JOURNAL OF FOOD, CULINARY, AND NUTRITION

RESEARCH ARTICLE

Physicochemical Modulation by Tapioca Starch in Oyster Mushroom (*Pleurotus ostreatus*) Powder

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ABSTRACT
Oyster mushroom (*Pleurotus ostreatus*) is a nutritious and affordable food ingredient; however, its high moisture content results in a short shelf life. This study aimed to evaluate the effect of tapioca concentration on the physicochemical properties of oyster mushroom powder. The experiment was arranged in a single-factor randomized block design with six levels of tapioca concentration (2.5, 5.0, 7.5, 10.0, 12.5, and 15.0%) and four replications. Observed parameters included moisture content, water activity (aw), color characteristics (lightness, chroma, and hue), protein content, and crude fiber content. Data were analyzed using analysis of variance (ANOVA) at a 5% significance level, followed by Duncan's Multiple Range Test when significant differences were observed. The results showed that oyster mushroom powder had moisture content of 2.65–5.84%, aw of 0.145–0.506, lightness of 64.26–74.70, chroma of 10.42–18.90, hue of 76.50–83.74, protein content of 7.93–13.00%, and crude fiber content of 4.95–9.57%. Increasing tapioca concentration significantly reduced moisture content, aw, protein content, and crude fiber content of the powder.

KEYWORDS: *Oyster mushroom powder, Pleurotus ostreatus, tapioca starch, physicochemical properties*

Introduction

Oyster mushroom (*Pleurotus ostreatus*) is a widely cultivated edible fungus that has gained increasing attention due to its nutritional value, affordability, and versatility in food applications. It is commonly utilized to enhance the nutritional profile of processed foods or consumed as snack products such as crispy mushrooms. Owing to its characteristic meaty texture and pronounced umami taste, oyster mushroom is frequently applied as a partial meat substitute in products including nuggets, meatballs, and dumplings, supporting the development of plant-based and hybrid food formulations (Das et al., 2021; Effiong et al., 2024).

From a nutritional perspective, *P. ostreatus* contains substantial amounts of protein, carbohydrates, and dietary fiber, which contribute to its classification as a functional food ingredient. Recent compositional analyses have reported crude protein contents ranging from approximately 15–25% on a dry weight basis, depending on cultivation substrate and postharvest conditions (Devi et al., 2024; Effiong et al., 2024). In addition, oyster mushrooms provide essential minerals and bioactive compounds that further enhance their nutritional relevance in human diets (Mkhize et al., 2022). Amino acid profiling of *P. ostreatus* demonstrates the presence of both essential and non-essential amino acids, with acidic amino acids such as glutamic acid and aspartic acid predominating. These amino acids are key contributors to umami perception and are consistently reported as major components of oyster mushroom protein fractions, supporting their application as natural flavor enhancers in savory food systems (Wang et al., 2025).

Fresh oyster mushrooms have a relatively high moisture content, ranging from 85 to 89% (Effiong et al., 2024). High moisture levels in food materials shorten the shelf life of oyster mushrooms, as the presence of free water can stimulate microbial activity. Therefore, strategies to extend the shelf life of oyster mushrooms are required, one of which is processing them into oyster mushroom powder. As a natural source of glutamic acid, oyster mushrooms can be processed into mushroom powder that functions as a natural flavor enhancer, with added value due to their dietary fiber content of approximately 11.5% (Y. Zhang et al., 2024).

The high moisture content of oyster mushrooms also results in prolonged drying time during the production of oyster mushroom powder. Extended drying periods may lead to the loss of umami flavor, which is a critical quality attribute when oyster mushroom powder is intended for use as a natural seasoning. Oyster mushrooms can be dried, ground using a grinder, and then mixed with seasonings and binding agents to produce oyster mushroom powder (Piskov et al., 2022). However, direct drying of oyster mushrooms requires a considerable amount of time. Therefore, the incorporation of materials that can accelerate the drying process while preserving the characteristic umami flavor of oyster mushrooms is necessary. Tapioca starch was added during the production of oyster mushroom powder due to its capability to significantly decrease the drying time of product (Aziz et al., 2018).

Tapioca starch is a carbohydrate source commonly used as a binding agent and coating material in the production of oyster mushroom powder (Ali et al., 2022). During processing, a portion of the water present in the mushroom slurry is bound by starch, thereby facilitating the drying process. Starch molecules contain hydrophilic functional groups that enable water absorption. The amorphous regions of starch can absorb cold water up to approximately 30% of their weight (Sarifudin et al., 2020). The high number of hydroxyl groups within starch molecules enhances their water-binding capacity (Qiu et al., 2022). The presence of these hydroxyl groups promotes hydrogen bonding interactions between starch and water molecules in oyster mushrooms. Hydrogen bonds are relatively weak, therefore, the bound water can be released and evaporated when heat is applied during drying, resulting in a faster drying process.

