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Effect of nano edible coating, storage temperature, and packaging on water content, weight loss, and color on oyster mushrooms (*Pleurotus ostreatus*)

Abstract. Oyster mushrooms are one of the most commonly consumed mushrooms due to their high nutritional content, including protein, fiber, vitamins, and minerals, as well as their antioxidant properties. However, these mushrooms are easily damaged by microbes and poor post-harvest handling, which affects their quality. The combination of nano-edible coating, packaging, and storage temperature offers a solution to these issues. This study aims to evaluate the effects of nano-edible coating, packaging, and storage temperature on water content, weight loss, and the color (L^* , a^* , and b^*) of oyster mushrooms. The study was conducted at the Horticulture Laboratory, Faculty of Agriculture, Universitas Padjadjaran. The experimental design used was a Completely Randomized Block Design (CRBD) with 19 combinations of nano-edible coating (sodium alginate and aloe vera), packaging (biodegradable, wrap, and vacuum plastic), and storage temperature (± 25 °C, 10 °C, and 5 °C). Each treatment was replicated twice, resulting in 38 experimental units, each consisting of three mushrooms weighing 100 g, with fresh white color, no physical damage, and uniform shape and weight. This resulted a total of 114 mushroom samples. The results showed that the combination of nano edible coating treatment, packaging, and storage temperature significantly affected the water content, weight loss, and color parameters (L^* , a^* , b^*) of mushrooms at 3, 6, and 9 DAT. The combination of nano sodium alginate and nano aloe vera, when vacuum-packaged at 5 °C, produced the best results for water content, weight loss, and colour. These results indicated the potential of the treatment to maintain the quality of oyster mushrooms during storage.

Keywords: *Pleurotus ostreatus* · nano sodium alginate · nano aloe vera · packaging · yield quality

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Introduction

Oyster mushrooms (*Pleurotus ostreatus*) are a popular type of mushroom. Besides their delicious taste, oyster mushrooms serve as functional foods, significantly enhancing the nutritional value of foods (Effiong et al., 2024). Oyster mushrooms have a high carbohydrate content and are considered a functional food, containing various oligosaccharides, ergothioneine, and mono- and disaccharides that function as prebiotics and are very beneficial for maintaining a healthy gut microbiome (Li et al., 2015; Mishra et al., 2022).

Oyster mushrooms are high in protein, fiber, vitamins, minerals, and antioxidants. Oyster mushrooms are low in fat and calories, making them very suitable for a healthy eating pattern (Sassine et al., 2022). Oyster mushrooms are native to China and are now distributed worldwide, except in the Northwest Pacific region due to Arctic conditions. Oyster mushrooms cultivation methods developed rapidly in Germany during World War I and were later successfully implemented on a large scale (Piska et al., 2017). Despite their nutritional value and health benefits, oyster mushrooms also face significant challenges in production and distribution: their short shelf life due to their high-water content makes them susceptible to microbial spoilage and oxidation (Sassine et al., 2022).

Nano-edible coating technology has been developed as an innovative solution. Nano-edible coating is a thin layer based on natural ingredients applied to the surface of food using nano particles. This technology not only extends shelf life but also maintains the nutritional quality, flavor, and texture of oyster mushrooms (Sassine et al., 2022).

The main ingredients used in edible coating technology are sodium alginate and aloe vera. Sodium alginate has the potential to maintain the quality and extend the shelf life of horticultural products by inhibiting water loss and gas exchange (Zhu et al., 2019). Meanwhile, the gel (mucilage) obtained from aloe vera leaves is a polysaccharide-based coating material with anti-browning, antioxidant, and antifungal properties due to its anthraquinone and saponin content (Raghav et al., 2016). This mucilage has low barrier properties against moisture loss in some fruits (Mohammadi et al., 2021). Storing mushrooms at low temperatures is also an effort

to maintain mushroom quality and reduce physiological damage. For example, mushrooms stored at 3°C will maintain their appearance in good condition for up to 7 days. This is because low temperatures can slow the respiration rate and microbial activity in oyster mushrooms (Rahman et al., 2020).

One way to solve postharvest handling issues is through packaging. Proper packaging can protect fresh oyster mushrooms from environmental influences (sunlight and humidity). Many types of packaging are used to store fresh produce, such as mushrooms. Currently, most food products are packaged using plastic materials (Mohammadi et al., 2022).

Vacuum-packaged mushrooms in plastic have the advantage of extending their shelf life. Vacuum plastic packaging allows for the air circulation necessary for respiration, thus preventing the buildup of water vapor. Vacuum packaging can also inhibit the activity of microorganisms, which is the primary cause of softening (hardening) of oyster mushrooms (Aftukha & Purbasari, 2021). In addition to vacuum plastic packaging, biodegradable plastic packaging offers another alternative for short-term storage and helps reduce the environmental risks associated with conventional, non-degradable plastics (Shaikh et al., 2021).

