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RESEARCH

Characterization of Aloe Vera Gel-Based Edible Coating with Orange Peel Essential Oil and Its Preservation Effects on Button Mushroom (*Agaricus bisporus*)

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Abstract

In the present study, the effects of orange peel essential oils (EOs) on the physiochemical, rheological, particle size and zeta potential distribution of the developed aloe vera gel-based edible coating were investigated. We also investigated the effects of prepared aloe vera gel-based edible coating (with or without incorporation of orange peel essential oil) on the postharvest shelf life and characteristics such as physiological loss of weight (PLW), color, respiration rate, firmness, total phenolic content (TPC), total flavonoid content (TFC), antioxidant activity, and antimicrobial activity of button mushroom (*Agaricus bisporus*) at 4 °C during 16 days of storage. The results revealed that the 50% concentration of aloe vera gel-based edible coating without addition of essential oil had significantly superior properties with higher stability zeta potential (−9.7 mV) as compared to other concentrations of aloe vera gel-based formulation. It also showed the highest potential to maintain the postharvest quality attributes of mushrooms throughout storage. The maximum concentration of orange peel essential oil (1500 µL/L) incorporated in the 50% aloe vera gel (F3)-based treatment significantly improved the postharvest quality attributes of mushrooms as compared to coating prepared with incorporation of 500 µL/L and 1000 µL/L concentration of EOs (orange peel essential oils) and helped extend the shelf life of mushrooms up to 4 days as compared to the control (50% AV (aloe vera gel) only). Further research should be performed to develop water and gas barrier composite edible coatings to further extend mushroom shelf life.

Keywords Edible coating · Aloe vera gel · Orange peel EOs · White button mushroom · Postharvest management · Shelf life

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Introduction

Button mushrooms (*Agaricus bisporus*) are known as functional food due to their taste as well as functional and therapeutic properties. Nowadays, consumers incorporate them in their diet because mushrooms are the only natural source of vitamin D2 for vegetarian consumers, which stimulates the production and marketing of mushrooms (Chen et al., 2022; Gholami et al., 2017; Guo et al., 2022; Kapri et al., 2021). In India, the mushroom industry focuses on cultivation of white button mushroom followed by oyster mushrooms. According to ICMR-DMR (The Indian Council of Medical Research and the Department of Medical Research), the white button mushroom produced is accountable for 73%, followed by the oyster mushroom, which contributes around 16% in India (Janakiram et al., 2019).

Therefore, the major drawbacks of the mushrooms is their highly perishable nature due to the epidermal fine porous

structure (lack of cuticle layer) on the surface, which makes them lose their quality rapidly after harvest and have a shorter shelf-life; for these reasons, it is difficult to commercialize them in the fresh state. Mushrooms can be stored at room temperature (20–25 ℃) for 2–3 days and refrigerated (4 ℃) for 5–7 days. Changes in post-harvest quality of mushrooms can be caused by mechanical damage, bacterial contamination, higher respiration rate, water loss, and enzyme activities. The browning of mushrooms can be caused by mechanical factors such as vibrations, rough handling, and aging; it can also result from biochemical changes due to the presence of enzymes (Appels et al., 2019; Lacroix & Ouattara, 2000).

The epidermal fine porous structure of mushrooms is the main reason for their higher respiration rate, resulting in accumulation of water vapor on the top of the package in droplet form. This increased moisture on the mushroom's surface favors microbial growth and decreases the shelf life. There are several postharvest management strategies such as thermal processing techniques, modified atmosphere packaging, controlled atmosphere packaging, chemical treatments (washing, edible coating, ozone, electrolyzed water), and physical treatments (irradiation, packaging, plasma) that can be used to improve the post-harvest quality of fresh mushrooms. Therefore, the most accepted preservation technique is combined chilling and conventional packing in plastic trays wrapped with PVC films. To overcome the problems related to use of plastic and synthetic based packaging, edible coatings are the best alternative method to extend the shelf life of mushrooms. They are non-toxic and biodegradable in nature; they also act as carriers of active agents. The edible coating creates a semi-permeable barrier to gas exchange and moisture, which creates a modified gaseous environment at the coating–product interface in fruits and vegetables (Kumar & Neeraj, 2019; Rodríguez et al., 2020; Suhag et al., 2020). It helps in retarding the respiration rate, physiological weight loss, firmness, and browning of mushrooms due to barrier properties against gas exchange and water transpiration (Kumar et al., 2020, 2021a, b; Yadav et al., 2022).

Biopolymers such as polysaccharide-, protein-, and lipid-based edible components can be used to develop natural edible coatings for fruits and vegetables; therefore, the gel (mucilage) obtained from the aloe vera leaves is a polysaccharide-based coating material, which has anti-browning, antioxidant, and antifungal properties due to the presence of anthraquinone and saponins (Ergun & Satici, 2012). It has a low barrier property for moisture loss in several fruits such as peach (Mohammadi et al., 2020), plum (Martinez-Romero et al., 2018), grapes, fresh cut papaya (Farina et al., 2020), and tomato fruit (Tzortzakis et al., 2019).

Nowadays, aloe vera extract is used in edible coatings on a large scale for increasing the post-harvest quality of perishable commodities such as fruits and vegetables. Aloe vera has medicinal properties and it is a semi-tropical plant. Aloe vera has another type of gel, which is known as yellow latex (exudate) and contains glycoproteins, polysaccharides, phenolic compounds, lignins, amino acids, vitamins, saponins, and enzymes which provide advantageous properties to aloe vera (Andreu et al., 2015; Nicolau-Lapeña et al., 2021). Aloin and aloe-emodin are the two main components of aloe vera gel. Several researchers have confirmed the antifungal, anti-bacterial, and anti-inflammatory properties with improved moisture and gas barrier properties of aloe vera gel-based edible coating (Minjares-Fuentes & Femenia, 2019; Ortega-Toro et al., 2017; Raghavan & Minnick, 2009).

In the present study, the effects of aloe vera gel-based edible coating with or without incorporation of orange peel essential oils on the post-harvest quality attributes of mushrooms were investigated at 4 °C up to 16 days of storage.

Materials and Methods

Biological Material

The freshly harvested white button mushrooms free from contamination were collected from Chauhan mushroom farm, Sonipat, India and directly transferred to the laboratory (FST-NIFTEM) in refrigerated conditions and until the application of the coating they were stored at 4 °C. The fresh leaves of the aloe vera to obtain the gel were harvested from Nutri garden, NIFTEM.