The amylose content of tapioca starch further contributes to water absorption, as amylose exhibits a greater ability to form hydrogen bonds compared to amylopectin (Zhiguang et al., 2022). As a coating material, tapioca starch can mix uniformly with the core material, remains relatively inert, and forms a protective layer surrounding the coated material due to its low solubility in cold water and its tendency to form a suspension (Breuninger et al., 2009). Therefore, this study focused on the processing of oyster mushrooms into mushroom powder with the addition of tapioca starch as both a binding and coating agent, as well as to accelerate the drying process. Accordingly, this study aimed to evaluate the effect of tapioca starch concentration on the physicochemical properties of oyster mushroom powder.

Material and Method

Materials or Respondents

The materials used in this study included oyster mushrooms obtained from a mushroom supplier located in Surabaya, Indonesia; commercial tapioca starch and salt purchased from a local market in Surabaya. Chemicals used for analytical purposes included asbestos, antifoaming agent, concentrated sulfuric acid (H_2SO_4), distilled water, selenium dioxide (SeO_2) powder, 95% ethanol, sodium hydroxide (NaOH), potassium sulfate (K_2SO_4), mercuric oxide (HgO), ice water, zinc plates, 4% potassium sulfide (K_2S), 0.1 N hydrochloric acid (HCl), boric acid (H_3BO_3), 96% ethanol, bromocresol green, and methyl red indicator. All chemicals used were purchased from Merck, Darmstadt, Germany.

Instrumentation

The equipment used in this study included a cabinet dryer (AMTD 6, Aneka Mesin), gas stove (RI-712A, Rinnai), infrared thermometer (GM320, Zoyi), a digital top-loading balance (MR 1002, Mettler Denver Instrument), analytical balance (PX224, Ohaus), food processor (FP 323, Cosmos), 45-mesh sieve (AS200, Retsch). Meanwhile, instruments used for analysis included oven (FD56, Binder), water activity meter (HygroPalm AW1, Rotronic), a color reader (CR-300, Konica Minolta), macro-Kjeldahl apparatus (JGD 525, Auxilab).

Procedure

The experimental design employed was a randomized block design (RBD) with a single factor, namely tapioca starch concentration. The tapioca concentration factor consisted of six levels: 2.5%, 5.0%, 7.5%, 10.0%, 12.5%, and 15.0% (w/w) based on oyster mushroom slurry. Each treatment was replicated four times, resulting in a total of 24 experimental units.

Oyster Mushroom Powder Production

The production of oyster mushroom (Pleurotus ostreatus) powder was initiated by processing fresh mushrooms into slurry, followed by mixing with salt and tapioca starch and subsequent drying using a cabinet dryer. Fresh oyster mushrooms were first separated from their stipes, and only the caps were used. The mushroom caps were washed thoroughly under running clean water to remove adhering impurities. The cleaned mushrooms were then steam-blanched at 80 ˚C for 10 min and subsequently cooled at room temperature for 10 min. After cooling, the mushrooms were homogenized using a food processor at a speed of 25,000 rpm for 5 min until a uniform mushroom slurry was obtained. The mushroom slurry was then mixed with 5% of salt and tapioca starch according to the designated treatment levels until a homogeneous mixture was achieved. The mixture was evenly spread onto perforated stainless-steel trays with dimensions of $67.5 \times 53 \times 2.71$ cm, which were lined with baking paper. Drying was carried out in a cabinet dryer at 60 ˚C for 5 h. The dried material was subsequently ground using a grinder for 1 min and sieved through a 45-mesh sieve. The resulting mushroom powder was stored in amber glass bottles until further analysis.

Moisture Content Determination

The weighing bottles and their lids were dried in an oven at 105 ˚C for 30 min, then cooled in a desiccator and weighed until a constant weight was obtained. Approximately 1 g of sample was accurately weighed into the pre-weighed weighing bottle. The sample was dried in an oven at 105 ˚C for 3 h. After drying, the weighing bottle containing the sample was cooled in a desiccator for 10 min and then weighed. The sample and weighing bottle were reheated in the oven and reweighed. This heating, cooling, and weighing procedure was repeated until a constant weight was achieved. The moisture content of the sample was calculated using the equation 1.

$$Moisture\ content\ (\%) = \frac{weight\ of\ initial\ sample\ (g) - weight\ of\ final\ sample\ (g)}{eight\ of\ initial\ sample\ (g)}\ x\ 100\%$$

Water Activity Determination

Oyster mushroom powder was placed into the sample cup of the water activity meter (aw meter) up to the indicated fill line. The instrument was turned on, and the water activity of the sample chamber was first measured. The measurement was allowed to proceed until the water activity and temperature values were displayed on the screen and stabilized, indicated by code “5.” Subsequently, the water activity of the chamber was measured again, followed by the measurement of the sample. The water activity of each sample was measured in triplicate.

