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Article

Evaluation of Straw Mushroom Color Stability during Storage: The Role of Nano Edible Coating, Packaging, and Temperature

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Abstract. Straw mushrooms are one of the nutritious edible mushrooms with high economic value. However, color changes during storage are one of the problems that impact the marketability. Post-harvest treatment in the form of the use of nano edible coatings, packaging, and storage temperatures can prevent gas exchange, control humidity and anti-browning agents in straw mushrooms. This study aims to evaluate the effect of nano edible coatings, packaging types, and different storage temperatures on the color stability of straw mushrooms. This study used a Completely Randomized Design consisting of a combination of nano edible coating treatments (nano sodium alginate and nano aloe vera), packaging types (vacuum, biodegradable, wrap packaging), and storage temperatures (room temperature (±25°C), 10°C, and 5°C), so that there are 18 treatment combinations. Each treatment was repeated twice so there were 36 experimental units. Each experimental unit consisted of two samples so that there were 72 samples at each observation time (1, 3, 5 days after storage), so that the total samples were 216. The results of the study showed that the combination treatment of nano sodium alginate with wrap packaging at a temperature of 10°C showed the best L^*, a^*, and hue values during 5 days of storage.

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1. Introduction

Straw mushrooms are a nutritious and economically valuable edible mushroom. They are nutritious due to their high nutritional content and delicious flavor, enjoyed by mushroom lovers worldwide [1]. Straw mushrooms contain more protein than other vegetables [2]. However, the perishable nature of the harvest means it has a relatively short shelf life.

A post-harvest problem with straw mushrooms is color changes that can reduce their visual appearance. Browning is one such color change caused by the oxidation of phenolic compounds by the enzyme polyphenol oxidase (PPO) [3]. Oxygen availability, temperature, and storage duration influence browning symptoms in straw mushrooms. Previous research has shown that storing straw mushrooms at room temperature and 4°C can increase malondialdehyde (MDA), a product of lipid oxidation [4]. Increased MDA is often an indicator of oxidative stress and cell damage [5].

Post-harvest color changes not only reduce the visual quality but also impact the marketability of straw mushrooms, affecting their economic value. Proper post-harvest treatment is expected to address color changes in straw mushrooms. One post-harvest treatment that can be applied to address color changes in straw mushrooms is edible coating.

Aloe vera and sodium alginate are examples of polysaccharides that can be used as edible coatings. Aloe vera contains natural antimicrobials and antioxidants, which can inhibit the oxidation reaction that causes browning [6]. Aloe vera coating can maintain quality by inhibiting browning and extending the shelf life of oyster mushrooms and button mushrooms [7-8]. Sodium alginate coating can also prevent weight loss and browning in button mushrooms during storage [9]. Edible coatings function as a barrier that inhibits gas transfer, but their permeability to water vapor is still high, especially in polysaccharide-based edible coatings [10].

Nano-edible coating technology functions as a moisture barrier and gas exchange agent, as well as an anti-browning agent [11]. The very small size of nanoparticles increases the surface area and improves the barrier properties against the movement of gases and water vapor [12]. Nano edible coating made from polysaccharides can function as a colorant, anti-browning agent to improve the appearance and maintain product quality during storage [13]. The use of nanotechnology-based edible coating can form an effective barrier, inhibit the rate of respiration and extend the shelf life of climacteric fruit [14]. Nanotechnology-based edible coating can slow down the decline in brightness index values compared to controls in button mushrooms with a storage temperature of 4±1°C [15].

The type of packaging used and the temperature at which straw mushrooms are stored majorly impact color retention. Packaging that regulates humidity and oxygen availability helps prevent color changes during storage. Vacuum packaging can minimize oxygen availability while maintaining humidity, which reduces oxidation reactions that produce browning. Enoki mushrooms can be stored in vacuum packaging for 6 days without losing color [16]. Wrap packaging can restrict gas exchange within and outside the package, directly impacting respiration. Biodegradable packaging is environmentally favorable but allows for significant gas and water vapor permeability. The application of nano edible coating before packaging is expected to overcome the weaknesses of biodegradable packaging, so that the color of straw mushrooms can be maintained during storage. Storage temperature also impacts humidity in the packaging, influencing color changes in straw mushrooms throughout storage.

