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# EFFECT OF PACKAGING ON POST-HARVEST QUALITY OF GREY OYSTER MUSHROOMS (*Pleurotus ostreatus*)

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**Abstract:** Purpose - Grey oyster mushroom (*Pleurotus ostreatus*) is one of the most sensitive vegetables when harvested and contributes to the increase of post-harvest losses in the market. It is highly susceptible to decay and undergoes deterioration after harvesting. Packaging materials may affect the quality of fresh produce, especially oyster mushrooms, prior to consumption. Therefore, the effect of different packaging materials on the post-harvest quality of oyster mushrooms stored at cool storage was examined in this study. Methodology - This study evaluated six types of packaging materials: Low-Density Polyethylene (LDPE) with and without vacuum, High-Density Polyethylene (HDPE) with and without vacuum, and Polypropylene (PP) with and without vacuum. Each treatment was conducted with three replications. The parameters assessed included weight loss, firmness, Total Soluble Solids (TSS) concentration, Browning Index (BI), and color measurements ($L$ and $b$ values). Data were collected at two-day intervals up to Day 12. All samples were properly packed and stored at a controlled temperature of 5°C. Findings - The study demonstrates that different packaging materials and vacuum conditions have a significant influence on the post-harvest quality of oyster mushrooms. Overall, HDPE and PP materials, particularly in non-vacuum applications, were most effective in preserving multiple quality parameters of oyster mushrooms during storage. Originality - This study presents an original idea that was designed and conducted to address questions related to the quality of mushroom shelf life, based on different packaging materials.

Keywords: Oyster mushroom, post-harvest, packaging material, quality, polyethylene.

## Introduction

Edible mushrooms, such as oyster mushrooms, are among the most popular food items worldwide and are in high demand in the market due to consumer interest in health and well-being. In recent years, the global production and consumption of mushrooms and truffles have increased significantly, with production rising from 31.78 million tonnes in 2012 to 48.34 million tonnes in 2022 (Shahbandeh, 2024). Accordingly, Mattila *et al*. (2000) and Lindequist *et al*. (2005) reported numerous health benefits of mushrooms and the compounds derived from them. These health benefits may be attributed to the mushroom-derived bioactive polysaccharides, such as lectin, antioxidants, dietary fiber, ergosterol, vitamins $B_1$, $B_2$, and C, folates, niacin, and minerals. Compared to vegetables, mushrooms are a good source of several mineral elements.

Oyster mushrooms are one of the most sensitive vegetables cultivated. Therefore, they require careful handling since they are perishable and easily damaged. Furthermore, they tend to lose quality after harvest, primarily due to their high respiration rate and the absence of a protective barrier that prevents water loss (Akbarirad *et al*., 2013). These factors render them vulnerable to mechanical damage, microbial growth, weight loss, and enzymatic browning, resulting in a rapid decline in quality after harvest (Castellanos-Reyes *et al*., 2021). Notably, mushroom cultivation is typically managed hygienically, as mushrooms are highly sensitive to cleanliness, odors, temperature, and noise levels. In particular, environmental conditions significantly affect mushroom growth, with deterioration of quality commonly arising from a combination of internal and external factors, resulting in reduced sensory and nutritional value. The quality of mushrooms and truffles is most frequently affected by moisture loss, color changes, textural alterations, microbial deterioration, and the loss of nutrients and flavor (Farokhian *et al*., 2017). A comprehensive review by Dawadi *et al*. (2022) highlighted that mushrooms begin to lose quality immediately after harvest, exhibiting signs such as discoloration, moisture loss, texture changes, increased microbial activity, and a loss of nutrients and flavor. These factors collectively contribute to their short shelf life, even under refrigeration, due to the elevated breathing rate and subsequent water loss. After harvest, several physiological and morphological changes can occur, including browning, changes in texture, and moisture loss. Such deterioration of mushroom quality reduces consumer acceptance and lowers the market price.

