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Effects of different packaging treatments and storage durations on the quality of enoki mushrooms (*Flammulina velutipes*) with nano edible coating

Kusumiyati Kusumiyati[*1,2], Mochamad Arief Soleh[3], Bambang Nurhadi[4], Wawan Sutari[3]

[1]Master Program of Agronomy, Faculty of Agriculture, Universitas Padjadjaran, Sumedang 45363, Indonesia
[2]Laboratory of Horticulture, Faculty of Agriculture, Universitas Padjadjaran, Sumedang 45363, Indonesia
[3]Department of Agronomy, Faculty of Agriculture, Universitas Padjadjaran, Sumedang 45363, Indonesia
[4]Department of Food Industrial Technology, Faculty of Agric. Industrial Technology, Universitas Padjadjaran, Jl. Raya Bandung Sumedang km. 21. Jatinangor Bandung 45363, Indonesia

[*]Corresponding author: Kusumiyati Kusumiyati
ORCID ID: 0000-0001-8974-5436

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Abstract: Enoki mushrooms are edible commodities that can support a healthy lifestyle due to their various beneficial compounds. However, improper post-harvest handling can cause significant damage, leading to the loss of nutrients and a short shelf life. To overcome the challenge, post-harvest technologies, such as nano edible coating and packaging offer various benefits, including slow spoilage, high quality, and extended shelf life. Therefore, this study aims to assess the impact of packaging treatments and storage durations on the quality of enoki mushrooms with nano edible coating. The experiment was conducted at the Horticulture Laboratory, Faculty of Agriculture, Universitas Padjadjaran, from April to August 2024 using a completely randomized design with 6 treatment combinations. These included packaging (vacuum and mica) and storage durations (0, 7, and 14 days). The treatments were replicated 4 times, leading to a total of 24 experimental units, which each consisted of 2 mushrooms (100 g/mushroom). The results showed that packaging treatments and storage duration affected moisture content, color (a^*, b^*, and C^*), total phenolics, total flavonoids, antioxidant activity, and antioxidant capacity of enoki mushrooms. The moisture content was higher in mica packaging after a 14-days storage period. The total phenolic content remained constant throughout the storage period for enoki mushrooms with vacuum packaging. Antioxidant activity and capacity remained constant throughout storage period for enoki mushrooms with vacuum packaging. We suggest that further research be conducted using different packaging methods, storage durations, temperature, and secondary metabolites.

Keywords: antioxidant activity, antioxidant capacity, mica packaging, nano sodium alginate, vacuum packaging.

Introduction

Enoki mushrooms (*Flammulina velutipes*) are widespread edible fungi, containing various nutrients that support a healthy lifestyle. These fungi are rich in dietary fiber, polysaccharides, and antioxidants, which help manage blood pressure and cholesterol levels (Yeh et al., 2014). In addition, several studies have reported their use in traditional Chinese medicine due to the residual medicinal properties and bioactive compounds (Tang et al., 2016). These compounds include vitamins, phenols, fiber, polysaccharides, and minerals that exhibit biological activities including antioxidant, immunomodulatory, and cholesterol-lowering effects (Tang et al., 2016; Yadav and Negi, 2021). Enoki mushrooms have also been reported to serve as a natural antioxidant and anti-cancer therapy (Ukaegbu et al., 2018).

According to previous studies, mushrooms are highly perishable, indicating the need for effective and proper post-harvest handling. Damage to these fungi can lead to nutrient loss due to reactions with oxygen. The dominant types of damage experienced include physical, mechanical, biological, microbiological, and chemical. Physical damage is often caused by environmental factors, such as temperature and sunlight, while the mechanical type is primarily due to friction or pressure. Several studies have shown biological damage occurs due to the autolysis of materials (Li et al., 2019), while the microbiological type is due to microbes, such as bacteria and molds, which exploit the nutrients in mushrooms and produce metabolites (Parlapani et al., 2017; Kumar et al., 2020). Meanwhile, respiration is a chemical reaction that contributes to chemical damage. The respiration process during post-harvest handling and storage shortens shelf life of mushrooms. Fresh mushrooms that are not appropriately treated post-harvest are likely to deteriorate and become unsuitable for consumption (Cahya et al., 2014).

The application of appropriate post-harvest technology is essential to reduce damage, maintain quality, and extend shelf-life of enoki mushrooms. In addition, edible coating technology helps protect the product from biological and microbiological damage, preserves phytochemical content and appearance, as well as slows down respiration (Pleșoianu and Nour, 2022). Several studies have also shown that nano edible coatings are crucial in reducing water loss, gas diffusion, and the evaporation of volatile flavors while limiting the transfer of oxygen and moisture as well as improving product appearance (Mahela et al., 2020). In this context, nano sodium alginate is a commonly used edible coating material because it is safe for consumption and environmentally friendly. A study by Louis et al. (2021) indicates

that the quality of mushrooms can be improved with the use of alginate-based edible coatings combined with cinnamaldehyde nanoemulsions. Apart from edible coatings, packaging also affects the shelf life of mushrooms.

