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The nutritional content and physical characteristics of sago starch and oyster mushrooms as potential functional food ingredients

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Abstract. The integration of sago starch and oyster mushrooms in food product development remains underexplored. Storage life can be enhanced by processing them into flour. This preliminary study seeks to evaluate the nutritional content and physical characteristics of both food materials. The research utilized proximate analysis and presented descriptive findings based on the average nutrient composition and physical attributes, analyzed in two repetitions. Proximate analysis encompassed protein content, moisture level, ash content, crude fat, carbohydrate content (by difference), and crude fiber. Additionally, this study examined phenolic compounds in oyster mushrooms and resistant starch in sago starch. Physical characterization involved analyzing pasting profiles and color properties of both foods. The results indicate that sago starch contains a notable amount of resistant starch (11.17 g), while oyster mushrooms are rich in crude fiber (12.86%) and phenolics (360.8 mg), with relatively low lipid content (5.81%). All nutrient compositions were analyzed per 100 g on a dry basis. Color and pasting profile tests suggest that white sago starch outperforms oyster mushrooms in these aspects. Despite their differences, both hold promising potential as ingredients for functional food innovations.

1 Introduction

Functional foods offer numerous health benefits, particularly in reducing the risk of various chronic or degenerative condition. However, functional foods must meet specific sensory, nutritional, and physiological criteria, while ensuring they are free from toxic or carcinogenic effects [1].

Sago starch (*Metroxylon sp*.) is a sustainable and highly productive starch source, presenting an excellent alternative for food diversification. As an energy source, sago starch is comparable to rice, corn, cassava, potatoes, and wheat flour. With its high retrogradation levels, sago starch serves as a suitable raw material for producing pasta, rice noodles, and

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traditional noodles. Its superior hardness, stickiness, elasticity, and compactness also make it a promising food stabilizer [2].

Sago contains resistant starch, which bypasses digestion in the small intestine and reaches the large intestine, where it acts as a prebiotic, stimulating the growth and activity of beneficial gut microbiota. Sago starch significantly lowers postprandial glucose levels and reduces total cholesterol and triglycerides, attributed to the viscous nature of resistant starch that inhibits glucose, cholesterol, and triglyceride absorption [3, 4].

Despite its benefits, sago is notably low in protein content. Its protein levels are much lower than those of rice, corn, and wheat flour. Similarly, its vitamin and mineral content falls below that of other staple foods. Given sago's limited nutritional profile compared to other staples, it is best paired with ingredients offering a more complete nutrient composition. One such ingredient is the white oyster mushroom *(Pleurotus ostreatus)*.

White oyster mushrooms are a rich protein source, with content ranging from 23.5% to 33.2%. Interestingly, it have a low fat content (0.9% to 2.6%) [5]. Additionally, oyster mushrooms are rich in fiber and phenolic compounds while being low in carbohydrates and fats [5, 7]. White oyster mushrooms contain soluble β-glucan fiber (9 g/100 g) [6] and exhibit a total phenolic content of 54.9 mg/g (wet weight). The total phenolic content in white oyster mushrooms is 54.9 mg/g wet weight [7]. Jeena et al. (2014) reported 1.32 mg/g (dry weight), demonstrating potential antioxidant properties against free radicals [8]. Fresh white oyster mushrooms contain 43.3 g of fiber per 100 g [5]. However, when made into flour, oyster mushrooms have a variety of contents. The results of Djimila *et al.* (2019), obtained a fiber content of around 11.8%-12.2%. The fiber content will decrease as it is heated, however, it is still classified as a high-fiber food group (>6%) [9].

Based on the aforementioned explanations, oyster mushrooms and sago present significant potential for functional food innovation. However, beyond their nutritional content, understanding the physical characteristics of these components is crucial for guiding product development based on their unique profiles. Thus, this study acts as preliminary research to evaluate the nutritional content and physical properties of these two food materials.

2 Methodology

White oyster mushrooms (*Pleurotus ostreatus*) and sago starch (*Metroxylon sp.)* were utilized as the primary raw materials for this product development study. Fresh white oyster mushrooms were processed into flour to enhance their shelf life. The processing stages included sorting, blanching for approximately 3–4 minutes at a temperature of ±80°C, followed by drum drying at 10 revolutions per minute (rpm) and 80°C, producing fine particles. The fine particles were ground further and sieved through an 80-mesh screen to produce smooth powder.