Color Examination using Color Reader

Color measurements were performed using a Minolta color reader by determining the L*, a*, and b* values. Oyster mushroom powder was packaged in polypropylene plastic. The sensor head of the instrument was directed toward the surface of the sample. The target button was pressed to record the color of the sample. The measured color parameters, namely L*, a*, and b* values, were recorded for each sample.

Protein Content Determination

Approximately 0.51 g of oyster mushroom powder was weighed and transferred into a 100 mL Kjeldahl flask. A total of 2 g of selenium catalyst mixture (composed of 2.5 g SeO_2, 100 g $K_2S_2O_4$, and 30 g $CuSO_4{\cdot}H_2O$) was added, followed by 25 mL of concentrated sulfuric acid (H_2SO_4). The mixture was heated on an electric heater or burner until boiling and digestion was continued until the solution became clear with a greenish tint, which required approximately 2 h. After cooling, the digest was diluted and transferred into a 100 mL volumetric flask, then brought to volume with distilled water. An aliquot of 5 mL of the diluted solution was pipetted into the distillation apparatus, followed by the addition of 5 mL of 30% NaOH and a few drops of phenolphthalein (PP) indicator. The mixture was distilled for approximately 10 min. The distillate was collected in 10 mL of 2% boric acid solution containing a mixed indicator. The condenser tip was rinsed with distilled water during distillation. The collected distillate was titrated with 0.01 N HCl. A blank determination was conducted under the same conditions. Protein content (%) was calculated using Equation (2).

$$Protein\ content\ (\%) = \frac{(V1\ -\ V2)\ \times\ N\ \times\ 0{,}014\ \times\ cf\ \times\ df}{W}\ x\ 100\%$$

Where W is the weight of the sample (g); V_1 is the volume (mL) of 0.01 N HCl used for titration of the sample; V_2 is the volume (mL) of 0.01 N HCl used for titration of the blank; N is the normality of the HCl solution; CF is the nitrogen-to-protein conversion factor; and DF is the dilution factor.

Crude Fiber Determination

Approximately 2 g of sample was weighed accurately. Fat was removed by Soxhlet extraction. The defatted sample was dried and transferred into a 500 mL Erlenmeyer flask. Subsequently, 50 mL of 1.25% H_2SO_4 solution was added, and the mixture was boiled for 30 min using a vertical condenser. Afterward, 50 mL of 3.25% NaOH solution was added, and the mixture was boiled again for 30 min. While still hot, the mixture was filtered through a Büchner funnel fitted with ashless filter paper (Whatman No. 42) that had been previously dried and weighed. The residue retained on the filter paper was washed sequentially with hot 1.25% H_2SO_4 solution, hot distilled water, and 96% ethanol. The filter paper containing the residue was then transferred into a pre-weighed weighing box, dried at 105 ˚C, cooled, and weighed repeatedly until a constant weight was obtained.

Data Analysis

Statistical analysis was performed using SPSS version 25. Data were analyzed by analysis of variance (ANOVA). When the ANOVA results indicated significant differences, mean comparisons were further conducted using Duncan's Multiple Range Test (DMRT) at a significance level of $\alpha = 5\%$.

Results and Discussion

Oyster mushroom powder is a promising alternative processed product that can expand the utilization of oyster mushrooms and serve as a natural flavor enhancer. However, the drying process of oyster mushrooms is time-consuming and may result in the loss of umami flavor compounds. Tapioca starch can function as a coating material to minimize umami flavor loss during drying while simultaneously facilitating a faster drying process.

Moisture Content

The moisture content of oyster mushroom powder ranged from 2.65% to 5.84%. The observed moisture levels were below 10%, which is considered low when compared with the moisture standard for powdered spices used as a reference, indicating that the product is sufficiently stable to inhibit the growth of molds and fungi. The quality requirement for moisture content of oyster mushroom powder was evaluated using the moisture standard for powdered spices according to SNI 01-3709-1995, which specifies a maximum moisture content of 12% (w/w) (National Standardization Agency, 1995). The addition of tapioca starch at different concentrations significantly affected the moisture content of the oyster mushroom powder. The results of moisture content analysis of oyster mushroom powder are presented in Figure 1.

