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Modification *of heat moisture treatment* (HMT) of sago and sweet potato starch for the diversification of dry noodle products

Shanti Fitriani[1*], Yusmarini[1], Emma Riftyan[1], Erpiani Siregar[1], Nizaha Juhaida Mohamad[2] Shauma Fithra Chairani[1], and Nur Lidya Ayu[1]

[1]Department of Agricultural Technology, Faculty of Agriculture, Universitas Riau, Pekanbaru, Riau, Indonesia
[2]Faculty of Fisheries and Food Science, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia

Abstract

Sago starch and sweet potato starch, rich in carbohydrates, exhibit considerable potential as raw materials for dried noodle production. However, the functional limitations of native starches in food processing require modification, such as heat-moisture treatment (HMT). While HMT enhances starch functionality, the resulting starches exhibit low protein content, requiring supplementation with protein-rich ingredients such as mung bean flour. This study aimed to evaluate the potential of HMT-modified sago and sweet potato starches, combined with mung bean flour, for the diversification of dried noodle products. The initial findings revealed that HMT modification significantly improved the water-holding capacity, swelling power, solubility, and amylose content of the native sago starch. Pasting analysis indicated similar functional profiles for sago and sweet potato starches, with notable differences observed in HMT-treated sweet potato starch. A one-factor completely randomized design was employed, incorporating six treatments (P1R1, P1R2, P1R3, P2R1, P2R2, P2R3), where P1 represents HMT sago starch and P2 represents HMT sweet potato starch, combined with mung bean flour in ratios of R1 (100:0), R2 (70:30), and R3 (50:50). Each treatment was conducted in triplicates. The findings demonstrated that the treatments significantly enhanced elongation, water absorption, ash content, and protein content, while reducing the rehydration time and moisture content in the dried noodles. Among the formulations, P2R3 (a 50:50 ratio of HMT sweet potato starch to mung bean flour) emerged as the best treatment. This study highlights the potential of HMT-modified starches combined with protein-rich flour to develop nutritionally enriched and functionally superior dried noodle products.

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1. Introduction

Noodles are a widely consumed food product in Indonesia and are enjoyed across all age groups, from children to adults. They serve as a significant source of energy due to their high carbohydrate content. Various types of noodles are available, including wet noodles, dry noodles, and instant noodles, with dry noodles being particularly popular among consumers. Dry noodles are traditionally prepared using wheat flour as the primary ingredient, with or without the inclusion of other permissible food substances and additives.

* Correspondence : **Shanti Fitriani** shanti.fitriani@lecturer.unri.ac.id

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The production process involves mixing, kneading, sheeting, slitting, and cutting the dough into noodle form, followed by drying or frying to obtain the final product (1).

Wheat, the primary raw material for dry noodle production, is derived from milled wheat grains. In Indonesia, wheat is entirely imported due to the lack of domestic production, with imports reaching 10.28 million tons in 2020 and increasing to 11.17 million tons in 2021 (2). This reliance on imported wheat underscores the urgency of diversifying local food ingredients to substitute wheat in noodle production. Among the promising alternatives are sago and sweet potatoes, both of which are abundant in Indonesia.

As a tropical country, Indonesia is rich in starch resources from tree-derived sago and tuber crops such as sweet potatoes. Indonesia boasts a potential sago cultivation area of approximately 5.5 million hectares; however only 4% of this area is currently utilized. In 2021, Riau has emerged as the leading sago-producing province, with production reaching 265.83 tons (3). Sago starch is characterized by its high carbohydrate content, comprising 85.20 g per 100 g, while its protein and fat contents are relatively low, at 0.90 g and 0.30 g per 100 g, respectively (4). The high carbohydrate concentration makes sago starch a viable raw material for noodle production, offering a potential pathway for enhancing the utilization of local starch resources and reducing the reliance on wheat imports.

Sweet potatoes, a locally available tuber crop, remain underutilized in food product development despite its rich nutritional profile (5). Per 85 g, sweet potatoes contain 18.8 g of carbohydrates, 1.5 g of protein, 0.2 g of fat, 78.4 g of water, 0.6 g of fiber, 1.1 g of ash, and small amounts of vitamins and minerals (4). Given their nutritional composition, there is significant potential to expand the use of sweet potatoes, particularly by processing them into starch.