In line with previous studies, storing mushrooms in packaging is crucial for maintaining their physical, physiological, and biochemical changes. It also helps reduce damage that affects quality in the distribution chain. The volume of packaging space influences the respiration rate of mushrooms, as the amount of available gas inside varies with the space volume. In addition, the type of packaging impacts the stability of quality during storage (Kumar et al., 2020). A previous study revealed that the choice of material must be matched with the product's characteristics, storage temperature, and duration. In this study, mica and vacuum packaging were studied. Vacuum packaging has a smaller volume than the mica, leading to different respiration rates. Therefore, this study aims to evaluate the benefits of post-harvest technologies, such as edible coating and packaging and maintaining mushrooms quality during storage.

Results and discussion

Moisture content of mushroom

Analysis of variance (ANOVA) showed that both the type of packaging and storage duration significantly impacted moisture content of enoki mushrooms. Moisture content in mica packaging with a storage duration of 14 days was the highest (91.35%) compared to other treatments as presented in Table 1. Vacuum packaging at 0 days of storage displayed a lower moisture content (88.85%) than other treatments, although it was not significantly different from the mica packaging at 7 days of storage.

Moisture content of mushrooms in vacuum packaging increased from 0 to 7 days of storage but was constant from 7 to 14 days. In addition, the initial spike in moisture content could be attributed to the high respiration rate during this period. An important basic fact in post-harvest handling was that plants remained living structures after harvest, continuing their metabolic processes (Kandasamy, 2022), including respiration. Moisture content in mica packaging at 14 days was the highest among all treatments. With longer storage duration, the plant's moisture content tended to increase.

The increase in moisture content was more obvious in mica packaging compared to vacuum packaging. This difference could be due to the varying atmospheric conditions in the 2 types of packaging, which affected respiration, and consequently, moisture content of mushrooms. CO_2 permeability in mica packaging is 3–6 times higher than O_2 (Singh and Singh, 2005). However, the ratio between CO_2 production and O_2 consumption in fresh products reaches 0.7 and 1.3 (Kader et al., 1989). One of the by-products of respiration was water (H_2O), and its presence around the mushrooms can influence the moisture content within the enoki mushrooms. Sodium alginate is a bio-based coating that can prevent water condensation in packaging, so that the water content of mushrooms can be maintained. The hydrophilic characteristic of bio-based coating showed potential in preventing water condensation inside the packaging (Mahajan and Lee, 2023).

Respiration rates could be reduced by modifying natural atmospheric conditions as needed (Kandasamy, 2022). Oxygen and moisture in the air can be isolated by vacuum packaging; thereby, slowing down the respiration process (Othman et al., 2021). Furthermore, vacuum packaging for storing fresh fruits and vegetables was a static form of hypobaric conditions, inhibiting packaged products' metabolism and respiration by reducing packaging oxygen content (Manju et al., 2007; You et al., 2004). Respiration rate can also be influenced by coating. Respiration rate of mushrooms treated with coating was lower than those not treated during 16 days of storage (Louis et al., 2021). This shows that nano sodium alginate can reduce O_2 consumption in mushroom.

Table 1. Moisture content of Enoki mushrooms during storage periods.

Treatments	Moisture Content (%)
Vacuum Packaging + 0 day	88.85 ± 0.17 a
Vacuum Packaging + 7 days	89.52 ± 0.20 b
Vacuum Packaging + 14 days	89.68 ± 0.29 b
Mica Packaging + 0 days	90.72 ± 0.23 c
Mica Packaging + 7 days	89.3 ± 0.51 ab
Mica Packaging + 14 days	91.35 ± 0.56 d

Note: Values with the same letter indicate no significant difference based on Duncan's Multiple Range Test at a 95% confidence level.

Color of mushroom

The type of packaging and storage duration predominantly affected a^*, b^*, and C^*, but not affected L^* color values, as indicated by the analysis of variance. L^* value represents the brightness of a product. Packaging treatment and storage time did not provide a significant difference in the L^* value. This shows that both did not experience a significant decrease in brightness so that vacuum and mica packaging can maintain the brightness of enoki mushrooms for 14 days. Mushroom color is a very important quality parameter that can increase consumer's purchasing interest (Cetin et al., 2024). Generally, consumers preferred enoki mushrooms with a bright white color that appeares fresh.