The combination of nano-edible coating and packaging, along with storage temperature, is essential for maintaining postharvest oyster mushroom quality. Several studies, such as those showing that a nano-edible coating of sodium alginate is effective at forming a barrier against water loss (Chen et al. 2021) and those showing that aloe vera gel has strong antimicrobial properties (Nishant et al., 2023), have separately extended the shelf life of mushrooms. However, studies systematically combining both types of nano-edible coating (nano-sodium alginate and nano-aloe vera) with various packaging types (vacuum, wrap, and biodegradable) and storage temperatures (5 °C, 10 °C, and 25 °C) remain very limited. Postharvest handling of oyster mushrooms, along with proper temperature control, is crucial to maintaining their quality. Therefore, this study aims to evaluate the effects of combinations of nano-edible coating types, packaging, and storage temperature on the quality of oyster mushrooms. Identify the most effective treatments for the quality and shelf life of oyster mushrooms. It is hoped that this research will contribute to scientific

understanding of the synergistic mechanisms underlying the most effective combination treatments for maintaining the quality and extending the shelf life of post-harvest oyster mushrooms.

Materials and Methods

This research was conducted at the Horticulture Laboratory, Faculty of Agriculture, Universitas Padjadjaran, from August 2024 to May 2025. The materials used in this research included oyster mushrooms, nano sodium alginate, nano aloe vera, biodegradable plastic, wrap plastic, vacuum plastic, Folin-Ciocalteu reagent, 7.5% sodium bicarbonate solution, gallic acid, methanol, 10% aluminium chloride, 2 M sodium acetate solution, distilled water, and quercetin. The tools used include an oven (Memmert, UM 300, Germany); analytical balance (Mettler Toledo, Switzerland); reflectance spectrophotometer (Konica Minolta, CM-600D, Japan); digital scales; thermo recorder; UV-Vis spectrophotometer (Shimadzu, Uv-1601, Japan); centrifuge; sonicator; pipette; measuring cup; 50 mL test tube; vacuum and sealer; knife; cutting board; grinder; water bath; and 10 mL glass bottle, cooler, refrigerator, and freezer.

The experiment design used a Completely Randomized Block Design (CRBD) with a combination of nano edible coating treatments consisting of nano sodium alginate (NSA) and nano aloe vera (NAV); packaging (biodegradable plastic, wrap plastic, and vacuum plastic), and storage temperatures (± 25 °C, 10 °C, and 5 °C). A total of 18 treatment combinations and one control without treatment (without coating and packaging, stored at room temperature) were each replicated twice, resulting 38 experimental units. Each unit consisting of 3 mushrooms (100 g) was observed at 0, 3, 6, and 9 days after treatment (DAT). The combination treatments are as follows:

- P0: Control (without coating treatment, packaging, storage 25 °C)
- P1: NSA + 25 °C + vacuum
- P2: NSA + 25 °C + wrap
- P3: NSA + 25 °C + biodegradable
- P4: NSA + 10 °C + vacuum
- P5: NSA + 10 °C + wrap
- P6: NSA + 10 °C + biodegradable
- P7: NSA + 5 °C + vacuum
- P8: NSA + 5 °C + wrap
- P9: NSA + 5 °C + biodegradable

- P10: NAV + 25 °C + vacuum
- P11: NAV + 25 °C + wrap
- P12: NAV + 25 °C + biodegradable
- P13: NAV + 10 °C + vacuum
- P14: NAV + 10 °C + wrap
- P15: NAV + 10 °C + biodegradable
- P16: NAV + 5 °C + vacuum
- P17: NAV + 5 °C + wrap
- P18: NAV + 5 °C + biodegradable

The data were analyzed using the F-test to assess the treatment effect, followed by the Scott-Knott test to compare treatments at the 5% level. The analysis was performed using Microsoft Excel software equipped with the Smart Stat XL add-in.

The observation parameters included water content, weight loss, and color. The measurements were conducted on days 0, 3, 6, and 9 DAT. Water content determination is in accordance with SNI 01-2891-1992. Samples (4 g) were weighed to obtain the initial weight, dried in an oven at 105 °C for 3 hours, cooled in a desiccator, and reweighed until the weight was constant. Water content (%) was calculated using the equation:

$$\text{Water content (\%)} = \frac{(W_{\text{wet}} - W_{\text{dry}})}{W_{\text{dry}}} \times 100$$

W_{wet} = wet weight, W_{dry} = dry weight

Weight loss was observed by weighing mushrooms using an analytical balance to determine weight loss during storage. Mushroom weight loss was calculated using the equation:

$$W = \frac{(m_i - m_t)}{m_i} \times 100$$

W = weight loss, m_i = initial weight (g), m_t = final weight (g)

Color was measured on the top and bottom of oyster mushrooms (3 body mushroom/sample) using a spectrophotometer reflectance (Konica Minolta, CM-600D, Japan) to obtain the values of L^* , a^* , and b^* (Cavusoglu et al., 2021).