Chemical and Reagents

All chemicals and regents were of analytical grade. They included glycerol (072,762, SISCO Research lab), 2,2-diphenyl-2-picrylhydrazyl (DPPH), Folin–Ciocalteu reagent (39,520, SISCO Research lab), gallic acid, sodium carbonate, quercetin, plate count agar and potato dextrose agar, and others, and were procured from Hi-Tech Ind. Pvt. Ltd and Hi-Media Ind. Pvt. Ltd, India. The essential oils of orange peel (*Citrus sinensis*) were obtained from Bonsoul, India.

Preparation of Aloe Vera Gel

The gel was extracted from the freshly harvested aloe vera leaves (Chandegara et al., 2013). Briefly, the tips and butts were removed after washing the freshly harvested mature aloe vera leaves using chlorinated water. To remove the aloe vera latex (aloin—bitter taste) the leaves were soaked in water for 15 min. In hand filleting, the spikes along their edges and the rind from the mucilage (clear gel) were removed using a knife to avoid contamination of mucilage with yellow latex. The mucilage was blended for 2 min and

Table 1 Composition of aloe vera-based edible coating material without essential oil

Formulations	Composition
Control	Distilled water
AV 10	10% aloe vera gel
AV 30	30% aloe vera gel
AV 50	50% aloe vera gel

pasteurized (heating 70 ℃ for 15 min, followed by cooling) (Mohammadi et al., 2021). The extracted gel was filtered to remove the fibrous portion and concentrations of 10%, 30%, and 50% (v/v) were prepared using distilled water.

Preparation and Characterization of Aloe Vera Gel-Based Edible Coating Formulations Without Essential Oil

Three different concentrations of AV gel were prepared (10%, 30%, and 50%) by immersion in distilled after. The mixture was homogenized using a tissue homogenizer (T 25 digital ULTRA-TURRAX). Table 1 shows the composition of different concentrations of aloe vera gel-based edible coating.

Preparation and Characterization of Aloe Vera Gel-Based Edible Coating Formulations with Different Concentrations of Orange Peel Essential Oil

Based on the results obtained from previous testing (10%, 30%, and 50% AV gel), the 50% concentration of aloe vera gel (AV 50) was used to prepare the course emulsion by adding orange peel essential oil at three different concentrations (500 µL/L, 1000 µL/L, and 1500 µL/L). Glycerol (10% v/v of AV gel) was used as an emulsifier. This dispersion (AV gel + glycerol + EO) was homogenized using a tissue homogenizer (T 25 digital ULTRA-TURRAX) at 10,000 rpm for 5 min. The composition of the 50% AV gel containing EOs is depicted in Table 2.

Characterization of Edible Coating Formulations

Whiteness Index

The color CIE L^*, a^*, and b^* values of different concentrations of aloe vera gel (C, AV 10, AV 30, and AV 50) were measured by a Chroma-meter (Minolta CR-400, Konica Minolta Sensing, Inc., B 8210786, Japan) at atmospheric temperature and calibrated with a standard white plate (Salvia-Trujillo et al., 2015). The whiteness index (WI) of samples was calculated using Eq. (1).

Table 2 Formulations of aloe vera gel-based coating incorporated with orange peel essential oil

Formulation	Concentration of AV gel (%)	Glycerol (v/v of AV gel)	Orange peelessential oil (µl/L)
AV 50 (control)	50	10	0.00
F1	50	10	500
F2	50	10	1000
F3	50	10	1500

$$WI = 100 - ((100 - L)^2 + (a^2 + b^2))^{0.5} \quad (1)$$

Total Soluble Solids and pH

A digital refractometer (Abbe refractometer, ATAGO) was used for the determination of TSS (total soluble solids) of coating material at 25 °C, with the unit of °Brix. A digital PH meter (EUTECH) was used to determine the pH of the samples.

Particle Size, Zeta Potential Distribution, and Polydispersity Index

The particle size, zeta (ζ-) potential, and polydispersity index (PDI) of aloe vera gel-based coating formulations were analyzed by the principle of dynamic light scattering (DLS). A laser diffractometer (Particle analyzer, Litesizer 500, Anton paar) was used. The droplet size was characterized in terms of the mean droplet size (z-diameter) and PDI by measuring the backscattered (173°) light of the samples. Results of particle size, zeta potential, and PDI of the coating material are expressed in terms of nm, mV, and percentage (%) (Louis et al., 2021).

Rheological Characteristics

Rheology is the science of deformation and flow behavior of matter. Rheological properties of coating material are important to know how the viscosity changes correspond to the change in shear rate, which indicate the nature of materials in terms of Newtonian and non-Newtonian fluids. The rheology of aloe vera gel-based edible coatings with and without addition of orange peel essential oils was analyzed by a modular compact rheometer (Anton paar MCR 52, Austria) with a concentric cylinder (33,280 and base — DG26.7). The steady state rheology of edible coating material with and without essential oils was equilibrated at 20 °C for 1 min and then linearly increasing the shear rate from 0.01 to 500 per second. Triplicate results were taken and the rheological

constants were derived from the power law model (2) using Origin Pro 8.5.0SR1 (2021) version 8.5 software.

$$\sigma = K \cdot (y)^n \quad (2)$$

where σ is shear stress (Pa); K = consistency constant (pa. s^n); y = shear rate (1/s), and n = flow behavior index.

Application of Aloe Vera Edible Coating Material on White Button Mushrooms (Agaricus bisporus)

Freshly harvested mushrooms of uniform sizes (10–12 g and 4–6 cm diameter) free from microbial contamination and mechanical damage were stored for 4 h at refrigeration temperature before coating. The graded 600 uniform mushrooms were divided into 4 different sub lots according to the number of coating treatments in three replicates. After washing the mushrooms, they were air-dried (at 20 °C for 30 min) and immersed (dipping) in coating solution for 5 min. After coating, the samples were dried by circulating air (Fan) at 20 °C for 1.5 h. After drying, these treated samples were packed in PVC trays (138 * 110 * 47 mm) and stored in refrigerated conditions at 4 °C with 90% relative humidity for further analysis throughout the 16 days of storage at 3-day intervals.