The a^* values for mushrooms in vacuum packaging in all storage periods were lower compared to mica packaging, showing that vacuum packaging could effectively slow down the aging process. The emergence of red coloration (indicated by an increase in the a^* value) is the main trend that occurs in the color changes of the fruit body during storage (Cetin et al., 2024). Lower color changes can also be caused by edible coating which can inhibit color changes. Mushrooms treated with edible coating showed significantly less color changes during storage than controls (Amininasab et al., 2023). In contrast, the b^* and C^* values experienced significant changes in both types of packaging. However, enoki mushrooms with vacuum packaging experienced slow changes and only occurred from 0 to 7 days of storage, while from 7 to 14 days of storage the values were constant. In contrast, the mica packaging treatment showed very significant changes in the b^* and C^* values from 0 to 14 days of storage. The slow color change in enoki mushrooms with vacuum packaging can be attributed to low oxygen levels in the packaging and low storage temperatures. Color changes are associated with high oxygen content in the packaging environment and high oxygen permeability of the packaging material (Yu et al., 2023). Vacuum packaging treatment provides low oxygen environmental conditions and poor oxygen and moisture permeability. Color changes are closely related to the barrier material and sealing properties of the packaging material, where a weaker barrier allows higher oxygen permeability (Yu et al., 2023). Therefore, vacuum packaging was judged to be superior packaging treatments for maintaining the color of enoki mushrooms and slowing down the aging process.

Apart from packaging type, the duration of storage also played a crucial role in color changes. Notably, significant color changes occurred during storage (Nakilcioğlu-Taş and Ötleş, 2020). Color changes during storage are a result of the aging process (Cetin et al., 2024). Mica packaging treatment at 14 days of storage had the highest a^* and b^* color values compared to other treatments, with values of 3.87 and 25.68, respectively. This may indicate the presence of reddish tones in fruit bodies with mica packaging treatments. Vacuum packaging revealed an increase in b^* values from 0 to 7 days of storage. The b^* values of mushrooms tended to increase more from the first day of storage (Nakilcioğlu-Taş and Ötleş, 2020).

In this study, C^* value indicated color intensity. Mica packaging at 14 days of storage provided the highest C^* value compared to other treatments. A low C^* value signified lower color intensity or a paler color with less significant change. The higher the C^* value, the higher the color intensity that humans can see visually

Table 2. Color of Enoki mushrooms during storage periods.

Treatments	L^*	a^*	b^*	C^*
Vacuum Packaging + 0 days	83.09 ± 0.67 a	-0.84 ± 0.08 a	12.82 ± 0.39 a	12.85 ± 0.39 a
Vacuum Packaging + 7 days	82.78 ± 0.91 a	-0.95 ± 0.07 a	14.37 ± 0.99 ab	14.40 ± 0.98 ab
Vacuum Packaging + 14 days	71.89 ± 18.62 a	-0.99 ± 0.08 a	15.16 ± 0.71 b	15.19 ± 0.70 b
Mica Packaging + 0 days	72.24 ± 1.69 a	2.63 ± 0.24 b	23.93 ± 1.20 c	24.08 ± 1.21 c
Mica Packaging + 7 days	80.11 ± 1.55 a	-0.63 ± 0.18 a	15.98 ± 1.34 b	15.99 ± 1.34 b
Mica Packaging + 14 days	70.83 ± 1.13 a	3.87 ± 0.43 c	25.68 ± 1.33 d	25.97 ± 1.35 d

Note: Values with the same letter indicate no significant difference based on Duncan's Multiple Range Test at a 95% confidence level.

Table 3. Total phenolic content of Enoki mushrooms during storage periods.

Treatments	Total Phenolic (mg GAE/100 g dry weight)
Vacuum Packaging + 0 day	504.55 ± 14.70 c
Vacuum Packaging + 7 days	554.13 ± 9.18 c
Vacuum Packaging + 14 days	521.65 ± 34.72 c
Mica Packaging + 0 day	523.05 ± 24.73 c
Mica Packaging + 7 days	411.21 ± 128.84 b
Mica Packaging + 14 days	248.79 ± 53.52 a

Note: Values with the same letter indicate no significant difference based on Duncan's Multiple Range Test at a 95% confidence level; GAE: Gallic Acid Equivalent.

Table 4. Total flavonoid content of Enoki mushrooms during storage periods.

