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Rachman AA · Hamdani JS · Kusumiyati

Evaluation of color, water content, and antioxidant properties of wood ear mushroom with nano edible coating, packaging, and storage temperature

Abstract. Wood ear mushrooms are often consumed in Asia and Tropical America for their jelly-like texture, health, and freshness. However, they are easily damaged due to microbes and poor postharvest handling, which affects quality. The combination of nano edible coating, packaging, and storage temperature offers a solution to these issues. This study aims to evaluate the effect of nano edible coating, packaging, and storage temperature on the color (L^*, a^*, and b^*), water content, and antioxidant properties (total phenolic and flavonoid) of wood ear mushrooms. The study was conducted at the Horticulture Laboratory, Faculty of Agriculture, Universitas Padjadjaran. The experimental design used was a Completely Randomized Design with a total of 18 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 36 experimental units, with 3 mushrooms per unit for a total of 108 mushrooms. The results showed a significant effect of the combination treatments on L^* at 9 days after treatment (DAT), a^* at 6 DAT, water content at 6 and 9 DAT, total phenolics, and total flavonoids during the storage period. Nano aloe vera with vacuum packaging at 5 °C gave the best effect on L^* value at 9 DAT, water content at 6 and 9 DAT, total phenolic at 3 and 6 DAT, and total flavonoid at 6 DAT. These results indicated the potential of the treatment in maintaining the quality of the wood ear mushroom during storage.

Keywords: *Auricularia auricula* · Nano sodium alginate · Nano aloe vera · Vacuum packaging · Yield quality

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Rachman AA[1] · Hamdani JS[2] · Kusumiyati[2*]
[1] Master Program of Agronomy, Faculty of Agriculture, Universitas Padjadjaran, Sumedang, 45363, Indonesia
[2] Department of Agronomy, Faculty of Agriculture, Universitas Padjadjaran, Sumedang, 45363, Indonesia
*Correspondence: kusumiyati@unpad.ac.id

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Introduction

Mushrooms have been widely used as both food and medicine do to their rich nutritional content. The wood ear mushroom (*Auricularia auricula-judae* (Bull.) Quél.) is the third most cultivated among the four major edible mushrooms and is considered highly important globally (Rawiningtyas et al., 2023; Zhou et al., 2023). It contains secondary metabolites, such as total phenolics and flavonoids (Herawati et al., 2021). A high content of phenolics and flavonoids indicates strong antioxidant activity (Indriyah et al., 2023), enhancing the functional value of wood ear mushrooms as a healthy food ingredient.

Global production and market demand for wood ear mushrooms are significantly high. In China, it ranks as the second most-produced edible mushroom (Guan et al., 2024), with the total production reaching 7.06 million tons in 2020, making China the world's largest producer (Feng et al., 2024). In 2022, mushroom production in Indonesia, including wood ear mushrooms, reached 63.16 tons, and the largest production is in Central Java (Arista et al., 2024). Wood ear mushrooms are often consumed because of their jelly-like character, dark greyish-brown color, and flavorless taste (Faridah et al., 2023). High market demand requires the mushroom industry to supply sustainably (Nur Sakinah et al., 2020). Their quality and safety increase consumer preference (Fu et al., 2020).

Mushrooms are more perishable than other commodities due to their high respiration and transpiration, as well as weak epidermis structure (Lu et al., 2016). After harvest, mushrooms continue to grow (Nur Sakinah et al., 2020), which causes high catabolic activity, which is 200–500 mg/kg/hour at 20 °C (Kim et al., 2006). Wood ear mushrooms have a high water content, ranging from 85–95% (Khaskheli et al., 2015; Zhu et al., 2024), which makes the mushrooms more easily damaged by microorganisms and have a short shelf-life (Lestari et al., 2023). If not treated in time, it will cause a high possibility of rotting and damage due to the growth of microorganisms (Castellanos-Reyes et al., 2021; Zhu et al., 2024).

Various factors can affect the chemical composition and nutritional value of wood ear mushrooms, including the environment and storage conditions (Fan et al., 2023; Ma et al., 2015). Optimal post-harvest technology can extend the shelf-life of wood ear mushrooms and maintain the yield quality. The common post-harvest treatment for wood ear mushrooms is drying, but this treatment can increase the purine content, which can cause gout if often consumed by humans (Kaneko et al., 2014). Therefore, we used fresh wood ear mushrooms in this research.

Edible coating is an eco-friendly solution to extend the shelf-life of crop yield (Tahir et al., 2019). Sodium alginate, an edible coating made from algae, acts as a barrier to reduce gas transfer by reducing the respiration rate and is effective in controlling the enzyme process that causes browning (Díaz-Mula et al., 2012). Color changes were inhibited in plums coated with sodium alginate at concentrations of 1% and 3% (Valero et al., 2013). Aloe vera, edible coating made from leaves of aloe vera contain carbohydrates, saccharides, and others, can protect the fruit body surface, so that it can reduce respiration, decay, and water loss (Misir et al., 2014). The color decrease was higher in the uncoated fruit body by aloe vera (Ates et al., 2022).

Coating materials with larger particle sizes may inhibit absorption, making them less effective. Nano edible coatings tend to be more easily absorbed by agricultural products due to their very small particle size, which allows for more effective penetration and adhesion (Gidagiri et al., 2025). Nano edible coatings have been developed to improve the adhesion of coating materials to the surface of fresh-cut fruits (Bassey et al., 2021; Sánchez et al., 2020). Alginate-based ZnO (Alg-ZnO) nanoparticles have been shown to preserve fruit quality, reduce decay, and extend the shelf life of mangoes (Hmmam et al., 2023). Similarly, nano-formulated aloe vera has proven effective in prolonging the shelf life of mangosteen and fresh-cut mangoes (Suriati et al., 2020, 2021).