Packaging is an alternative method for extending the shelf life of mushrooms during post-harvest storage and commercialisation. It also increases the quality of the product and protects fresh produce from damage. According to Coles (2005), food packaging is incredibly vital for maintaining the freshness of fresh produce, preventing contamination from dirt, and facilitating transportation and storage. Over 1,500 distinct packaging varieties are employed in the United States for manufacturing purposes. The industry consistently enhances the innovative idea of packaging materials to meet the requirements of wholesalers, customers, food service buyers, and processing operations. For instance, improper storage conditions, including packaging materials and temperature, reduce mushrooms' shelf life (Singh & Sagar, 2010).

Recent studies have underscored that inadequate knowledge among farmers, marketers, and wholesalers regarding appropriate packaging techniques significantly contributes to high levels of produce waste in markets. Muganyizi and Rejikumar (2023) identified limited awareness and understanding of improved post-harvest technologies, including packaging, as a significant barrier to their adoption among smallholder farmers in sub-Saharan Africa and South Asia. This knowledge gap leads to continued reliance on traditional, often ineffective, packaging methods, resulting in substantial post-harvest losses. Therefore, this study was conducted to investigate the impact of different packaging materials on the post-harvest quality of oyster mushrooms during cool storage at 5℃. It aims to extend the shelf life and quality of mushrooms in the market, at home, and in other settings.

## Materials and Methods

### *Samples Preparation*

The grey oyster mushrooms used in this experiment were collected from a private farm in Setiu, Terengganu, owned by SR Mushroom Industries. The mushroom used in this study was a mature specimen, characterised by a fully developed cap that was still slightly curled downward at the edges. Notably, the optimal harvesting time for oyster mushrooms is typically three to five days after pinhead formation.

Accordingly, the mushrooms were cleaned by removing dirt and dust from their surfaces and ensuring that any impurities were removed from the mushrooms' surfaces. Subsequently, 100 g of mushrooms were weighed using an electronic balance and covered according to the prescribed treatment. The packaging materials used in this experiment are Polypropylene (PP) plastic, Low-Density Polyethylene (LDPE) plastic, and High-Density Polyethylene (HDPE) plastic. Each type of packaging material was further processed using two methods: Vacuum and non-vacuum (sealed). The sealing process was performed using a plastic bag sealer, and all samples were stored at the same temperature (5℃) for observation. The parameter assessments were conducted over a period of 14 days at two-day intervals, specifically on days 0, 2, 4, 6, 8, 10, and 12.

### Measurement of Product Quality

This study measured several produce qualities, including weight, firmness, Total Soluble Solid (TSS) concentration, Browning Index (BI), and color (L* and b*). Meanwhile, weight was determined using an electronic balance at two-day intervals until day 12 by recording the samples before and after storage. As such, the lighter the weight of the mushroom, the higher the rate of weight loss. Following this, browning is a key quality indicator used to assess the degree of deterioration in the appearance of mushrooms (Lin *et al*., 2017). The BI was calculated using the formula according to Mohammadi *et al*. (2008):

$$BI = 100 \, X \frac{X\text{-}0.31}{0.17},$$

where

$$X = \frac{(a_* + 1.75L_*)}{(5.645L_* + a_* + 3.012b_*)}$$

For the color parameter, the surface color of mushrooms was measured using a Konica Minolta Chromameter. Based on Peter and Charles (2000), L* represents lightness, and b* represents yellowness or blueness. Correspondingly, data were collected from three distinct spots on the surface of each mushroom in the package for every replicate.

The firmness of the mushrooms was measured using a texture analyser. This method was conducted using a mechanical instrument fitted with a probe, which applied a load to insert the probe into the fruit and measure the resistance. A texture analyser equipped with a 2-mm-diameter needle probe was used to measure firmness as a force for puncturing (Zivanovic *et al*., 2000). Simultaneously, insertion was performed at the surface part, which is the top, middle, and bottom of the mushrooms.

Furthermore, the sugar content of mushrooms is crucial for obtaining the best quality to meet consumer demands. This method is one of the attributes that determine the freshness of mushrooms, measured using a refractometer. Concurrently, the mushroom was cut into slices and smashed using a mortar and pestle until the mushroom juice was obtained. Subsequently, a small amount of the juice was transferred to the refractometer, and the readings were recorded.

### Experimental Design

All treatments in this experiment were arranged using a Complete Randomised Design (CRD), with three replicates prepared for each treatment. Note that all samples involved in this study were stored in a 5°C cold room.