The color stability of packed straw mushrooms during storage is highly dependent on storage temperature. High temperatures promote respiration and ethylene synthesis [17]. High respiration rates produce water vapor as a byproduct, which raises humidity in the packing [18]. Increased humidity in the container stimulates the action of spoilage-causing microorganisms, resulting in straw mushroom discolouration.

Storing edible mushrooms at low temperatures helps prevent the action of enzymes that cause browning, but excessively low temperatures can promote browning. Button mushrooms brown enzymatically after storage at low temperatures (4°C) and room temperature (21°C) [19]. Storing shiitake mushrooms at 5°C and 10°C was more effective in inhibiting browning than at 15°C [20]. Thus, temperature management considerably impacts the color stability of straw mushrooms throughout storage.

Although various studies have been conducted, most are still limited to the use of conventional edible coatings added with nanoparticles as a single treatment, so they have not explored combinations with other post-harvest variables, and are more often applied to climacteric fruit and edible mushrooms other than straw mushrooms. Research on the effect of the combination of post-harvest nano edible coating treatment, packaging type, and storage temperature on the color stability of straw mushrooms has never been conducted. Therefore, this study aims to evaluate the effect of the combination of application of various nano edible coatings, packing type, and temperature on the color stability of straw mushrooms during storage.

2. Experimental Section

2.1. Materials

The research was conducted from May to July 2025 at the Horticulture Laboratory, Faculty of Agriculture, Universitas Padjadjaran. The straw mushroom samples used came from straw mushroom farmers in Subang, West Java, at the same harvest age. This research used the following tools: a digital scale, a Konica Minolta CM-600D (Japan) reflectant spectrophotometer, a vacuum sealer, cooling storage, and a refrigerator. The materials used were semi-edge straw mushrooms, nano sodium alginate, nano aloe vera, distilled water, vacuum-sealed plastic, biodegradable plastic, plastic wrap, and Styrofoam.

2.2 Sample Preparation and Application of Nano Edible Coating

The straw mushroom samples used had the same harvest age (15 days after spreading the seeds into the growing medium) and were not damaged. The samples were cleaned first before applying nano aloe vera 2% and nano sodium alginate 2%. A 2% nano aloe vera coating solution was obtained by dissolving 2 g of nano aloe vera powder in 100 ml of distilled water. A 2% nano sodium alginate solution was also obtained in the same way. The application of the nano edible coating on the straw mushrooms was carried out using the brushing method.

2.3 Packaging and Storage

Straw mushrooms that have been coated with nano aloe vera or nano sodium alginate 2% are dried first before being packaged. Three types of packaging were used: vacuum packaging using vacuum plastic and a vacuum sealer, biodegradable packaging, and wrap packaging using plastic wrap and Styrofoam. Straw mushrooms that have been packaged in vacuum, biodegradable, and wrap packaging are stored at three temperature conditions, namely room temperature (±25°C), 10°C in cooling storage, and 5°C in the refrigerator for 5 days. Color observations were made at 1, 3, and 5 days after storage (DAS).

2.4 Color Measurement

Color measurements were carried out using a reflectant spectrophotometer (Konica Minolta type CM-600, Japan) using the CIE Lab method [21]. Measurements were taken at two points on the straw mushroom fruit body (front and back) and repeated three times. The values displayed by the instrument are L^* (lightness), a^* (red-green), and b^* (yellow-blue). The data obtained were then averaged. The hue angle (H) and chromaticity (C) were calculated using the formula:

$$\text{Hue} = \tan^{-1}\left(\frac{b^*}{a^*}\right)$$

$$\text{Chromaticity}=\sqrt{a^{*2}+b^{*2}}$$

2.5 Experimental Design and Data Analysis

This study used a Completely Randomized Design. The treatment consisted of a combination of variations of nano edible coating (nano sodium alginate and nano aloe vera), packaging type (vacuum packaging, biodegradable, and wrap), and storage temperature (room temperature (±25°C), 10°C, and 5°C), so that 18 treatment combinations were obtained. Each treatment combination was repeated twice, so that there were 36 experimental units, with each unit consisting of two packages. Each experimental unit was observed at 1, 3, and 5 DAS. A total of 72 samples were observed per observation period, resulting in a total of 216 samples observed during storage. The obtained color data were analyzed using analysis of variance (ANOVA) with a significance level of 5% to determine the effect of the given treatment. If the calculated F value is greater than the F table of 5%, further testing was carried out using the Scott-Knott test analysis method at a significance level of 5% using smartstatsXl.

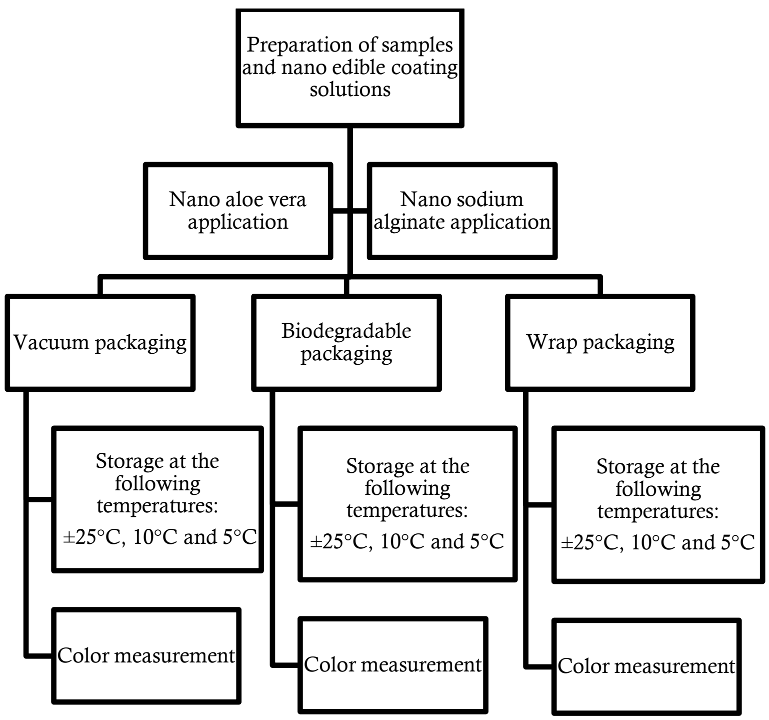

Figure 1. Flowchart of the experiment implementation

3. Results and Discussion

3.1 Color: L^* Value

The results of the analysis of variance showed that the nano edible coating treatment, packaging type, and storage temperature had a significant effect on the L^* value of the straw mushrooms. The combination treatment of nano sodium alginate with wrap packaging at a temperature of 10°C showed a stable L^* value and was significantly different from most other combination treatments, especially at a temperature of 5°C (Table 1). The stability of the L value shows the effectiveness of nano sodium alginate, wrap packaging at a temperature of 10°C can maintain the brightness of the color of straw mushrooms. The L^* value indicates brightness; the higher the value, the brighter and fresher the product [22].

Table 1. Effect of the combination of nano edible coating, type of packaging, and different storage temperatures on L^* value of straw mushrooms at 1, 3, and 5 DAS