Various types of packaging have been widely used to store fresh products, including mushrooms. Currently, most food products are packaged using plastic materials (Mohamad et al., 2022; Shimazu, 2018). However, the varying permeability of plastic to gas, light, and moisture is considered one of its major limitations (Opara & Mditshwa, 2013). Biodegradable plastic offers an alternative for short-term storage and helps reduce the environmental risk associated with conventional, non-degradable plastics (Shaikh et al., 2021). In modern markets, wood ear mushrooms are commonly packaged using styrofoam trays and plastic wrap; however, this packaging often traps air inside. Vacuum

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packaging provides a more efficient alternative by reducing oxygen levels to less than 1% (Meena et al., 2022), thereby inhibiting the growth of aerobic bacteria and fungi and improving food preservation (Quaglia et al., 2020). It also prevents the evaporation of volatile compounds (Galli et al., 2024), reduces weight loss and total soluble solids, lowers the browning index, and increases the total phenolic content, as observed in jujube fruit (Moradinezhad & Dorostkar, 2021).

Temperature fluctuations during transportation and storage cause mushrooms to undergo physiological changes such as softening, discoloration (browning), off-flavor, and nutrient loss, thereby reducing their postharvest quality (Xia et al., 2024; Zhang et al., 2018). Storage temperature also significantly affects plant secondary metabolites. Flavonoids and phenolic acids increase markedly after low-temperature storage treatments (Liu et al., 2023a; Liu et al., 2023b). For example, the total flavonoid content of shiitake mushrooms increased one week after storage at 3 ℃, while the total phenolics increased after two weeks at 5 ℃ (Kim et al., 2023). In general, increased phenolic and flavonoid levels reflect high antioxidant activity. However, such increases can also indicate oxidative stress or tissue damage due to environmental stress, so stable levels are more ideal during storage.

The combination of nano edible coating and packaging, with the right storage temperature, is important in maintaining the quality of post-harvest wood ear mushrooms during storage. However, there is still few research about various types of packaging and nano edible coating in post-harvest handling of wood ear mushrooms, as well as the appropriate temperature that can maintain the quality of the mushrooms. Therefore, this study aims to evaluate the effect of combinations of different types of nano edible coating, packaging, and storage temperatures on the quality of wood ear mushrooms, and to identify the most effective treatment for preserving their quality.

Materials and Methods

The research was conducted at the Horticulture Laboratory, Faculty of Agriculture, Universitas Padjadjaran, from January to April 2025. The materials used in this study included wood ear 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% aluminum chloride, 2 M sodium acetate solution, distilled water, and quercetin. The tools used included oven (Memmert, UM300, Germany); analytical balance (Mettler Toledo, Switzerland); spectrophotometer reflectance (Konica Minolta, CM-600D, Japan); digital scales; thermo recorder; spectrophotometer UV-Vis (Shimadzu, Uv-1601, Japan); centrifuge; sonicator; pipette; aluminum cup; measuring flasks; 50 mL test tubes; vacuum and sealer; knife; chopping board; grinder; water bath; and 10 mL glass bottles, cooling storage, refrigerator, and freezer.

The research design used was a Completely Randomized Design (CRD) with a combination of nano edible coating treatments—Nano Sodium Alginate (NSA) and Nano Aloe Vera (NAV)—packaging (biodegradable, wrap, and vacuum plastic), and storage temperature (±25 ℃, 10 ℃, and 5 ℃). A total of 18 treatment combinations were each replicated twice, resulting in 36 experimental units. Each unit, consisting of 3 mushrooms, was observed at 3, 6, and 9 days after treatment (DAT), for a total of 108 mushrooms.

Wood ear mushroom samples were sourced from farmers in the Sukatani Village, Garut, West Java. Mushrooms were selected based on uniform harvest age (4 weeks after pinhead emergence), with fully bloomed fruit bodies weighing 20–60 g each, free from visible signs of disease or blemishes. Samples were grouped in portions of approximately 100 g (3–4 fruit bodies). The 1% nano edible coating, made from aloe vera and sodium alginate (300 nm), was provided by the Functional Nano powder University Center of Excellence (FiNder U-CoE), Universitas Padjadjaran.

The samples were coated by brushing (Momin et al., 2021), air-dried (10 min), and then packaged with vacuum, wrap, and biodegradable. After being packaged, the mushrooms were stored at ±25 ℃ (room temperature), 10 ℃ (cooling storage), and 5 ℃ (refrigerator). Measurements were conducted on 3, 6, and 9 DAT, using two samples per treatment (two replications).

The observation parameters consisted of color characteristics, water content, total phenolic, and total flavonoid. Color was measured on both upper and lower parts of wood ear mushrooms (3 fruit bodies/samples) using a spectrophotometer reflectance (Konica Minolta,

CM-600D, Japan) to obtain the L^*, a^*, and b^* values (Cavusoglu et al., 2021). Chroma was calculated using the formula from Ates et al. (2022):

$$\text{Chroma}=\sqrt{(a^*)^2+(b^*)^2}$$

Water content determination refers to SNI 01-2891-1992. Samples (4 g) were weighed to obtain the initial weight, dried in an oven (105 °C, 3 hours), cooled in a desiccator, and reweighed until constant weight. Water content (%) was calculated as:

$$\text{Water content (\%)}=\frac{(W_0-W_1)}{W_0}\text{x } 100$$

W_0 = weight before drying (g), W_1 = weight after drying (g).

