

Sago starch (*Metroxylon* sp.) and oyster mushroom (*Pleurotus ostreatus*) flour as a novel raw material for healthy product development

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Abstract

Non-communicable diseases are a major global health concern, often associated with unhealthy eating habits. Addressing this issue requires innovation, including the development of alternative raw materials that promote health. The combination of sago starch (*Metroxylon* sp.) and oyster mushroom (*Pleurotus ostreatus*) flour, both rich in bioactive compounds, remains largely underexplored as a food ingredient. Utilizing this combination offers an innovative strategy for developing functional foods with additional health benefits. This study aimed to analyze the nutritional content and physical characteristics of the sago starch and oyster mushroom flour combination as an alternative raw material. A completely randomized design was used, and data were presented descriptively based on the mean of duplicate analyses of chemical and physical properties. Results showed that the combination of sago starch and oyster mushroom flour yielded a dietary fibre content ranging from 18.93% to 30.73%, and protein contents from 7.71% to 12.61%. Resistant starch content ranged between 12.09 and 12.88 g, while total phenolic content varied from 124.47 to 151.35 mg GAE. Compared to pure sago starch, the combination of sago starch and oyster mushroom flour showed a decrease in carbohydrate, starch, amylose, and amylopectin contents. In the combination flour, the carbohydrate content ranged from 80.60% to 86.33%; starch content from 64.36% to 73.91%; amylose from 25.30% to 29.17%; and amylopectin from 36.61% to 48.61 (all on dry basis except for starch, amylose, and amylopectin, which were measured on wet basis). Increasing the proportion of oyster mushroom flour led to a decrease in the carbohydrate content, while starch and amylopectin contents slightly increased, and amylose remained relatively stable. In addition, fat content increased from 0.36% (in sago starch) to between 2.68% and 3.52% after adding oyster mushroom flour. These findings provide a foundation for further formulations optimizing and highlight the potential of this combination to enhance the functional properties of food products without significantly compromising cooking quality and texture.

1. Introduction

Non-communicable diseases (NCDs) are a major global health concern, often linked to unhealthy eating habits. Diabetes and obesity, in particular, are associated with carbohydrate-dense food products that lack essential nutrients (Karunarathna *et al.*, 2024). Addressing this issue requires innovative approaches, such as developing alternative raw materials that promote health.

Sago starch (*Metroxylon* sp.) is a potential local food ingredient and an alternative carbohydrate source to rice in Indonesia. It can be used in various non-wheat processed food products, including noodles, biscuits,

cakes, bread, puddings, and other preparations. Its versatility highlights its strategic role in promoting local food diversity and supporting food security (Dewayani *et al.*, 2024).

One notable feature of sago starch is its resistant starch (RS) content, which resists digestion in the human gastrointestinal tract. Resistant starch offers several health benefits, including hypoglycemic and hypocholesterolemic effects, prebiotic properties, and a role in preventing colon cancer. Despite its potential, the utilization of sago starch remains limited. Processing sago starch into more diverse and value-added products can enhance both its marketability and nutritional value

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(Du et al., 2020; Rashid et al., 2020; Karunarathna et al., 2024).

Oyster mushrooms (*Pleurotus ostreatus*) are another nutrient-rich food ingredient with significant health benefits. They are particularly valued for their protein content, dietary fiber (including bioactive beta-glucans), and phenolic compounds. Additionally, oyster mushrooms have relatively low carbohydrate and fat contents, making them suitable as a substitute or fortifying ingredient in food products. They also contribute to improved sensory quality and physicochemical properties in functional foods (Bulam et al., 2022).

However, the combination of sago starch and oyster mushrooms in the form of flour as a raw material has been minimally explored. Combining these two ingredients could provide a novel and valuable raw material for developing functional foods with health benefits. This innovation aligns with the Indonesian Government's program to accelerate food diversification and reduce dependency on rice and wheat as staple carbohydrate sources (Hassan, 2014). Therefore, this study aimed to analyze the nutritional content and physical characteristics of the combination of sago starch and oyster mushrooms as an alternative raw material for long-term health-oriented product development.