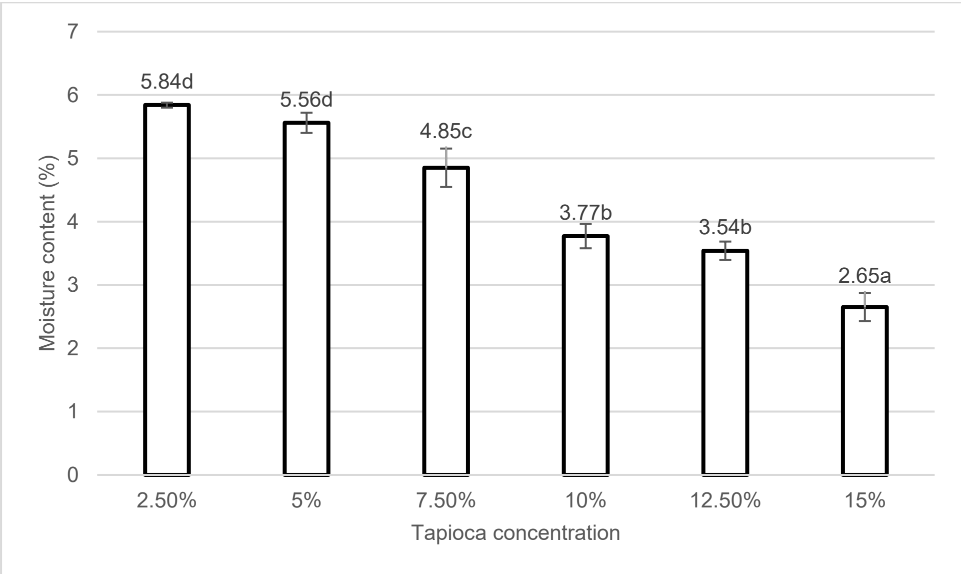

Figure 1. Moisture content of oyster mushroom powder.

The moisture content analysis demonstrated a clear decreasing trend in oyster mushroom powder as the concentration of tapioca starch increased, indicating that moisture content was strongly influenced by the level of starch addition. This reduction in moisture content can be attributed to the function of tapioca starch as a starch-based binding agent during powder production. Tapioca starch consists of approximately 17% amylose and 83% amylopectin (Chamorro et al., 2025), both of which contain abundant hydrophilic hydroxyl groups capable of interacting with water molecules. The amorphous regions of starch granules are known to absorb water, contributing to initial water binding within the food matrix (Li et al., 2024). Recent studies have further confirmed that starch–water interactions are governed by starch composition, molecular structure, and the availability of hydroxyl groups that form hydrogen bonds with water (J. Zhang et al., 2024).

In the present study, tapioca starch incorporated into the mushroom slurry did not undergo gelatinization; therefore, its water absorption capacity remained limited. Under non-gelatinized conditions, water bound to starch hydroxyl groups is relatively weakly associated and can be readily released during thermal processing. Hydrogen bonding between starch molecules and water is inherently weak (Zhiguang et al., 2022), and increasing tapioca concentration increases the number of hydroxyl groups available for such interactions. Upon heating during drying, these weak bonds are disrupted, facilitating moisture release. Similar mechanisms have been reported in recent studies, which demonstrated that higher starch concentrations enhance moisture mobility and promote water removal during drying due to increased starch–water interactions within the amorphous regions of starch granules (Jia et al., 2023). Consequently, the addition of higher tapioca starch concentrations accelerated the drying process, resulting in greater evaporation of free and weakly bound water during the 5 h cabinet drying period. This behavior aligns with findings reported that increasing starch concentration significantly alters hydration behavior and enhances moisture loss during thermal processing (Mauro et al., 2023).

Water Activity (a_w)

The water activity (a_w) of the oyster mushroom powder was in the range of 0.145–0.506, which is well below the critical a_w required for microbial growth. This indicates that the product is microbiologically stable and has a low risk of spoilage during storage. The results also revealed that differences in tapioca starch concentration added to the mushroom slurry significantly affected the a_w of the resulting powder. The water activity values of oyster mushroom powder at different tapioca starch concentrations are shown in Figure 2.