Dried samples were used for total phenolic and flavonoid measurement. Samples were oven-dried at 60 °C for 24 hours, ground using a grinder. 500 mg of powder was extracted in 10 mL of methanol, sonicated (60 min), and centrifuged (4000 rpm, 10 min). The supernatant was transferred into a 10 mL glass bottle. The total phenolic measurement based on Sytar et al. (2018) with modifications. A 0.5 mL extract was mixed with 2.5 mL of 10% Folin-Ciocalteu reagent and incubated (5 min). Next, 2 mL of 7.5% sodium bicarbonate solution was added, homogenized, incubated (60 min), and the absorbance was measured at 765 nm. The standard solution was prepared using gallic acid concentration (8–128 ppm). Results were expressed as Gallic Acid Equivalent (GAE) mg/100 g:

$$\text{Total Phenolic (mg GAE/100 g)}=\frac{\text{C.V}}{\text{B}}\text{ x } 100$$

Total flavonoid measurement refers to Sytar et al. (2018), modified. 1 mL of extract was mixed with 2.0 mL of methanol, 0.1 mL of 10% aluminum chloride, 0.1 mL of 2 M sodium acetate, and 1.8 mL of distilled water, incubated (30 min), and measured at 435 nm. Quercetin standards (2–128 ppm) were used for calibration. Results were expressed as mg quercetin equivalent (QE)/100 g:

$$\text{Total Flavonoid (mg QE/100 g)}=\frac{\text{C.V}}{\text{B}}\text{ x } 100$$

Where: C = Concentration (ppm), V = Volume (L), B = Sample weight (g).

Data were analyzed using the F-test to determine the effect of the treatments, followed by the Scott-Knott test to compare the treatments at a 5% significance level. The analysis was performed using Microsoft Excel software equipped with the SmartstatXL add-in.

Results and Discussion

Lightness (L^*). The surface color of the mushroom was evaluated based on the L^* value (lightness). Visually, the surface of the wood ear mushroom appeared dark red. The color of the wood ear mushroom is influenced by both external and internal factors. External factors include toxins, mechanical damage, and the development of pathogens that cause damage to the intracellular membrane (Hanula et al., 2021). Internal factors involve enzymatic reactions with substrates, for example, tyrosinase, the main PPO enzyme responsible for browning in mushrooms (Jolivet et al., 1998; Oms-Oliu et al., 2008). Tyrosinase catalyzes the conversion of phenolic substrates into intermediate compounds that initiate melanin synthesis (Lin & Sun, 2019; Zhang et al., 2018). The results of this study indicate that the combination of nano edible coating, packaging type, and storage temperature did not significantly affect the L^* value of the wood ear mushroom during the storage period, except on 9 DAT. On days 3 and 6 of storage, the Scott-Knot test showed that all treatments belonged to the same group (denoted by letter a) (Table 1). This suggests that there was no significant difference in the L^* among the treatment combinations, and the treatments were effective in maintaining the brightness of the wood ear mushroom up to 6 DAT. Li et al. (2022) observed that the color change, indicated by browning degree, showed no significant differences across treatments (untreated and treated) during 0–4 days of storage.

On day 9 after treatment (DAT), a significant difference was observed among the treatment combinations. Treatment using nano sodium alginate and nano aloe vera at approximately 25 °C with all types of packaging— except nano sodium alginate with vacuum packaging at that temperature —were classified into group b, exhibiting a higher L^* value. This increase in the L^* value indicates greater brightness, which did not align with the visually optimal appearance of the wood ear mushroom. The elevated brightness suggests discoloration, likely caused by the high respiration rate at ±25 °C. Storing mushrooms at such temperatures (20–25 °C) leads to quality deterioration, including stem elongation, cap opening, texture softening, and discoloration (Zhang et al., 2021).

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Table 1. Effect of various combinations of nano edible coating, packaging, and storage temperature on the lightness (L*) of wood ear mushroom

Treatment	L*		
	3 DAT	6 DAT	9 DAT
NSA+ ±25 ℃ + vacuum	22.78 a	23.46 a	23.93 a
NSA+ ±25 ℃ + wrap	26.42 a	25.83 a	29.50 b
NSA+ ±25 ℃ + biodegradable	22.43 a	26.91 a	30.17 b
NSA+ 10 ℃ + vacuum	23.12 a	25.43 a	23.11 a
NSA+ 10 ℃ + wrap	20.28 a	26.94 a	22.41 a
NSA+ 10 ℃ + biodegradable	21.92 a	23.37 a	23.64 a
NSA+ 5 ℃ + vacuum	21.39 a	21.29 a	26.80 b
NSA+ 5 ℃ + wrap	24.09 a	20.15 a	23.05 a
NSA+ 5 ℃ + biodegradable	22.27 a	25.12 a	25.15 a
NAV+ ±25 ℃ + vacuum	24.07 a	24.00 a	25.87 b
NAV+ ±25 ℃ + wrap	25.50 a	28.13 a	27.61 b
NAV+ ±25 ℃ + biodegradable	31.67 a	29.93 a	30.44 b
NAV+ 10 ℃ + vacuum	22.75 a	24.92 a	26.96 b
NAV+ 10 ℃ + wrap	24.88 a	25.29 a	22.45 a
NAV+ 10 ℃ + biodegradable	24.19 a	22.73 a	23.01 a
NAV+ 5 ℃ + vacuum	24.71 a	21.00 a	23.36 a
NAV+ 5 ℃ + wrap	24.23 a	21.48 a	22.69 a
NAV+ 5 ℃ + biodegradable	23.05 a	24.32 a	22.42 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.

