 5% significance level.

K. Ash Content

The ash content test on flour products was conducted to determine the mineral content, purity, and cleanliness of the flour as well as to assess its quality and potential applications [56]. In this study, the dry ashing method was employed, where the sample was placed in a constant-weight crucible and incinerated at 600°C. The average ash content obtained in this study ranged from 1.32% to 2.10%, which is higher than the findings of Widowati et al. [53]. They reported an ash content between 0.22% and 0.41%. Differences in ash content values are influenced by processing conditions, particularly pretreatment methods and drying parameters. Kuyu et al. [57] reported that differences in pretreatment and convective drying temperatures significantly affect the nutritional composition, including mineral-related components reflected in ash content. In addition, fermentation duration (24, 48, and 72 hours) and inherent mineral composition of the raw material also contribute to the observed differences.

As in other parameters, fermentation duration and *tapai* yeast concentration had a significant effect ($P<0.05$) on the reduction of ash content in modified honey sweet potato flour (see **Table 6**). Ogunnaike et al. [58] explained that the decrease in ash content during fermentation might be caused by the dissolution of minerals into the soaking water and contamination by microbes. Mahendra et al. [59] added that fermentation can dissolve minerals such as sodium and potassium, which are then lost in the soaking water. This decrease in ash content is primarily attributed to the biochemical and physicochemical transformations that occur during fermentation. The activity of fermentative microorganisms, particularly lactic acid bacteria and yeasts, alters the ionic balance of the medium and promotes the solubilization of mineral salts such as potassium, calcium, and magnesium. These ions may diffuse into the soaking solution or form soluble complexes with organic acids such as lactic and acetic acids, which are subsequently removed during washing. In addition, microbial enzymatic activity contributes to the degradation of the cell wall matrix, leading to the release and loss of bound minerals. Longer fermentation durations and higher yeast concentrations enhance these effects by increasing acid production and ion exchange, ultimately resulting in a lower residual mineral content in the final flour.

TABLE 6
ASH CONTENT OF MODIFIED HONEY SWEET POTATO FLOUR BASED ON FERMENTATION DURATION AND *TAPAI* YEAST CONCENTRATION

Fermentation Duration (S)	*Tapai* Yeast Concentration (T)				Average
	1.25% (T1)	2.5% (T2)	3.75% (T3)	5% (T4)	
12 hours (S1)	2.10±0.02^{a}	1.93±0.01^{ab}	1.74±0.02^{b}	1.74±0.02^{b}	1.88^{A}
24 hours (S2)	1.32±0.04^{c}	0.82±0.02^{d}	1.26±0.05^{c}	1.12±0.01^{c}	1.13^{B}
36 hours (S3)	0.81±0.08^{d}	0.68±0.04^{de}	0.79 ±0.05^{de}	0.58±0.10^{e}	0.72^{C}
Average	1.41^{P}	1.15^{R}	1.26^{Q}	1.15^{R}	1.24

Note: Numbers followed by different letters in the same column or row indicate a significant difference based on the Tukey HSD test at a 5% significance level.

L. Starch content

The starch content was analyzed using the Nelson-Somogyi method. **Table 7** shows a fluctuating trend in starch content due to microbial activity and fermentation conditions. The reduction in starch content in modified honey sweet potato flour is associated with the progressive hydrolysis of starch molecules as fermentation time increases and microbial metabolism intensifies. A similar reduction in starch content during fermentation has been reported in cassava root flour, where prolonged natural fermentation resulted in significant biochemical transformations, including starch hydrolysis and carbohydrate modification [60]. The degradation of starch during fermentation is primarily driven by microbial activity. Yeasts and bacteria involved in fermentation are known to produce amylolytic enzymes that catalyze the breakdown of starch polymers into simpler sugars, thereby reducing total starch content. This enzymatic conversion of starch into fermentable sugars during microbial processing has been widely documented in fermented food systems [61].

Specifically, the highest starch content was observed at 24 hours of fermentation with 5% *tapai* yeast (S2T4) at 75.95%, while the lowest starch content was recorded at 36 hours of fermentation with 3.75% *tapai* yeast (S3T3) at 71.38%. These variations are closely related to microbial growth dynamics during fermentation. Microorganisms typically undergo an initial adaptation (lag phase), followed by rapid proliferation (log phase), and subsequently enter a decline phase as nutrients become limited. Such growth-phase-dependent metabolic activity strongly influences carbohydrate utilization and starch degradation during fermentation processes [62]. Furthermore, starch serves as a primary carbon and energy source for fermentative microorganisms. As fermentation progresses, starch is increasingly consumed to support microbial growth and metabolic functions, leading to a gradual reduction in starch content over time. This relationship between microbial energy demand and starch depletion has been clearly demonstrated in studies investigating carbohydrate metabolism in fermented starchy substrates [63].