This study is a preliminary study which is only carried out once.. The study employed proximate analysis and descriptively presented findings based on average chemical and physical data from two replicates (duplo). Proximate analysis included crude protein, water, ash, crude fat, and crude fiber, conducted using AOAC methods. Carbohydrate content was calculated using the 'by difference' method. Phenolic content in oyster mushroom powder and resistant starch in sago starch were quantified using spectroscopy techniques at the LDITP Laboratory, IPB University. Pasting profile analysis was conducted using the Rapid Visco Analyzer (RVA) at the Food Process Technology Laboratory of ITP IPB. Color analysis was performed using a chromometer at the Nutritional Sciences Chemistry Laboratory, IPB University. Commercial sago starch was sourced from Pondok Sagu Metro in Bogor, West Java, while freshly harvested white oyster mushrooms were obtained from

Cipayung and purchased at Pasar Teknik Umum (TU), Bogor, West Java. The study was conducted over a span of six months, from January to July 2024.

This study is a preliminary study which is only carried out once. This study conducted proximate analysis and descriptively presented findings based on average chemical and physical data with two repetitions analysis (duplo). Proximate analysis included crude protein, water, ash, crude fat, and also crude fiber, conducted using AOAC methods. Carbohydrate content was calculated using the 'by difference' method. Phenolic content in oyster mushroom flour and resistant starch in sago starch were quantified using spectroscopy techniques at the LDITP Laboratory, IPB University. Pasting profile analysis was conducted using the Rapid Visco Analyzer (RVA) at the Food Process Technology Laboratory of ITP IPB. Color analysis was performed using a chromometer at the Nutritional Sciences Chemistry Laboratory, IPB University. Commercial sago starch was sourced from Pondok Sagu Metro in Bogor, West Java, while freshly harvested white oyster mushrooms were obtained from Cipayung and purchased at Pasar Teknik Umum (TU), Bogor, West Java. The study was conducted over a span of six months, from January to July 2024.

3 Result and discussion

The findings in Table 1 highlight the remarkable nutritional benefits of sago starch and white oyster mushroom flour. Sago starch contains 11.17 g of resistant starch per 100 g (dry basis). This study confirms that sago starch is a rich source of resistant starch. While the recommended daily intake (RDI) of resistant starch is at least 6 g for Americans, there are no established guidelines for Indonesia. Based on this recommendation, our study confirms that consuming at least 55% of 100 g of sago starch per day (6.14 g resistant starch) meets the criteria [10].

Table 1. Nutritional content of sago starch and oyster mushrooms

Nutritional value	Unit	Sago starch		Fresh oyster mushrooms		Oyster mushroom flour	
		wb	db	wb	db	wb	db
Energy	kcal/100g	354.23	*NA*	32.92	*NA*	352.32	*NA*
Carbohydrate	%	87.59	99.34	4.91	59.23	56.52	65.08
Protein	%	0.27	0.31	2.15	25.95	20.22	23.28
Lipid	%	0.31	0.36	0.52	6.29	5.04	5.81
Moisture	%	11.82	*NA*	91.71	*NA*	13.16	*NA*
Ash	%	0	0	0.71	8.53	5.07	5.84
Crude fiber	%	0.93	1.06	1.82	21.88	11.17	12.86
Resistant starch	g/100g	9.85	11.17	*NA*	*NA*	*NA*	*NA*
Phenol	mg/100g	17.81	20.20	9.69	116.81	360.8	415.46

Note: average, wb, wet basis; db, dry basis; n,3; values are from two repetitions of analysis (Duplo); NA, Not Analysis

Resistant starch (RS) is classified into five types (RS1–RS5). Types 2, 3, and 4 are commercially produced or modified and added as functional ingredients, while types 1, 2, 3, and 5 occur naturally in foods. Resistant starch exhibits low digestibility, which helps reduce glucose absorption and insulin resistance while promoting short-chain fatty acid (SCFA) absorption, contributing to weight loss. SCFAs regulate insulin secretion in the pancreas, free fatty acid flow in adipocytes, and appetite control in the brain, while also serving as an energy source for muscles. Resistant starch refers to a fraction of starch resistant to hydrolysis by amylase enzymes. It reaches the large intestine as colonic food, where it is fermented by microbiota into SCFAs, primarily acetic acid, propionic acid, and butyric acid [3]. SCFAs have multiple effects on the human body. SCFAs influence the reduction in cholesterol and triglyceride levels in the blood, provide the energy for colonocytes and promote themaintenance of a proper colonic epithelial status [11].