Treatments	Total Flavonoid (mg QE/100 g dry weight)
Vacuum Packaging + 0 day	86.24 ± 3.01 bc
Vacuum Packaging + 7 days	107.28 ± 12.31 d
Vacuum Packaging + 14 days	89.92 ± 6.36 bc
Mica Packaging + 0 day	64.48 ± 7.07 a
Mica Packaging + 7 days	93.74 ± 8.29 cd
Mica Packaging + 14 days	77.54 ± 17.00 ab

Note: Values with the same letter indicate no significant difference based on Duncan's Multiple Range Test at a 95% confidence level; QE: Quercetin Equivalent.

(Pathare et al., 2013). The visual color of enoki mushrooms was pale white. Therefore, lower color intensity aligned with consumer preferences. Vacuum packaging at 14 days revealed a lower C^* value than mica packaging at the same time, suggesting that vacuum packaging could slow down color changes in mushrooms.

Total phenolic

Analysis of variance revealed that total phenolic content of enoki mushrooms was affected by packaging type and storage duration. Vacuum packaging across all storage times displayed higher phenolic content in enoki mushrooms compared to other treatments, although it was not significantly different from mica packaging at 0 days of storage (Table 3). This indicated that vacuum packaging could maintain total phenolic content of enoki mushrooms for up to 14 days. Enoki mushrooms stored in mica packaging for 14 days exhibited the lowest total phenolic content.

Changes in phenolic compounds were due to polyphenol oxidase activity (Salfi et al., 2024). The decrease in total phenolics observed with mica packaging during storage was attributed to using phenolic compounds as polyphenol oxidase (PPO) substrates. Typical substrates for PPO activity included phenolic substrates derived from catechols (Gul Guven et al., 2017). In addition, the constant total phenolic content in vacuum-packaged enoki mushrooms demonstrated that vacuum packaging could minimize PPO activity over 14 days of storage. In this study, higher PPO activity led to more obvious browning (Kim et al., 2023). This indicates that the appearance of enoki mushrooms with vacuum packaging during storage was better and more consistent with consumer preferences than mica packaging. The increase in the loss of total phenolic and flavonoid content occurs along with the increase in oxygen permeability and oxygen content in the packaging material. Therefore, it can be concluded that the loss of these compounds may be caused by the permeability and oxygen content of the packaging material (Yu et al., 2023). The total phenolic content of the product is easily oxidized by chemicals and enzymes during storage (Christopoulos and Tsantili, 2011). Therefore, the decrease in total phenolic content in enoki mushrooms may be due to simultaneous auto oxidation and enzyme oxidation.

Total flavonoid

Packaging type and storage duration significantly affected total flavonoid content in enoki mushrooms. Both vacuum and mica packaging at 7 days of storage showed the highest flavonoid content compared to other storage durations (Table 4). This result was consistent with the study by Kim et al. (2023), indicating that total flavonoids increased gradually during the storage. Yu et al. (2023) also stated that the total flavonoid content increased during storage. The accumulation of antioxidants like flavonoid was stimulated by cell membrane integrity disruption caused by lipid peroxidation, which helped repair oxidative damage (Kim et al., 2023). This suggested that by the 7th day of storage, damage to mushrooms began to occur. Total flavonoid content in mushrooms with vacuum and mica packaging at 7 days of storage showed values of 107.28 and 93.74 mg QE/100 g, respectively, which are lower values than those reported by Azieana et al. (2017). They reported that total flavonoid content in 10 mushroom extracts ranged between 0.025 and 0.131 mg QE/g. The lower in total phenolic and flavonoid content may be due to the low oxygen content in the packaging (Yu et al., 2023).

Antioxidant activity and capacity

IC_{50} value indicated antioxidant activity, namely a lower IC_{50} value corresponded to higher antioxidant activity and vice versa. Ascorbic Acid Equivalent Antioxidant Capacity (AEAC) reflects the antioxidant capacity of plants. IC_{50} and AEAC values were inversely related. This analysis of variance revealed a significant effect of packaging type and storage duration on antioxidant activity and capacity of enoki mushrooms. Mica packaging with a 14-day storage period revealed the highest IC_{50} value compared to other treatments (Table 5). This result had practical implications, as it indicates that the antioxidant activity in this treatment is the lowest, resulting in the lowest antioxidant capacity.

Antioxidant activity is one of the main indicators used to evaluate the quality of enoki mushrooms. Antioxidant activity

Table 5. Antioxidant activity and capacity of Enoki mushrooms during storage periods.