The oyster mushrooms, white, clean, and unpolluted, are damaged and then stored in a container with each weighing 100 g which has been coated 1% edible nano coating, made of Aloe vera and sodium alginate (300 nm),

provided by the Functional Nano University Centre of Excellence (FiNder U-CoE), Universitas Padjadjaran. The coating method is carried out by pouring nano sodium alginate and nano aloe vera powder evenly over the sieve onto the mushrooms that have been stored in the container, then brushing the powder over the surface of the mushroom fruit body evenly, let it sit for 5 - 10 minutes, then packing some of the mushrooms using plastic wrapping with a styrofoam *base* tightly, some mold packed inserted into biodegradable plastic, tied securely meeting and some mold again packed put in plastic vacuum. The oyster mushrooms have been packed in cans and stored at room temperature ($\pm 25^\circ\text{C}$), 5°C , and 10°C . Meanwhile, the oyster mushrooms treatment control, without coating and packaging, was stored at $\pm 25^\circ\text{C}$ on a bamboo-based tray lined with HVS paper.

Results and Discussion

Water content. Water content is a critical indicator of oyster mushroom quality. Based on Table 1, observations of water content in oyster mushrooms on days 0, 3, 6, and 9 DAT showed that water content decreased over time. Observations on day 0 DAT showed not significant differences between treatments based on anova (data not shown). The highest variation in water content was found in treatment P7 (NSA + 5°C + wrap) at 99.98%, while the lowest was

found in treatment P12 (NSA + 25°C + biodegradable) at 80.85 %. This indicated that oyster mushrooms naturally have a fairly high-water content. Observation on day 3 DAT showed different results across all treatments. Based on the Scott-Knot test at the 5% level, the treatments were grouped into two groups based on significant differences in water content. Treatment at room temperature (25°C) is marked with the notation 'a' (first group), namely P0, P1, P2, P3, P10, P11, P12, which have a lower water content value of 80.64 - 84.47% with faster water loss marked by the white color of the oyster mushrooms becoming less fresh and slightly brownish. Treatment at low temperatures of 5°C and 10°C is marked with the notation b (second group) with a water content of 86.30 - 93.72% with closed packaging (P4, P5, P6, P7, P8, P9, P13, P14, P15, P16, P17, P18) with the physical characteristics of the white color of the oyster mushrooms can still maintain their freshness. On day 6 DAT, the room-temperature treatment (25°C) generally showed lower water content (73.44 - 81.70%) than the low-temperature treatments (5°C and 10°C), with still high-water content (81.22 - 93.72%). Low storage temperatures (5°C and 10°C) can reduce water loss from respiration and transpiration. Observations on day 9 DAT showed rotting, dry, and damaged mushrooms, especially in the treatments stored at 25°C (room), which were not observed in treatments P1, P2, P3, P10, P11, and P12. An increase in respiration rate causes this.



Figure 1. Mushroom coating process; (a) mushrooms weighed 100 g; (b) sprinkle coating powder over the mushrooms using a sieve; (c) coating process with a brush; (d) coated mushrooms are left to rest for 10 minutes, ready to be packaged and stored

Table 1. Effect of various combinations of nano coating, packaging, and storage temperature on the water content of the oyster mushrooms

Treatment	Water content (%)			
	0 DAT	3 DAT	6 DAT	9 DAT
P0 = Control (without treatment <i>coating</i> , packaging, storage 25 °C)	91.67 a	83.77 a	81.70 a	49.60 b
P1: NSA + 25 °C + vacuum	86.49 a	83.35 a	80.03 a	0.00 a
P2: NSA + 25 °C + wrap	84.87 a	82.82 a	80.80 a	0.00 a
P3: NSA + 25 °C + biodegradable	83.48 a	81.63 a	73.44 a	0.00 a
P4: NSA + 10 °C + vacuum	93.88 a	92.45 b	92.20 b	91.70 e
P5: NSA + 10 °C + wrap	94.40 a	92.27 b	91.50 b	90.40 e
P6: NSA + 10 °C + biodegradable	89.99 a	86.30 b	84.64 b	80.99 d
P7: NSA + 5 °C + vacuum	99.73 a	93.70 b	92.45 b	91.98 e
P8: NSA + 5 °C + wrap	99.98 a	92.76 b	91.75 b	91.09 e
P9: NSA + 5 °C + biodegradable	92.16 a	88.52 b	81.22 a	70.75 c
P10: NAV + 25 °C + vacuum	89.44 a	82.35 a	80.36 a	0.00 a
P11: NAV + 25 °C + wrap	84.51 a	84.47 a	81.21 a	0.00 a
P12: NAV + 25 °C + biodegradable	80.85 a	80.64 a	78.20 a	0.00 a
P13: NAV + 10 °C + vacuum	91.47 a	90.21 b	90.15 b	84.42 a
P14: NAV + 10 °C + wrap	93.72 a	93.70 b	91.79 b	83.81 a
P15: NAV + 10 °C + biodegradable	91.45 a	89.60 b	84.91 a	83.71 a
P16: NAV + 5 °C + vacuum	92.43 a	92.30 b	91.15 b	90.51 e
P17: NAV + 5 °C + wrap	92.90 b	90.36 b	90.06 b	89.28 e
P18: NAV + 5 °C + biodegradable	90.37 a	86.89 b	84.64 a	80.33 d

Note: Means followed by the same lowercase alphabet in the same column are not significantly different based on the Scott-Knot test at 5%, DAT: Day After Treatment, NSA: Nano Sodium Alginate, NAV: Nano Aloe Vera. A value of 0.00 indicates that the samples had completely deteriorated and were unavailable for further analysis at 9 DAT