TABLE 7
STARCH CONTENT OF MODIFIED HONEY SWEET POTATO FLOUR BASED ON FERMENTATION DURATION AND *TAPAI* YEAST CONCENTRATION

Fermentation Duration (S)	*Tapai* Yeast Concentration (T)				Average
	1.25% (T1)	2.5% (T2)	3.75% (T3)	5% (T4)	
12 hours (S1)	67.59±0.09^{i}	67.04±0.17^{j}	71.97±0.09^{e}	69.79±0.00^{g}	69.10^{A}
24 hours (S2)	68.66±0.09^{h}	73.48±0.04^{c}	74.98±0.09^{b}	75.95±0.13^{a}	73.27^{C}
36 hours (S3)	75.28±0.23^{b}	72.81±0.09^{d}	71.38±0.23^{f}	72.50±0.09^{d}	72.99^{B}
Average	70.50^{P}	71.11^{Q}	72.77^{R}	72.74^{R}	71.79

Note: Numbers followed by different letters in the same column or row indicate a significant difference based on the Tukey HSD test at a 5% significance level.

M. Amylose content

Amylose content was measured using a UV–Vis spectrophotometer at 625 nm after the preparation of a standard amylose calibration curve. The amylose level obtained in this study was higher than values generally reported for sweet potato flour.

Variability in amylose content among sweet potato flours is well documented and is closely related to cultivar-dependent genetic traits that control starch biosynthesis and molecular structure [41]. In addition to genetic background, growing conditions such as soil characteristics and climate have also been shown to influence starch composition and amylose proportion [64], Therefore, the relatively high amylose content observed in this study is likely the result of both inherent raw material characteristics and the processing treatments applied.

Table 8 shows that fermentation duration had a significant effect ($P<0.05$) on the increase in amylose content in modified honey sweet potato flour, with a 23.85% rise after 36 hours of fermentation. This pattern suggests that fermentation time plays an important role in modifying starch structure. Under acidic conditions generated during fermentation, amylopectin molecules may undergo partial depolymerization, particularly through the cleavage of α-1,6 glycosidic linkages, which results in a higher proportion of linear starch chains and an apparent increase in amylose content [65]. Similar behavior has been

reported in fermented tuber flours, where gradual molecular rearrangement of starch polymers occurred as fermentation progressed [66].

Likewise, the concentration of *tapai* yeast had a significant effect ($P<0.05$) on the decrease in amylose content in modified honey sweet potato flour, as shown in **Table 8**. This reduction is most likely associated with enhanced enzymatic activity at higher inoculum levels. Fermentative microorganisms are known to produce α-amylase, which hydrolyzes starch into maltose and maltotriose, thereby reducing the measurable amylose fraction [67]. As microbial activity intensifies, starch degradation becomes more pronounced, resulting in a further decline in amylose content [68]. Similar trends have been observed in fermented cereal-based flours, where higher starter concentrations accelerated starch hydrolysis and carbohydrate utilization [69]. Comparable effects have also been reported in other fermented flour systems, indicating that excessive inoculum levels promote enzymatic breakdown of starch and consequently reduce amylose content [70].

TABLE 8
AMYLOSE CONTENT OF MODIFIED HONEY SWEET POTATO FLOUR BASED ON FERMENTATION DURATION AND *TAPAI* YEAST CONCENTRATION

Fermentation Duration (S)	*Tapai* Yeast Concentration (T)				Average
	1.25% (T1)	2.5% (T2)	3.75% (T3)	5% (T4)	
12 hours (S1)	20.92 ± 0.88^{bcd}	21.45 ± 0.55^{bcd}	18.88 ± 1.21^{d}	19.38 ± 0.43^{cd}	20.16^{C}
24 hours (S2)	22.17 ± 0.49^{bc}	21.86 ± 0.19^{bc}	22.16 ± 0.59^{bc}	20.06 ± 0.70^{cd}	21.56^{B}
36 hours (S3)	29.88 ± 0.17^{a}	23.16 ± 0.45^{b}	21.00 ± 0.90^{bcd}	21.35 ± 0.56^{bcd}	23.85^{A}
Average	24.32^{P}	22.16^{Q}	20.68^{R}	20.26^{R}	21.86

Note: Numbers followed by different letters in the same column or row indicate a significant difference based on the Tukey HSD test at a 5% significance level.