Treatments	IC_{50} (mg/L)	AEAC (mg/100 g dry weight)
Vacuum Packaging + 0 day	2,524.29 ± 72.69 a	124.18 ± 3.48 b
Vacuum Packaging + 7 days	2,347.57 ± 38.20 a	133.59 ± 1.99 b
Vacuum Packaging + 14 days	2,152.28 ± 85.35 a	145.98 ± 5.54 b
Mica Packaging + 0 day	2,509.59 ± 138.98 a	125.47 ± 6.30 b
Mica Packaging + 7 days	2,483.94 ± 717.49 a	138.25 ± 47.17 b
Mica Packaging + 14 days	7,108.24 ± 1,634.86 b	49.12 ± 11.13 a

Note: Values with the same letter indicate no significant difference based on Duncan's Multiple Range Test at a 95% confidence level. AEAC: Antioxidant Equivalent Ascorbic Acid.

and capacity of enoki mushrooms in vacuum packaging did not show significant differences in the storage periods. This suggested that vacuum packaging effectively maintained the antioxidant content of mushrooms for up to 14 days of storage. Similar results were observed for total phenolic content with vacuum packaging, as no significant differences were shown across the storage periods. Several studies have shown that there is a strong positive correlation between the antioxidant capacity of mushrooms and the total phenolic content (Cetin et al., 2024). However, antioxidant properties can also be influenced by other substances such as flavonoids, tocopherols, β-carotene, and ascorbic acid (Parcheta et al., 2021). Bioactive compounds degrade more slowly in vacuum packaging than in other packaging (Yu et al., 2023). Vacuum packaging showed the lowest IC_{50} value compared to other packaging (Yu et al., 2023). It indicated higher antioxidant activity. Changes in antioxidant activity corresponded with changes in total phenolic content (Salfi et al., 2024). A higher total phenolic content indicated that more electrons were available to neutralize free radicals; thereby, enhancing antioxidant activity. The decrease in antioxidant capacity occurred in enoki mushrooms with vacuum packaging for 14 days of storage. Several previous studies explained that this phenomenon is related to the process of proanthocyanidin polymerization (Del Bubba et al., 2009).

Materials and methods

Mushroom and nano coating materials

Enoki mushrooms (*Flammulina velutipes*) were purchased from the local market in Bandung, Indonesia. Nano coating material was sodium alginate, processed by the Functional Nano Powder University Center of Excellence (Finder U-CoE) at Universitas Padjadjaran.

Treatments

Nano coating was applied by brushing, with a dosage of 16.7 mg per sample in all experimental treatments. After the application of coating, the mushroom samples (100 g/sample) were packaged using vacuum and mica packaging and then stored in a cooling storage unit at a temperature of 10 °C. Antioxidant analysis was carried out at 3 different storage times, namely 0, 7, and 14 days.

Conduction of study and experimental design

This experiment was conducted at the Horticulture Laboratory, Faculty of Agriculture, Universitas Padjadjaran, using Completely Randomized Design (CRD) with treatment combinations of packaging (vacuum and mica) and storage durations (0, 7, and 14 days), with each treatment repeated 4 times. Each experimental unit consisted of 2 mushrooms, resulting in a total of 48 enoki mushrooms.

Traits measured

Quality parameters observed included color and moisture content in the fresh mushroom form as well as total phenolics, flavonoids, antioxidant activity, and antioxidant capacity in the extract.

Sample extraction

Fresh mushrooms were cut into pieces and dried in an oven at 50 °C for 18 hours, then ground into a fine powder. A 0.25 g portion of the powder was weighed and placed into a 10 mL volumetric flask. Subsequently, 10 mL of methanol was added to the flask. The solution was sonicated using a sonicator (Hanker BK 2000) at 50 °C for 30 minutes and then centrifuged using a centrifuge (Corona 80-2) at 4000 rpm for 10 minutes. The resulting supernatant was transferred into a vial bottle.

Moisture content of mushroom

Mushrooms were cut into smaller pieces and placed in aluminum foil dishes, which had been pre-weighed. A total of 4 g mushroom samples were added to each dish, then placed on a baking tray in an oven at 105 °C for 3 hours. Before weighing, the dishes were placed in a desiccator for 10 minutes. The samples were weighed and returned to the oven for an additional hour at 105 °C. Subsequently, this process was repeated until a constant dry weight was achieved. Moisture content calculation formula referred to SNI 01-2891 (1992):

$$\text{Moisture Content} = \frac{\text{Fresh Weight - Dry Weight}}{\text{Fresh Weight}} \times 100\%$$

Color of mushroom

Color measurement was performed at 2 points on the mushroom sample, namely the front and the back. The color was measured using a CM-600D spectrophotometer (Konica Minolta, Tokyo, Japan), as referenced in Kusumiyati et al. (2022). The quantitative data obtained included L*, a*, and b* values. The chroma (C*) value was calculated using the following formula:

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

Total phenolic

0.1 mL of enoki mushroom extract was placed into a test tube, and then 0.4 mL of methanol (analytical grade) and 2.5 mL of 10% Folin–Ciocâlteu reagent (v/v) were added. The solution was incubated for 5 minutes at room temperature, 2 mL of 7.5% Na_2CO_3 (w/v) was added, and the mixture was incubated for 60 minutes at room temperature. The phenolic content of the solution was measured using a Shimadzu UV-VIS spectrophotometer UV-1601 at a wavelength of 765 nm (Kumla et al., 2021; Sintuya et al., 2019). The results were expressed as mg gallic acid equivalent (GAE)/100 g, calculated using the following equation (Sintuya et al., 2019).

$$\text{Total phenolic } (\text{mg}\frac{\text{GAE}}{100}\text{g}) = \frac{\text{C x V}}{\text{m}} \times 100$$

Notes: C = gallic acid concentration (ppm); V = volume of test solution (L); m = sample weight (g).

Total flavonoid

0.5 mL of the extracted sample was placed into a test tube, then 0.1 mL of 10% aluminum chloride (w/v), 0.1 mL of 1 M sodium acetate, 2 mL of methanol (analytical grade), and 2.3 mL of distilled water were added. The mixture was incubated for 30 minutes at room temperature. The flavonoid content was measured using a Shimadzu UV-VIS spectrophotometer UV-1601 at a wavelength of 435 nm (Sytar et al., 2018). The results were expressed as mg quercetin equivalent (QE)/100 g, while the calculation was performed using the following equation:

$$\text{Total flavonoid } (\text{mg}\frac{\text{QE}}{100}\text{g}) = \frac{\text{C x V}}{\text{m}} \times 100$$

Notes: C = quercetin concentration (ppm); V = volume of test solution (L); m = sample weight (g).

Antioxidant activity and capacity

With modifications, antioxidant activity and capacity were evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) method, as described by Petraglia et al. (2023). The testing included adding 1.5 mL of enoki mushroom extract at various concentrations to 1.5 mL of a 0.0085% (w/v) DPPH solution. The mixture was incubated for 30 minutes at room temperature. Furthermore, absorbance was measured at 515 nm using a Shimadzu UV-VIS spectrophotometer UV-1601. The results were expressed in terms of ascorbic acid equivalent antioxidant capacity (AEAC) and Trolox equivalent antioxidant capacity (TEAC) in mg/100 g using the following equation:

$$\text{AEAC}\left(\frac{\text{mg}}{100\text{ g}}\right) = \frac{IC_{50}(\text{Ascorbic acid})}{IC_{50}(\text{sample})} \times 100{,}000$$

$$\text{TEAC (mg/100 g)} = \frac{IC_{50}(\text{Trolox})}{IC_{50}(\text{sample})} \times 100{,}000$$

Statistical analysis

Data were assessed using Microsoft Excel and IBM Statistical Product and Service Solutions (SPSS) version 25 (IBM Corp., Armonk, NY, USA). Data distribution was tested for normality, and data transformation was performed when the distribution was abnormal. An F-test with a significance level of 5% was conducted to determine whether the treatments affected the test parameters. When the treatments had a significant impact, a post-hoc analysis was performed using the Duncan Multiple Range Test (DMRT) to compare the means among the treatments.

Conclusion

In conclusion, packaging type and storage duration significantly affected the quality of enoki mushrooms, such as moisture content, color, total phenolic, total flavonoid, as well as antioxidant activity and capacity. The moisture content was higher in mica packaging after a 14-days storage period. The total phenolic content remained constant throughout the storage period for enoki mushrooms with vacuum packaging. The total flavonoid content was higher in enoki mushrooms with vacuum packaging after a 7-days storage periods. Antioxidant activity and capacity remained constant throughout storage period for enoki mushrooms with vacuum packaging. Based on the findings of this study, we suggest that further research be conducted using different packaging methods, storage durations, storage temperature, as well as secondary metabolites in mushrooms.

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Statement of contributions

Kusumiyati Kusumiyati: Conceptualization, Methodology, Validation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. Mochamad Arief Soleh, Bambang Nurhadi, and Wawan Sutari: Conceptualization, Methodology, Investigation, Visualization, Writing – review.

References

Amininasab SMH, Hojjati M, Noshad M, Soltani M (2023) Combining active edible coating of Salvia macrosiphon seed enriched with liquid smoke with UV-B irradiation for button mushroom preservation. Lwt. 189:1–7. https://doi.org/10.1016/j.lwt.2023.115557

Azieana J, Zainon MN, Noriham A, Rohana MN (2017) Total phenolic and flavonoid content and antioxidant activities of ten malaysian wild mushrooms. OALib. 04(11):1–9. https://doi.org/10.4236/oalib.1103987

Cahya M, Hartanto R, Novita DD (2014) The study of decreasing of quality and shelf life of fresh white oyster mushroom (pleurotus ostreatus) in the polypropylene packaging at room and low temperature. Jurnal Teknik Pertanian Lampung. 3(1):35–48.