2. Materials and methods

2.1 Materials

The raw materials used in this study included fresh white oyster mushrooms (*P. ostreatus*) obtained from Pasar TU Kemang, sourced from oyster mushroom cultivators in Cipayang, Bogor, Indonesia. These mushrooms were delivered daily at 11:00 AM and were collected continuously until the requisite quantity for flour production was attained. The sago starch (*Metroxylon* sp.) used as the second raw material was commercially available dried sago starch purchased from Pondok Sago Metro, Bogor, West Java.

2.2 Preparation of raw material flour

A completely randomized design (CRD) was employed in this study to evaluate the effects of various treatments on the observed variables. Although CRD typically involves multiple blocks to account for uncontrolled variation, this experiment was conducted within a single experimental block due to resource constraints such as limited space, time, and budget. The flour preparation process took place from February to July 2024. The process of producing flour from sago starch (*Metroxylon* sp.) and oyster mushrooms (*P. ostreatus*) was modified from the method of Suarti et al.

(2015). The preparation stages involved cleaning, weighing, washing, and draining the mushrooms as part of the sorting process. The mushrooms were then shredded into smaller pieces. Next, the mushrooms were blanched (steamed) at 80°C for approximately 3 min. After steaming, they were blended and mixed with commercially dried sago starch in formulation ratios of 70:30, 60:40, and 50:50 (sago starch: oyster mushroom). The total quantity of raw materials utilized for formulations F0, F1, F2, and F3 was standardized at 350 g. This quantity was established based on a review of the literature, taking into account the minimal impact on nutritional composition. The formulations were subsequently prepared according to predetermined percentage ratios. The control sample (F0), comprising 100% sago starch (100:0), contained 350 g of sago starch. Formulation F1 (70:30) consisted of 245 g of sago starch and 105 g of oyster mushroom flour; F2 (60:40) contained 210 g of sago starch and 140 g of oyster mushroom flour; and F3 (50:50) was composed of equal parts sago starch and oyster mushroom flour, each at 175 g. The mixtures were dried using a single drum dryer (Simon™, www.simon-dryers.co.uk) at 80°C. After drying, the samples were ground into flour using a Fomac-brand, Indonesian herb grinder for approximately 10 min. The ground flour was sieved through an 80-mesh sieve to achieve a fine consistency. The resulting flour was then packaged in standing pouch aluminum foil bags and stored in a box at room temperature for subsequent analysis.

2.3 Characterization of the flour combination

The flour combination of sago starch (*Metroxylon* sp.) and oyster mushrooms (*P. ostreatus*) was characterized through physical and chemical analyses. The physical properties analyzed included yield, flour color (measured using a Kroma AMT511 device from Amtast, Lakeland, FL, USA) based on the CIELab system, and pasting properties, which were determined using a Rapid Visco Analyzer (RVA) (Perten, TecMaster model, Sweden). A sample with a known moisture content was placed in a canister, and distilled water was added to prepare a starch suspension. The canister was subsequently placed in a Rapid Visco Analyzer (RVA), with the test commencing at 50°C for a duration of 1 minute. The temperature was then elevated to 95°C and maintained for 5 min, followed by a cooling phase back to 50°C over a period of 5 min. This procedure facilitated the measurement of key pasting properties, including pasting temperature (°C), peak viscosity (cP), holding (or trough) viscosity (cP), breakdown viscosity (cP), final viscosity (cP), setback viscosity (cP), and peak time (min).

The chemical properties were analyzed as follows:

according to the AOAC Official Method 2002.02.

2.3.1 Moisture content

Moisture content was determined according to the AOAC Official Method 925.10 (AOAC INTERNATIONAL, 2019).

2.3.2 Ash content

The ash content was determined according to the AOAC Official Method 923.03.

2.3.3 Protein content

The protein content was determined using the Kjeldahl method, in accordance with the AOAC Official Method 984.13.

2.3.4 Fat content

The fat content was determined according to the AOAC Official Method 920.39.