However, native starches, including those derived from sweet potatoes, exhibit limitations that restrict their application in food products. These limitations include poor solubility in cold water, high gelatinization temperatures, prolonged cooking times, and the production of firm and less elastic pastes (6). Additionally, native sago and sweet potato starches are prone to retrogradation and syneresis, which further limits their functional properties (7). Starch modification techniques are employed to overcome these shortcomings and enhance the physical and chemical properties of native starch. Modification methods can be categorized into chemical, physical, enzymatic, and genetic approaches (8). Physical modification techniques, such as pregelatinization, heat-moisture treatment (HMT), and annealing, are widely used to improve starch functionality (9).

HMT is a hydrothermal process involving the treatment of starch granules with limited moisture content (less than 35%) at elevated temperatures ranging from 80 to 140°C for a specific duration (1–24 h) (10). This method is particularly advantageous as it avoids the use of chemical reagents, thereby eliminating concerns about residual chemical contaminants in the modified starch (11). By improving the functional properties of starch without introducing chemical residues, HMT presents a sustainable and consumer-friendly approach for enhancing the applicability of sweet potato and sago starches in food products.

Previous studies by Mandei (12) investigated the application of heat-moisture treatment (HMT)-modified sago starch as a potential substitute for wheat in noodle production. HMT-modified sago starch has demonstrated its feasibility as a wheat replacement in dry noodle formulations. However, previous studies have not explored its combination with protein-rich flours to enhance the nutritional profile of noodles. In contrast, the incorporation of mung bean flour, a protein-rich ingredient, has been studied in wet noodle production (13). Formulations using varying ratios of sago starch to mung bean flour (100:0, 90:10, 80:20, 70:30, and 60:40) identified a 70:30 ratio as the optimal blend for wet noodle preparation. To date, there has been no reported research on the use of HMT-modified sweet potato starch in the production of dry noodles. This study aims to address these gaps by investigating the potential of sago starch and sweet potato starch, both modified by HMT, as raw materials for the diversification of dry noodle products. The findings are expected to contribute to the development of nutritionally enhanced and locally sourced noodle alternatives, reducing reliance on wheat imports while promoting the utilization of indigenous starch resources.

2. Materials and Methods

2.1. Materials and Tools

This study utilized dried native sago starch purchased from PT. Martabat Sagu Sejati in Meranti Islands Regency, native sweet potato starch purchased from Mega Samudera brand and mung beans obtained from local shop in Pekanbaru. The gelatinization and pasting properties of the samples were analyzed using a Rapid Visco Analyzer (RVA) Techmaster model (Newport Scientific, Warriewood, Australia).

2.2. Methods

The research was conducted in two stages. The first stage involved the modification of native sago starch and sweet potato starch using the Heat Moisture Treatment (HMT) method. A completely randomized design was employed, consisting of four treatments and four replications (except for RVA). Native and modified starches were analyzed for their physicochemical properties.

The second stage focused on the production of dried noodles using modified HMT sago starch and sweet potato starch as the main ingredients, substituted with mung bean flour. This stage utilized a completely randomized design with six treatments: P1R1, P1R2, P1R3, P2R1, P2R2, and P2R3. Here, P1 refers to sago starch, P2 to sweet potato starch, and R represents the ratio of starch to mung bean flour (R1 = 100:0, R2 = 70:30, R3 = 50:50). Each treatment was replicated three times. The dried noodle treatments were then analyzed for their physicochemical properties.

2.2.1. Starch modification by *heat moisture treatment* (HMT) method

The manufacture of HMT-modified sago starch refers to Agustiani et al. (14). Water was added to the sago starch by spraying until the moisture content reached 28%. The amount of water added is calculated by the mass balance method. The mass balance formula used is as follows:

$$(100\%–KA_1) \times BP_1 = (100\%–KA_2) \times BP_2 \quad (1)$$

Note:
KA1 = Initial condition moisture content (% bb)
KA2 = Desired starch moisture content (%bb)
BP1 = Starch weight at initial condition
BP2 = Starch weight after reaching KA_2

Subsequently, the sago starch is wrapped in aluminum foil, placed on a baking tray with dimensions of 30 × 25 × 2 cm, and stored in a refrigerator at 4–5°C for 24 hours to ensure uniform moisture content. After that, the starch that is still wrapped in aluminum foil is heated in an oven at a temperature of 80°C for 5 hours. Starch that has been given a heating treatment is then opened in aluminum foil packaging and then heated with an oven at 50°C for 4 hours, to reduce the moisture content of starch. The dried starch was then milled and sifted with an 80 mesh sieve.