Cetin M, Atila F, Sen F, Yemen S (2024) The effect of different LED wavelengths used in the cultivation of Pleurotus ostreatus on quality parameters of the mushroom during the storage process. Scientia Horticulturae. 336:1–7. https://doi.org/10.1016/j.scienta.2024.113422

Christopoulos MV, Tsantili E (2011) Effects of temperature and packaging atmosphere on total antioxidants and colour of walnut (Juglans regia L.) kernels during storage. Scientia Horticulturae. 131:49–57. https://doi.org/10.1016/j.scienta.2011.09.026

Del Bubba M, Giordani E, Pippucci L, Cincinelli A, Checchini L, Galvan P (2009) Changes in tannins, ascorbic acid and sugar content in astringent persimmons during on-tree growth and ripening and in response to different postharvest treatments. Journal of Food Composition and Analysis. 22(7–8):668–677. https://doi.org/10.1016/j.jfca.2009.02.015

Gul Guven R, Guven K, Matpan Bekler F, Acer O, Alkan H, Dogru M (2017) Purification and characterization of polyphenol oxidase from purslane. Food Science and Technology (Brazil). 37(3):356–362. https://doi.org/10.1590/1678-457x.03216

Kader AA, Zagory D, Kerbel EL, Wang CY (1989) Modified atmosphere packaging of fruits and vegetables. Crit. Rev. Food Sci. Nutr. 28:1–30. https://doi.org/%0A10.1080/10408398909527490

Kandasamy P (2022) Respiration rate of fruits and vegetables for modified atmosphere packaging: a mathematical approach. Journal of Postharvest Technology. 10(1):88–102.

Kim Y, Lee U, Eo HJ (2023) Influence of storage temperature on levels of bioactive compounds in shiitake mushrooms (lentinula edodes). Mycobiology. 51(6):445–451. https://doi.org/10.1080/12298093.2023.2273028

Kumar N, Kaur P, Devgan K, Attkan AK (2020) Shelf life prolongation of cherry tomato using magnesium hydroxide reinforced bio-nanocomposite and conventional plastic films. Journal of Food Processing and Preservation. 44(4):1–11. https://doi.org/10.1111/jfpp.14379

Kumla J, Suwannarach N, Tanruean K, Lumyong S (2021) Comparative evaluation of chemical composition, phenolic compounds, and antioxidant and antimicrobial activities of tropical black bolete mushroom using different preservation methods. Foods. 10(4):1–13. https://doi.org/10.3390/foods10040781

Kusumiyati K, Hadiwijaya Y, Sutari W, Munawar AA (2022) Global model for in-field monitoring of sugar content and color of melon pulp with comparative regression approach. AIMS Agriculture and Food. 7(2):312–325. https://doi.org/10.3934/agrfood.2022020

Li Y, Lu Y, Li L, Chu Z, Zhang H, Li H, Fernie AR, Ouyang B (2019) Impairment of hormone pathways results in a general disturbance of fruit primary metabolism in tomato. Food Chemistry. 274:170–179. https://doi.org/10.1016/j.foodchem.2018.08.026

Louis E, Villalobos-Carvajal R, Reyes-Parra J, Jara-Quijada E, Ruiz C, Andrades P, Gacitúa J, Beldarraín-Iznaga T (2021) Preservation of mushrooms (agaricus bisporus) by an alginate-based-coating containing a cinnamaldehyde essential oil nanoemulsion. Food Packaging and Shelf Life. 28. https://doi.org/10.1016/j.fpsl.2021.100662

Mahajan PV, Lee DS (2023) Modified atmosphere and moisture condensation in packaged fresh produce: Scientific efforts and commercial success. Postharvest Biology and Technology. 198:1–12. https://doi.org/10.1016/j.postharvbio.2022.112235