2.3.5 Carbohydrate content

The carbohydrate content was determined by difference, calculated as the remainder after subtracting the moisture, ash, protein, fat, and crude fiber contents from 100%. Therefore, the total carbohydrate content is influenced by the accuracy of these component measurements. This approach is based on the principle that carbohydrates contribute significantly to the overall nutrient composition of food products. The total carbohydrate content was calculated using the following formula:

$$\text{Total carbohydrate content (\%)} = 100\% - A - B - C - D - E$$

Where A = Moisture content (% w/w), B = Ash content (% w/w), C = Protein content (% w/w), D = Fat content (% w/w) and E = Crude fiber content (% w/w)

2.3.6 Energy value

The energy value was estimated using the Atwater general factors: 4 kcal/g for carbohydrates and proteins, and 9 kcal/g for fats.

2.3.7 Dietary fiber content analysis (insoluble and soluble dietary fiber)

The dietary fiber content, including both insoluble dietary fiber (IDF) and soluble dietary fiber (SDF), was determined according to the AOAC Official Method 985.29

2.3.8 Resistant starch content

The resistant starch content was determined

2.3.9 Total phenols content

The total phenolic content was determined using the Folin–Ciocalteu spectrophotometric method, as modified by Ainsworth and Gillespie (2007). The extract was diluted to a final concentration of 102.4 ppm and the total reaction volume was 25 mL. Absorbance was measured, and the total phenolic content was calculated based on a gallic acid standard curve and expressed as mg gallic acid equivalents (GAE) per 100 g of dry weight (DW). Specifically, for the standard curve, a stock solution of 24.6 mg in 25 mL was prepared, which was equivalent to 0.984 mg/mL or 984 ppm. This standard solution was serially diluted tenfold to obtain a working concentration of 102.4 ppm.

2.3.10 Starch, amylose, and amylopectin content

The total starch content was determined using the titrimetric method according to the AOAC Official Method 996.11.

2.4 Data analysis

All data are presented descriptively as mean values from two repetitions of each chemical and physical property analysis.





3. Results

3.1 Physical characteristics

Table 1 shows that increasing the proportion of oyster mushrooms (*P. ostreatus*) in the flour formulation reduces the yield. The lowest yield was observed in F3 (11.29%), while the highest yield was found in F1 (15.79%). The addition of oyster mushrooms to the flour caused the color to become increasingly brownish. The control sample, namely sago starch (*Metroxylon* sp.) exhibited the highest brightness (L^*) value of 94.25, whereas the combination flours with oyster mushrooms had L^* values ranging from 80.30 to 83.32. In contrast, the green-red (a^*) and blue-yellow (b^*) values were higher in the combination flours, with a^* values ranging from 5.97 to 7.95 and b^* values ranging from 14.05 to 16.63, compared to the control ($a^* = 2.95$ and $b^* = 4.71$).

Table 1 also highlights the differences in pasting properties between pure sago starch and the combination of flours of sago starch and oyster mushroom for pasta production. Pure sago starch had a higher pasting profile compared to the combination flours. The peak viscosity of sago starch was 4820 cp, while the combination flours exhibited peak viscosities ranging from 372.50 to 591.00 cp. The breakdown viscosity of sago starch was 3526 cp, which is considered high. However, the breakdown

Table 1. Physical characteristics of oyster mushroom starch, sago starch, and oyster mushroom-sago starch mixture as raw material for pasta production.

Parameter	Unit	Sago starch (Control)	Raw material ratio (sago starch:oyster mushroom)		
			F1 (70:30)	F2 (60:40)	F3 (50:50)
Yield	%	NA	15.79	14.26	11.29
Color					
<i>L</i> *		94.25	83.32	81.90	80.30
<i>a</i> *		2.95	5.97	6.86	7.95
<i>b</i> *		4.71	14.05	15.64	16.63
Color illustration					
Pasting profile					
Pasting temperature	°C	73.50	50.34	50.45	54.13
Peak time	min	6.07	3.17	3.14	3.07
Peak viscosity	cP	4820	591.00	372.50	573.00
Holding viscosity	cP	1294	257.50	179.00	197.50
Breakdown viscosity	cP	3526	333.50	193.50	375.50
Final viscosity	cP	2443	499.00	329.00	321.00
Setback viscosity	cP	1149	241.50	150.00	123.50

Values presented are from duplicate analysis (n = 4).