Storage temperature has a direct impact on respiration rate, with higher temperatures accelerating respiration (Zhang et al., 2018). Srivastava et al. (2020) reported that when the storage temperature decreased from 16 to 4 ℃, the respiration rate dropped from 96% to 61%. Wang et al. (2021) also found that edible mushrooms respiration rate, ranged from 132–158 mL CO_2 at 20 ℃ and 20–30 mL CO_2 kg/h at 5 ℃. This high-respiration activity is attributed to the thin and porous epidermal layer of the mushrooms (Sharma et al., 2024). During storage, respiration leads to the release of large amounts of CO_2 and heat, which contribute to softening, weight loss, cap opening, rotting, wrinkling, water soaking, and browning of the mushroom fruit body (Gong et al., 2025). Water soaking results in the tissue appearing more translucent compared to healthy tissue, which corresponds to a higher L* value in the wood ear mushroom. This discoloration may also influence the a* and b* color parameters, as changes in red and yellow tones are associated with browning processes (Walkowiak-Tomczak et al., 2020).

Nano sodium alginate with vacuum packaging at ±25 ℃ yielded consistent results. This is due to the low oxygen content in the packaging (Moradinezhad & Dorostkar, 2021), minimizing color changes in the form of increased lightness and maintaining a stable L* value. In addition, the high lightness value in nano sodium alginate treatment with vacuum packaging at 5 ℃ is likely due to the coating effect of nano sodium alginate, which makes the surface of the mushroom appear brighter or slightly shiny, thereby increasing the lightness value (Ning et al., 2025; Song et al., 2011).

a* Value. The Scott-Knot test showed that all treatments on the 3rd day of storage were grouped into the same category (denoted by letter a) (Table 2). This indicates that at the early stage of storage, the combination of nano edible coating, packaging, and storage temperature did not result in a significant difference in the a* value of the wood ear mushroom. This may be because color changes were not yet prominent at the beginning of the storage period. This finding is consistent with the study by Yeo et al. (2022), which reported that noticeable color changes in horticultural products, such as mango, typically begin to occur around the 7th day after storage. This is due to enzymatic activity and pigment oxidation reactions. The a* value defines greenness when negative and redness when positive (Nakilcioğlu-Taş & Ötleş, 2020).

Entering the 6th day after storage, the separation of the groups was clearer. Nano sodium alginate treatment at ±25 ℃ and 10 ℃ using vacuum packaging, as well as nano aloe vera at ±25 ℃ and 10 ℃ with vacuum packaging, are included in group c with higher a* values. This indicates that

the combination of nano-based edible coating and vacuum packaging is effective in maintaining the color of the wood ear mushroom better than plastic wrap or biodegradable packaging. The color change to brown on the mushroom cap increases due to enzymatic reactions (Mohapatra et al., 2008). The enzymes responsible for the browning process react with the substrate, causing brown pigmentation (Cavusoglu et al., 2021). Vacuum packaging plays a role in creating an environment with lower oxygen levels, so that it can slow down the activity of the polyphenol oxidase (PPO), which triggers browning and degradation of color pigments (Perera et al., 2010). Polyphenol oxidase activity increases in the fruit body after harvest, and phenol activity is closely related to the browning development (Abou-Elwafa et al., 2023). Browning occurs due to two definite mechanisms of phenol oxidation, namely through tyrosinase activation or spontaneous oxidation (Jolivet et al., 1998; Vamos-Vigyázó, 1981).

Meanwhile, treatments with plastic wrap and biodegradable tend to be included in groups a and b with lower a^* values, indicating faster color loss. Lower a^* values indicate that the color tends to change towards greenish/brown. This can be caused by the high gas permeability of plastic wrap and biodegradable materials, so that oxygen can enter more easily, which results in faster respiration rates and phenolic oxidation. The presence of oxygen in uncontrolled packaging can accelerate the formation of oxidation compounds that cause browning/greening (decrease in a^*). Modifying the packaging atmosphere can be an effective strategy to limit gas exchange, thereby reducing oxygen availability (Cavusoglu et al., 2021). Vacuum packaging, by minimizing oxygen exposure, has been shown to effectively inhibit browning (Martha & Daniel, 2025).

On the 9th day of storage, the results of the Scott-Knot test once again showed that all treatments were classified into group a, indicating that the treatment combinations no longer had a statistically significant effect on the a^* value. Although the highest a^* value was recorded for the nano sodium alginate treatment with vacuum packaging at 5 °C (7.94), the difference was not statistically significant. This suggests that after 9 days, the color degradation process had progressed uniformly across all treatments, potentially due to the reduced activity of the nano edible coatings, the stabilization of the internal atmosphere within the packaging, or the accumulation of metabolic byproducts during storage. This finding aligns with the study by Garnida et al. (2022), which reported that the effectiveness of edible coatings in maintaining the visual quality of fresh products is optimal within the first 5-10 days of storage and tends to diminish thereafter.