Table 1: Treatments based on wrapping material and vacuum condition for mushroom storage

| Treatment | Material for wrapping |
|---|---|
| Treatment 1 | PP plastic vacuum |
| Treatment 2 | PP plastic non-vacuum |
| Treatment 3 | LDPE plastic vacuum |
| Treatment 4 | LDPE plastic non-vacuum |
| Treatment 5 | HDPE plastic vacuum |
| Treatment 6 | HDPE plastic non-vacuum |
| Treatment 7 (Control) | Without wrapping |

### Statistical Analysis

In this study, all data were analysed using one-way Analysis of Variance (ANOVA) to determine whether there was a significant difference ($p < 0.05$) between the different packaging materials. Tukey's test was used to follow up on the analysis, calculating means and standard deviations, and to run multiple comparison tests. In addition, the Statistical Package for the Social Sciences (SPSS 20.0) software was used in this experiment to collect data and assess the effect of all treatments.

## Result and Discussion

### *Postharvest parameter*

Table 2 provides data on the effects of various packaging methods (T1-T7) on the weight, firmness, and TSS concentration of oyster mushrooms at six time points (days 2, 4, 6, 8, 10, and 12).

Table 2: Post-harvest parameter based on treatment

| Day | Treatment | Weight | Firmness | TSS concentration |
|---|---|---|---|---|
| D2 | T1 | 99.70 ± 0.100b | 0.66 ± 0.038a | 3.67 ± 0.577a |
| | T2 | 99.20 ± 0.529b | 0.62 ± 0.092a | 3.83 ± 0.764a |
| | T3 | 99.57 ± 0.451b | 0.78 ± 0.099a | 3.67 ± 0.577a |
| | T4 | 99.13 ± 0.379b | 0.76 ± 0.138a | 5.50 ± 1.500a |
| | T5 | 99.83 ± 0.288b | 0.72 ± 0.075a | 4.67 ± 1.155a |
| | T6 | 99.63 ± 0.306b | 0.69 ± 0.056a | 5.00 ± 1.000a |
| | T7 | 97.13 ± 0.306a | 0.56 ± 0.017a | 4.17 ± 0.764a |
| D4 | T1 | 99.63 ± 0.351b | 0.65 ± 0.038b | 4.17 ± 0.764a |
| | T2 | 99.10 ± 0.265b | 0.57 ± 0.041ab | 4.67 ± 0.577a |
| | T3 | 99.40 ± 0.361b | 0.53 ± 0.053ab | 3.83 ± 1.041a |
| | T4 | 98.83 ± 0.231b | 0.55 ± 0.003ab | 4.33 ± 0.577a |
| | T5 | 99.73 ± 0.379b | 0.52 ± 0.052ab | 3.50 ± 0.866a |
| | T6 | 99.50 ± 0.458b | 0.55 ± 0.061ab | 4.17 ± 0.764a |
| | T7 | 96.43 ± 0.208a | 0.38 ± 0.050a | 3.50 ± 0.500a |
| D6 | T1 | 99.60 ± 0.361b | 0.76 ± 0.040a | 3.50 ± 0.500a |
| | T2 | 99.03 ± 0.493b | 0.66 ± 0.070a | 3.17 ± 0.764a |
| | T3 | 99.23 ± 0.551b | 0.70 ± 0.058a | 3.00 ± 0.000a |
| | T4 | 98.60 ± 0.100b | 0.56 ± 0.023a | 3.17 ± 0.289a |
| | T5 | 99.63 ± 0.252b | 0.76 ± 0.151a | 3.00 ± 0.000a |
| | T6 | 99.30 ± 0.625b | 0.51 ± 0.049a | 3.67 ± 0.577a |
| | T7 | 95.70 ± 0.625a | 0.59 ± 0.091a | 2.83 ± 0.289a |
| D8 | T1 | 99.57 ± 0.289b | 0.65 ± 0.038b | 3.40 ± 0.721a |
| | T2 | 98.87 ± 0.987b | 0.62 ± 0.059b | 2.53 ± 0.503a |
| | T3 | 98.80 ± 0.173b | 0.53 ± 0.053ab | 3.33 ± 0.577a |
| | T4 | 98.33 ± 0.451b | 0.55 ± 0.003ab | 3.33 ± 0.115a |
| | T5 | 99.53 ± 0.404b | 0.52 ± 0.052ab | 3.13 ± 0.808a |
| | T6 | 98.83 ± 0.586b | 0.55 ± 0.061ab | 2.87 ± 0.306a |
| | T7 | 94.07 ± 0.493a | 0.38 ± 0.050a | 2.20 ± 0.200a |