Effects of Edible Coating on Post-Harvest Characteristics of White Button Mushrooms (Agaricus bisporus)

Physiological Loss in Weight

Physiological loss in weight (PLW) of the control and treated samples was determined by the weight difference method using a digital balance (electronic balance, HiTech). The weight difference between the initial and final measurement was calculated using Eq. (3) and results were reported as percentage (%) loss (Mohebbi et al., 2012).

$$PLW\% = (W_o - \frac{W_f}{W_o}) \cdot 100 \quad (3)$$

where W_o is the weight on the first day, and W_f is the weight on the final storage day.

Color and Browning Index

The effects of the different edible coatings on the surface color (L^*, a^*, and b^*) of mushroom caps were evaluated by a Chroma-meter (Minolta CR-400, Konica Minolta Sensing, Inc., B 8210786, Japan) at atmospheric temperature. The browning index (BI) of the control and treated mushrooms was evaluated using the following Eqs. (4 and 5).

$$BI = \frac{[100 \cdot (x - 0.31)]}{0.17 \cdot x} = \frac{(a + 1.75 \cdot L)}{[5.645 \cdot L + (a - 3.012 \cdot b)]} \quad (4)$$

$$x = \frac{(a + 1.75L)}{(5.645L + a - 3.012b)} \quad (5)$$

Respiration Rate

The respiration rate of the control and edible coating treated mushroom samples was determined according to Louis et al. (2021) with a slight modification using a closed system. The head space analyzer was used to estimate the consumption of oxygen and production of carbon dioxide by the mushrooms. A total of 100 g of mushrooms was packed in a hermetic glass container (0.75 L) and kept at 20 °C. The needle which is connected with a gas analyzer (PBI Dansensor) determined the composition of gas in the head space of the sealed container. The respiration rate (CO_2 mg/kg.h) of the samples was determined by calculating CO_2 production and O_2 exhaustion.

Firmness

The effects of the treatment of different aloe vera gel-based edible coatings with or without orange peel essential oils on the texture properties such as firmness and springiness of mushrooms were determined using a textural analyzer (TA-HD plus C, Stable micro systems) with a 75 mm diameter cylindrical probe (P/75, TA32) in compression mode. The speeds of the probe were 5 mm/s during the test and post-test and 1 mm/s during the pretest with 10 nm of compression distance (Zalewska et al., 2018).

Antioxidant Activity

Antioxidant Activity (DPPH Assay)

The antioxidant activity of the treated and untreated mushrooms during the storage period was investigated using the standard DPPH (2,2-diphenyl-2-picrylhydrazyl) assay method following Mirshekari et al. (2019) with slight modification in the dark. For extract preparation, 6 g of mushroom cap tissues was homogenized and blended with 20 mL of methanol and centrifuged at 6000 × g for 15 min at 4 °C. Supernatant extract (100 µL) was mixed with 3.9 mL of methanolic DPPH solution (0.1 mM). The mixture was allowed to incubate in the dark for 30 min. The absorbance was measured using a UV spectrophotometer at 517 nm and the results expressed as % inhibition as antioxidant activity against free radicals.

Total Phenolic Content

Total phenolic content (TPC) of the control and edible coating treated mushroom was determined using the standard Folin–Ciocalteu (FC) reagent (Grobelna et al., 2019; Kalisz et al., 2020) with slight modifications. A total of 0.2 mL of supernatant extract of mushroom was mixed with 2.5 mL of 10% Folin–Ciocalteu phenol reagent and 2 mL of 7.5% (w/v) sodium carbonate, the volume made up to 5 mL with distilled water. The sample was vortexed for 2 min and incubated in the dark for 30 min. Then, the absorbance was recorded at 765 nm using a UV spectrophotometer. A gallic acid standard curve was used to calculate the TPC of the control and treated mushrooms and the results were expressed as gallic acid equivalent (mg/g of FW).

Total Flavonoid Content

Total flavonoid content (TFC) of mushroom samples was determined according to the method of Qu et al. (2020) with some modifications. A total of 0.2 mL of supernatant of mushroom extract was added to a test tube which contained 0.15 mL of 5% (w/w) sodium nitrite and 0.15 mL of 10% (w/w) aluminum chloride reagent and was shaken gently and kept for 15 min at room temperature. Afterwards, 2 mL of 4% (w/w) sodium hydroxide solution was added to the mixture and kept in the dark for 15 min to end the reaction. The absorbance was measured at 510 nm using a UV spectrophotometer. The flavonoid content was calculated using quercetin as a standard and the results expressed as g/kg.

Open Cap Percentage of Mushrooms

In matured mushroom caps, the veil detachment will create an umbrella-like structure and this is calculated as the open cap percentage using Eq. (6) (Mahshid Nasiri et al., 2019).

$$\%Open\ caps = \left(\frac{N_{oc}}{N_t}\right) \cdot 100 \tag{6}$$

where N_{oc} is the number of opened cap mushrooms; N_t is the total number of mushrooms.

Microbiological Analysis

The effects of edible coating treatments on microbial load in terms of mesophiles, yeast, and molds were assessed in the microbiology laboratory, NIFTEM, according to the process followed by Karimirad et al. (2019). Plate count agar was used for culturing of total aerobic mesophilic bacteria using the pour plate method and incubated at 35 ± 1 °C for 48 h. Yeast and molds were determined in potato dextrose agar (PDA) following incubation at 25 ± 1 °C for 96 h.

Sensory Evaluation

The effects of the different aloe vera gel-based edible coatings with or without essential oil on the sensory quality of mushrooms were determined based on the odor, whiteness (color), intention to purchase and appearance. A total of 10 trained panelists (food technologist/scientists) were appointed to score the mushroom samples based on parameters using a 5-point scale. The 5-point scale indicated 5 as excellent, 4 as good, 3 as medium, 2 as poor, and l as very poor quality.

Statistical Analysis

All the data were obtained in triplicate and average values are reported as results with standard deviation. The data were analyzed using one-way ANOVA with Duncan's multivariate range test with a significance level of 0.05 using SPSS (20.0) software. The graph of results and other graphical presentations were prepared using SigmaPlot 14.0.