Control, F1, F2, F3: % substitution of sago starch with oyster mushroom, *L**: brightness, *a**: red-green, *b**: blue-yellow, cP: centipoise, NA: not analysed.

viscosity decreased significantly in the combination flours, ranging from 193.50 to 375.50 cp. Similarly, sago starch exhibited a higher final viscosity of 2443 cp. When mixed with oyster mushroom, the final viscosity of the combination flours decreased to values between 321 and 499 cp. Additionally, the setback viscosity of sago starch (1149 cp) was reduced to 123.50–241.50 cp after the addition of oyster mushrooms.

3.2 Nutritional content

Table 2 highlights the nutritional advantages of sago starch (*Metroxylon* sp.) and the combination flours of sago starch and oyster mushrooms (*P. ostreatus*). Dietary fiber content increased significantly from 2.90% in pure sago starch to 18.93–30.73% in the combination flours. Protein content also increased as the proportion of oyster mushrooms increased in the formulation, rising from 0.31% in sago starch to 7.71–12.61% in the combination flours. Conversely, carbohydrate content decreased from 99.34% in pure sago starch to 80.60–36.33% in the combination flours. Interestingly, the resistant starch content increased from 11.17 g/100 g (db) in sago starch to 12.09–12.64 g/100 g (db) in the combination flours. Similarly, the phenolic content showed a notable increase, rising from 20.20 mg GAE/100 g (db) in sago starch to 124.47–151.35 mg GAE/100 g (db) in the combination flours. The fat content, initially 0.36% in sago starch, increased slightly to a range of 2.68–3.52%

after adding oyster mushroom.

4. Discussion

4.1 Physical characteristics

The yield of flour reflects the amount of product obtained after the drying process. In this study, a drum dryer was used for drying, and a grinder was employed to produce flour. As the proportion of oyster mushrooms increased, the drying time also became longer.

Processing fresh oyster mushrooms into flour has the potential to induce a browning reaction due to the activity of oxidase enzymes, which are responsible for the distinctive brown color. Browning reactions can be mitigated through pretreatment methods, such as blanching, which inactivates oxidase enzymes. Pretreatment is particularly effective in reducing enzymatic browning, which occurs when phenolase enzymes in oyster mushrooms catalyze the reaction between phenolic substrates and oxygen (O₂). This enzymatic activity affects not only the browning index but also the water content, protein content, ash content, fat content, carbohydrate content, and the overall color of the resulting oyster mushroom flour. Studies have shown that blanching results in the lowest browning index compared to other pretreatments, primarily due to enzyme inactivation during the process (Nadhifah *et al.* 2021; Lin *et al.* 2022).

Table 2. Nutrient content of oyster mushroom starch, sago starch, and oyster mushroom-sago starch mixture as raw material for pasta production.

Parameter	Unit	Sago starch (Control)	Raw material ratio		
			(sago starch:oyster mushroom)		
			F1 (70:30)	F2 (60:40)	F3 (50:50)
Energy (kcal)	kcal/100 g	354	368	372	370
Carbohydrate	% (db)	99.34	86.33	83.85	80.60
Starch	%(wb)	91.78	64.36	65.78	73.91
Amyloza	%(wb)	43.60	25.63	29.17	25.30
Amylopectin	%(wb)	48.18	38.73	36.61	48.61
Total fiber	% (db)	2.90	18.93	27.17	30.73
Soluble dietary fiber	% (db)	1.83	3.19	0.57	1.56
Insoluble dietary fiber	% (db)	0.84	12.69	20.70	23.05
Protein	% (db)	0.31	7.71	9.82	12.61
Fat	% (db)	0.36	2.68	3.14	3.52
Moisture	%(wb)	11.82	8.07	7.64	8.63
Ash	% (db)	0.00	3.29	3.19	3.27
Resistant starch	g/100 g (db)	11.17	12.64	12.88	12.09
Phenols	mg GAE/100 g (db)	20.20	133.09	124.47	151.35

Control, F1, F2, F3: % substitution of sago starch with oyster mushroom, wb: wet basis, db: dry basis, NA: not analysed.