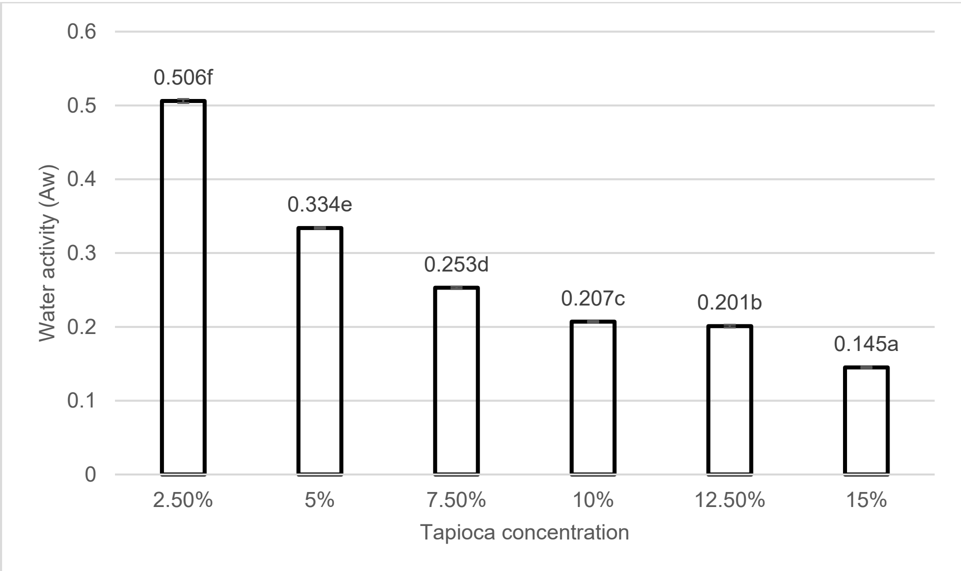

Figure 2. Water activity of oyster mushroom powder.

The results of water activity (a_w) testing for the oyster mushroom powder shown in Figure 2 indicate that the highest aw value occurred at the 2.5% tapioca starch treatment (0.506), and a_w decreased progressively with increasing tapioca concentration. All treatments exhibited significantly different a_w values. The reduction in a_w with increasing tapioca concentration corresponds with the observed decrease in moisture content, as both parameters are closely related measures of available water in dehydrated food systems. Lower water activity values reduce the amount of free water available for microbial metabolism, which in turn inhibits the growth of spoilage organisms and pathogens; most bacteria require an a_w above approximately 0.90 for growth, while molds and yeasts generally are unable to proliferate below a_w ~0.65 (Peleg, 2022).

The addition of tapioca starch likely contributed to this effect by increasing the binding of water within the powder matrix. Higher tapioca concentrations provide more hydroxyl groups capable of interacting with water molecules through hydrogen bonding, thereby reducing the availability of free water during drying and further lowering the a_w of the finished product. This mechanism is consistent with the role of dry ingredients and carrier matrices in reducing water activity by immobilizing water within the solid matrix during dehydration processes (Pereira et al., 2024).

These findings demonstrate that tapioca starch effectively enhances the drying process and contributes to the production of oyster mushroom powder with a water activity below levels that support microbial growth, thereby improving its microbiological stability and shelf life.

Color

The results of color analysis of the oyster mushroom powder showed that the L* values ranged from 64.26 to 74.70, indicating moderate to high lightness. The a* values ranged from 1.14 to 4.41, reflecting a slight tendency toward redness, while the b* values ranged from 10.36 to 18.38, indicating a dominant yellow coloration. In addition, the chroma values ranged from 10.42 to 18.90, suggesting variations in color intensity, whereas the °hue values ranged from 76.50 to 83.74, corresponding to a yellowish color region (Table 1).

Table 1. Color of oyster mushroom powder.

Color parameters	Tapioca concentrations					
	2.5%	5%	7.5%	10%	12.5%	15%
L	64.26 ± 0.16[a]	64.63 ± 0.23[a]	65.64 ± 0.25[ab]	66.63 ± 0.18[b]	68.45 ± 0.30[c]	74.70 ± 0.42[d]
a*	4.41 ± 0.30[e]	3.34 ± 0.23[d]	2.58 ± 0.23[c]	1.79 ± 0.25[b]	1.46 ± 0.09[a]	1.14 ± 0.08[a]
b*	18.38 ± 0.29[f]	16.45 ± 0.31[e]	14.41 ± 0.28[d]	12.34 ± 0.31[c]	11.53 ± 0.99[b]	10.36 ± 0.27[a]
C	18.90 ± 0.32[f]	16.79 ± 0.35[e]	14.64 ± 0.27[d]	12.47 ± 0.3 [c]	11.62 ± 0.27[b]	10.42 ± 0.28[a]
°h	76.50 ± 0.82[a]	78.54 ± 0.60[b]	79.87 ± 0.99[c]	81.76 ± 1.14[d]	82.76 ± 0.62[e]	83.74 ± 0.32[f]

Note: Values with different superscript letters are significantly different ($p < 0.05$).