Results and Discussion

Physiochemical Characterization

The difference in dilution of the aloe vera gel significantly influenced ($p < 0.05$) the whiteness index and TSS of aloe vera-based edible coating material. The 50% aloe vera gel-based edible coating showed a higher whiteness index (38.806) and TSS (0.667) as compared to other gel-based formulations. In contrast, the 10% aloe vera gel exhibited the lowest whiteness index (36.03) and L^* value (63.01) followed by AV 30 (63.42, 37.632, respectively). The results indicated that the whiteness index of the coating material increased with the increasing concentration of the aloe vera gel (Table 3). The pH (acidity) of the different aloe vera gel ranged from 4.92 to 5.21. Results of the present study revealed that the pH of the formulations decreased with concentration of aloe vera gel-based formulations. The results of the physiochemical characterization of edible coating material with incorporation of orange peel essential oils are also depicted in Table 3. The results revealed that the incorporation of orange peel essential oil used in the formulation significantly affected ($p < 0.05$) the whiteness index of coarse emulsions. F1 coarse emulsion containing 500 µL/L of essential oil had a higher whiteness index (40.09), while a lower whiteness index was observed in the intermediate essential oil concentration of 1000 µL/L. The results showed

Table 3 Characterization of aloe vera-based coating material with or without orange peel essential oils

Formulations	WI	TSS	pH	Zeta potential (mV)	Polydispersity index (%)	Particle size (nm)
Control (DW)	Colorless	0.0 ± 0.00^{g}	6.86 ± 0.00^{a}	0.0 ± 0.00^{g}	0.0 ± 0.00^{g}	0.0 ± 0.00^{g}
AV 10	36.03 ± 0.0^{e}	0.13 ± 0.04^{f}	5.21 ± 0.01^{b}	-6.9 ± 0.02^{c}	34.3 ± 0.03^{c}	117.2 ± 0.00^{f}
AV 30	37.63 ± 0.00^{d}	0.39 ± 0.01^{e}	5.02 ± 0.00^{c}	-8.3 ± 0.00^{b}	35.3 ± 0.01^{b}	1301 ± 0.01^{e}
AV 50	38.80 ± 0.01^{b}	0.66 ± 0.00^{d}	4.92 ± 0.00^{de}	-9.7 ± 0.00^{a}	37.0 ± 0.01^{a}	1312 ± 0.03^{d}
F1	40.09 ± 0.02^{a}	5.05 ± 0.01^{c}	4.93 ± 0.01^{d}	-4.1 ± 0.02^{e}	32.6 ± 0.23^{d}	2092 ± 0.05^{c}
F2	35.78 ± 0.01^{f}	5.66 ± 0.01^{b}	4.93 ± 0.00^{d}	-5.5 ± 0.05^{d}	24.0 ± 0.31^{e}	2280 ± 0.17^{b}
F3	38.82 ± 0.02^{bc}	5.70 ± 0.01^{a}	4.93 ± 0.01^{d}	-4.0 ± 0.01^{ef}	23.7 ± 0.01^{ef}	2713 ± 0.06^{a}

Mean ± SD, where: superscript a,b,c…n indicated the significant differences between the sample. AV 10 = 10% aloe vera gel; AV 30 = 30% aloe vera gel; AV 50 = 50% aloe vera gel; F1 = 50% AV gel + 10% (v/v) glycerol + 500 µL/L orange peel essential oils; F2 = 50% AV gel + 10% (v/v) glycerol + 1000 µL/L orange peel essential oils; where, F3 = 50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils

that the whiteness index of the coating material decreased with increasing concentration of the aloe vera gel. It was observed that the pH of the coating material did not significantly affect with each other's, whereas the TSS (total soluble solids) of the coating materials increased with increasing concentration of orange peel essential oils. This might have been due to increasing hydrophobicity of the materials.

Particle Size, Zeta Potential, and Polydispersity Index

The particle size, polydispersity index (PDI), and ζ-potential of coating material were significantly affected ($p < 0.05$) by the difference in dilution of the aloe vera gel (Table 3). Particle size varied from 117.2 to 1313 nm, which increased due to insufficient homogenization of the gel. The AV 50 showed significantly larger particle size (1312 nm) with higher stability (9.7 mV) and PDI (37) respectively. The lowest stability of the material and PDI was found in the formulation prepared with 10% of aloe vera gel followed by 20 AV. However, based on the results of PDI, these formulations can be considered polydisperse (Louis et al., 2021). Based on the results of zeta potential of different concentrations of aloe vera gel-based edible coating, these materials are slightly stable due to the presence of different electrostatic repulsion forces. The values of ζ-potential of the coating material were negative because of the negative surface charge of the aloe vera gel particles.

Therefore, the incorporation of essential oils and their concentration significantly affected ($p < 0.05$) the particle size, zeta potential, and polydispersity of the aloe vera (50%) coating materials. Increasing concentration of orange peel essential oils increased the TSS and particle size while reducing the stability and PDI of the coating materials due to the hydrophobic nature of EOs. The range of particle size varied from 1312.1 to 2713 nm. With increasing essential oil concentration, the smallest and largest particle sizes were observed in the AV 50 and F3 coating formulation respectively. The results also indicated that the TSS of the coating materials also increased with increasing concentration of orange peel essential oils. PDI decreased with increasing concentration of essential oil. The formulation F3 showed the lowest PDI as compared to other coating formulations. Uniformity of the particle distribution increases with increasing gel concentration (Louis et al., 2021). The concentration of essential oil significantly affected the stability of edible coating formulation. The highest zeta potential was observed at an intermediate concentration of essential oil.