Table 2. Effect of various combinations of nano edible coating, packaging, and storage temperature on the a^* and b^* value of wood ear mushroom

Treatment	a^*			b^*		
	3 DAT	6 DAT	9 DAT	3 DAT	6 DAT	9 DAT
NSA+ ±25 °C + vacuum	5.72 a	6.49 c	6.22 a	5.89 a	6.09 a	5.38 a
NSA+ ±25 °C + wrap	5.06 a	4.77 b	5.11 a	6.60 a	6.70 a	8.20 a
NSA+ ±25 °C + biodegradable	4.91 a	3.69 a	3.50 a	5.38 a	5.67 a	6.65 a
NSA+ 10 °C + vacuum	6.16 a	5.90 c	5.51 a	6.45 a	6.42 a	6.23 a
NSA+ 10 °C + wrap	5.24 a	6.13 c	5.56 a	6.08 a	7.69 a	6.89 a
NSA+ 10 °C + biodegradable	4.77 a	5.16 b	4.67 a	6.06 a	6.05 a	6.17 a
NSA+ 5 °C + vacuum	4.61 a	4.55 b	7.94 a	4.52 a	4.79 a	9.82 a
NSA+ 5 °C + wrap	6.61 a	4.02 a	5.15 a	7.55 a	3.09 a	5.09 a
NSA+ 5 °C + biodegradable	5.12 a	6.68 c	7.11 a	5.32 a	8.13 a	8.29 a
NAV+ ±25 °C + vacuum	6.31 a	5.97 c	6.89 a	7.19 a	6.39 a	8.56 a
NAV+ ±25 °C + wrap	4.18 a	4.71 b	4.13 a	6.10 a	7.77 a	6.31 a
NAV+ ±25 °C + biodegradable	5.86 a	5.25 b	5.20 a	8.78 a	8.11 a	8.67 a
NAV+ 10 °C + vacuum	5.85 a	5.93 c	5.90 a	7.04 a	7.11 a	8.18 a
NAV+ 10 °C + wrap	6.31 a	5.07 b	5.47 a	7.67 a	7.00 a	6.44 a
NAV+ 10 °C + biodegradable	6.67 a	4.76 b	5.35 a	7.36 a	5.76 a	7.43 a
NAV+ 5 °C + vacuum	6.76 a	4.66 b	6.50 a	8.36 a	4.53 a	6.35 a
NAV+ 5 °C + wrap	4.96 a	4.29 a	6.00 a	5.87 a	5.07 a	6.53 a
NAV+ 5 °C + biodegradable	5.14 a	5.01 b	5.61 a	5.92 a	6.39 a	6.00 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.

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Overall, the results of this study showed the importance of combination of edible coatings, packaging types, and storage temperatures, especially in the first 6 days after harvest. The combination of nano aloe vera and nano sodium alginate with vacuum packaging at 10 °C is an effective choice in maintaining the color of wood ear mushrooms during storage. Nanomaterials have specific characteristics including antimicrobial, oxygen absorbers, and as a barrier to gas or moisture (Rai et al., 2019).

b* Value. The results showed that nano edible coatings, packaging, and storage temperatures did not affect the b* value of the wood ear mushroom during the entire storage period. At 3, 6, and 9 DAT all treatments were in the same group (a), which indicates a relatively constant value during the storage period (Table 2). The b* value represents the level of yellowness or bluishness, where positive values indicate a tendency towards yellowish color, while negative values indicate a bluish color (Ali et al., 2014). The constant b* value during storage indicates that the color changes that occur are more dominant in the L* and a* components, while the yellowish component of the wood ear mushroom does not experience significant fluctuations. Mushroom pigments that contribute to the b* value (yellow-blue) in the CIELAB color space are generally more stable to oxidation than the a* value (red-green) (Toma et al., 2023; Hinsch et al., 2022). This is because the yellow to blue pigments in mushrooms, such as isoprenoid-based carotenoids, have conjugated double bonds that can be more resistant to oxidative damage compared to other chemical structures (Toma et al., 2023; Hinsch et al., 2022).

In addition, the stable b* value can also be caused by the low content of carotenoids or yellow phenolic compounds (Meléndez-Martínez et al., 2006), which are susceptible to degradation during storage. Thus, even though there are changes in lightness (L*) or in the red-green color balance (a*), the yellowish color component of the mushroom remains relatively stable. The stability of the b* value during storage can also indicate that the nano edible coatings, packaging, and storage temperatures treatments are effective in suppressing non-enzymatic browning reactions, which generally also affect the b* value. This treatment can play a role in maintaining the visual quality of wood ear mushrooms, especially in maintaining the natural color characteristics expected by consumers.

Table 3. Effect of Various Combinations of Nano Edible Coating, Packaging, and Storage Temperature on the Chroma of Wood Ear Mushroom

Treatment	Chroma		
	3 DAT	6 DAT	9 DAT
NSA+ ±25 °C + vacuum	8.28 a	9.04 a	8.33 a
NSA+ ±25 °C + wrap	8.55 a	8.30 a	9.87 a
NSA+ ±25 °C + biodegradable	7.41 a	7.21 a	7.81 a
NSA+ 10 °C + vacuum	8.98 a	8.80 a	8.38 a
NSA+ 10 °C + wrap	8.11 a	9.89 a	8.98 a
NSA+ 10 °C + biodegradable	7.74 a	8.00 a	7.86 a
NSA+ 5 °C + vacuum	6.55 a	6.69 a	12.73 a
NSA+ 5 °C + wrap	10.19 a	5.09 a	7.34 a
NSA+ 5 °C + biodegradable	7.52 a	10.70 a	11.04 a
NAV+ ±25 °C + vacuum	9.65 a	8.85 a	11.04 a
NAV+ ±25 °C + wrap	7.65 a	9.23 a	7.76 a
NAV+ ±25 °C + biodegradable	10.70 a	9.93 a	10.24 a
NAV+ 10 °C + vacuum	9.18 a	9.30 a	10.26 a
NAV+ 10 °C + wrap	9.99 a	8.74 a	8.54 a
NAV+ 10 °C + biodegradable	9.96 a	7.58 a	9.21 a
NAV+ 5 °C + vacuum	10.85 a	6.54 a	9.15 a
NAV+ 5 °C + wrap	7.85 a	6.71 a	8.97 a
NAV+ 5 °C + biodegradable	7.92 a	8.31 a	8.33 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.