The results showed that the lightness (L*) value of oyster mushroom powder increased with increasing concentrations of tapioca starch. This increase in lightness can primarily be attributed to the higher proportion of tapioca starch incorporated into the mushroom slurry. Tapioca starch is inherently white in color, and its addition dilutes the darker pigments of the mushroom matrix, resulting in a brighter final powder. Similar whitening effects of starch addition have been reported in starch-based composite powders and encapsulated food ingredients (Li et al., 2025; Zhu, 2015). In addition to formulation effects, lightness is also influenced by moisture content. Lower moisture levels generally produce lighter-colored products, as water can enhance light absorption by darker components in food matrices. Products with higher moisture content tend to appear darker due to increased light absorption and reduced reflectance. In the present study, the reduction in moisture content with increasing tapioca concentration likely contributed to the observed increase in L* values, reinforcing the combined effect of starch addition and moisture reduction on powder brightness.

The a* values of oyster mushroom powder were positive, indicating the presence of reddish tones in all treatments. This reddish coloration is associated with non-enzymatic browning reactions, particularly the Maillard reaction, which occurs during thermal processing. Oyster mushrooms contain amino acids and reducing sugars that readily participate in Maillard reactions during drying, leading to the formation of brown-colored melanoidin compounds (Rohmah et al., 2022; Zhao et al., 2024).

Previous studies have shown that drying temperature plays a critical role in the development of Maillard browning in mushrooms, likely due to the initiation of polymerization stages forming melanoidins (Wang et al., 2024). In the present study, drying was conducted at 60 °C for 5 h using a cabinet dryer, a temperature range conducive to Maillard reactions. Under these conditions, melanoidin formation likely intensified, contributing to the reddish-brown hues reflected by positive a* values. Red is one of the fundamental color components contributing to brown coloration, explaining the observed increase in a* values in the mushroom powder.

Moreover, starch addition may indirectly influence Maillard browning by reducing water activity and shortening effective drying time, which can modify reaction kinetics. Lower water activity favors Maillard reactions up to an optimum level, after which browning intensity may decrease (El Hosry et al., 2025). Therefore, the combined effects of drying temperature, reduced moisture content, and tapioca starch incorporation played a significant role in determining the color characteristics of the oyster mushroom powder.

The yellow coloration observed in oyster mushroom powder is primarily associated with the formation of brown-colored melanoidin compounds produced through the Maillard reaction during the drying process. Yellow is one of the fundamental color components contributing to brown hues; therefore, the presence of yellow tones in the powder reflects intermediate stages of melanoidin formation. Thermal processing of oyster mushrooms, which are rich in amino acids and reducing sugars, promotes Maillard reactions that generate yellowish to brown pigments depending on reaction intensity and processing conditions (El Hosry et al., 2025).

The b* values decreased progressively with increasing concentrations of tapioca starch. This trend can be attributed to the whitening effect contributed by tapioca starch, which diluted the brown pigments formed during drying. The white color of tapioca starch increasingly dominated the visual appearance of the powder as its concentration increased, resulting in reduced yellow–brown color intensity. Similar dilution effects of starch addition on color attributes have been reported in starch-based composite powders and encapsulated food systems (Schlindweinn et al., 2022; Sultana et al., 2025) . Meanwhile, the hue angle (°hue), which represents the qualitative aspect of color on a scale ranging from 0° to 360°, indicated that the oyster mushroom powder fell within the red–yellow region (54°–90°). This red–yellow hue range is characteristic of food products undergoing Maillard browning, where melanoidin pigments impart yellowish-brown to reddish-brown coloration. The red–yellow color tones observed in this study further confirm the occurrence of Maillard reactions during cabinet drying at elevated temperatures.

Chroma values, which describe color saturation or intensity, decreased with increasing tapioca starch concentration. Higher chroma values indicate more vivid or saturated colors, whereas lower chroma values reflect duller or more faded coloration. The reduction in chroma observed in this study suggests that increasing tapioca concentration led to a gradual fading of color intensity in oyster mushroom powder. This phenomenon is consistent with the increasing dominance of white starch particles within the powder matrix, which reduces the visual prominence of melanoidin pigments formed during drying. Similar reductions in chroma have been reported in starch-enriched dried food powders and encapsulated flavor (Bao et al., 2024). Overall, the combined changes in b*, hue angle, and chroma values demonstrate that tapioca starch addition significantly modified the color profile of oyster mushroom powder by reducing the intensity of Maillard-derived pigments and producing a lighter, less saturated appearance.