Rheological and Flow Behavior Properties of Aloe Vera Gel

The rheological characteristics of the aloe vera gel indicated that the increasing shear rate significantly affected ($p < 0.05$) the viscosity (Table 4). The viscosity (Pa.s) of all concentrations of aloe vera gel decreased with increasing shear rate (1/s). The viscosity of AV 50 changes from 310 m.Pa.s (at shear rate (1/s) 0.1) to 1.7 m.Pa.s (at shear rate (1/s) 500),

Table 4 Steady state rheology of the coating material using the power law model

Sample	K (pa.s^n)	*n* (Dimensionless)	R^2
Control	0.010 ± 0.005^{de}	0.604 ± 0.089^{bc}	0.453^{g}
AV10	0.020 ± 0.009^{c}	0.497 ± 0.077^{de}	0.463^{f}
AV30	0.067 ± 0.010^{ab}	0.326 ± 0.026^{f}	0.759^{a}
AV50	0.076 ± 0.014^{a}	0.311 ± 0.032^{fg}	0.643^{d}
F1	0.002 ± 0.001^{f}	0.895 ± 0.065^{a}	0.758^{ab}
F2	0.013 ± 0.004^{d}	0.617 ± 0.053^{b}	0.691^{c}
F3	0.020 ± 0.007^{c}	0.544 ± 0.060^{cd}	0.587^{e}

Where, σ is shear stress (Pa); K = consistency constant (pa.s^n); y = shear rate (1/s) and n = flow behavior index; AV 10 = 10% aloe vera gel; AV 30 = 30% aloe vera gel; AV 50 = 50% aloe vera gel; F1 = 50% AV gel + 10% (v/v) glycerol + 500 µL/L orange peel essential oils; F2 = 50% AV gel + 10% (v/v) glycerol + 1000 µL/L orange peel essential oils; where, F3 = 50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils; superscript a,b,c…n indicated the significant differences between the sample

for AV 30, it changes from 50 m.Pa.s (at shear rate (1/s) 0.1) to 2.91 m.Pa.s (at shear rate (1/s) 500), and for AV 10, it changes from 36 m.Pa.s (at shear rate (1/s) 0.1) to 2.1 m. Pa.s (at shear rate (1/s) 500), thus proving that the edible coating material is pseudo-plastic in nature. The viscosity of shear thinning material will be reduced by applying shear stress (vigorous mixing); again, it recovers along the same path when reducing the shear stress.

The increasing concentration of aloe vera gel in edible coating resulted in higher consistency and lower flow of behavior due to formulation of thick materials. The mathematical model derived from the power law model or Ostwald–de Waele model (Fig. 1A, B) proved the non-Newtonian and shear thinning property of coating material by n values. As depicted in the table, the n values of 10%, 30%, and 50% aloe vera gel are 0.4976, 0.32673, and 0.3110, then values are less than one ($n < 1$), which again confirms the shear thinning property of edible coating material. The R^2 value of AV 30 is approximately 0.76, which indicated that the model explains 76% of the fitted data in the power law model.

Rheological Characteristics and Flow Behavior of EO-Enriched Edible Coating

The results of rheological characteristics of coating material incorporated with essential oil are shown in Table 4. The results showed that the increasing shear rate significantly affected ($p < 0.05$) the viscosity. The viscosity (Pa.s) of all coating materials decreased with increasing shear rate (1/s). The viscosity of AV 50 changes from 310 m.Pa.s (at shear rate (1/s) 0.1) to 1.7 m.Pa.s (at shear rate (1/s) 500). F3 coating formulation viscosity changes from 320 m.Pa.s (at shear rate (1/s) 0.1) to 0.9 m.Pa.s (at shear rate (1/s) 500), for F2, it