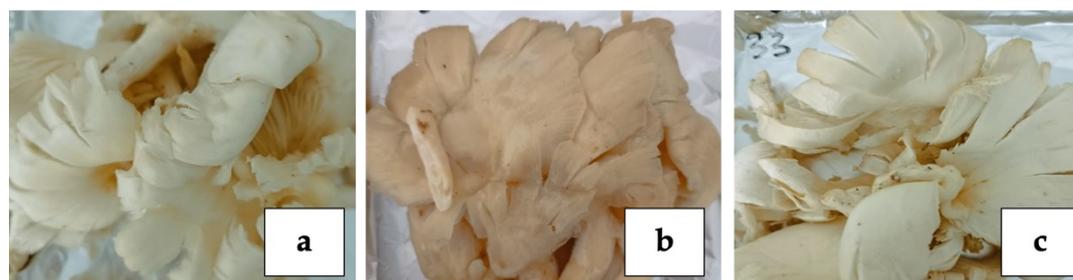


Figure 2. Visual comparison of the freshness of oyster mushrooms at 9 DAT at a temperature of 5 °C with nano sodium alginate and different packaging treatments: a. Vacuum plastic; b. Wrapping plastic, and c. Biodegradable plastic

Treatment control (P0) oyster mushrooms without packing will experience the process of respiration and transpiration, which is caused by the existence of interaction in a way constant to gas composition in the environment storage, so that metabolic activity happens normally, which shows degradation color going very fast browning (Yuniarto et al., 2024). Storage at 25 °C, open to air, results in severe damage with inferior texture and color. Under normal conditions, the water content of oyster mushrooms ranges from 85–95%. However, the surface structure of oyster mushrooms was less effective at protecting the fruit body, making it susceptible to water loss

through transpiration (Gong et al., 2025). This study showed that storage temperature played a more significant role in maintaining moisture content than packaging type. While packaging type had a slight effect on storage results, it wasn't as significant as temperature. For example, biodegradable plastic packaging has higher water vapor and oxygen permeability than vacuum packaging and plastic wrap (Kumari et al., 2023).

Visually, mushrooms packaged in biodegradable plastic appeared less fresh at the end of the observation period, with a rough and dry texture compared to those packaged in

vacuum packaging or plastic wrap. Low water content during storage is one of the main factors contributing to the decline in mushroom quality (Silva et al., 2025). The decrease in water content is often caused by cell damage and redistribution of internal water within the mushroom tissue (Zhang et al., 2018).

Vacuum and wrap packaging were more stable at maintaining oyster mushrooms water content on days 3, 6, and 9 DAT. This is because low oxygen in packaging can suppress oyster mushrooms respiration and prevent the production of water vapor, thereby increasing water content (Kusumiyati et al., 2025). Storage determines the stable water content if it is carried out using an edible layer, which can reduce breathing and the final products in the form of water vapor. The respiration rate can also be reduced by modifying natural atmospheric conditions as needed (Kandasamy, 2022). Vacuum packaging can prevent oxygen and water from entering. Evaporate, thus slowing down the respiration process (Othman et al., 2021).

Weight Loss. Based on Table 2, on the observation day 0 DAT, most treatments showed weight loss that was not significantly different (marked with the letter a), except for treatment P7 (NSA + 5 °C + vacuum) which showed the highest

weight loss (115.50 g), and P8 (NSA + 5 °C + biodegradable plastic) which showed lower weight loss (86.20 g). The value weight loss ranges from 86.20 to 103.30 g. However, from day 3, 6, and 9 DAT, there were significant differences among treatments, and the weight loss value of oyster mushrooms decreased over the 9 days of storage.

However, during storage, there was a decrease in different weights; real tend decreased in all treatments on observation days 3, 6, and 9 DAT. The most drastic weight shrinkage occurred in the treatment control (P0), namely oyster mushrooms without coating, without packaging, and stored at room temperature (25 °C). This showed that the transpiration and respiration processes are not under control during storage of oyster mushrooms without coating treatment and packaging at 25 °C. The is best, temporary treatments are, P4, P8, P13, P14, P16, and P17, with weight loss <20 g; influence temperature and packaging also affect storage. At low temperatures, it slows the respiration rate in fungi and oyster mushrooms with high water content. In contrast, vacuum packaging with plastic was known to reduce contact with oxygen, which can slow the oxidation and growth of microorganisms, compared to packaging with plastic wrap or biodegradable plastic.