Treatment	L^*		
	1 DAS	3 DAS	5 DAS
Nano sodium alginate + vacuum + temperature ±25°C	63.37 c	55.71 b	56.12 d
Nano sodium alginate + biodegradable + temperature ±25°C	60.52 c	59.41 c	57.58 d
Nano sodium alginate + wrap + temperature ±25°C	63.26 c	60.06 c	59.16 d
Nano sodium alginate + vacuum + temperature 10°C	65.90 c	58.19 c	50.74 c
Nano sodium alginate + biodegradable + temperature 10°C	65.49 c	55.60 b	50.76 c
Nano sodium alginate + wrap + temperature 10°C	61.80 c	60.24 c	55.09 d
Nano sodium alginate + vacuum + temperature 5°C	64.15 c	51.83 b	47.30 b
Nano sodium alginate + biodegradable + temperature 5°C	54.55 b	44.01 a	37.44 a
Nano sodium alginate + wrap + temperature 5°C	50.06 a	38.17 a	43.09 b
Nano aloe vera + vacuum + temperature ±25°C	60.93 c	53.29 b	49.08 c
Nano aloe vera + biodegradable + temperature ±25°C	62.95 c	56.86 c	52.86 c
Nano aloe vera + wrap + temperature ±25°C	64.89 c	60.35 c	57.14 d
Nano aloe vera + vacuum + temperature 10°C	59.12 c	50.72 b	50.85 c
Nano aloe vera + biodegradable + temperature 10°C	65.11 c	52.57 b	52.68 c
Nano aloe vera + wrap + temperature 10°C	61.75 c	53.93 b	52.95 c
Nano aloe vera + vacuum + temperature 5°C	56.11 b	51.86 b	47.40 b
Nano aloe vera + biodegradable + temperature 5°C	53.11 b	41.83 a	39.81 a
Nano aloe vera + wrap + temperature 5°C	47.55 a	38.86 a	43.45 b

The combination treatment of nano aloe vera with wrap packaging at a temperature of 10°C showed a lower L^* value, which was significantly different from the combination of nano sodium alginate. This shows that nano sodium alginate is more effective in maintaining the L^* value of straw mushrooms. Cavusoglu et al. (2021) [9] also reported that sodium alginate was able to maintain a higher L^* value of button mushrooms compared to the control.

Sodium alginate can form a gel with low oxygen permeability, which can inhibit browning [23]. The ability to inhibit oxygen can prevent a decrease in the L^* value of straw mushrooms. The mechanism occurs because oxygen causes the PPO enzyme to catalyze phenolic oxidation, which causes browning [24].

The color quality of straw mushrooms during storage is significantly influenced by temperature. At 5°C, the decrease in L^* value is more significant than at 10°C. The decrease in L^* value indicates enzymatic browning and reduces the quality of straw mushrooms. Lin & Sun (2019) [25] also, stated that a decrease in L^* value indicates a darker color of button mushrooms, thus reducing their visual quality.

A higher L^* value at 10°C may be due to lower respiration rates and enzymatic activity, thus effectively preventing browning during storage. Enzymatic activity that causes browning occurs because phenolic compounds are oxidized by the PPO enzyme [26]. This enzyme increases with increasing storage duration and temperature [27]. Li et al. (2022) [20] °Calso reported that storage temperatures of 5 and 10°C effectively inhibited browning of shiitake mushrooms compared to 15°C. However, the study showed that a temperature of 5°C can cause cold stress in straw mushrooms, resulting in decreased brightness.

A decrease in brightness is one indicator of browning. This is because straw mushrooms cannot tolerate low temperatures (<10°C), resulting in cold damage such as tissue softening and liquefaction [28]. Storage temperatures that are too low can cause chilling damage and accelerate the browning process [24]. Storage at these temperatures can damage cells, thereby triggering an increase in the activity of the free PPO enzyme that causes browning [29]. Kaniyamparambil et al. (2025) [19] also reported that storing button mushrooms at 4°C can cause browning. Therefore, the combination of nano sodium alginate with wrap packaging at a temperature of 10°C has been proven to be able to maintain the brightness of the color of straw mushrooms during storage.

3.2 Color: a^* Value

The results of the analysis of variance showed that the nano edible coating treatment, type of packaging, and storage temperature had a significant effect on the a^* value of straw mushrooms at 3 and 5 DAS, whereas at 1 DAS. The combination treatment of nano sodium alginate and nano aloe vera with all types of packaging at a temperature of 10°C showed the lowest and stable a^* value, which was significantly different from other treatments (Table 2). This shows that the treatment is able to maintain the a^* (red/green) color and visual quality of straw mushrooms during storage.