Table 1 highlights the relatively high fiber and phenolic content of oyster mushrooms. Fiber plays a crucial role in delaying gastric emptying, reducing hunger, aiding digestion, promoting weight loss, and lowering cholesterol levels. The fiber content in products enriched with oyster mushrooms positively influences health outcomes. Adequate fiber intake is linked to a reduced risk of metabolic diseases, including hypercholesterolemia and heart disease**.** Additionally, phenolic compounds exhibit potential antioxidant properties, which may inhibit free radical formation.

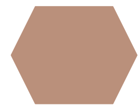
White oyster mushrooms are notable for their high protein content, as higher protein levels in food ingredients typically indicate superior quality. Our findings reveal a protein content of 23.28 g/100 g (dry basis). This discrepancy may be attributed to differences in drying methods, as their study employed an oven dryer, whereas we utilized a drum dryer for processing oyster mushrooms. Protein content from drum-dried mushrooms is comparable to those dried using other methods: 22.86 g via oven drying, 20.36 g via sun drying, and 21.79 g via osmotic drying techniques. The drying process, particularly temperature and duration, is critical for producing mushroom flour, as it significantly impacts shelf life [12].

Using an oven may cause mushroom pieces to clump together, hindering moisture evaporation and resulting in lower protein content. Drum drying is ideal for various starchy food products, including baby food and high-viscosity pastes. It is recognized as one of the most energy-efficient drying methods, as it exposes materials to high temperatures for only a few seconds. This informed our decision to adopt a suitable drying method to preserve the nutritional content of white oyster mushrooms.

The development of non-wheat pasta products depends on the processes of starch gelatinization and retrogradation. Table 2 demonstrates that sago flour exhibits a higher pasting profile compared to oyster mushroom flour. Sago starch demonstrates a peak viscosity of 4820 cp, significantly higher than the 50.5 cp exhibited by oyster mushrooms. Peak viscosity refers to the point at which starch granules have gelatinized to their maximum expansion. Sago starch exhibits strong gelatinization properties. When heated in water, sago starch absorbs moisture and swells, contributing to its high peak viscosity. Conversely, oyster mushrooms exhibit limited swelling properties. This research establishes that incorporating white oyster mushrooms, which contain polysaccharide compounds, can enhance molecular interactions between starch molecules, thereby optimizing peak viscosity. Water-binding capacity, as reflected by peak viscosity, positively correlates with the quality of the final product, particularly in terms of polymer release and expansion.

In this study, the breakdown viscosity of sago starch was measured at 3526 cp, which is relatively high. This is likely due to the brittleness of swollen starch granules, causing them to break apart under heat. In contrast, the breakdown viscosity of oyster mushrooms is significantly lower at only 2.0 cp. Breakdown viscosity refers to the reduction in viscosity after reaching its peak value. Oyster mushrooms contain enzymes that aid in gelatinization and reduce amylopectin levels, thereby enhancing viscosity stability. Lower breakdown viscosity reflects better starch stability under heat. With the lowest breakdown viscosity, oyster mushroom flour exhibits high heat stability. Thus, combining both ingredients can reduce breakdown levels and enhance the stability of products such as pasta.

Table 2. Physical characteristics of sago starch and oyster mushroom flour

Physical characteristics	**Unit**	**Sago starch**	**Oyster mushroom flour**
Color measurement			
L^*		94.25	63.09
a^*		2.95	12.95
b^*		4.71	17.3
Image			
Pasting profile			
Pasting temp	°C	73.5	0
Peak time	minute	6.07	11.63
Peak viscosity	cP	4820	50.5
Holding viscosity	cP	1294	48.5
Breakdown viscosity	cP	3526	2.0
Final viscosity	cP	2443	64.5
Setback viscosity	cP	1149	16

Note: average, L^*, lightness; a^*, green-red; b^*, blue-yellow; cP, centipoise n,2; values are from two repetitions of analysis (Duplo)

High final viscosity and rapid retrogradation are critical starch properties required for producing high-quality extruded products. Table 2 shows that sago starch exhibits a higher final viscosity of 2443 cp, compared to only 64.5 cp for oyster mushrooms. Final viscosity reflects the viscosity of starch paste after the final cooling stage (holding). This stage helps assess the stability of starch viscosity during processing, including heating, stirring, and cooling.