Table 2. Effect of various combinations of nano coating, packaging, and storage temperature on the weight loss of the oyster mushrooms

Treatment	Weight loss (g)			
	0 DAT	3 DAT	6 DAT	9 DAT
P0 = Control (without treatment <i>coating</i> , packaging, storage 25 °C)	103.30 a	33.80 a	24.55 a	9.20 a
P1: NSA + 25 °C + vacuum	99.55 a	62.35 b	59.27 b	0.00 a
P2: NSA + 25 °C + wrap	99.90 a	87.00 c	56.00 b	0.00 a
P3: NSA + 25 °C + biodegradable	98.65 a	66.00 b	40.70 a	0.00 a
P4: NSA + 10 °C + vacuum	100.10 a	96.51 c	95.88 c	88.40 e
P5: NSA + 10 °C + wrap	99.90 a	97.70 c	91.91 c	87.65 e
P6: NSA + 10 °C + biodegradable	99.90 a	87.05 c	65.65 b	40.35 b
P7: NSA + 5 °C + vacuum	115.50 a	105.65 c	99.15 c	93.50 e
P8: NSA + 5 °C + wrap	94.55 a	94.25 c	93.45 c	89.75 e
P9: NSA + 5 °C + biodegradable	86.20 a	72.75 b	52.50 b	49.55 c
P10: NAV + 25 °C + vacuum	98.85 a	93.60 c	55.00 b	0.00 a
P11: NAV + 25 °C + wrap	99.65 a	87.70 c	61.65 b	0.00 a
P12: NAV + 25 °C + biodegradable	99.20 a	68.35 b	44.05 a	0.00 a
P13: NAV + 10 °C + vacuum	100.30 a	97.53 c	89.77 c	96.30 e
P14: NAV + 10 °C + wrap	99.80 a	92.36 c	90.20 c	90.36 e
P15: NAV + 10 °C + biodegradable	99.50 a	87.29 c	86.24 c	53.90 c
P16: NAV + 5 °C + vacuum	108.35 a	102.90 e	100.45 c	96.00 e
P17: NAV + 5 °C + wrap	112.25 a	101.70 c	93.90 c	75.00 d
P18: NAV + 5 °C + biodegradable	96.05 a	69.85 b	64.30 b	64.25 d

Note: Means followed by the same lowercase alphabet in the same column are not significantly different based on the Scott-Knot test at 5%, DAT: Day After Treatment, NSA: Nano Sodium Alginate, NAV: Nano Aloe Vera

The application of a nano-edible coating containing sodium alginate and aloe vera showed significant effectiveness in reducing weight loss. Treatment with sodium alginate (P1-P9) and aloe vera (P10-P18) maintained weight loss better than the control. Like nano-edible coatings, aloe vera is a natural ingredient that contains a gel/hydrocolloid (Ababiel et al., 2023). Aloe vera gel, composed of polysaccharides and mucilage, acts as a deterrent to food spoilage by blocking the entry of O₂ and moisture. Furthermore, aloe vera gel contains various antibiotic and antifungal components, such as quinones and phenolic compounds (flavonoids), which play a role in delaying or inhibiting the growth of microorganisms that cause foodborne illness in humans or food spoilage (Ali & Abdul-Aziz, 2021).

Sodium alginate is known to help maintain oyster mushrooms during storage. This is caused by sodium alginate forming a potent gel that reacts with calcium ions. Hence, the sodium alginate film provides several benefits in preserving food, namely increasing the barrier to water, preventing microbial contamination, maintaining taste, and reducing weight (Jiang, 2013). Significant weight loss correlates with oyster mushroom mortality. The greater the weight loss, the greater the decline in oyster mushroom quality. This is indicated by damage to the fungus's cell membrane and cell wall, which results in the release and activation of the polyphenol oxidase (PPO) enzyme. The activated PPO enzyme catalyzes the oxidation of phenolic compounds to quinones, which then polymerize to form the brown pigment melanin, causing browning.

This suggests that weight loss is an important indicator in evaluating the quality decline of oyster mushroom products during storage (Liu et al., 2020). This shows that weight loss is an important indicator in evaluating the quality decline of oyster mushroom products during storage. The weight loss in oyster mushrooms is due to physiological changes, including water loss. Due to their high moisture content and respiratory activity, mushrooms rapidly lose moisture after harvest, leading to continuous weight loss, shrinkage, and turgor loss, accelerating their quality degradation (Castellanos-Reyes et al., 2021). Another factor causing weight loss is external factors related to storage, i.e., storage temperature, relative

humidity, and mechanical damage (Zhang et al., 2018). Unpackaged oyster mushrooms stored at high temperatures have a shelf life of only one day and may experience weight losses of up to 50%. This occurs because the oyster mushroom caps expand, leading to browning and a loss of turgor (Azevedo et al., 2017).

Brightness (L*). The surface color of oyster mushrooms was evaluated based on the L* value (brightness). Oyster mushrooms underwent significant changes over 9 DAT of storage. The L* value represents brightness, an important indicator of the visual quality of fresh horticultural products, including oyster mushrooms. Visually, the surface of oyster mushrooms appears white.

Based on Table 3. There was a drastic decrease in the L* value in the control treatment (P0) from 76.55 (0 DAT) to 52.80 (9 DAT). The occurrence of browning in oyster mushrooms indicates a decrease in brightness due to the enzymes polyphenol oxidase (PPO) and tyrosinase, which oxidize phenolic compounds into melanin. According to Jiang (2013), the high water content of oyster (85-95%) and their high respiratory activity after harvesting make them very susceptible to enzymatic browning. Respiratory activity is caused by a thin and porous layer on the surface epidermis of the mushroom (Sharma et al., 2024). This causes pigment degradation, altering the mushroom's surface color.