Table 2. Effect of the combination of nano edible coating, type of packaging, and different storage temperatures on the a^* value of straw mushrooms at 1, 3, and 5 DAS

Treatment	a^*		
	1 DAS	3 DAS	5 DAS
Nano sodium alginate + vacuum + temperature ±25°C	6.10 a	9.63 b	9.64 a
Nano sodium alginate + biodegradable + temperature ±25°C	6.83 a	7.17 a	8.25 a
Nano sodium alginate + wrap + temperature ±25°C	7.40 a	10.14 b	9.84 a
Nano sodium alginate + vacuum + temperature 10°C	6.01 a	7.01 a	8.71 a
Nano sodium alginate + biodegradable + temperature 10°C	6.49 a	8.88 a	8.52 a
Nano sodium alginate + wrap + temperature 10°C	7.48 a	7.73 a	7.39 a
Nano sodium alginate + vacuum + temperature 5°C	6.30 a	9.52 b	8.63 a
Nano sodium alginate + biodegradable + temperature 5°C	7.70 a	11.83 c	12.49 b
Nano sodium alginate + wrap + temperature 5°C	8.62 a	10.88 c	12.74 b
Nano aloe vera + vacuum + temperature ±25°C	6.26 a	8.34 a	9.54 a
Nano aloe vera + biodegradable + temperature ±25°C	5.97 a	7.02 a	7.82 a
Nano aloe vera + wrap + temperature ±25°C	6.74 a	9.30 b	10.44 a
Nano aloe vera + vacuum + temperature 10°C	7.71 a	8.15 a	8.77 a
Nano aloe vera + biodegradable + temperature 10°C	5.88 a	7.52 a	7.66 a
Nano aloe vera + wrap + temperature 10°C	7.86 a	8.76 a	8.62 a
Nano aloe vera + vacuum + temperature 5°C	8.35 a	9.93 b	9.89 a
Nano aloe vera + biodegradable + temperature 5°C	8.92 a	11.63 c	12.72 b
Nano aloe vera + wrap + temperature 5°C	8.41 a	10.01 b	11.33 b

A low a^* value indicates a dull color in fresh straw mushrooms. The application of nano aloe vera and nano sodium alginate was able to maintain the stability of the a^* value during storage. The stability of the a^* value indicates the ability of the two nano edible coatings to inhibit browning. Aloe vera contains natural antioxidant compounds that can ward off free radicals, thereby slowing the oxidation process [30-31]. This proves that nano sodium alginate and nano aloe vera are able to inhibit changes in the a* value, which is an indicator of browning in straw mushrooms.

Sodium alginate can form a gel with relatively low oxygen permeability [23]. This oxygen barrier can inhibit the oxidation reaction that causes browning in straw mushrooms. Plesoianu et al. (2022) [32]reported significantly lower browning of straw mushrooms coated with sodium alginate compared to other coatings and the control. However, the conventional sodium alginate layer formed was less dense, resulting in relatively high permeability to oxygen and water vapor compared to the nano sodium alginate.

Storage of straw mushrooms with all packaging at 10°C showed a stable a* value compared to temperatures of 25°C. Singh et al. (2010) [33] reported that higher storage temperatures can accelerate the color degradation of button mushrooms. A temperature of 10°C can suppress the activity of the PPO enzyme that causes browning [34]. However, a temperature of 25°C increases the rate of respiration and pigment degradation, resulting in changes in the color of straw mushrooms [28].

Storage at a temperature of 5°C also causes an increase in the a* value of straw mushrooms, which is an indicator of color change. A temperature of 5°C causes cold stress, resulting in cell and tissue damage in straw mushrooms. Cell and tissue damage cause an increase in the PPO enzyme, which causes browning [24]. This is in line with research by Kaniyamparambil et al. (2025) [19], storing button mushrooms at too low a temperature (4°C) and room temperature (21°C) causes browning.