N. Amylopectin content

Amylose plays a role in stimulating the puffing process, giving products with high amylopectin content a crispy, crunchy, and porous texture. According to C. Qiu *et al.*, the structure and ratio of amylose–amylopectin in starch govern physicochemical transformations during processing that directly influence the development of desired textural properties such as crispness and porosity [71]. It is calculated as the difference between total starch and amylose content. In this study, the amylopectin content ranged from 45.40% to 55.89% (**Table 9**), which is lower than the 75% amylopectin and 25% amylose found in mocaf flour studied by Wiraswati [72].

This study shows that fermentation duration and *tapai* yeast concentration significantly affect ($P<0.05$) the amylopectin content of modified honey sweet potato flour. As shown in **Table 9**, fermentation duration tends to decrease amylopectin levels, with a significant drop after 24 hours (from 51.71% to 49.15%). However, no significant difference was observed between 12 hours (48.93%) and 36 hours (49.15%).

This reduction in amylopectin is primarily attributed to enzymatic hydrolysis during fermentation. The amylolytic enzymes secreted by fermentative microorganisms, particularly α-amylase and debranching enzymes, cleave the α-(1,6)-glycosidic bonds within amylopectin, converting its branched structure into shorter linear chains of amylose [73]. Simultaneously, acidification of the medium by lactic acid bacteria promotes partial depolymerization and rearrangement of starch granules, further decreasing the proportion of amylopectin. These biochemical reactions explain the inverse relationship observed between amylose and amylopectin content, in which starch restructuring during fermentation results in a relative increase in amylose and a corresponding decrease in amylopectin. This transformation enhances the flour's functional stability and contributes to desirable textural characteristics in baked and fried products.

TABLE 9
AMYLOPECTIN CONTENT OF MODIFIED HONEY SWEET POTATO FLOUR BASED ON FERMENTATION DURATION AND *TAPAI* YEAST CONCENTRATION

Fermentation Duration (S)	*Tapai* Yeast Concentration (T)				Average
	1.25% (T1)	2.5% (T2)	3.75% (T3)	5% (T4)	
12 hours (S1)	46.66 ± 0.79^{d}	45.95 ± 0.73^{d}	53.08 ± 1.12^{b}	50.41 ± 0.42^{bc}	48.93^{B}
24 hours (S2)	46.49 ± 0.40^{d}	51.61 ± 0.14^{bc}	52.82 ± 0.49^{b}	55.89 ± 0.57^{a}	51.71^{A}
36 hours (S3)	45.40 ± 0.40^{d}	49.66 ± 0.53^{c}	50.38 ± 0.66^{bc}	51.15 ± 0.66^{b}	49.15^{B}
Average	46.18^{R}	48.96^{Q}	52.09^{P}	52.48^{P}	49.93

Note: Numbers followed by different letters in the same column or row indicate a significant difference based on the Tukey HSD test at a 5% significance level.

Conversely, a moderate increase in *tapai* yeast concentration may initially raise the apparent amylopectin level. This can be explained by partial enzymatic hydrolysis, which shortens long amylopectin chains into smaller branched units, thereby

increasing the relative proportion of short- and medium-chain amylopectin, as described by Sun et al. [74]. However, prolonged fermentation or excessive yeast concentration enhances enzymatic breakdown, leading to further depolymerization and overall reduction of amylopectin content.

O. Determining the Best Treatment

The best sample was selected using the multiple-attribute Zeleny method, based on test parameters that influenced the final results, prioritizing treatments with the lowest L_1, L_2, and $L\infty$ values. The ranking results of honey sweet potato flour using the Zeleny method are shown in Table 10. The ranking results obtained using the Zeleny multiple-attribute decision-making method showed that treatment S3T4 had the highest composite score (1.000), indicating the treatment combination with the most favorable balance of physicochemical properties, including higher whiteness and amylose content and lower moisture and ash levels. The highest-ranked sample was obtained from a fermentation duration of 36 hours with a *tapai* yeast concentration of 5% (S3T4). This result confirms that S3T4 exhibited the most desirable overall characteristics and therefore was selected as the best treatment according to the Zeleny method. The selected sample was then tested for its functional characteristics, including water-holding capacity (WHC), oil-holding capacity (OHC), swelling power, and syneresis.