2.2.2. Making dry noodles

The manufacture of dry noodles refers to Mandei (12) with the formulation referring to Effendi et al. (15). The making of dry noodles begins by mixing all ingredients consisting of HMT sago starch, mung bean flour, eggs, Carboxymethyl Cellulose (CMC), salt and water manually while stirring until evenly distributed until smooth dough is formed. CMC is a food additive that is widely used in food and is a derivative of the carboxymethyl group ($-CH_2-COOH$), which functions as a stabilizer and contributes to the water absorption capacity of dry noodles during cooking (16). The dough that has formed is put into *ampia* and sheets are obtained. The sheets obtained are then printed using *ampia* until they are noodle shaped. The printed noodles are dried in the oven at 55°C for ±5 hours, until dry noodles are produced.

2.3. Observation

2.3.1. Physicochemical Properties of Starch

The parameters observed for the physicochemical properties of starch include water holding capacity (17), swelling power (18), solubility (19), and amylose content (20).

2.3.2. Pasting Properties of Starch

The starch pasting profile was observed using a Rapid Visco Analyzer (RVA) model RVA-S4, following the standard 1 analysis profile as recommended by Newport Scientific (2009). The parameters for this profile are as follows. A sample of 3.5 g of starch was mixed with 25 g of distilled water in the sample container. The RVA was set to stir the container with the sample, beginning with an initial rotation at a speed of 160 rpm and a temperature of 50°C for the first minute. The heating temperature was then increased from 50°C to 95°C, reaching this point by the 8.5-minute mark. The temperature was maintained at a constant 95°C for 5 minutes. After this steady heating period, the temperature was reduced back to 50°C, continuing until the 21-minute mark, after which the temperature was held at 50°C for an additional 2 minutes, ending at the 23-minute mark.

2.3.3. Physicochemical Properties of Dry Noodles

The parameters observed for the dry noodles are physical properties such as elongation (21) water absorption (22), and rehydration time (12). The chemical properties of the proximate content were analyzed using AOAC (2016); moisture and ash content by the gravimetric method, while protein content (%) by the Micro Kjeldahl method.

2.4. Statistical Analysis

Statistical data processing for the characterization of physicochemical properties of starch and dry noodle was carried out by Analysis of Variance (ANOVA) using IBM SPSS Statistics 22 software. If the ANOVA results were significant, then Duncan's multiple range comparison test was performed to differentiate the average between treatments.

3. Results and Discussion

3.1. Physical Properties and Amylose Content of Starch

Several physical properties of starch observed in this study include water holding capacity (WHC), swelling power, and solubility. WHC refers to the ability of starch to retain absorbed water, swelling power is related to the expansion capacity of a material, and solubility indicates the ability of a material to dissolve in water. Additionally, amylose content analysis was conducted. The type and modification of starch significantly ($P<0.05$) affected the values of WHC, swelling power, solubility, and amylose content in both native and heat-moisture treated (HMT) sago starch, as well as native and HMT sweet potato starch. The physical properties and amylose content results are presented in table 1.

Table 1. Physical properties and amylose content of native and HMT sago starch and sweet potato starch.

Treatment	Water holding capacity (g/g)±SD	Swelling power (g/g)±SD	Solubility (%)±SD	Amylose content (%)±SD
Native sago starch	0.97 ± 0.07^{a}	7.30 ± 0.79^{a}	3.62 ± 1.08^{a}	29.72 ± 0.16^{a}
HMT sago starch	1.24 ± 0.11^{c}	8.52 ± 0.68^{b}	6.48 ± 0.96^{b}	37.42 ± 0.11^{d}
Native sweet potato starch	1.08 ± 0.03^{ab}	8.58 ± 0.46^{b}	2.96 ± 1.08^{a}	33.19 ± 0.37^{b}
HMT sweet potato starch	1.18 ± 0.08^{bc}	9.48 ± 0.43^{b}	6.88 ± 1.30^{b}	35.61 ± 0.09^{c}

Note: Numbers followed by different letters indicate that the samples are significantly different at the 5% level by Duncan's test.