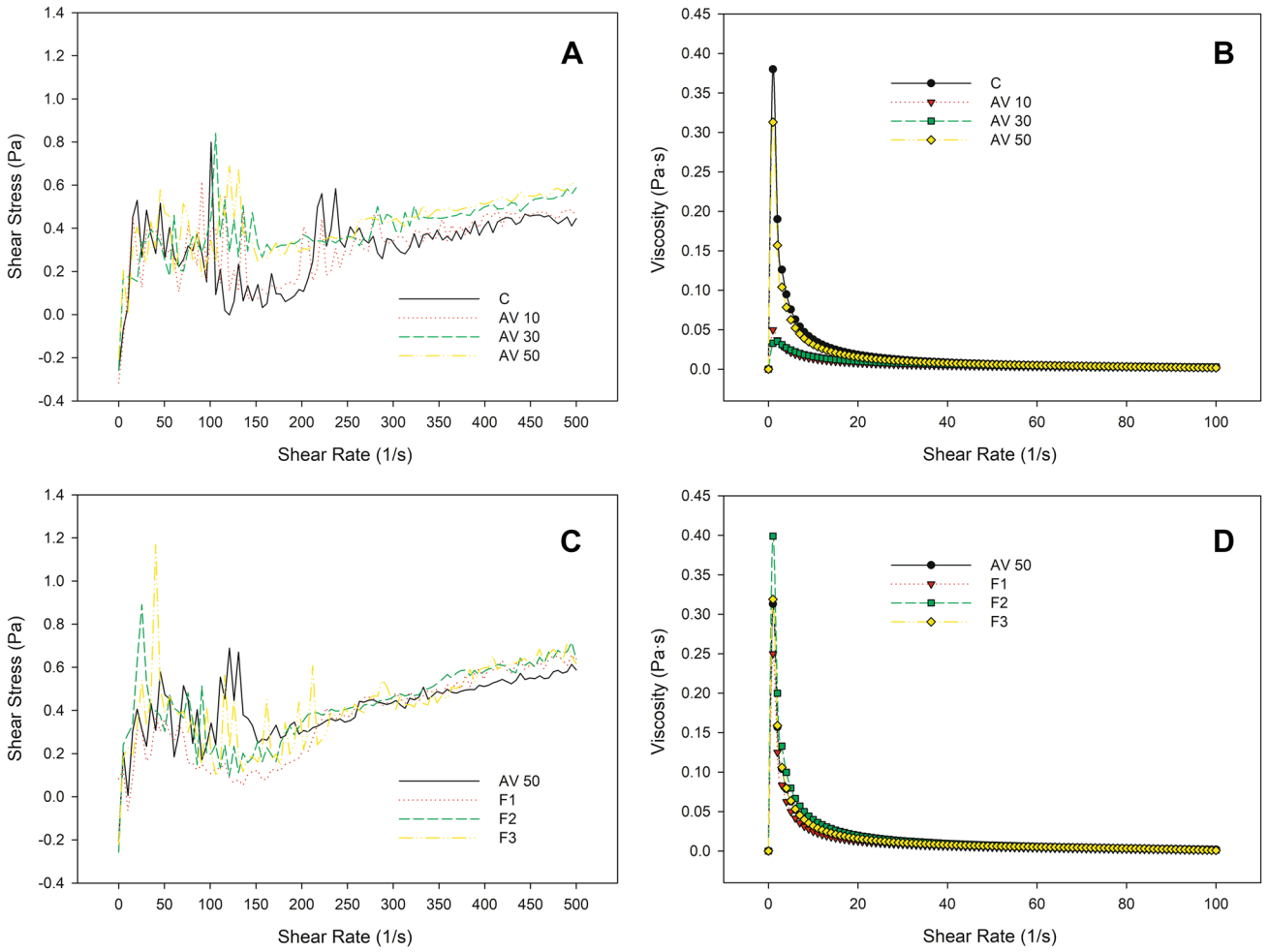

Fig. 1 Effect of shear rate on the shear stress (**A**), flow viscosity (**B**) of aloe vera gel-based edible coatings and the shear stress (**C**) and flow viscosity (**D**) of EOs enriched edible coatings. (AV 10, AV 30, AV 50 — 10%, 30%, and 50% aloe vera gel respectively; Av50 = AV gel; F1 = 50% AV gel + 10% (v/v) glycerol + 500 µL/L orange peel essential oils; F2 = 50% AV gel + 10% (v/v) glycerol + 1000 µL/L orange peel essential oils; F3 = 50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils)

changes from 400 m.Pa.s (at shear rate (1/s) 0.1) to 1.31 m. Pa.s (at shear rate (1/s) 500), and finally for F1, it changes from 250 m.Pa.s (at shear rate (1/s) 0.1) to 0.84 m.Pa.s (at shear rate (1/s) 500), thus proving that the edible coating material is pseudo-plastic in nature.

The mathematical model derived from the power law model (Ostwald-deWaele model) proved the non-Newtonian and shear thinning property of coating material by n values (Fig. 1C, D). The n values of AV 50, F1, F2, and F3 are 0.3, 0.6, 0.8, and 0.5, respectively, i.e., the n values are less than one ($n < 1$), which again confirms the shear thinning property of edible coating material. The R^2 values of the all coating materials ranged from 0.5 to 0.75. Whereas the F1 formulation showed an R^2 value of 0.75, which means that the model explains 75% of the fitted data in the power law model, the R^2 value of 0.58 for F3 indicates that the model explains about 58% of the fitted data.

Effects of Aloe Vera Gel-Based Edible Coating With or Without Essential Oil on Postharvest Quality of Mushrooms

Color and Browning Index (BI)

The results of the color and browning index of control and treated mushrooms are shown in Fig. 2A and B for aloe vera edible coating without EOs and Fig. 3A and B for EOs incorporated in aloe vera gel-based edible coating. The aloe vera gel concentration significantly reduced the L^* values of treated mushrooms, as shown in Fig. 2A. The L^* values in the range 80–85 are categorized as acceptable quality, values of 69–79 are considered inferior quality, and a value lower than 69 indicates the unacceptable color of button mushrooms; thus, AV 30 and AV 50 preserve the L^* value of mushrooms between 69 and 79. The surface

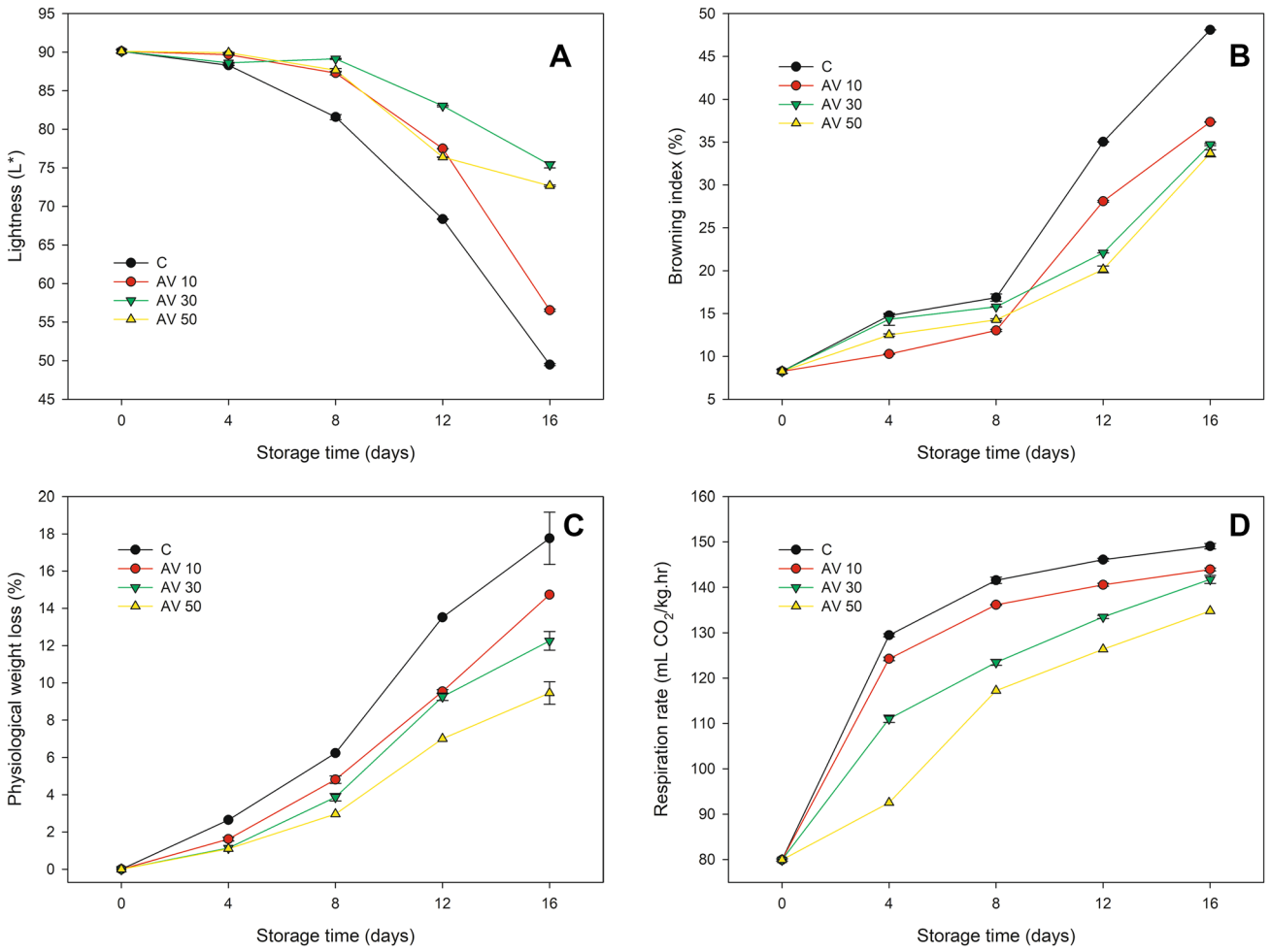

Fig. 2 Effects of aloe vera edible coating without essential oils on lightness (**A**), browning index (**B**), physiological weight loss (**C**), and respiration rate (**D**) of mushrooms. (AV 10, AV 30, AV 50 — 10%, 30%, and 50% aloe vera gel respectively; Av50=AV gel; F1=50% AV gel+10% (v/v) glycerol+500 µL/L orange peel essential oils; F2=50% AV gel+10% (v/v) glycerol+1000 µL/L orange peel essential oils; F3=50% AV gel+10% (v/v) glycerol+1500 µL/L orange peel essential oils)