3.3 Color: b* Value

The results of the analysis of variance showed that the nano edible coating treatment, type of packaging, and storage temperature had a significant effect on the b* value of straw mushrooms at 3 and 5 DAS, whereas at 1 DAS. The combination treatment of nano sodium alginate with wrap packaging at a temperature of 5°C showed the lowest b value, which was significantly different from most of the combination treatments at a temperature of 25°C at 5 DAS (Table 3). The combination treatment of nano sodium alginate and nano aloe vera with wrap packaging at a temperature of 5°C showed a stable b* value during storage. A stable b* value indicates the ability of the combination treatment to maintain the yellow color of straw mushrooms during storage.

The b* value indicates the yellow and blue color axes; a positive b* value indicates yellow, while a negative b* value indicates blue [35]. Semi-ripe straw mushrooms generally have a brownish-yellow color and will experience color changes during storage. Nano sodium alginate and nano aloe vera coating treatment can maintain the brownish-yellow color of straw mushrooms during storage. Sodium alginate coating has low oxygen permeability, thus limiting enzymatic activity that causes browning [36,37]. Zhu et al. (2019) [38] also reported that sodium alginate coating can inhibit browning, MDA, PPO, and POD enzymes of Pholiota nameko fungus.

Nano aloe vera contains natural flavonoid compounds that have antioxidant activity [39]. Mirshekari et al. (2019) [40] reported that aloe vera can reduce the activity of the PPO enzyme, which causes browning in button mushrooms. This decrease is associated with an increase in the total phenolic compounds in button mushrooms [41]. Total phenolic compounds include flavonoids and anthocyanins [42]. Nano aloe vera coating treatment can inhibit the oxidation of flavonoid compounds and maintain the yellow color of straw mushrooms. Flavonoid compounds are mostly yellow [43].

Table 3. Effect of the combination of nano edible coating, type of packaging, and different storage temperatures on the b* value of straw mushrooms at 1, 3, and 5 DAS

Treatment	b*		
	1 DAS	3 DAS	5 DAS
Nano sodium alginate +vacuum + temperature ±25°C	27.29 a	33.87 d	35.16 b
Nano sodium alginate + biodegradable + temperature ±25°C	26.32 a	27.19 c	29.06 b
Nano sodium alginate + wrap + temperature ±25°C	29.96 a	32.57 d	31.29 b
Nano sodium alginate + vacuum + temperature 10°C	26.72 a	27.06 c	26.85 a
Nano sodium alginate + biodegradable + temperature 10°C	26.72 a	28.23 c	25.75 a
Nano sodium alginate + wrap + temperature 10°C	27.79 a	27.64 c	26.41 a
Nano sodium alginate + vacuum + temperature 5°C	26.29 a	28.48 c	25.43 a
Nano sodium alginate + biodegradable + temperature 5°C	26.24 a	24.71 b	21.07 a
Nano sodium alginate + wrap + temperature 5°C	25.79 a	19.53 a	24.52 a
Nano aloe vera + vacuum + temperature ±25°C	26.89 a	28.82 c	29.91 b
Nano aloe vera + biodegradable + temperature ±25°C	24.74 a	25.19 b	26.15 a
Nano aloe vera + wrap + temperature ±25°C	27.39 a	30.07 c	32.28 b
Nano aloe vera + vacuum + temperature 10°C	28.05 a	23.54 b	26.69 a
Nano aloe vera + biodegradable + temperature 10°C	25.06 a	23.62 b	25.60 a
Nano aloe vera + wrap + temperature 10°C	28.71 a	26.25 c	27.03 a
Nano aloe vera + vacuum + temperature 5°C	26.55 a	28.91 c	25.50 a
Nano aloe vera + biodegradable + temperature 5°C	26.68 a	23.76 b	23.43 a
Nano aloe vera + wrap + temperature 5°C	22.60 a	18.89 a	24.14 a

A temperature of 5°C can slow down the yellow pigment degradation reaction so that the b* value can be maintained. In line with Xue et al. (2024), [44] which states that lower temperatures can maintain the stability of the pigment structure or slow down pigment degradation. However, lower temperatures can also affect the texture or surface reflectance so that the L* value is not optimal at 5°C. Thus, the combination of nano sodium alginate and nano aloe vera with wrap packaging at a temperature of 5°C is effective in maintaining the yellow color of straw mushrooms.