| | | | | |
|---|---|---|---|---|
| D10 | T1 | 99.30 ± 0.265b | 0.56 ± 0.049a | 3.80 ± 0.529ab |
| | T2 | 98.83 ± 0.723b | 0.48 ± 0.017a | 4.00 ± 0.500ab |
| | T3 | 98.70 ± 0.100b | 0.60 ± 0.169a | 4.73 ± 0.115b |
| | T4 | 98.23 ± 1.242b | 0.44 ± 0.075a | 4.20 ± 0.721ab |
| | T5 | 99.47 ± 0.351b | 0.53 ± 0.092a | 4.27 ± 0.642ab |
| | T6 | 98.57 ± 1.450b | 0.50 ± 0.067a | 4.33 ± 0.577ab |
| | T7 | 93.80 ± 2.000a | 0.47 ± 0.019a | 2.90 ± 0.361a |
| D12 | T1 | 99.13 ± 0.058a | 0.57 ± 0.091a | 3.27 ± 0.643ab |
| | T2 | 98.33 ± 1.761a | 0.46 ± 0.071a | 3.93 ± 0.611ab |
| | T3 | 95.23 ± 1.286a | 0.73 ± 0.034a | 3.87 ± 0.231ab |
| | T4 | 96.67 ± 3.349a | 0.44 ± 0.055a | 4.00 ± 0.000ab |
| | T5 | 99.40 ± 0.520a | 0.48 ± 0.059a | 3.73 ± 0.230ab |
| | T6 | 97.60 ± 3.732a | 0.46 ± 0.098a | 4.07 ± 0.115b |
| | T7 | 93.80 ± 3.223a | 0.44 ± 0.054a | 3.00 ± 0.000a |

Mean values with different letters in the same column for each attribute are significantly different at $p < 0.05$. T1: PP plastic vacuum, T2: PP plastic non-vacuum, T3: LDPE plastic vacuum, T4: LDPE plastic non-vacuum, T5: HDPE plastic vacuum, T6: HDPE, T7: control plastic non-vacuum

### *Weight of Mushroom*

At day 2, results revealed significant differences ($p < 0.001$) for all treatments (except control) with mean weights ranging from 99.13 g to 99.83 g. Similar trends continued until day 10, whereas T7 presented a marked decrease, which is only 93.8 g compared to T1-T6, while T5 maintained the highest weight retention (99.47 g). At day 12, differences were no longer statistically significant ($p = 0.103$). On most days (D2 until D10), the weight loss differences between T7 and other treatments were highly significant ($p < 0.001$). Based on the table, T5 (HDPE plastic vacuum) demonstrated the most consistent performance in preserving the weight of the mushroom.

Environmental factors such as temperature and relative humidity during mushroom cultivation significantly impact the moisture content. For instance, maintaining high relative humidity (85% to 95%) is crucial during the growth of Pleurotus species to ensure optimal moisture levels and prevent desiccation (Bellettini *et al*., 2019). Furthermore, increasing the weight loss of oyster mushrooms or transpiration is an essential physiological mechanism. It impacts key qualitative attributes of fresh mushrooms, including weight, appearance, and texture (Singh *et al*., 2010). Consistent with this, Niazmand *et al*. (2009) stated that mushrooms respire after harvest, and therefore, their moisture content is reduced during storage. PP represents a material with a high molecular weight, high melt strength, and enhanced characteristics, including elevated modulus and tensile strength, as well as stiffness. It is also characterised by exceptional heat resistance and barrier properties, which produce strong films with strong side sealing and strong adhesive strips on the lip (Hisham, 2016). Based on the results obtained, the percentage of weight loss was higher when the HDPE plastic was applied. As a result of water loss, the produce will be sold at a lower price or may become unmarketable, leading to food loss since the percentage of water loss is higher than the original mass of the produce.