Protein Content

Protein content is an important physicochemical parameter because oyster mushrooms are naturally rich in proteins and amino acid precursors that contribute to umami taste. During processing and formulation with tapioca starch, changes in protein concentration may occur due to dilution effects or interactions between mushroom components and starch. Since umami perception is largely associated with free amino acids, particularly glutamic acid and aspartic acid, the protein content can serve as an indicator of the potential availability of taste-active compounds. Therefore, determining protein content helps evaluate how tapioca starch incorporation affects the nutritional quality and the potential umami characteristics of the mushroom powder. The protein content of oyster mushroom powder for each treatment is presented in Figure 3. The results demonstrate a decreasing trend in protein content with increasing concentrations of tapioca starch. This decline is expected, as the addition of tapioca starch characterized by a very low protein content dilutes the overall protein concentration of the resulting powder. Fresh oyster mushrooms are known to contain relatively high protein levels, reported to be in the range of 31-38% on a dry weight basis (Maseko et al., 2024). However, the protein content of oyster mushroom powder obtained in this study was lower than that of fresh mushrooms. This reduction can be attributed in part to protein losses during preliminary processing, particularly the blanching step. Blanching involves exposure to heat and moisture, which can cause partial denaturation and solubilization of mushroom proteins, leading to their leaching into the blanching medium and subsequent loss from the solid matrix. Several recent studies have confirmed that blanching significantly affects protein retention in mushrooms and other plant-based foods. Heat treatment disrupts cell membranes and protein structures, facilitating the diffusion of soluble proteins and nitrogenous compounds into surrounding water or steam condensate (Daud et al., 2024; Pursito et al., 2022).

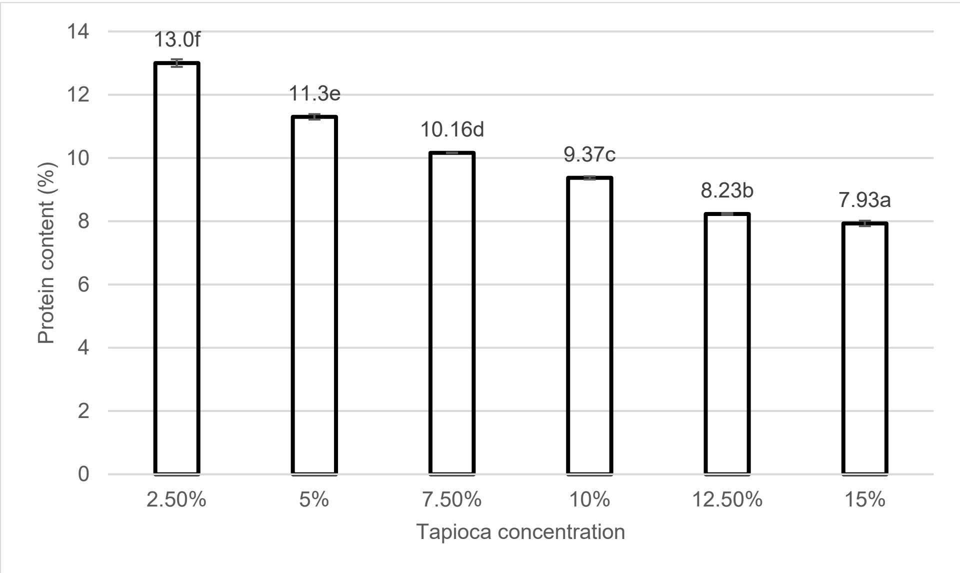

Figure 3. Protein content of oyster mushroom powder.

Crude Fiber Content

Crude fiber is an important parameter because it reflects the dietary fiber content that contributes to the nutritional value of oyster mushroom powder. The addition of tapioca starch may alter the fiber concentration through dilution effects, making fiber analysis necessary to assess compositional changes in the product. Furthermore, fiber influences water-holding capacity and other functional properties that affect product quality. The results of crude fiber analysis are presented in Figure 4. The crude fiber content of oyster mushroom powder ranged from 4.95% to 9.57%. The highest crude fiber content (9.57%) was observed in the treatment with 2.5% tapioca starch, and it progressively decreased with increasing tapioca concentration. This trend indicates that tapioca addition significantly influenced the crude fiber content of the final product.

Fresh oyster mushrooms are reported to contain approximately 23.63% crude fiber (Effiong et al., 2024). The lower crude fiber values observed in the mushroom powder compared to fresh mushrooms can be attributed to both processing effects and formulation composition. The reduction in crude fiber content with increasing tapioca concentration is primarily associated with the dilution effect caused by the addition of tapioca starch. Tapioca starch is composed almost entirely of digestible carbohydrates and does not contain fiber; therefore, increasing its proportion in the mushroom slurry reduces the relative contribution of fiber-rich mushroom material in the final powder. Moreover, to achieve optimal physical stability with lower Aw and moisture content via tapioca addition, the formulation must sacrifice a degree of protein and fiber content.