Treatment at 10°C showed the best results in maintaining brightness, such as P4 (NSA + 10°C + vacuum), which maintained the L* value up to 74.68 until the 9 DAT, while P6 (NSA + 10°C + biodegradable) reached 82.4. In addition, the low temperatures of 10 °C and 5 °C showed consistent brightness. The treatment of P9 (NSA + 5°C + biodegradable) produced an L* value of 82.41, an increase from the initial value of 62.96. Low temperatures can inhibit enzymatic activity, inhibit microorganism growth, and slow pigment degradation. This is in line with the research of Mohammadi et al. (2021), who reported that the combination of nano-coating and low-temperature storage, such as 4 °C, can maintain the L* value of button mushrooms (*Agaricus bisporus*). Nano-coating with cold storage (4 - 10 °C) has been shown to effectively slow pigment degradation and maintain mushroom visual quality for up to 12 days (Choi et al., 2016).

Table 3. Effect of various combinations of nano coating, packaging, and storage temperature on color L* value of the oyster mushrooms

Treatment	L*			
	0 DAT	3 DAT	6 DAT	9 DAT
P0 = Control (without treatment <i>coating</i> , packaging, storage 25 °C)	76.55 a	75.51 b	60.67 b	52.80 b
P1: NSA + 25 °C + vacuum	72.63 a	64.49 a	63.05 b	0.00 a
P2: NSA + 25 °C + wrap	81.68 a	59.84 a	55.15 a	0.00 a
P3: NSA + 25 °C + biodegradable	73.53 a	72.68 b	77.13 c	0.00 a
P4: NSA + 10 °C + vacuum	59.26 a	69.92 b	70.82 c	74.68 d
P5: NSA + 10 °C + wrap	71.12 a	66.91 a	64.30 b	71.21 c
P6: NSA + 10 °C + biodegradable	63.92 a	75.66 b	77.88 c	82.41 e
P7: NSA + 5 °C + vacuum	70.59 a	69.98 b	70.27 c	74.68 d
P8: NSA + 5 °C + wrap	67.48 a	71.36 b	70.55 c	71.21 c
P9: NSA + 5 °C + biodegradable	62.96 a	79.99 b	77.69 c	82.41 e
P10: NAV + 25 °C + vacuum	74.58 a	61.38 a	62.30 b	0.00 a
P11: NAV + 25 °C + wrap	74.77 a	56.24 a	52.05 a	0.00 a
P12: NAV + 25 °C + biodegradable	80.07 a	75.72 b	73.44 c	0.00 a
P13: NAV + 10 °C + vacuum	67.53 a	71.96 b	66.67 b	66.88 c
P14: NAV + 10 °C + wrap	68.17 a	71.65 b	68.88 c	68.41 c
P15: NAV + 10 °C + biodegradable	67.04 a	73.23 b	74.02 c	82.75 e
P16: NAV + 5 °C + vacuum	69.07 a	71.37 b	65.03 b	66.88 c
P17: NAV + 5 °C + wrap	61.95 a	62.99 a	67.25 b	68.41 c
P18: NAV + 5 °C + biodegradable	60.80 a	84.54 b	79.65 c	82.75 e

Note: Means followed by the same lowercase alphabet in the same column are not significantly different based on the Scott-Knot test at 5%, DAT: Day After Treatment, NSA: Nano Sodium Alginate, NAV: Nano Aloe Vera

In contrast, high temperatures such as 25 °C in the NSA and NAV 25 °C treatments (P1-P3 and P10-P12) resulted in values of 0.00 because storage at high temperatures accelerates respiration and microbial activity, rendering the tissue unable to maintain viability and storing mushrooms at 20–25°C results in a decline in quality, including stem elongation, cap opening, texture softening, and color changes (Zhang et al., 2021). Oyster mushroom storage affects the effectiveness of edible coatings; high temperatures can cause pigment damage, accelerating the formation of brown pigments through non-enzymatic browning processes, including the Maillard reaction. In contrast, low temperatures, such as 4 °C, can delay undesirable changes in microbial counts (Kic, 2018). In the three comparisons of L* values at 5 °C, 10 °C, and 25 °C, it was reported that the combination of NSA + 5 °C or 10 °C + biodegradable packaging (P6, P9) is a fairly optimal method for maintaining the brightness of oyster mushrooms during storage. This is supported by the storage temperature and the packaging type. The packaging used by P6 and P9 is biodegradable plastic, which provides optimal gas exchange,

preventing the accumulation of CO₂ and ethylene. A high L* value (>80) indicates that the product remains visually attractive and marketable.

a* value. The a* value measures the level of redness-greenness. An increase in the a* value in oyster mushrooms indicates a decay process caused by enzymatic and non-enzymatic browning. This process, catalyzed by enzymes, results in brown pigmentation of the substrate (Cavusoglu et al., 2021). In Table 4, oyster mushrooms during storage showed that significant variations between treatments. At the beginning of storage (0 DAT), all treatments showed relatively low a* values, ranging from -4.48 to 0.83, with the control (P0) at 0.30. On day 3 DAT, a reddish color change was observed, indicated by an increase in the a* value in most treatments, including the control (P0), which showed a drastic increase to 2.95. Treatment P2 (NSA + 25 °C + wrap) showed the greatest increase, reaching 4.96, while treatments with vacuum plastic and biodegradable plastic at various temperatures tended to maintain lower a* values (0.42-0.84).