Lin *et al.* (2022) demonstrated that polyphenol oxidase (PPO) activity was minimal at a blanching temperature of approximately 90°C for 180 s (3 min), leading to reduced browning (Lin *et al.*, 2022). However, our results indicate that heating at 80°C for approximately 3 min effectively prevents excessive browning of the flour. Similarly, in this study, sago starch alone had a higher brightness value (L^*) of 94.25 compared to the combination flours of sago starch and oyster mushrooms, which ranged from 80.30 to 83.32 (Table 2). However, the green-red (a^*) and blue-yellow (b^*) values were higher in the combination flours compared to pure sago starch. This suggests that when these flours are used in formulations such as pasta products, they produce a distinctive brownish color.

The natural pigments in oyster mushrooms significantly influence the final product color. Fresh oyster mushrooms have a yellowish-white appearance, while their flour exhibits a yellow-brown hue. The yellowish tint in oyster mushroom flour may be attributed to the Maillard reaction, which occurs between reducing sugars and amino acids, producing melanoidins that contribute to the brownish coloration (Rahmawati *et al.*, 2025). The positive values for the a^* parameter in the combination flours (Table 2) support the occurrence of the Maillard reaction (Nadhifah *et al.*, 2021). Non-enzymatic browning reactions, such as the Maillard reaction, are more likely to occur during drying processes, particularly at elevated temperatures (Andrea *et al.*, 2018). Sun *et al.* (2020) noted that the umami flavor and the distinctive aroma of mushrooms are closely linked to nucleotide metabolism, amino acid metabolism, fatty acid metabolism, and the Maillard

reaction. In this study, the neutral color of sago starch interacted with the natural pigments of oyster mushrooms, resulting in an appealing brownish color for the flour, which may enhance its visual appeal in food products.

The development of products such as non-wheat pasta relies on the gelatinization and retrogradation processes of starch (Mayasti *et al.*, 2018). Table 1 presents the differences between sago starch and the blend of sago starch and oyster mushrooms as raw materials for pasta. The results indicate that sago starch exhibits a higher pasting profile compared to flour substituted with oyster mushrooms. Specifically, sago starch achieved a peak viscosity of 4820 cp, whereas the peak viscosity of the oyster mushroom-substituted sago starch ranged from 372.50 to 591 cp. Peak viscosity reflects the stage where starch granules are fully gelatinized and have reached their maximum swelling capacity (Fitriani *et al.*, 2023). Sago starch demonstrates excellent gelatinization properties, allowing it to absorb water and expand significantly when heated in water, thus increasing its peak viscosity. Conversely, flour made from sago starch substituted with oyster mushrooms tends to exhibit limited expansion. This study suggests that the addition of white oyster mushrooms, which contain polysaccharide compounds, enhances the interaction between starch molecules, optimizing peak viscosity. According to Lestari *et al.* (2015), water-binding capacity, as indicated by peak viscosity, is positively correlated with the quality of the final product, particularly the amount of polymer released and the extent of granule development (Lestari *et al.*, 2015).

The breakdown viscosity of sago starch in this study was 3526 cp, which is classified as high. This is attributed to the swelling of starch granules to the point where they become brittle and break, indicating low heat resistance. In contrast, the breakdown viscosity of oyster mushroom-substituted sago starch ranged from 195.50 to 333.50 cp. Breakdown viscosity reflects the reduction in viscosity after reaching the peak. A lower breakdown viscosity is preferable as it indicates greater starch stability during heating (Mayasti *et al.*, 2018). Oyster mushrooms contribute to this stability by providing enzymes that promote gelatinization and reduce amylopectin levels, thereby enhancing viscosity stability. Mayasti *et al.* (2018) also noted that lower breakdown viscosity signifies improved starch resistance to thermal stress. Flour made from oyster mushroom-substituted sago starch exhibited the lowest breakdown viscosity and demonstrated stability under heat. Therefore, combining sago starch with oyster mushrooms reduces the breakdown rate and enhances product stability, making it suitable for applications such as pasta production. As shown in Table 2, the breakdown viscosity of the raw material flour decreased from 3526 cp (sago starch) to a range of 193.50–375.50 cp after mixing with oyster mushrooms.