Based on table 1, the lowest WHC was observed in native sago starch, which was not significantly different from native sweet potato starch, while HMT sago starch exhibited the highest WHC, not significantly different from HMT sweet potato starch. HMT modification significantly increased the WHC of sago starch but not that of sweet potato starch, likely due to differences in amylose content between the starches. In this study, native sago starch contained 29.72% amylose, whereas native sweet potato starch contained 33.19% amylose (Table 1). HMT modification can increase amylose content by breaking α-1,6-glycosidic bonds in amylopectin branches, resulting in straight-chain polymers that constitute amylose (23). Amylose, being hydrophilic and amorphous, enhances water absorption; therefore, higher amylose content correlates with increased WHC (24). Table 1 also indicates that native sago starch exhibits the lowest swelling power among the treatments, with significant differences compared to others. This is attributed to its low WHC, as swelling power is closely related to WHC. Native sago starch has a lower WHC compared to native sweet potato starch and their respective modified starches, resulting in reduced water absorption and expansion capacity. Granule swelling occurs due to the absorption of water into each starch granule, leading to an increase in swelling power (25). Swelling power is also influenced by amylose content, with native sago starch having the lowest amylose content among the samples. Lower amylose content reduces water absorption, as amylose readily absorbs water, thus limiting the granule expansion volume (26).

Table 1 shows that the WHC values of native sago and sweet potato starches were not significantly different; however, HMT modification significantly increased the solubility of both starch types. This increase is attributed to the higher amylose content in the modified starches compared to their native counterparts. Higher amylose content enhances solubility, as more amylose molecules dissolve in water (25). The breakdown of hydrogen bonds within amylose molecules during modification allows the released amylose to disperse and dissolve, thereby increasing solubility (26).

In addition to amylose content, starch granule size and morphology may also influence WHC following HMT. Sweet potato starch generally exhibits smaller granules, ranged from 12.1 to 18.2 µm depending on the variety (27). Sago starch granules have a broad size range, between 10 and 50 µm in diameter with an average granule diameter of 32 µm (6). Generally, smaller starch granules possess a larger surface area-to-volume ratio compared to larger granules, providing more sites for water interaction. However, HMT may induce greater structural modifications in larger starch granules, such as those of sago starch, potentially increasing their porosity and internal water-binding capacity. Meanwhile, the compact structure of smaller sweet potato starch granules may limit the extent of HMT-induced changes, contributing to the comparatively lower increase in WHC observed.

3.2. Gelatinization and Pasting Properties of Starch

Gelatinization is the process in which starch granules transition from an ordered to a disordered structure during heating in excess water, while pasting refers to the subsequent phenomenon characterized by viscosity changes during controlled heating and cooling with stirring (28). The gelatinization profile of starch paste is essential for predicting its functional properties and optimizing its application in various products. This profile can be measured using a Rapid Visco Analyzer (RVA), a viscometer that combines heating and cooling cycles to assess a sample's resistance under controlled stirring. The data generated by RVA include pasting temperature, peak viscosity, holding viscosity at 95°C, breakdown viscosity, final viscosity, and setback viscosity. The gelatinization profiles of native and modified sago and sweet potato starches are illustrated in figure 1, with the average gelatinization parameters presented in table 2.

The gelatinization curves in figure 1 indicate that the profiles of sago and sweet potato starches generally exhibit similar patterns, except for HMT-treated sweet potato starch. Additionally, almost all viscosity values of sago starch were lower than those of sweet potato starch (table 2). The observed lower viscosity values of sago starch compared to sweet potato starch suggest that sago-based noodles may exhibit a softer texture and reduced gel strength, which could affect their cooking performance and structural integrity. Conversely, sweet potato starch’s higher viscosity contributes to firmer, more elastic noodles, enhancing their cooking stability and textural quality. These differences highlight the importance of selecting appropriate starch sources or combining starches to achieve desirable noodle characteristics. Factors influencing starch gelatinization profiles include starch source, granule size, the presence of acids, sugars, fats, and proteins, as well as cooking temperature and stirring conditions (29). Table 2 shows that HMT modification in sago starch resulted in minimal changes to its paste profile compared to its native form, both in terms of pattern and viscosity values. In contrast, the paste profile of sweet potato starch differed significantly between its native and HMT-modified forms, particularly in breakdown and setback viscosity values, reflecting distinct functional properties.