Chroma. The chroma value indicates the degree of color saturation and is proportional to the intensity of the color (Gupta et al., 2011)**.** Chroma or saturation is defined as the property of chromatic content in color perception. Chroma is also the degree of difference from the gray of the same lightness. The higher the chroma value, the clearer the color will appear, while the lower the color will look faded. A high chroma value indicates that the dominant colors of the pumpkin, namely yellow and red, are pure and concentrated (Onwude et al., 2017). In this study, nano edible coatings, packaging types, and storage temperatures did not have a significant effect on the chroma value at any storage period (Table 3).

The chroma values remained stable over time, with no significant fluctuations observed. In other mushrooms, such as enoki mushrooms, an increase in chroma value has been associated with color changes from pale white to brownish, indicating a shift in color intensity (Kusumiyati et al., 2025). However, the stability of the chroma value in this study implies that the color saturation of wood ear mushrooms remained consistent, despite minor variations in the a^* parameter. This condition shows that the post-harvest treatment, nano edible coatings, packaging, and storage temperatures are effective in suppressing excessive color changes, both due to enzymatic and non-enzymatic reactions. Chroma stability also reflects that the pigments that make up the color of the wood ear mushroom are relatively stable against oxidation or degradation during storage.

Thus, the stability of the chroma value in wood ear mushrooms in this study can be one indicator of the success of post-harvest treatment in maintaining the visual quality of the product. Chroma stability is important because color is one of the main factors that influence consumer purchasing decisions for fresh products, including wood ear mushrooms. A consistent chroma value suggests that the intensity of the mushroom's natural color remains visually appealing throughout the storage period, thereby contributing to an extended commercial shelf life.

Water Content. The results of this study indicate that nano edible coatings, packaging types, and storage temperatures had no significant effect on the water content of wood ear mushroom at 3 DAT, but significant effects were observed at 6 and 9 DAT. Water content is a critical factor determining the quality of edible mushrooms during storage. High water content increases susceptibility to deterioration, leading to water soaking, rapid rotting, undesirable odors, and off-flavor. Based on the Scott-Knot test, all treatments were grouped into the same category (a) on day 3 (Table 4), suggesting that, at the early stage of storage, the combination of nano edible coating, packaging, and storage temperature did not significantly influence the mushrooms' water content.

Table 4. Effect of various combinations of nano edible coating, packaging, and storage temperature on the water content of wood ear mushroom

Treatment	Water Content (%)		
	3 DAT	6 DAT	9 DAT
NSA+ ±25 °C + vacuum	91.95 a	91.18 c	91.22 c
NSA+ ±25 °C + wrap	91.74 a	91.69 c	90.98 c
NSA+ ±25 °C + biodegradable	88.11 a	84.58 a	84.53 b
NSA+ 10 °C + vacuum	91.37 a	91.16 c	91.57 c
NSA+ 10 °C + wrap	92.28 a	91.71 c	90.35 c
NSA+ 10 °C + biodegradable	89.14 a	88.23 b	88.29 c
NSA+ 5 °C + vacuum	91.54 a	91.32 c	91.97 c
NSA+ 5 °C + wrap	89.89 a	91.90 c	90.23 c
NSA+ 5 °C + biodegradable	89.10 a	88.78 b	82.81 b
NAV+ ±25 °C + vacuum	90.42 a	92.43 c	92.60 c
NAV+ ±25 °C + wrap	90.90 a	91.27 c	92.85 c
NAV+ ±25 °C + biodegradable	87.61 a	83.09 a	82.41 b
NAV+ 10 °C + vacuum	91.72 a	91.20 c	92.21 c
NAV+ 10 °C + wrap	91.53 a	91.61 c	91.14 c
NAV+ 10 °C + biodegradable	89.12 a	87.79 b	88.22 c
NAV+ 5 °C + vacuum	90.41 a	91.82 c	91.13 c
NAV+ 5 °C + wrap	91.90 a	91.60 c	90.96 c
NAV+ 5 °C + biodegradable	90.29 a	88.86 b	75.95 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.

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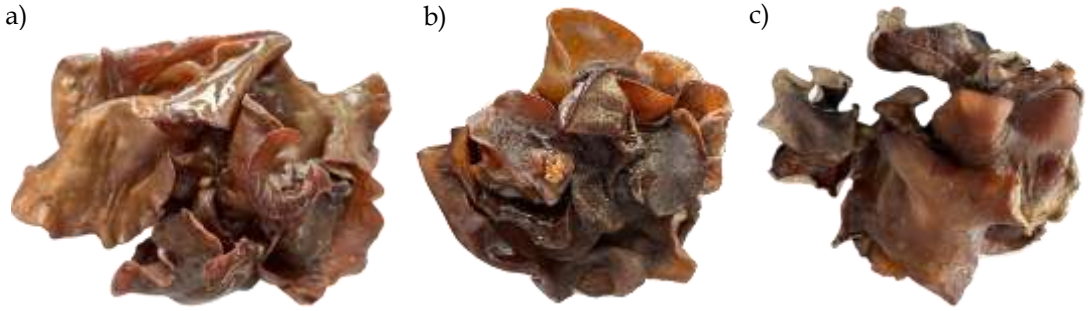

Figure 1. Visual comparison of the freshness of wood ear mushrooms at 9 dat at 5 °C with nano sodium alginate and different packaging treatments: a) Vacuum, b) Wrap, and c) Biodegradable