***Firmness Analysis***

Table 2 outlines the firmness values of oyster mushrooms under different packaging methods. Note that day 2 noted no statistically significant differences ($p$ = 0.510). At day four, differences in firmness became statistically significant ($p$ = 0.042). T1 (0.65 ± 0.038) retained the highest firmness, while T7 recorded the lowest (0.38 ± 0.050). Other treatments (T2-T6) fell between these extremes, with moderate firmness values ranging from 0.52 to 0.57. For day 6, no significant differences were stated ($p$ = 0.238), while on day 8, the firmness differences were again statistically significant ($p$ = 0.038). Days 10 and 12 noted firmness values with no statistical significance ($p$ = 0.847 and 0.90). All treatments exhibited a decline in firmness, with T3 displaying the highest value, and T7 and T4 had the lowest values (both 0.44). Moreover, trends over time indicated that T1 generally maintained higher firmness values compared to other treatments, especially in earlier days (D4 and D8). Conversely, T7 consistently displayed the lowest firmness across all days, highlighting it as the least effective packaging method.

A prior investigation demonstrated that the softening of mushrooms after harvesting could be attributed to the degradation of cell walls by bacterial enzymes, accompanied by a spike in the activity of internal autolysins (Zivanovic *et al*., 2000). Gholami *et al*. (2019) examined the effects of chitosan coating, nanopackaging, and modified atmosphere packaging on white button mushrooms. The combination of chitosan coating and nanopackaging under MAP conditions (10% $O_2$ and 10% $CO_2$) significantly reduced the respiration rate and preserved the physical, chemical, and mechanical properties of the mushrooms during storage. Firmness, in particular, serves as a crucial quality indicator, with any change in the firmness of mushrooms being considered a sign of deterioration.

***Total Soluble Solid Analysis***

Table 2 presents the TSS concentration of oyster mushrooms. At days 2, 4, 6, and 8, no significant differences were observed in TSS among treatments ($p$ = 0.199, 0.455, 0.291, and 0.090). However, on day 10, significant differences emerged ($p$ = 0.022). Meanwhile, T3 (4.73) retained the highest TSS concentration, significantly higher than T7 (2.90), which continued to demonstrate poor performance. Other treatments (T1, T2, T4, T5, T6) presented moderate TSS values ranging from 3.80 to 4.33. At day 12, the TSS differences remained statistically significant ($p$ = 0.018). Furthermore, T6 (4.07) noted the highest TSS, followed by T4 (4.00), while T7 (3.00) consistently displayed the lowest concentration. The overall trends over time indicated that T7 (control) consistently recorded the lowest TSS values across most time points, suggesting inferior performance in maintaining the TSS levels of the mushrooms. In conclusion, packaging methods had a significant influence on the TSS concentration of oyster mushrooms, particularly during later storage periods (days 10 and 12).

The trends of change in the graph were comparable for all treatments. This is due to the decline in moisture content of mushrooms held under aerobic conditions, which results in the conversion of TSS into energy (Nourian et al., 2003). A study by Niazmand *et al*. (2009) observed that mushrooms and other products respire after harvest, and aerobic respiration leads to sugar breakdown. Consequently, the amount of sugar decreases during storage. This could occur during post-harvest growth, maturation, and gill development.

***Surface Color Analysis***

Table 3 summarises the effect of different packaging methods on BI and color (L* and b) of oyster mushrooms during 12 days of storage at 5°C.

***Browning Index***

The BI serves as a key indicator for assessing the extent of discoloration in oyster mushrooms over time under various treatment conditions. This parameter is critically linked to the visual quality and perceived freshness of the mushrooms. On Day 2, BI values indicated no statistically significant differences observed ($p = 0.222$). Similarly, on Day four, the treatments continued to exhibit no significant variation in BI ($p = 0.139$). However, by Day 6, significant differences emerged ($p = 0.008$). Treatments T6 and T4 exhibited the lowest BI, whereas the control (T7) yielded the highest BI (40.97), indicating a pronounced browning effect and potential quality deterioration.