Table 4. Effect of various combinations of nano coating, packaging, and storage temperature on color a* value of the oyster mushrooms

Treatment	a*			
	0 DAT	3 DAT	6 DAT	9 DAT
P0 = Control (without treatment coating, packaging, storage 25 °C)	0.30 a	2.95 c	6.24 b	10.37 d
P1: NSA + 25 °C + vacuum	0.02 a	0.65 a	2.76 a	0.00 a
P2: NSA + 25 °C + wrap	-4.48 a	4.96 e	6.39 b	0.00 a
P3: NSA + 25 °C + biodegradable	0.01 a	0.72 a	0.60 a	0.00 a
P4: NSA + 10 °C + vacuum	0.22 a	0.48 a	-2.39 a	0.30 a
P5: NSA + 10 °C + wrap	0.20 a	2.06 b	2.04 a	1.65 b
P6: NSA + 10 °C + biodegradable	0.32 a	0.79 a	1.06 a	0.27 a
P7: NSA + 5 °C + vacuum	0.17 a	0.60 a	0.42 a	0.30 a
P8: NSA + 5 °C + wrap	0.12 a	1.18 a	2.29 a	1.65 b
P9: NSA + 5 °C + biodegradable	0.44 a	0.42 a	1.27 a	0.27 a
P10: NAV + 25 °C + vacuum	-0.04 a	0.13 a	3.28 a	0.00 a
P11: NAV + 25 °C + wrap	0.13 a	3.86 d	6.93 b	0.00 a
P12: NAV + 25 °C + biodegradable	-0.15 a	0.45 a	1.33 a	0.00 a
P13: NAV + 10 °C + vacuum	0.08 a	0.84 a	0.77 a	0.18 a
P14: NAV + 10 °C + wrap	0.57 a	1.63 b	2.24 a	2.37 c
P15: NAV + 10 °C + biodegradable	0.07 a	0.66 a	1.45 a	1.27 b
P16: NAV + 5 °C + vacuum	0.23 a	0.56 a	0.46 a	0.18 a
P17: NAV + 5 °C + wrap	0.53 a	2.04 b	2.05 a	2.37 c
P18: NAV + 5 °C + biodegradable	0.83 a	0.12 a	0.92 a	1.27 b

Note: Means followed by the same lowercase alphabet in the same column are not significantly different based on the Scott-Knot test at 5%, DAT: Day After Treatment, NSA: Nano Sodium Alginate, NAV: Nano Aloe Vera

Table 5. Effect of various combinations of nano coating, packaging, and storage temperature on color b* of the oyster mushrooms

Treatment	b*			
	0 DAT	3 DAT	6 DAT	9 DAT
P0 = Control (without treatment coating, packaging, storage 25 °C)	14.96 a	27.40 c	29.17 c	0.00 a
P1: NSA + 25 °C + vacuum	12.04 a	18.63 a	25.92 c	4.00 b
P2: NSA + 25 °C + wrap	13.94 a	26.47 c	26.66 c	4.00 b
P3: NSA + 25 °C + biodegradable	14.06 a	14.68 a	17.57 a	4.00 b
P4: NSA + 10 °C + vacuum	13.00 a	16.61 a	17.35 a	0.00 a
P5: NSA + 10 °C + wrap	14.92 a	18.91 a	22.37 b	0.00 a
P6: NSA + 10 °C + biodegradable	13.83 a	16.99 a	18.89 a	0.00 a
P7: NSA + 5 °C + vacuum	15.05 a	18.35 a	17.85 a	0.00 a
P8: NSA + 5 °C + wrap	15.48 a	19.18 a	22.29 b	0.00 a
P9: NSA + 5 °C + biodegradable	25.19 b	16.46 a	19.83 a	0.00 a
P10: NAV + 25 °C + vacuum	12.57 a	18.82 a	26.11 c	4.00 b
P11: NAV + 25 °C + wrap	14.33 a	23.00 b	25.40 c	4.00 b
P12: NAV + 25 °C + biodegradable	13.48 a	14.94 a	19.31 a	4.00 b
P13: NAV + 10 °C + vacuum	13.84 a	18.38 a	17.67 a	0.00 a
P14: NAV + 10 °C + wrap	15.04 a	21.85 b	23.86 b	0.00 a
P15: NAV + 10 °C + biodegradable	13.82 a	16.96 a	18.64 a	0.00 a
P16: NAV + 5 °C + vacuum	15.99 a	18.23 a	18.45 a	0.00 a
P17: NAV + 5 °C + wrap	16.73 a	21.23 b	21.77 b	0.00 a
P18: NAV + 5 °C + biodegradable	17.18 a	15.27 a	17.49 a	0.00 a

Note: Means followed by the same lowercase alphabet in the same column are not significantly different based on the Scott-Knot test at 5%, DAT: Day After Treatment, NSA: Nano Sodium Alginate, NAV: Nano Aloe Vera