Setback viscosity indicates the starch's tendency to retrograde. With the lowest setback viscosity, oyster mushroom flour reduces the retrogradation capacity when added to pasta dough, potentially improving the quality of the final product. Increasing the proportion of oyster mushroom flour in the formulation enhances protein content but may compromise cooking quality and texture. The data from this study provide a foundation for optimizing formulations in future product development, aiming to minimize declines in cooking quality and texture.

Processing fresh oyster mushrooms into flour may trigger a browning reaction due to the presence of oxidase enzymes, which are responsible for the characteristic brown coloration. Browning reactions can be mitigated through pretreatment methods like blanching. Pretreatment processing aims to inactivate oxidase enzymes, thereby preventing browning reactions. Enzymatic browning arises from a reaction between the substrate and oxygen (O_2), catalyzed by phenolase enzymes present in oyster mushrooms. This reaction affects the water content, protein content, ash content, fat content, carbohydrate content, and color of oyster mushroom flour. Blanching oyster mushrooms yields the lowest browning index values among various pretreatments due to enzyme inactivation during the process [13].

Lin *et al.* (2022) demonstrated that polyphenol oxidase (PPO) activity was minimized at a blanching temperature of ±90°C and a blanching time of ±180 seconds (±3 minutes), indicating minimal browning [13]. In this study, sago starch exhibited a higher color brightness value (L) of 94.25, compared to 63.09 for oyster mushroom flour (Table 2). However, oyster mushroom flour displayed higher green-red (a) and blue-yellow (b) values than sago starch, indicating that when combined into formulations like pasta, these ingredients are expected to produce a unique color with a subtle brownish hue. Oyster mushrooms contain natural pigments that influence the final product's color. The natural color of oyster mushrooms when they become flour is brownish yellow and the color of oyster mushrooms before drying is yellowish white.

The yellow color of natural oyster mushroom flavoring can be caused by the Maillard reaction between reducing sugars and amino acids which can produce a brownish color. The Maillard reaction produces a brown material called melanoidin. It can be seen that the values are positive in oyster mushroom flour (Table 2), which indicates that it is possibly related to the Maillard reaction. This is because non-enzymatic browning reactions easily occur during pasta drying, especially at high and very high temperatures According to Sun *et al.* (2020), the umami taste and aroma of food mushrooms are closely linked to nucleotide metabolism, amino acid metabolism, fatty acid metabolism, and the Maillard reaction [14]. Additionally, the neutral color of sago starch can interact with the pigments of oyster mushrooms to create an appealing brownish tone.

The differences between these two foods present valuable opportunities to combine and complement them as functional food ingredients. Oyster mushrooms are rich in phenols, protein, and fiber, while sago provides a significant source of resistant starch. Additionally, the two ingredients possess distinct flour characteristics, making them suitable alternatives for developing gluten-free extruded products such as pasta (spaghetti) or noodles. Extrusion is an ideal technology for producing gluten-free pasta or noodles, as it facilitates gelatinization while applying pressure and kneading to form a robust structure.

Extrusion is an effective technology for producing gluten-free noodles, as it supports gelatinization and applies pressure and kneading to achieve a sturdy structure.The structure formation mechanism of gluten-free noodles differs significantly from that of wheat-based noodles. While wheat noodles depend on gluten protein for structure, gluten-free noodles rely on gelatinization and retrogradation processes. Nutritional content and profile are crucial factors and serve as key indicators for assessing the quality of gluten-free pasta or noodle products [15].

4 Conclusions

Sago starch is rich in resistant starch, while oyster mushroom flour offers high fiber and phenol content along with low lipid levels, making it a nutritious food ingredient. The substantial protein content in oyster mushrooms enhances the nutritional quality of functional food products under development. The diverse profiles and natural colors of these components make them ideal for developing extrusion-based food products, such as pasta and other culinary applications.

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