Table 3: Surface color analysis

| Day | Treatment | Brown Index (mean) | Mean Color-L | Mean Color B |
|---|---|---|---|---|
| D2 | T1 | 20.71 ± 1.262a | 71.82 ± 1.081a | 12.04 ± 0.386a |
| | T2 | 24.13 ± 2.158a | 68.10 ± 2.555a | 12.92 ± 0.116a |
| | T3 | 23.36 ± 0.838a | 66.39 ± 0.321a | 13.11 ± 1.112a |
| | T4 | 19.11 ± 1.024a | 66.94 ± 1.602a | 12.69 ± 0.705a |
| | T5 | 23.64 ± 2.284a | 69.91 ± 1.556a | 11.12 ± 0.854a |
| | T6 | 21.75 ± 0.855a | 72.83 ± 2.927a | 13.04 ± 0.556a |
| | T7 | 21.42 ± 0.604a | 67.41 ± 0.191a | 11.54 ± 0.213a |
| D4 | T1 | 25.77 ± 0.916a | 70.10 ± 2.096a | 11.86 ± 0.347a |
| | T2 | 26.91 ± 1.898a | 69.73 ± 1.019a | 11.59 ± 0.758a |
| | T3 | 25.33 ± 2.133a | 68.88 ± 2.711a | 12.06 ± 0.646a |
| | T4 | 26.49 ± 3.533a | 71.56 ± 2.759a | 12.98 ± 1.637a |
| | T5 | 23.80 ± 2.482a | 72.13 ± 1.958a | 12.82 ± 1.532a |
| | T6 | 18.66 ± 2.003a | 73.34 ± 2.182a | 11.21 ± 0.799a |
| | T7 | 21.43 ± 0.850a | 66.70 ± 0.177a | 12.09 ± 0.514a |
| D6 | T1 | 35.09 ± 3.242ab | 63.07 ± 2.215a | 16.95 ± 0.787ab |
| | T2 | 30.15 ± 1.561a | 69.70 ± 1.014a | 16.21 ± 0.532ab |
| | T3 | 28.90 ± 1.194a | 66.42 ± 2.040a | 15.94 ± 0.041ab |
| | T4 | 27.87 ± 1.607a | 66.46 ± 1.422a | 15.50 ± 0.408ab |
| | T5 | 30.54 ± 1.004ab | 69.27 ± 1.068a | 15.26 ± 0.717a |
| | T6 | 28.93 ± 3.567a | 68.45 ± 4.030a | 15.39 ± 0.552a |
| | T7 | 40.97 ± 1.468a | 62.53 ± 1.385a | 18.01 ± 0.210b |
| D8 | T1 | 33.79 ± 1.722a | 63.19 ± 1.611ab | 16.59 ± 0.490a |
| | T2 | 28.53 ± 0.914a | 70.28 ± 0.573b | 15.69 ± 0.918a |
| | T3 | 27.36 ± 2.054a | 61.25 ± 1.522a | 17.35 ± 0.226a |
| | T4 | 29.65 ± 3.359a | 68.41 ± 0.919ab | 15.69 ± 0.388a |
| | T5 | 37.17 ± 1.241a | 70.01 ± 2.199b | 16.14 ± 0.711a |
| | T6 | 29.60 ± 0.747a | 67.26 ± 2.243ab | 15.63 ± 0.350a |
| | T7 | 37.79 ± 3.720a | 61.50 ± 1.298a | 17.99 ± 1.550a |