A significant browning color change occurred on day 6 DAT, with the control (P0) reaching an a^* value of 6.24. Treatment P1 (NSA + 25 °C + vacuum) showed a value of 2.76, while P3 (NSA + 25 °C + biodegradable) was only 0.60. Treatment with low temperature (5 °C) showed a lower a^* value than high temperature. There was a color change indicating severe damage to oyster mushrooms on the day 9 DAT. The control (P0) experienced an increase in the a^* value, reaching 10.37, indicating severe color deterioration. Most treatments with nano coating showed a value of 0.00, indicating that the mushrooms had undergone severe color changes or damage. Treatments P5 (NSA + 10 °C + wrap), P8 (NSA + 5 °C + wrap), P14 (NAV + 10 °C + wrap), P15 (NAV + 10 °C + biodegradable), P17 (NAV + 5 °C + wrap), and P18 (NAV + 5 °C + biodegradable) still showed positive a^* value ranging from 1.27 - 2.37, indicating relatively better color quality.

A combination of nano-coating with low-temperature storage, such as 5 - 10 °C, and packaging under vacuum is highly recommended compared to packaging otherwise. The lower of oxygen created in the packaging vacuum. Unlike biodegradable packaging, high gas permeability allows oxygen to enter more readily, thereby accelerating decomposition. Uncontrolled packaging that allows oxygen to enter can accelerate oxidation, which causes browning/greening. The strategy to overcome this is to limit gas exchange, thereby reducing oxygen availability (Cavusoglu et al., 2021). Vacuum packaging, by minimizing oxygen exposure, is effective in inhibiting browning (Martha & Daniel, 2025).

The type of packaging, the combination of edible coatings, and storage temperature determine the color retention of oyster mushrooms. For example, a combination of nano aloe vera and nano sodium alginate at low temperatures is an effective option for maintaining color during storage of oyster mushrooms. This acts as an antimicrobial, an oxygen absorber for moisture, and a gas barrier (Rai et al. 2019).

Value b^* . The b^* value represents the colour coordinates of yellow (+) to blue (-) in the CIE $L a b^*$ color system. Browning is an indicator of quality decline, as evidenced by the b^* value of oyster mushrooms, which increases significantly during storage. The results of measuring the b^* value (yellowness) in white oyster mushrooms during storage with various nano coating

treatments, packaging, and storage temperatures are presented in Table 5.

The b^* value indicates the intensity of the yellow color in the sample, with higher values indicating a deeper yellow color. Values approaching zero indicate a loss of yellow color toward a neutral grayish color. On the initial observation day (0 DAP), b^* values ranged from 12.04 to 25.19. The control treatment (P0) showed that b^* value of 14.96, while the highest value was found in treatment P9 (NSA + 5 °C + biodegradable) with a value of 25.19. Treatment P9 had a high b^* value, indicating a more intense yellow color at the beginning of storage. In the initial stage, b^* values generally varied between treatments with nano sodium alginate (NSA) and various temperature and packaging combinations.

On 3 DAT, a significant increase in b^* values occurred in several treatments, particularly in the control (P0), which reached 27.40, as well as in P1 (18.63) and P2 (26.47). This increase in b^* values indicated an intensification of the yellow color in oyster mushrooms. However, it should be noted that the browning of oyster mushrooms is not only determined by an increase in b^* but also by a combination of a decrease in the L^* value (brightness) and an increase in the a^* value (redness). Interpretation of color changes requires consideration of all three color parameters (L , a^* , b^*). Treatments with low-temperature storage (5 °C and 10 °C) tend to show higher b^* values than storage at 25 °C, indicating greater inhibition of the degradation process and better color.

On day 6 (DAT), the control reached the highest b^* value of 29.17, indicating very significant color degradation. Treatment P3 (NSA + 25 °C + biodegradable) showed the lowest value, namely 17.57, indicating coating capability with biodegradable packaging in maintaining color. Treatment at low temperatures (5 °C and 10 °C) shows higher b^* values than 25 °C. On day 9 (DAT), some big samples show a b^* value of 0.00 or very low (0.00), indicating the sample has experienced total damage or is not worth analyzing further.

Edible coatings cover the entire exterior of the mushroom, acting as a barrier to oxygen, thus preventing gas exchange and moisture loss while maintaining quality (Dawadi et al., 2022). The use of nano-edible coatings, both nano sodium alginate (NSA) and nano aloe vera (NAV), has shown effectiveness in hindering improvements

in b^* value during storage. Smaller particle sizes effectively connect bulk materials and atomic or molecular structures. Smaller particles are known to have the potential to be effective catalysts for plant metabolism, providing better penetration into cells and enhancing protective activity on plant surfaces (Rosyada et al., 2019).

Conclusion

Based on the results of the research that has been done, some conclusions can be taken as follows:

1. The combination of nano-edible coating treatment, storage temperature, and packaging type had a significant effect on water content, weight loss, and color parameters (L^* , a^* , and b^* values) of oyster mushrooms on the 3, 6, and 9 DAT.
2. The combination of nano sodium alginate and nano aloe vera with vacuum packaging at 5 °C gave the best effect on water content, weight loss and colour value. These results indicated the potential of the treatment to maintain the quality of oyster mushrooms during storage.

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