Tapioca starch functions as a filler and binding agent in the formulation. As its concentration increases, the proportion of oyster mushroom decreases, resulting in a corresponding decline in crude fiber content. Similar findings have been reported in starch-enriched food systems, where the incorporation of starch-based fillers led to significant reductions in crude fiber due to compositional dilution (Feng et al., 2025). Recent studies on mushroom-based powders and seasoning formulations have also confirmed that the addition of carrier agents such as starch or maltodextrin reduces fiber content by decreasing the fraction of plant cell wall components, including cellulose, hemicellulose, and lignin (Pamalka et al., 2026). Overall, these results suggest that while tapioca starch improves drying efficiency and physical properties, its concentration must be carefully optimized to maintain the nutritional quality, particularly the dietary fiber contentof oyster mushroom powder.

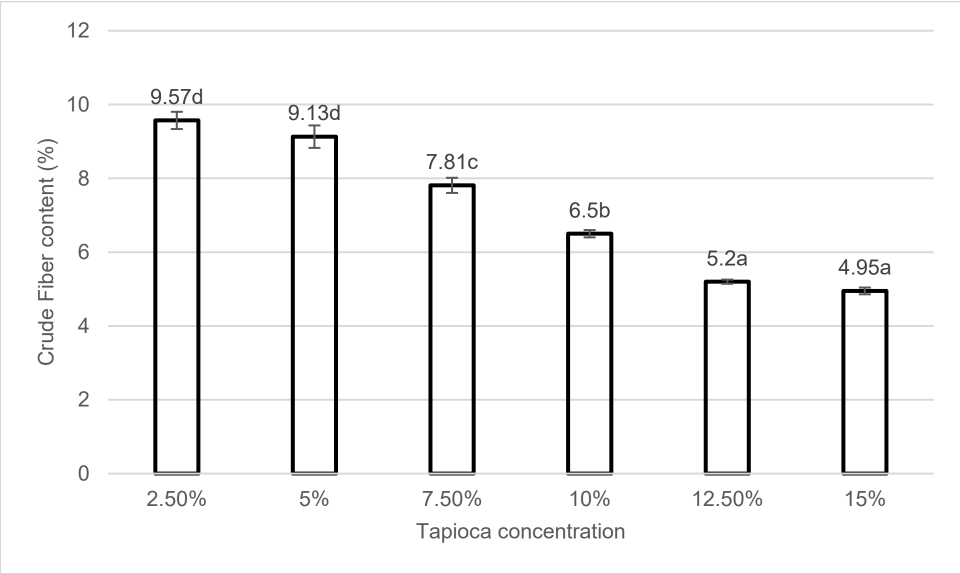

Figure 4. Crude fiber content of oyster mushroom powder.

Conclusion

The addition of tapioca starch significantly affected the physicochemical properties of oyster mushroom powder, particularly moisture content and water activity (Aw). Increasing tapioca concentration resulted in a reduction in moisture content (from 5.84% to 2.65%), Aw (from 0.506 to 0.145), protein content (from 13.00% to 7.93%), and crude fiber content (from 9.57% to 4.95%). Meanwhile, the lightness (L*) values of the oyster mushroom powder ranged from 64.26 to 74.70, and the hue angle ranged from 76.50 to 83.74, indicating a color shift toward lighter yellow–reddish tones with increasing tapioca levels. Tapioca starch shows strong potential as a binding and coating agent in oyster mushroom formulations, as its incorporation facilitates faster drying while producing mushroom powder with favorable physical stability and acceptable chemical quality. This study is limited to the evaluation of basic physicochemical properties and does not directly quantify umami-related compounds. Consequently, the effect of tapioca starch on the actual umami intensity of oyster mushroom powder could not be fully elucidated. Future research should investigate the profile of taste-active compounds and conduct sensory evaluation to better understand the relationship between starch addition and umami perception. Additionally, storage stability and functional performance of the powder in food applications warrant further investigation.

Conflict of Interest

The authors declares no conflict of interest.

Author Contributions

IRAPJ designed the experiment, performed statistical analysis, and revised the manuscript, ES conducted the experiment, calculation of the data, and wrote the initial manuscript. SM conducted the experiment, performed the analysis, and wrote the initial manuscript All authors agreed to the final version of this manuscript.

Ethical Statement

There is no human or animal study involved in this manuscript

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Cite this article: Maru, S., Setijawaty, E., & Jati, I.R.A.P. (2026). Physicochemical Modulation by Tapioca Starch in Oyster Mushroom (*Pleurotus ostreatus*) Powder. *Journal of Food, Culinary, and Nutrition*, 2(2), 117-130. https://doi.org/10.24167/jfcn.v2i2.15033