Under normal conditions, the water content of wood ear mushrooms ranges from 85–95% (Lestari et al., 2023). In this study, the water content of the wood ear mushroom in all treatments was within the normal range, except in several treatments with nano sodium alginate and nano aloe vera combined with biodegradable plastic, especially at temperatures of ±25 °C and 5 °C at 6 and 9 DAT, were classified a and b, which showed lower water content. This is likely due to the higher permeability of biodegradable plastic to water vapor and oxygen, compared to vacuum packaging and wrap plastic (Kumari et al., 2023; Mensitieri et al., 2011). Visually, mushrooms packaged in biodegradable plastic appeared less fresh by the end of the observation period, with a rough texture and dryness (Figure 1c), compared to vacuum packaging (Figure 1a), or plastic wrap (Figure 1b). Low water content during postharvest storage is a major contributor to quality deterioration in mushrooms (Silva et al., 2025). The reduction in water content is often caused by cellular damage and internal water redistribution within the mushroom tissues (Zhang et al., 2018).

Vacuum and wrap packaging are more stable in maintaining the water content of mushrooms at 6 and 9 DAT. This is because of the low oxygen content in the packaging, so that the respiration of wood ear mushrooms can be suppressed and does not produce water vapor, which will increase the water content (Kusumiyati et al., 2025). Fresh mushroom fruit bodies generally contain more than 88% water content after harvest. However, due to the absence of an effective network structure on the surface to prevent water loss, there is rapid spread and loss of water through the transpiration process (Gong et al., 2025). Biodegradable plastic produces lower water content in mushrooms than other packaging, indicating that the packaging has not been able to suppress the transpiration process of the wood ear mushroom, even when coated with a nano edible coating.

The water content in all nano edible coating treatments, storage temperatures, with vacuum packaging and wrap showed optimal values, although there were significant differences between parameters throughout the observation time. Stable water content during storage can also be caused by the use of edible coating, which can reduce respiration in mushrooms, which produce the final product in the form of water vapor. In line with Louis et al. (2021) that the respiration rate of coated mushrooms was significantly lower than uncoated mushrooms. Stable water content during storage can also be caused by the use of edible coating, which can reduce respiration and the final product in the form of water vapor. Respiration rate also could be reduced by modifying natural atmospheric conditions as needed (Kandasamy, 2022). Vacuum packaging can isolate oxygen and water vapor, thereby slowing down the respiration process (Othman et al., 2021).

Total Phenolic. Mushrooms contain phenolic compounds, which are secondary metabolites with dual functions (Hanula et al., 2021)**.** Browning in mushrooms is primarily caused by postharvest stress, which triggers the oxidation of phenolic compounds mediated by PPO. However, phenolics also possess strong antioxidant capacity that can inhibit oxidation chain reactions and prevent lipid peroxidation (Dokhanieh & Aghdam, 2016; Gao et al., 2014). The results of this study indicate that nano edible

coatings, packaging types, and storage temperatures had a significant effect on the total phenolic content of wood ear mushrooms throughout the storage period (Table 5). This suggests that postharvest treatments can influence the biochemical stability of mushrooms by modulating the retention or degradation of phenolic compounds during storage.

At the beginning of storage (3 DAT), treatments using nano aloe vera across all packaging types and storage temperatures—except nano aloe vera with vacuum packaging at ±25 ℃—exhibited higher total phenolic content compared to those using nano sodium alginate. The same thing also happened at 3 and 9 DAT, where the treatment of nano aloe vera with plastic wrap at 5 ℃ showed a higher phenolic content compared to nano sodium alginate under the same conditions. This showed that bioactive compounds in nano aloe vera, such as aloin, emodin, and other phenolic compounds, have better antioxidant stability during storage. However, at 6 DAT, there was a decrease in phenolic content in the treatment with nano aloe vera at ±25 ℃ and 10 ℃. In line with research by Abou-Elwafa et al. (2023) that the extension of shelf-life causes a decrease in total phenolic content. This can be caused by the phenolic oxidation process due to oxygen exposure and phenolase activity during storage. The decrease in total phenolic content can be associated with the oxidation of the PPO enzyme, which produces colored quinones, and quercetin is directly oxidized by PPO (Abou-Elwafa et al., 2023).

In contrast, at both 6 and 9 DAT, nano aloe vera treatments stored at 5 ℃, regardless of packaging types, were classified into group d, showing higher total phenolic content. This indicated that lower storage temperatures are more effective in preserving phenolic compounds, as they suppress the activity of phenol-degrading enzymes and slow the oxidation of bioactive molecules. Edible coatings also contribute to the preservation of total phenolics (Abou-Elwafa et al., 2023) by forming a barrier that limits oxygen diffusion. Interestingly, at 6 DAT, an increase in total phenolic content was observed in treatments using nano sodium alginate, compared to the initial measurement. This aligns with the findings of Hanula et al. (2021), that total phenolic levels may increase at subsequent storage days relative to day 0. This potentially occurs due to a stress-induced accumulation of secondary metabolites as part of the mushroom's defense response.