Mahela U, Rana DK, Joshi U, Tariyal YS (2020) Nano edible coatings and their applications in food preservation. Journal of Postharvest Technology. 8(4):52–63.
Manju S, Jose L, Gopal TKS, Ravishankar CN, Lalitha KV (2007) Effects of sodium acetate dip treatment and vacuum-packaging on chemical, microbiological, textural and sensory changes of pearlspot (etroplus suratensis) during chill storage. Food Chemistry. 102(1):27–35.
Nakilcioğlu-Taş E, Ötleş S (2020) Kinetics of colour and texture changes of button mushrooms (agaricus bisporus) coated with chitosan during storage at low temperature. Anais Da Academia Brasileira de Ciencias. 92(2):1–15. https://doi.org/10.1590/0001-3765202020181387
Othman SH, Abdullah NA, Nordin N, Abdul Karim Shah NN, Mohd Nor MZ, Md Yunos KF (2021) Shelf life extension of Saba banana: Effect of preparation, vacuum packaging, and storage temperature. Food Packaging and Shelf Life. 28:1–7. https://doi.org/10.1016/j.fpsl.2021.100667Parcheta M, Świsłocka R, Orzechowska S, Akimowicz M, Choińska R, Lewandowski W (2021) Recent developments in effective antioxidants: The structure and antioxidant properties. Materials. 14(8):1–24. https://doi.org/10.3390/ma14081984
Parlapani FF, Mallouchos A, Haroutounian SA, Boziaris IS (2017) Volatile organic compounds of microbial and non-microbial origin produced on model fish substrate un-inoculated and inoculated with gilt-head sea bream spoilage bacteria. LWT. 78:54–62. https://doi.org/10.1016/j.lwt.2016.12.020
Pathare PB, Opara UL, Al-Said FAJ (2013) Colour measurement and analysis in fresh and processed foods: a review. Food and Bioprocess Technology. 6(1):36–60. https://doi.org/10.1007/s11947-012-0867-9
Petraglia T, Latronico T, Fanigliulo A, Crescenzi A, Liuzzi GM, Rossano R (2023) Antioxidant activity of polysaccharides from the edible mushroom pleurotus eryngii. Molecules. 28(5). https://doi.org/10.3390/molecules28052176
Pleșoianu AM, Nour V (2022) Effect of some polysaccharide-based edible coatings on fresh white button mushroom (agaricus bisporus) quality during cold storage. Agriculture (Switzerland). 12(9). https://doi.org/10.3390/agriculture12091491
Salfi WON, Ningrum A, Supriyadi (2024) Effects of postharvest storage temperature on physical characteristic, phenolic compounds, and antioxidant activity of cocoa pod husk. Indonesia Planta Tropika. 12(1):45–57. https://doi.org/10.18196/pt.v12i1.19574
Singh RK, Singh N (2005) Quality of packaged foods. In: Han, J.H. (Ed.), Innovations in Food Packaging. Academic Press.
Sintuya P, Narkprasom K, Varith J, Jaturonglumlert S, Whangchai N, Peng-Ont D, Nitatwichit C (2019) Degradation kinetics of diazinon and triazophos pesticides in dried chili under gaseous ozone fumigation. Pertanika J. Sci. & Technol. 27(S1):169–178.
Sytar O, Hemmerich I, Zivcak M, Rauh C, Brestic M (2018) Comparative analysis of bioactive phenolic compounds composition from 26 medicinal plants. Saudi Journal of Biological Sciences. 25(4):631–641. https://doi.org/10.1016/j.sjbs.2016.01.036
Tang C, Hoo PCX, Tan LTH, Pusparajah P, Khan TM, Lee LH, Goh BH, Chan KG (2016) Golden needle mushroom: a culinary medicine with evidenced-based biological activities and health promoting properties. In Frontiers in Pharmacology. 7. https://doi.org/10.3389/fphar.2016.00474
Ukaegbu CI, Shah SR, Hazrulrizawati AH, Alara OR (2018) Acetone extract of flammulina velutipes caps: a promising source of antioxidant and anticancer agents. Beni-Suef University Journal of Basic and Applied Sciences. 7(4):675–682. https://doi.org/10.1016/j.bjbas.2018.07.012
Yadav D, Negi PS (2021) Bioactive components of mushrooms: processing effects and health benefits. In Food Research International. 148:1–23. https://doi.org/10.1016/j.foodres.2021.110599
Yeh MY, Ko WC, Lin LY (2014) Hypolipidemic and antioxidant activity of enoki mushrooms (flammulina velutipes). BioMed Research International. 2014(1). https://doi.org/10.1155/2014/352385
You YL, Su XG, Jiang YM, Li YB, Lin WB, Sun, Y (2004) Effects of Vacuum Packaging on Postharvest Longan Fruit Quality. Food Science. 25(10):327–331.
Yu J, Jing N, Yang F, Wang S, Yan J, Ma Y, Wei A (2023) Effects of packaging and storage temperatures on the bioactive compounds and antioxidant capacity of dried Zanthoxylum bungeanum Maxim. During long-term storage. Scientia Horticulturae. 321:1–12. https://doi.org/10.1016/j.scienta.2023.112231