3.4 Color: Chroma

The results of the analysis of variance showed that the nano edible coating treatment, type of packaging, and storage temperature had a significant effect on the chroma value of straw mushrooms at 3 and 5 DAS, and vice versa at 1 DAS. The combination treatment of nano sodium alginate with wrap packaging at a temperature of 5°C showed a chroma value that was significantly different from most of the combination treatments at a temperature of 25°C at 5 DAS (Table 4). The combination treatment of nano sodium alginate and nano aloe vera with wrap packaging at a temperature of 5°C showed stable chroma values for 5 days of storage.

Chroma is the color intensity or saturation [45]. Stable chroma values during storage indicate the ability of the post-harvest combination treatment to maintain the visual quality of straw mushrooms. An increase in chroma value is one indicator for measuring the browning index. Nunas et al. (2024) [46] reported an increase in chroma value in line with browning of white shimeji mushrooms.

Table 4. Effect of the combination of nano edible coating, type of packaging, and different storage temperatures on the chroma value of straw mushrooms at 1, 3, and 5 DAS

Treatment	Chroma		
	1 DAS	3 DAS	5 DAS
Nano sodium alginate +vacuum + temperature ±25°C	27.98 a	35.22 d	36.47 b
Nano sodium alginate + biodegradable + temperature ±25°C	27.20 a	28.12 b	30.21 a
Nano sodium alginate + wrap + temperature ±25°C	30.86 a	34.12 d	32.80 b
Nano sodium alginate + vacuum + temperature 10°C	27.39 a	27.96 b	28.28 a
Nano sodium alginate + biodegradable + temperature 10°C	27.50 a	29.59 c	27.18 a
Nano sodium alginate + wrap + temperature 10°C	28.80 a	28.70 c	27.43 a
Nano sodium alginate + vacuum + temperature 5°C	27.04 a	30.04 c	26.87 a
Nano sodium alginate + biodegradable + temperature 5°C	27.36 a	27.40 b	24.50 a
Nano sodium alginate + wrap + temperature 5°C	27.22 a	22.36 a	27.68 a
Nano aloe vera + vacuum + temperature ±25°C	27.62 a	30.01 c	31.40 b
Nano aloe vera + biodegradable + temperature ±25°C	25.46 a	26.17 b	27.31 a
Nano aloe vera + wrap + temperature ±25°C	28.21 a	31.48 c	33.94 b
Nano aloe vera + vacuum + temperature 10°C	29.10 a	24.94 a	28.09 a
Nano aloe vera + biodegradable + temperature 10°C	25.74 a	24.79 a	26.73 a
Nano aloe vera + wrap + temperature 10°C	29.77 a	27.69 b	28.38 a
Nano aloe vera + vacuum + temperature 5°C	27.85 a	30.60 c	27.40 a
Nano aloe vera + biodegradable + temperature 5°C	28.14 a	26.45 b	26.71 a
Nano aloe vera + wrap + temperature 5°C	24.14 a	21.48 a	26.69 a

Color changes during storage in agricultural products, including mushrooms, mostly occur due to enzymatic activity, which causes browning of the product [47]. Sodium alginate coating can coat and block the product from oxygen exposure, so that the oxidation reaction can be inhibited [48]. Jiang (2013) [49] reported that sodium alginate coating can delay the color change of button mushrooms.

Aloe vera coating can inhibit enzymatic activity because it contains natural antioxidant compounds that can ward off oxidative damage [50]. Mirshekari et al. (2019) [40] also reported that aloe vera coating can inhibit color changes in button mushrooms during storage. Thus, the synergy between nano sodium alginate and/or nano aloe vera, wrap packaging, and a temperature of 5°C can inhibit chroma changes, which are indicators of color changes.