| | | | | |
|---|---|---|---|---|
| D10 | T1 | 33.70 ± 1.439b | 59.84 ± 2.815a | 13.78 ± 0.427a |
| | T2 | 34.43 ± 2.007b | 69.42 ± 0.653c | 13.06 ± 0.444a |
| | T3 | 25.25 ± 2.412a | 63.25 ± 1.951abc | 17.78 ± 0.297c |
| | T4 | 25.67 ± 0.423a | 63.36 ± 1.067abc | 14.65 ± 0.575ab |
| | T5 | 25.04 ± 0.381a | 67.22 ± 1.289abc | 14.17 ± 0.496a |
| | T6 | 25.85 ± 0.601a | 67.60 ± 0.481bc | 14.33 ± 0.215a |
| | T7 | 33.71 ± 1.483b | 60.75 ± 1.225ab | 16.68 ± 0.557bc |
| D12 | T1 | 37.83 ± 0.470ab | 57.01 ± 0.784a | 16.81 ± 0.376ab |
| | T2 | 36.10 ± 3.551ab | 68.08 ± 0.634b | 15.58 ± 0.262a |
| | T3 | 29.88 ± 0.839a | 59.64 ± 1.658a | 18.75 ± 0.605b |
| | T4 | 34.30 ± 1.898a | 61.60 ± 1.695ab | 18.00 ± 0.494ab |
| | T5 | 40.72 ± 2.437ab | 64.68 ± 1.246ab | 17.43 ± 0.527ab |
| | T6 | 35.74 ± 1.786ab | 64.45 ± 2.859ab | 18.30 ± 0.507ab |
| | T7 | 46.07 ± 3.045b | 59.30 ± 1.197a | 23.35 ± 1.087c |

Mean values with different letters in the same column for each attribute are significantly different at $p < 0.05$. T1: PP plastic vacuum, T2: PP plastic non-vacuum, T3: LDPE plastic vacuum, T4: LDPE plastic non-vacuum, T5: HDPE plastic vacuum, T6: HDPE, T7: control plastic non-vacuum

By Day 8, the BI values had no significant result ($p = 0.063$). On Day 10, the differences in BI were highly significant ($p = 0.000$). Treatments T1, T2, T5, and T7 recorded the highest BI values, while T3 to T6 maintained significantly lower values, averaging around 25. By Day 12, a similar trend persisted, with significant differences ($p = 0.005$). That is, treatment T7 demonstrated the highest BI (46.07), while T3 exhibited the lowest (29.88).

Overall, the BI exhibited a progressive increase over time, reflecting the natural degradation of the mushrooms. In particular, treatments T3 to T6 consistently displayed superior performance in mitigating browning compared to T1, T2, and T7. Conversely, T7 consistently resulted in the highest BI, indicating suboptimal quality preservation. These findings highlight the significance of BI as a measure for evaluating the impact of various treatments on mushroom quality. It also provides critical insights for optimising storage and processing strategies.

The elevated BI in unwrapped mushrooms (T7) can be attributed to increased exposure to oxygen, which accelerates enzymatic browning processes. Enzymatic browning in mushrooms is primarily due to the activity of Polyphenol Oxidase (PPO), which catalyses the oxidation of phenolic compounds to quinones, leading to brown pigments. Furthermore, packaging materials that limit oxygen exposure can thus effectively reduce PPO activity and subsequent browning (Gholami *et al*., 2019). Vacuum packaging, as utilised in Treatment T3, reduces the availability of oxygen, thereby slowing down the enzymatic browning process. Meanwhile, LDPE films, when used in vacuum conditions, have been noted to effectively maintain the quality of mushrooms by minimising moisture loss and oxidative reactions. Moreover, studies have proven that vacuum-packaged mushrooms exhibit lower BI values over storage periods, indicating better preservation of color and texture (Ajayi *et al*., 2015)

### *Color L**

Table 3 summarises the "L" value results (lightness) of oyster mushrooms stored under different packaging methods across multiple observation days (D2, D4, D6, D8, D10, and

D12). On Days 2, 4, and 6, no significant differences were observed for any of the treatments. By Day 8, significant differences in lightness emerged ($p = 0.003$). Specifically, T2 and T5 achieved the highest lightness values (70.28 ± 0.573 and 70.01 ± 2.199, respectively), demonstrating superior retention of lightness. Conversely, T3 and the control (T7) yielded the lowest values, suggesting a decline in lightness under these conditions. On Day 10, significant differences were again observed ($p = 0.004$). T2 maintained the highest lightness value (69.42). By Day 12, lightness differences remained significant ($p = 0.003$). T2 resulted in the best lightness retention (68.08). Additionally, non-vacuum packaging, especially using PP and HDPE, consistently demonstrated better lightness retention compared to vacuum packaging. In contrast, vacuum-sealed LDPE tended to yield lower lightness values, indicating diminished visual quality. Overall, across all observation days, PP and HDPE materials outperformed LDPE in maintaining lightness, particularly under non-vacuum conditions.