Table 5. Effect of various combinations of nano edible coating, packaging, and storage temperature on the total phenolic and total flavonoid of wood ear mushroom

Treatment	Total Phenolic (mg GAE/100 g)			Total Flavonoid (mg QE/100 g)		
	3 DAT	6 DAT	9 DAT	3 DAT	6 DAT	9 DAT
NSA+ ±25 ℃ + vacuum	42.47 a	59.17 b	76.72 d	17.50 b	33.88 b	28.29 c
NSA+ ±25 ℃ + wrap	45.23 a	56.21 b	53.48 b	11.68 a	13.20 a	10.13 a
NSA+ ±25 ℃ + biodegradable	43.11 a	35.10 a	32.79 a	18.28 b	17.80 a	11.52 a
NSA+ 10 ℃ + vacuum	47.95 a	97.41 d	71.13 d	16.12 b	18.70 a	19.23 b
NSA+ 10 ℃ + wrap	46.82 a	63.70 b	51.21 b	10.70 a	12.18 a	11.03 a
NSA+ 10 ℃ + biodegradable	56.72 b	59.59 b	36.61 a	18.06 b	15.95 a	11.80 a
NSA+ 5 ℃ + vacuum	62.60 b	78.19 c	55.83 b	26.39 c	51.99 e	21.58 b
NSA+ 5 ℃ + wrap	54.13 a	72.83 c	45.57 b	32.14 d	41.34 c	13.78 a
NSA+ 5 ℃ + biodegradable	59.14 b	77.40 c	58.45 c	56.36 g	45.73 d	26.68 c
NAV+ ±25 ℃ + vacuum	40.02 a	84.21 d	70.32 d	17.20 b	35.51 b	27.85 c
NAV+ ±25 ℃ + wrap	58.19 b	48.13 a	62.62 c	16.58 b	15.36 a	10.56 a
NAV+ ±25 ℃ + biodegradable	62.97 b	42.16 a	44.67 b	18.55 b	11.62 a	11.25 a
NAV+ 10 ℃ + vacuum	62.89 b	50.26 a	63.12 c	13.32 a	11.71 a	9.44 a
NAV+ 10 ℃ + wrap	75.52 b	48.16 a	49.96 b	10.11 a	10.33 a	9.85 a
NAV+ 10 ℃ + biodegradable	80.10 b	74.24 c	64.56 c	19.80 b	12.23 a	13.30 a
NAV+ 5 ℃ + vacuum	70.25 b	90.29 d	65.52 c	38.67 e	54.56 e	20.24 b
NAV+ 5 ℃ + wrap	62.81 b	70.00 c	77.20 d	36.23 e	31.19 b	47.67 d
NAV+ 5 ℃ + biodegradable	70.71 b	57.74 b	55.11 b	50.83 f	31.38 b	31.36 c

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

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Total Flavonoid. This study demonstrates that the total flavonoid content of wood ear mushrooms was significantly influenced by all treatments and storage periods. On the third day after treatment (3 DAT), the combination of plastic wrap, nano sodium alginate, and storage temperatures of ±25 ℃ and 10 ℃ were classified into group a, indicating the lower total flavonoid content (Table 5). In contrast, the combination of nano sodium alginate with biodegradable plastic at 5 ℃ was classified into group g, showing the highest total flavonoid levels. Nano sodium alginate with plastic wrap at 25 ℃ and 10 ℃, as well as nano aloe vera with vacuum packaging and wrap at 10 ℃, showed stable total flavonoid values from day 3 to day 9 after treatment (DAT). This indicates that the treatment was able to maintain flavonoid content until the end of the storage period.

The high flavonoid content in biodegradable plastic packaging may be due to the higher total flavonoid and phenolic content in starch-based packaging compared to conventional plastic packaging (Lopes et al., 2021; Vieira et al., 2024). However, at 6 DAT, the total flavonoid content was higher in vacuum packaging with nano sodium alginate and aloe vera at 5 ℃. This also shows that vacuum packaging can reduce oxidation reactions that can damage flavonoids due to the lack of oxygen in the packaging. The higher total flavonoid content is not because the mushroom fruit body produces more flavonoids, but because the flavonoids contained in the mushrooms are not damaged during storage. Vacuum packaging can also limit exposure to aerobic microorganisms that can produce enzymes that destroy phenolic compounds, including flavonoids, such as polyphenol oxidase (PPO) and peroxidase (POD) (Singh et al., 2018). At low temperatures, these enzymes are inactive or very slow, so flavonoids remain stable.

Throughout the storage period, mushrooms stored at 5 ℃ consistently exhibited higher total flavonoid content compared to other storage temperatures, indicating a strong effect of temperature and packaging type on the total flavonoid retention. This may be attributed to abiotic stress induced by low temperature. When exposed to abiotic stress, mushrooms will activate various metabolic pathways to produce protective compounds, one of which is flavonoids. Flavonoids have antioxidant properties that can ward off free radicals and reduce cell damage due to oxidative stress, including that resulting from cold stress (Banjarnahor & Artanti, 2014; Chandimali et al., 2025; Hassanpour & Doroudi, 2023). Low temperatures can also trigger the expression of genes involved in flavonoid biosynthesis, such as the enzymes chalcone synthase (CHS) and flavonoid synthase (FNS) (Dao et al., 2011; Li et al., 2025; Peng et al., 2019; Yu et al., 2024; Zhao et al., 2024). These enzymes become more active at low temperatures, producing more flavonoids. At low temperatures, cell metabolism can also be disrupted, producing more free radicals (ROS). Flavonoids function as antioxidants that neutralize ROS, thereby helping to maintain the stability of cell membranes and other internal components.

Conclusion

The results showed a significant effect of the combination treatments on L^* at 9 DAT, a^* at 6 DAT, water content at 6 and 9 DAT, total phenolics, and total flavonoids during the storage period. Nano aloe vera with vacuum packaging at 5 ℃ gave the best effect on L^* value at 9 DAT, water content at 6 and 9 DAT, total phenolic at 3 and 6 DAT, and total flavonoid at 3 and 6 DAT. These results indicated the potential of the treatment in maintaining the quality of the wood ear mushroom during storage.

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