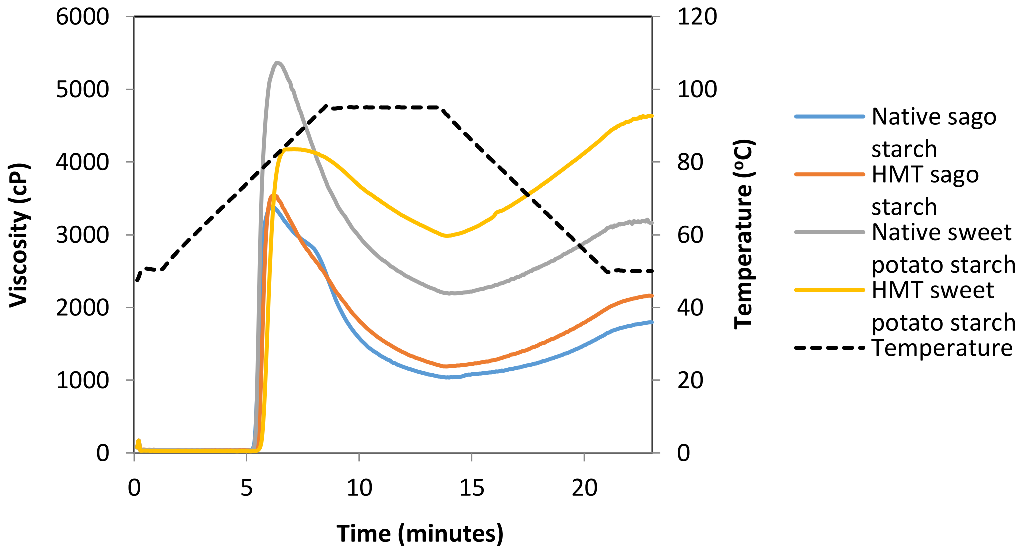

Figure 1. Pasting profile curve of native and HMT sago starch and sweet potato starch.

Table 2. Pasting profile of native and HMT sago starch and sweet potato starch.

Treat-ment	Viscosity (cP)					Peak time (min.)	Pasting temp. (°C)
	peak	trough	breakdown	final	setback		
NSS	3383	1036	2347	1796	760	6.13	76.15
HSS	3541	1189	2352	2162	973	6.20	76.95
NSPS	5364	2191	**3173**	3164	973	6.33	76.15
HSPS	4175	2986	1189	4635	1649	7.07	76.65

Note: NSS=native sago starch, HSS=HMT sago starch, NSPS=native sweet potato starch, HSPS=HMT sweet potato starch.

The paste profile of sago starch in table 2 shows that HMT modification resulted in an increase in peak viscosity and high-temperature viscosity, accompanied by an increase in gelatinization temperature. This subsequently led to a slight increase in breakdown viscosity. A similar trend was observed for final viscosity, resulting in a more pronounced increase in setback viscosity compared to the increase in breakdown viscosity. In contrast, sweet potato starch exhibited a decrease in peak viscosity with increasing gelatinization temperature, leading to a reduction in breakdown viscosity. Similar to sago starch, HMT modification in sweet potato starch caused an increase in setback viscosity, which was attributed to a reduction in final viscosity.

Based on the gelatinization profiles in table 2, native sweet potato starch exhibited higher peak viscosity and breakdown viscosity compared to native sago starch. Peak viscosity represents the point at which starch granules gelatinize and achieve maximum expansion, reflecting the starch's water-binding capacity and its positive correlation with the quality of the final product, including expansion and polymer release (30). Breakdown viscosity indicates the stability of the starch paste during heating, with lower breakdown values signifying greater thermal stability. A high breakdown viscosity, as observed in native sweet potato starch, suggests that its swollen granules are fragile and less resistant to heating (31). This fragility likely results from the granules' inability to withstand thermal stress despite their expansion.

Final viscosity represents the viscosity of the starch paste after the final cooling phase (holding) and is crucial for assessing the stability of starch during processing involving heating, stirring, and cooling. According to table 2, both HMT-modified sago starch and HMT-modified sweet potato starch exhibited higher final viscosity values compared to their native counterparts. This indicates that HMT modification effectively enhanced the final viscosity of sago starch, with higher final viscosity signifying greater resistance of the paste to mechanical stirring during processing.

Table 2 shows that HMT-modified sago starch and HMT-modified sweet potato starch had higher setback viscosity values than their native forms, with the difference being more pronounced in sweet potato starch. Setback viscosity is an indicator of the tendency of starch paste to undergo retrogradation or syneresis. A higher setback viscosity reflects a stronger retrogradation tendency, while increasingly negative values indicate the occurrence of syneresis.