TABLE 10
BEST TREATMENT RANKING USING THE ZELENY METHOD

Treatment	Alternative Value (Sum)	Ranking
S1T1	0.374	12
S1T2	0.356	11
S1T3	0.350	10
S1T4	0.350	9
S2T1	0.276	8
S2T2	0.220	5
S2T3	0.269	7
S2T4	0.264	6
S3T1	0.134	2
S3T2	0.203	4
S3T3	0.201	3
S3T4	0.110	1

Note: Based on the Zeleny method and predetermined criteria, the modified sweet potato flour ranks the highest.

Swelling Power

The swelling power test aims to measure the expansion level of starch-containing flour during cooking [75]. Sample S3T4 exhibited a swelling power of 3.19%, which is considered low. Wu et al. [76] stated that starch with limited granule swelling is more resistant to shear during cooking, making it suitable for noodle products.

Water Holding Capacity

Water Holding Capacity (WHC) refers to a flour's ability to absorb and retain water in a food system. WHC plays a crucial role in determining the water availability for starch gelatinization during cooking, as a lack of water can hinder optimal gel formation [48]. The WHC measurement for the S3T4 treatment was 276.831%, which is considered high. This is in line with the findings of Lavlinesia et al. [77], who observed that steaming before drying effectively reduced moisture content and enhanced water retention in Dioscorea alata flour. The higher the water holding capacity, the better the hydration and distribution of water during mixing, which facilitates the homogeneous dispersion of flour components and starch granules in the dough when water is added [78].

Oil Holding Capacity

The Oil Holding Capacity (OHC) test is an important parameter for starch, as the oil helps retain flavor and enhances the mouthfeel of food [79]. The OHC measurement for the S3T4 sample was 1.22 mL/g. It is suspected that the longer the fermentation duration, the greater the changes in granule structure, thereby increasing oil absorption capacity [22].

Syneresis

Syneresis refers to the separation of water from a starch paste when stored at low temperatures. Measuring syneresis in flour products is essential for determining product quality and shelf life [33]. In the best-performing sample, syneresis was measured over five days by weighing the separated water every 24 hours. The syneresis measurement results for the S3T4 sample are presented in **Table 11.**

TABLE 11
SYNERESIS (G/G) OF THE SELECTED MODIFIED HONEY SWEET POTATO FLOUR (S3T4)

Syneresis	
Measurement time (hour)	**Value (g/g)**
24	0.350
48	0.357
72	0.360
96	0.397
120	0.419

Syneresis increased over storage time, indicating greater water separation from the starch paste (**Table 8**). This value is slightly higher than that reported by Putri et al. [14], who found that MOCAF flour processed by dry milling and fermented for 18 hours had a syneresis value below 0.20 g/g. The high syneresis observed in this sample suggests instability during low-temperature storage, but it is suitable for products stored at room temperature. Additionally, high syneresis in food products can reduce cooking loss and may be applicable to noodle or vermicelli products [80].

IV. CONCLUSION

Modification of honey sweet potato flour through fermentation and optimization of *tapai* yeast concentration plays a crucial role in enhancing the whiteness degree, reducing moisture content to meet the Indonesian National Standard (SNI 7622:2011) for mocaf flour, and producing flour with desirable expansion properties and no off-flavors. Several parameters, including yield, whiteness degree, moisture content, amylose content, ash content, amylopectin content, starch content, and viscosity, showed statistically significant differences. Fermentation duration and *tapai* yeast concentration were identified as the main factors influencing improvements in flour whiteness and physicochemical characteristics. At the same time, their interaction did not significantly affect whiteness, moisture content, or pH. Based on the Zeleny multi-attribute decision-making method, the best treatment was obtained from S3T4 (72-hour fermentation with 4 % *tapai* yeast). This treatment achieved the highest whiteness degree (83.72 %), lowest moisture content (7.60 %), and lowest ash content (0.58 %), along with increased amylose content (29.88 %) and a pH of 3.97. Functional characterization of this treatment demonstrated a swelling power of 3.19 %, water-holding capacity (WHC) of 276.83 %, oil-holding capacity (OHC) of 1.19 mL g^{-1}, and syneresis ranging from 0.350 to 0.419. Collectively, these properties suggest that the optimized S3T4 flour possesses improved hydration, mixing behavior, and thermal stability, making it particularly suitable for bakery, noodle, and other composite-flour applications as a local substitute for imported wheat flour. Future research should focus on process scaling, nutritional fortification, and sensory evaluation in final products to expand the industrial application and market potential of fermented sweet potato flour as a sustainable, functional, and economically viable ingredient in food processing.

CONFLICT OF INTEREST

The authors declare no conflict of interest to disclose.

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