High final viscosity and rapid retrogradation are crucial characteristics of starch required to produce high-quality extruded heating products (Mayasti *et al.*, 2018). Table 1 indicates that sago starch exhibits a higher final viscosity of 2443 cp. However, after blending sago starch with oyster mushrooms to produce flour, the final viscosity decreased significantly, ranging from 321 to 499 cp. This finding demonstrates that the addition of oyster mushrooms reduces the final viscosity. Final viscosity refers to the viscosity value of the starch paste after final cooling (holding). This parameter is critical for determining the stability of starch viscosity during processing, including the heating, stirring, and cooling stages (Fitriani *et al.*, 2023).

Additionally, the setback viscosity values in Table 2 illustrate the tendency of starch to retrograde. Flour-containing oyster mushrooms had the lowest setback viscosity, ranging from 132.50 to 241.50 cp. Therefore, increasing the proportion of oyster mushrooms in flour formulations for pasta-like products is likely to decrease the retrogradation capacity, thereby enhancing the quality of the resulting pasta. However, an increase in the percentage of oyster mushroom substitution is also associated with an increase in protein content, but may lead to a reduction in the cooking quality and texture of the pasta (Mayasti *et al.*, 2018). It is evident from Table 1 that the setback viscosity of sago starch decreases with the addition of oyster mushrooms, dropping from 1149

cp to a range of 123.50–241.50 cp. These data provide a foundation for optimizing future product formulations to minimize declines in cooking quality and texture across different formulations.

4.2 Nutritional content

The results presented in Table 2 demonstrate that sago starch and oyster mushrooms possess notable nutritional advantages. Sago starch contains 11.17 g/100 g (db) of resistant starch, which is higher than the findings of Puspita *et al.* (2020), who reported a resistant starch content of 8.8 g, classified as high (6.89–8.8 g) (Puspita *et al.*, 2020). These findings confirm that sago starch is rich in resistant starch. The recommended consumption of resistant starch is at least 6 g/day for Americans, but in Indonesia, there is no established reference. However, based on this reference, it is evident that our study meets the recommendation if consumed at least 55% of 100 g/day (6.14 g/day).

Resistant starch (RS) is categorized into five types (RS1–RS5), some of which are commercially modified or added to foods as functional ingredients (RS2, RS3, and RS4), while others occur naturally in foods (RS1, RS2, RS3, and RS5) (Raigond *et al.* 2015; Ashwar *et al.* 2016; Lockyer and Nugent 2017; Tian and Sun 2020; Patterson *et al.* 2020). Resistant starch is characterized by its low digestibility, which offers several health benefits, such as reducing glucose absorption and insulin secretion, enhancing short-chain fatty acid (SCFA) production, and promoting weight management (Regmi *et al.*, 2011). SCFAs play a crucial role in regulating insulin production in the pancreas, modulating free fatty acid release in adipocytes, and influencing appetite control centers in the brain while also serving as an energy source for muscles (Morrison and Preston, 2016). Resistant starch is a form of starch that resists hydrolysis by amylase enzymes and reaches the colon, where it serves as a substrate (colonic food) for microbiota fermentation. This fermentation process produces SCFAs, particularly acetic acid, propionic acid, and butyric acid (Daniëlle *et al.* 2013; Harsono *et al.* 2020). The resistance of RS to amylase enzymes contributes to its slower glucose release, reduced energy absorption in intestinal cells, and low glycemic index, which can aid in body weight control (Liu *et al.*, 2012).