Retrogradation is the recrystallization process of starch after gelatinization, whereas syneresis refers to the expulsion of water from starch granules (31). Factors such as starch type, the amylose and amylopectin content, molecular weight of amylose and amylopectin, granule size distribution, and the length and distribution of amylopectin's outer chains influence the occurrence of starch retrogradation (29). Starches with high amylose content are more prone to rapid retrogradation, as gel formation and retrogradation are predominantly driven by amylose molecules rather than amylopectin (32). In this study, sweet potato starch exhibited stronger retrogradation compared to sago starch, and HMT modification tended to enhance the likelihood of retrogradation. According to Karim et al. (33), retrogradation in starch- or flour-based food products is generally undesirable due to its impact on texture, structure, and organoleptic properties, as observed in parboiled rice or breakfast cereals. This phenomenon results in starch-based food products becoming harder or less sticky, affecting their quality and consumer acceptability. Although HMT modification improved the thermal and functional properties of the starches, it also resulted in higher setback viscosities, indicating a greater retrogradation tendency. To address this, future formulations could incorporate hydrocolloids or explore dual-modification techniques to reduce retrogradation and enhance noodle quality during storage.

3.3. Physical Properties of Dry Noodles

HMT-modified sago and sweet potato starches were applied to dried noodle products as substitutes for mung bean flour, and their physical properties, including elongation, water absorption, and rehydration time, were evaluated. The type of starch and the starch-to-mung bean ratio significantly ($P<0.05$) influenced the elongation, water absorption, and rehydration time of the dried noodles. The average physical properties of the dried noodles are presented in table 3.

Table 3. Average of physical properties of dry noodles.

Treatment	Elongation (%)	Water absorption (%)	Rehydration time (min.)
P1R1	36.33±0.58[e]	121.58±0.82[a]	6.43±0.12[e]
P1R2	15.33±0.58[c]	148.02±0.87[c]	5.11±0.09[c]
P1R3	3.33±0.58[a]	163.09±0.85[e]	4.27±0.03[b]
P2R1	47.33±0.58[f]	139.18±0.92[b]	6.25±0.09[d]
P2R2	29.67±0.58[d]	157.07±0.62[d]	5.10±0.09[c]
P2R3	11.67±0.58[b]	174.17±0.75[f]	4.03±0.03[a]

Note: numbers followed by different letters indicate that the samples are significantly different at the 5% level by Duncan's test.

3.3.1. Elongation

As shown in table 3, the elongation of dried noodles ranged from 3.33 to 47.33%, with the highest elongation observed in treatment P2R1, which was significantly different from other treatments, whereas the lowest elongation was recorded in P1R3, also significantly different from the others. Both types of starch produced dried noodles with decreasing elongation as the proportion of starch decreased and mung bean flour increased. This trend is attributed to the amylopectin content in the starch, which imparts stickiness and acts as an effective binder for the components of dried noodles. Strong adhesive properties enhance the molecular bonds within the noodle structure, reducing the likelihood of breakage after cooking (10). This finding aligns with research by Effendi et al. (15) indicating that reduced tapioca and increased potato flour usage in wet noodles result in lower elongation, as the adhesive properties contributed by amylopectin in tapioca were diminished.

3.3.2. Water absorption

The water absorption capacity of dried noodles, as presented in table 3, ranged from 121.58% to 174.17%. The highest water absorption was observed in treatment P2R3, while the lowest was recorded in P1R1, with both showing significant differences compared to other treatments. Dried noodles made with both sago and sweet potato starches demonstrated increased water absorption capacity as the proportion of starch decreased and mung bean flour increased. Among the two types of starch, noodles made with HMT-modified sweet potato starch exhibited higher water absorption than those made with HMT-modified sago starch at the same starch-to-mung bean flour ratio. This is attributed to the higher amylose content in HMT-modified sweet potato starch (33.19%) compared to HMT-modified sago starch (29.72%) (Table 1). The high amylose content enhances water absorption due to amylose's affinity for water, as its linear chains and numerous hydroxyl groups facilitate water retention (15,34).

The increase in mung bean flour substitution also significantly contributed to higher water absorption in dried noodles. This effect is due to the amylose content in mung bean flour, which is considerably higher (55.39%) (35) compared to HMT-modified sago and sweet potato starches. The substitution of mung bean flour increased the overall amylose content in the noodle mixture, thus enhancing the water absorption capacity of the final product. Consequently, regardless of whether HMT-modified sago or sweet potato starch was used, increasing mung bean flour substitution consistently resulted in noodles with higher water absorption.

In addition to amylose content, water absorption capacity is influenced by the moisture content of dried noodles. Products with lower moisture content tend to be more hygroscopic, which increases their ability to absorb water. Furthermore, the protein content in mung bean flour also contributed to this property, as proteins are hydrophilic and enhance water retention (36). Thus, the use of mung bean flour as a substitution in formulations with both HMT-modified sago and sweet potato starches resulted in dried noodles with progressively higher water absorption capacities.