Non-vacuum packaging, particularly with PP and HDPE, is more effective in preserving the lightness of oyster mushrooms, which is an essential factor for consumer acceptance and marketability. These materials offer moderate barrier properties that balance gas exchange, reducing oxygen ingress while allowing for the release of carbon dioxide produced during respiration. Notably, this balance is crucial in slowing down enzymatic activities responsible for browning. A study by Aadhilakshmi *et al*. (2024) investigated the combined effect of Potassium Metabisulfite (KMS) at 0.2% concentration with different packaging films, including LDPE and HDPE, under various oxygen conditions. The findings revealed that mushrooms packaged in HDPE under Medium Oxygen Packaging (MOP) conditions, combined with KMS treatment, exhibited an extended shelf life of up to 16 days. This is in addition to improved physical, biochemical, and microbiological qualities compared to other treatments. Additionally, these findings emphasise the significance of selecting suitable packaging materials and methods to maintain product quality and visual appeal over time.

### *Color b**

The color b* value measures the blue-yellow chromatic component on the surface of oyster mushrooms, with higher values indicating a more intense yellow coloration. This parameter is crucial for assessing color quality and monitoring potential discoloration during storage. On Day 2, no statistically significant differences ($p = 0.259$) were presented. At this early stage, the treatments had a minimal impact on the mushrooms' yellowish color, resulting in uniform coloration across all groups. A similar trend continued on Day 4, with no significant differences between treatments. By Day 6, significant differences emerged ($p = 0.023$). Specifically, T7 recorded the highest color b* value (18.01), reflecting a more intense yellow tone, while T5 had the lowest (15.26). On Day 8, no significant differences were observed ($p = 0.286$). Significant differences were observed on Days 10 and 12 ($p = 0.000$). On Day 10, T3 (17.78) and T7 (16.68) presented the most intense yellowish coloration, while T2 (13.06) and T1 (13.78) exhibited the lowest values. By Day 12, T7 displayed the highest color b* value (23.35), followed by T3 (18.75), whereas T2 recorded the lowest (15.58). The color b* values increased progressively across all treatments over time, reflecting a natural trend toward yellowing as the mushrooms aged. Notably, T2 consistently yielded lower color b* values, indicating its effectiveness in minimising yellowing. In contrast, T7 exhibited the highest values, correlating with accelerated aging or less effective preservation. This analysis highlights the substantial impact of treatments on the yellowish tone of oyster mushrooms, offering valuable insights into color stability and shelf-life management strategies.

Consumers initially assess the quality features of oyster mushrooms based on their color. Dhalsamant *et al*. (2015) measured the surface color of oyster mushrooms in terms of the L* value, which represents whiteness. This choice was made since oyster mushrooms do not exhibit noticeable yellowness or redness. Generally, post-harvest, mushrooms undergo enzymatic browning due to the oxidation of phenolic compounds by PPO, leading to surface discoloration. Hence, this process is a significant contributor to quality loss in mushrooms (Xiaohui Lin & Da-Wen Sun, 2019).

## Conclusions

The study demonstrates that different packaging materials and vacuum conditions have a significant influence on the post-harvest quality of oyster mushrooms. In particular, HDPE plastic under vacuum (T5) was the most effective in minimising weight loss, while PP plastic under vacuum (T1) best preserved firmness. Meanwhile, HDPE plastic without vacuum presented the highest TSS concentration, indicating better retention of soluble nutrients. In terms of BI, both LDPE and HDPE plastics without vacuum, particularly T6, were effective in minimising browning. For color attributes, PP and HDPE materials performed better than LDPE in maintaining lightness (Color-L), especially under non-vacuum conditions. Although Color-B values increased over time across all treatments, indicating natural yellowing, PP plastic without vacuum (T2) consistently resulted in lower values, suggesting superior color stability. Overall, HDPE and PP materials, particularly in non-vacuum applications, were most effective in preserving multiple quality parameters of oyster mushrooms during storage. Therefore, it is up to the user to select the appropriate method that achieves the desired quality characteristics and appearance.

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## Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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