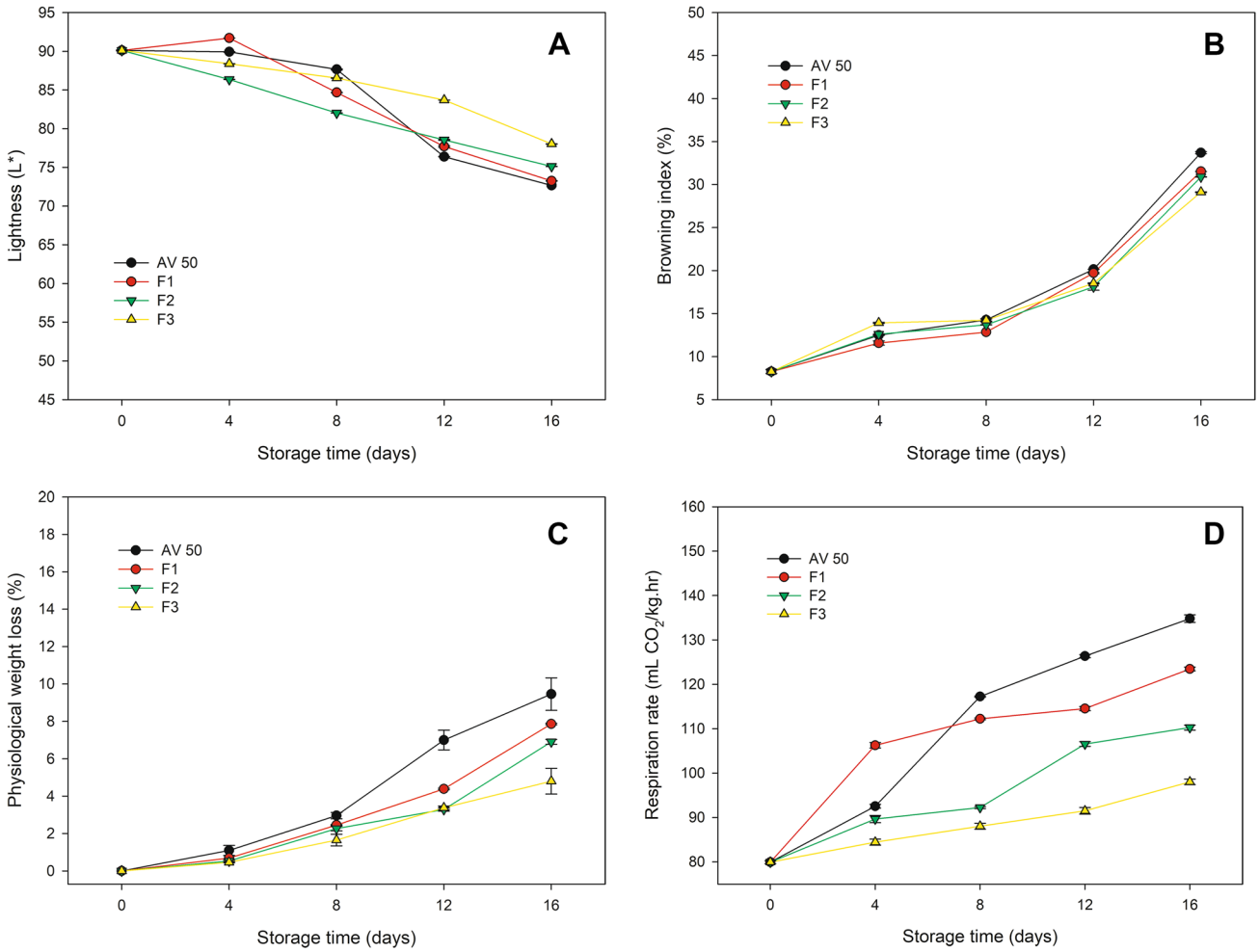

Fig. 3 Effects of 50% aloe vera edible coating enriched with essential oils on lightness (**A**), browning index (**B**), physiological weight loss (**C**), and respiration rate (**D**) of mushrooms. (AV 10, AV 30, AV 50 — 10%, 30%, and 50% aloe vera gel respectively; Av50=AV gel; F1=50% AV gel+10% (v/v) glycerol+500 µL/L orange peel essential oils; F2=50% AV gel+10% (v/v) glycerol+1000 µL/L orange peel essential oils; F3=50% AV gel+10% (v/v) glycerol+1500 µL/L orange peel essential oils)

browning of mushrooms is an important factor that limits the consumer acceptance. The experiment showed that the aloe vera gel concentration significantly delayed ($p < 0.05$) the post-harvest browning of coated mushrooms compared with uncoated mushrooms. AV 50 exhibited the highest retardation in browning and this ability decreases with the decrease in the aloe vera gel concentration. Uncoated samples showed the highest browning on the end day of storage with the value of 48%. These results add strong value to the fact that a lower browning index is associated with loss of moisture in samples (Mirshekari et al., 2019). These results are comparable with the previous finding of Valverde et al. (2005), who reported that the application of aloe vera-based coating reduced the browning index of table grapes.