3.3.3. Rehydration time

The rehydration time of dried noodles, as shown in table 3, ranged from 4.03 to 6.43 minutes, with the shortest rehydration time observed in treatment P2R3, significantly different from the other treatments. Both sago and sweet potato starches produced dried noodles with decreasing rehydration times as the proportion of starch decreased and mung bean flour increased. Dried noodles made from HMT-modified sweet potato starch exhibited shorter rehydration times compared to those made with HMT-modified sago starch. This difference is attributed to the amylose content in the ingredients, as amylose facilitates water absorption, allowing water to penetrate the noodles more easily and accelerating the attainment of optimal cooking time.

The substitution of mung bean flour further reduced rehydration times, making the noodles ready for consumption more quickly. This effect is due to the higher amylose content in mung bean flour compared to both types of starches. As mung bean flour substitution increased, the overall amylose content of the noodle formulations rose, resulting in faster water absorption. Additionally, the moisture content of the dried noodles also influenced rehydration time. Lower moisture content enhances water absorption capacity, leading to faster rehydration. This finding aligns with Ramdayani et al. (37), which suggests that higher water absorption allows water to permeate the material more rapidly, reducing the time required to reach optimal cooking conditions.

3.4. Chemical Properties of Dried Noodles

The chemical analysis of dried noodles in this study included moisture content, ash content, and protein content. Moisture content was analyzed to determine the percentage of water present in the food product, a factor often associated with the product's shelf life. Ash content analysis was conducted to measure the mineral content remaining after combustion, reflecting the mineral composition of the material. Protein analysis aimed to quantify the protein content in dried noodles, especially influenced by the incorporation of mung bean flour, a rich protein source. Statistical analysis showed that both the type of starch and the ratio of starch to mung bean flour significantly affected ($P<0.05$) the moisture, ash, and protein content of the dried noodles. The average chemical composition of the dried noodles is presented in figure 2.

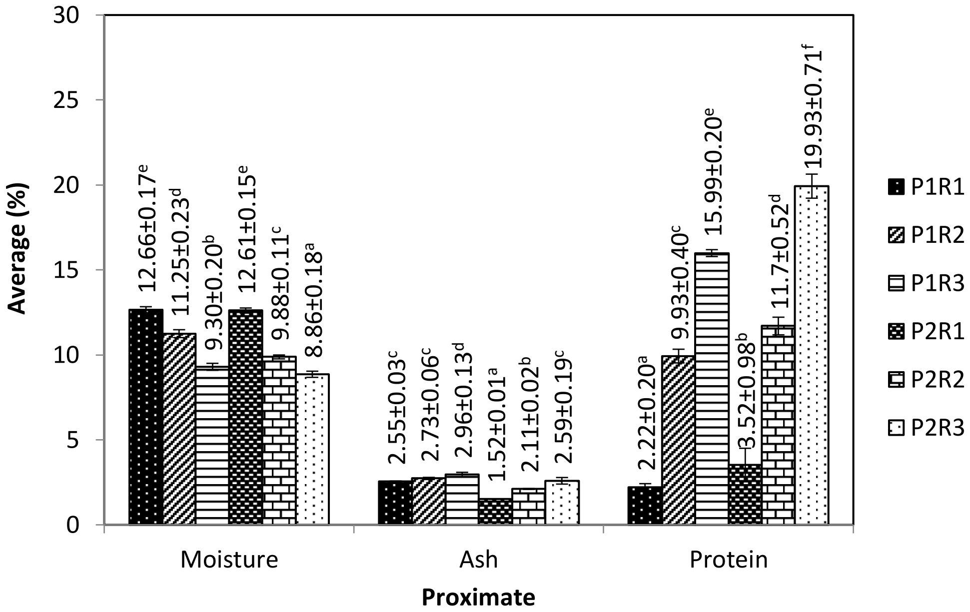

Figure 2. Moisture, ash, and protein content of dry noodles.

3.4.1. Moisture content

Based on figure 2, the moisture content of dried noodles ranged from 8.86% to 12.66%, with the lowest moisture content observed in treatment P2R3, which was significantly different from other treatments. Conversely, the highest moisture content was found in P1R1 and P2R1. Both types of starch produced dried noodles with decreasing moisture content as the proportion of starch decreased and the proportion of mung bean flour increased. However, dried noodles made with HMT sago starch had higher moisture content than those made with HMT sweet potato starch, except for the 100:0 starch-to-mung bean flour ratio. This difference was attributed to the higher moisture content of the HMT sago starch (8.78%) compared to the HMT sweet potato starch (7.65%), as determined from raw material analysis.