Table 2 also highlights the relatively high fiber and phenol content in flour produced from the combination of sago starch and oyster mushroom compared to sago starch alone. Fiber plays a crucial role in delaying gastric emptying, reducing hunger, aiding digestion, promoting weight loss, and lowering cholesterol levels (Nofiatika and Prasetyaningrum, 2020). The addition of oyster mushrooms positively enhances the fiber content in the

product, contributing to improved health outcomes. Adequate fiber intake has been shown to reduce the risk of metabolic diseases such as hypercholesterolemia, heart disease, and other related conditions (Ambari *et al.*, 2014). Phenols, on the other hand, have the potential to prevent the formation of free radicals, thereby offering antioxidant benefits (Jeena *et al.*, 2014).

In addition, white oyster mushrooms are relatively high in protein, which is an essential determinant of the quality of food ingredients. The data show that the protein content in the produced flour ranged from 7.71–12.61 g/100 g after sago starch was substituted with oyster mushrooms. The drying process, particularly the temperature and duration, plays a significant role in determining the quality and shelf life of the resulting flour. The use of an oven can cause the sago starch flour to clump when substituted with oyster mushroom, making it difficult for moisture to evaporate, which can result in lower protein content. Drum drying is an appropriate method for processing various starchy food products, including baby food, maltodextrin, suspensions, and heavy pastes. It is also recognized as one of the most energy-efficient drying methods for such products. Due to its ability to expose products to high temperatures for only a few s, the drum dryer is particularly suitable for heat-sensitive materials. This consideration formed the basis of our decision to utilize this drying method to preserve the nutritional content of white oyster mushrooms (Rahmawati *et al.*, 2025).

The data acquired in this study sufficiently represent the composition of flour derived from a combination of sago starch and oyster mushrooms. However, we encountered limitations in replicating the flour production process multiple times due to time constraints. The production of a single batch of flour required a considerable amount of time. Our data indicated that the moisture content of fresh oyster mushrooms was approximately 91%, consistent with findings reported by Rahmawati *et al.* (2025). Based on this, in formulation F1 (70:30), where 70% sago starch is combined with 30% fresh oyster mushrooms to yield a total of 350 g of raw material, approximately 1.2 kg of fresh oyster mushrooms is required to obtain 105 g of mushroom flour. Similarly, F2 (60:40) necessitates about 1.6 kg of fresh oyster mushrooms to produce 140 g of mushroom flour, and F3 (50:50) requires approximately 1.9 kg of fresh mushrooms to obtain 175 g of flour.

In this study, replicating sample preparation within a single day proved challenging. Oyster mushrooms, procured from Cipayung, were only available at 11:00 AM. Upon their arrival at the laboratory, additional time was required for cleaning, blanching, and blending the

mushrooms with sago starch, a process that typically extended until approximately 5:00 PM. Due to these time constraints, the blended material was stored in a refrigerator and processed into flour using a drum dryer the following day for all formulation ratios. Consequently, it was not feasible to repeat the flour production process multiple times in a single day. In future research, repetitions may be more feasible if the study focuses on mixing the flours of sago starch and oyster mushrooms directly, rather than blending fresh ingredients. However, this approach may lead to a significant reduction in nutritional content due to repeated heat exposure. Therefore, the novelty of our method, which involves directly mixing fresh ingredients prior to flour processing, provides an important reference point for future studies.

5. Conclusion

The combination of sago starch and oyster mushroom into flour enhances and enriches the nutrient content, offering significant health benefits and serving as an innovative alternative functional food. The development of products such as non-wheat pasta using this combination relies on the gelatinization and retrogradation processes of starch. Increasing the proportion of oyster mushrooms in the mixture elevates the protein content but reduces the cooking quality and texture of the pasta. Oyster mushrooms contain natural pigments that influence the final color of the product by interacting with the neutral color of sago starch, resulting in an appealing brownish hue. The findings of this study provide a foundation for future formulation optimization to address and minimize reductions in cooking quality and texture across different formulas. The combination of sago starch and oyster mushroom contributes to an improved nutritional profile. These findings provide a foundation for further formulation optimization in the development of functional food products.

Conflict of interest

The authors declare no conflicts of interest.

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