3.5 Color: Hue

The results of the analysis of variance showed that the nano edible coating treatment, type of packaging, and storage temperature had a significant effect on the hue value of straw mushrooms at 3 and 5 DAS, and vice versa at 1 DAS. The combination treatment of nano sodium alginate with wrap and vacuum packaging at a temperature of 10°C showed a significantly different hue value compared to several combination treatments at a temperature of 5°C at 5 DAS (Table 5). This combination treatment also showed stable hue values over 5 days of storage. Stable hue values indicate no significant color changes during storage.

The hue value indicates the color spectrum seen by the eye in degrees (°) [51]. A hue value approaching 90° indicates yellow, a decrease towards 0° indicates red, while an increase towards 180° indicates green [52]. A hue value approaching 90° indicates a pale yellow color in fresh straw mushrooms. A decrease in the hue value indicates a color change to red or browning in the straw mushrooms.

The results of the study indicate that the combination treatment of nano sodium alginate with wrap and vacuum packaging at a temperature of 10°C can maintain the highest hue value compared to temperatures of 5°C and 25°C. Choi et al. (2022) [16] reported that vacuum packaging of enoki mushrooms can maintain their color for 6 days of storage. A storage temperature of 10°C can slow down enzymatic activity that causes browning without causing chilling injury. Storing straw mushrooms at temperatures <10°C causes the fruiting body to experience cold damage and autolysis [53]. This demonstrates the treatment's ability to suppress enzymatic activity that causes browning in straw mushrooms.

Table 5. Effect of the combination of nano edible coating, type of packaging, and different storage temperatures on the hue value (h°) of straw mushrooms at 1, 3, and 5 DAS

Treatment	Hue (h°)		
	1 DAS	3 DAS	5 DAS
Nano sodium alginate +vacuum + temperature ±25°C	77.49 b	74.10 d	74.67 b
Nano sodium alginate + biodegradable + temperature ±25°C	75.47 b	75.22 d	74.15 b
Nano sodium alginate + wrap + temperature ±25°C	76.19 b	72.69 c	72.51 b
Nano sodium alginate + vacuum + temperature 10°C	77.40 b	75.46 d	71.98 b
Nano sodium alginate + biodegradable + temperature 10°C	76.36 b	72.49 c	71.97 b
Nano sodium alginate + wrap + temperature 10°C	75.05 b	74.39 d	74.48 b
Nano sodium alginate + vacuum + temperature 5°C	76.49 b	71.49 c	71.39 b
Nano sodium alginate + biodegradable + temperature 5°C	73.66 a	64.44 b	59.29 a
Nano sodium alginate + wrap + temperature 5°C	71.49 a	60.90 a	62.41 a
Nano aloe vera + vacuum + temperature ±25°C	77.00 b	73.74 d	72.29 b
Nano aloe vera + biodegradable + temperature ±25°C	76.54 b	74.41 d	73.31 b
Nano aloe vera + wrap + temperature ±25°C	76.17 b	72.90 c	72.11 b
Nano aloe vera + vacuum + temperature 10°C	74.73 b	70.68 c	71.83 b
Nano aloe vera + biodegradable + temperature 10°C	76.85 b	72.35 c	73.33 b
Nano aloe vera + wrap + temperature 10°C	74.69 b	71.75 c	72.31 b
Nano aloe vera + vacuum + temperature 5°C	72.62 a	71.21 c	68.97 b
Nano aloe vera + biodegradable + temperature 5°C	71.64 a	63.91 b	61.10 a
Nano aloe vera + wrap + temperature 5°C	69.58 a	61.68 a	65.03 a

4. Conclusion

Color change is one of the main problems with straw mushrooms during storage which can affect their appearance and selling value. Different nano edible coating treatments, packaging types, and storage temperatures significantly impact the color quality of straw mushrooms. The combination of nano sodium alginate and wrap packaging at 10°C maintained the color quality, including L^*, a^*, and hue values, of straw mushrooms for 5 days of storage. This post-harvest treatment can reduce losses during storage and distribution of straw mushrooms, thereby increasing their economic value. Further research needs to be focused on scaling up this treatment for commercial applications, evaluating consumer acceptance, and ensuring that this post-harvest treatment not only maintains color stability but also aligns with sustainable agriculture goals.

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