The decrease in the moisture content of dry noodles along with the increase in mung bean flour substitution was caused by two main factors that contributed to each other. First, mung bean flour had a lower initial water content (5.85%) compared to both types of starch. This condition directly affects the final moisture content of the product after the drying process, because raw materials with lower initial moisture content tend to produce final products with lower moisture content. As the proportion of mung bean flour increases in the formulation, the total moisture content of the dough mixture before drying becomes lower, so the moisture content of the resulting dry noodles also decreases.

Second, the higher amylose content of mung bean flour compared to the two starches also plays a role in reducing the moisture content of dry noodles. Amylose has a linear structure that tends to form a tight gel during the cooling and drying process. This structure can reduce the water holding capacity because the space between amylose molecules is more limited than branched amylopectin molecules. In addition, materials with high amylose content tend to release water faster during drying (38), so the final water content of dry noodles also becomes lower as the proportion of mung bean flour increases.. The moisture content of dried noodles in this study met the quality standard for dried noodles as specified by SNI 8217:2015 (1), which requires a maximum moisture content of 13%.

3.4.2. Ash Content

Figure 2 reveals that the average ash content of dried noodles ranges between 1.52% and 2.96%. The highest ash content was observed in the P1R3 treatment, which significantly differed from other treatments, while the lowest was found in the P2R1 treatment, also significantly different from the others. The use of different starches resulted in dried noodles with increasing ash content as the proportion of starch decreased and the amount of mung bean flour increased. Notably, dried noodles made from HMT sago starch exhibited higher ash content compared to those made from HMT sweet potato starch at the same ratio of starch to mung bean flour. This is attributed to the higher ash content of HMT sago starch (0.38%) compared to HMT sweet potato starch (0.30%).

As the substitution of mung bean flour for both types of starch increased, the ash content of the resulting dried noodles also increased. This is due to the higher ash content of mung bean flour (3.35%) compared to both HMT sago and sweet potato starches. Furthermore, the elevated ash content in noodles with higher mung bean flour levels can be explained by the significantly higher mineral content in mung bean flour. For every 100 g of mung beans, the mineral composition includes 223 mg calcium, 319 mg phosphorus, 7.5 mg iron, 42 mg sodium, 815.7 mg potassium, 1.90 mg copper, and 2.9 mg zinc (4). The ash content of dried noodles in this study complied with the quality standards set by SNI 01-2974-1992 (39), which stipulates a maximum ash content of 3%.

3.4.3. Protein content

Data presented in figure 2 indicates that the protein content of dried noodles increases with the rising substitution of mung bean flour for both types of starch. This is due to the higher protein content of mung bean flour, which was measured at 5.85%, compared to the starches used. These findings align with research by Pratama et al. (40), which demonstrated that the protein content of dried noodles increased as the proportion of mung bean flour rose and the proportion of lesser yam flour decreased, with protein levels ranging from 8.84% to 14.01%. The substitution of mung bean flour was conducted to ensure the protein content of the dried noodles met quality standards. According to the quality requirements for dried noodles set by SNI 8217:2015 (1), the minimum protein content is 10%. Accordingly, only the treatments P1R3, P2R2, and P2R3 met this standard, as their protein content exceeded 10%.

4. Conclusion

Based on the research that has been conducted, it can be concluded that sago starch has a lower water-holding capacity and *swelling power* than sweet potato starch. HMT modification significantly improved the WHC, swelling power, solubility, and amylose content of native starch. Pasting analysis indicated similar functional profiles for sago and sweet potato starches, with notable differences observed for HMT-treated sweet potato starch. The ratio of HMT starch and mung bean flour significantly enhanced elongation, water absorption, ash, and protein content while reducing rehydration time and moisture content in the dried noodles. Among the formulations, P2R3 (a 50:50 ratio of HMT sweet potato starch to mung bean flour) emerged as the best treatment, this is due to the highest value of physicochemical characteristics among others. This study highlights the potential of combining HMT-modified sweet potato starch with mung bean flour to develop nutritionally enriched and functionally superior dried noodle products.

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Author Contributions

S.F. conceived and designed the experiments; S.F., S.F.C., N.L.A, performed the experiments; S.F., Y.Y., E.R., E.S., N.J.M, S.F.C. and N.L.A. analyzed the data and wrote the paper.

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Not applicable.

Data Availability Statement

Available data was presented in the manuscript.

Conflicts of Interest

Authors may declare no conflict of interest. The funder has no role in any of the related stages.

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