The L^* values of mushrooms in the range of 80–85 are categorized under acceptable quality, 69–79 means inferior quality, and a value lower than 69 is considered unacceptable color of button mushroom; thus, all the three formulations containing orange peel essential oil showed value ranges between 69 and 79. F3, which has the highest concentration of essential oil (1500 µL/L), preserves the L^* value of mushrooms more than 80. The surface browning of mushrooms is an important factor that limits the consumer acceptance. The experiment showed that all three concentrations of essential oil significantly delayed ($p < 0.05$) the post-harvest browning of samples compared with AV 50 treatment. F3 exhibited the highest retardation in browning and this ability decreases with decrease in the orange peel essential oil concentration. The BI value of F3 during the 4th day of storage was higher than the AV 50 (without essential oil) treated mushrooms; this is due to the oil absorbance ability of the mushroom surface, which slightly changes the color of mushrooms. On the 16th day of storage, it showed the lowest BI compared with other treatments. When the essential oil concentration is too

high, it leads to mushroom tissue cell damage and it induces the deterioration of samples. The results of present study are in good agreement with the previous findings of Mirshekari et al. (2019), who investigated the effects of different aloevera concentrations (0, 25, 50, and 70%) coatings on mushrooms during 15 days of storage period at 4 °C. This study reported that the applications of all concentration of aloe vera gel-based coating significantly lower the browning index on white button mushrooms. These results are also supported that the lower browning of aloe vera gel-based edible coating treated mushroom was associated with the lower moisture loss throughout the storage period (Barman et al., 2014). On other side, Tzortzakis et al. (2019) were also demonstrated in his study that the application of aloe vera gel-based edible coating enriched with sage essential oil was potential to retarded browning index in tomatoes. The other researchers were used different types of edible coating formulations such as lipid based coating with monoestrate and thyme extract (Samadpour et al., 2020), composite of chitosan and guar gum (Huang et al., 2019), Arabic gum/CMC (Srivastava & Bala, 2016), chitosan/CMC/sodium alginate and modified starch (Minh & Hang, 2019), gum arabic/CMC (Sedaghat & Zahedi, 2012), aloe vera and gum tragacanth (Mohebbi et al., 2012), and sodium alginate (Zhu et al., 2019) to maintain the color properties of mushroom by retarding the enzymatic browning. The retardation of color browning of mushroom during storage might be possible due to barrier properties of edible coating against water loss and gas transpiration, which helps in the reducing respiration rate and inhibit peroxidase (POD) and polyphenol oxidase (PPO).

Physiological Loss in Weight

The physiological loss in weight (PLW) of coated and uncoated mushrooms showed an increasing tendency throughout the storage period up to 16 days in refrigerated conditions. The uncoated sample (control) exhibited the highest value at the end of the storage with the value of 17%. AV 50 coating (without essential oils) reduced the loss of weight by double the time compared to the uncoated sample (Fig. 2C). The ability to reduce the weight loss of the sample increased with increasing concentration of aloe vera gel in the edible coating. This might be due to creation of permeability between the surface of the mushroom and the edible coating, which helps in reducing the respiration rate and water loss. The absence of a cuticle layer on the mushroom surface causes rapid dehydration and mass transfer, thus leading to physiological weight loss in uncoated samples. The edible coating acts as a semi-permeable membrane, helps to prevent moisture loss, and acts as a barrier for gas exchange. These results are comparable with those of Arowora et al. (2013), whose studies showed that the aloe vera gel acts as a barrier for moisture transfer and suppresses the weight loss in coated oranges. Also, aloe vera-coated sweet cherries (Martínez-Romero et al., 2006) showed a reduction in PLW. These results confirm that the aloe vera gel-based edible coatings can reduce the physiological weight loss of fruits and vegetables by acting as a semi-permeable barrier against moisture.

The PLW of mushrooms coated with coating material with essential oils was significantly lower ($p < 0.05$) as compared to those without essential oil edible coatings. PLW of all treated mushrooms showed an increasing tendency throughout the storage period up to 16 days in refrigerated conditions (Fig. 3C). The coated sample with AV 50 without essential oil exhibited the highest value at the end of the storage, with the value of 9.4%. The F3 coating reduced the loss of weight compared to the other coated samples. The ability to reduce the weight loss of the sample increased with increasing concentration of orange peel essential oil in aloe vera gel coating material. This might be due to creation of permeability between the surface of the mushroom and the edible coating, which helps in reducing the respiration rate and water loss. The absence of a cuticle layer in the mushroom surface causes rapid dehydration and mass transfer, thus leading to physiological weight loss in uncoated samples. These results are comparable with the results of Louis et al. (2021) for PLW of coated mushrooms by alginate-based coatings with cinnamaldehyde essential oil. The wilting or shrinkage of mushroom will occur when the PLW value is more than 4%. The F2 and F3 coating treatments have the ability to reduce the PLW in *Agaricus bisporus* (Pinzon et al., 2020). It has been reported that the water vapor permeability is reduced in strawberries coated with aloe vera gel incorporated in chitosan-banana starch. Several researchers were applied different types of gum-based edible coatings and reported similar types of results. For example, Sedaghat and Zahdi (2012) applied gum arabic-based edible coating on white button mushrooms and reduced the weight loss during 10 days of storage period. On 10 days of storage, the treated mushroom showed 33% of weight loss on 10 days of storage. Whereas in our study, the aloe vera treatment with supplemented with orange peel essential oil showed better results and noticed 9.4% of PLW in mushroom on 16 days of storage. The results of the present study are also better in comparison with the previous finding of Mohebbi et al. (2012), those applied gum tragacanth-based edible coating on mushrooms and reported 25% of PLW at end of the 10 days of storage period. Moreover, Klangmuang and Sothornvit (2016) also mentioned that the incorporation of lipids (essential oils) with aloe vera gel resulted in reducing weight loss of fruits and vegetables due to creation of barrier properties against water loss. The physiological loss in weight of button mushroom was also reduced using L-argenine (10 mM) with maintained their other postharvest characterizes, enzymatic activity, phenolic and flavonoid content, electrolytic leakage and firmness during the storage period for 8 days at 4 °C (Li et al., 2019). In

comparison with this study, our results are best suitable for reducing weight loss of mushroom up to 16 days. Our results of the mushroom weight loss are also in conformity with findings of earlier researchers, Ding et al. (2016), who retarded the weight loss of mushroom using treatment of brassinolide during storage up to 16 days at 4 °C. Therefore, the application of aloe vera gel-based edible coating combined with orange peel essential oil is the best treatment to reducing weight loss in mushroom during storage with lower economic cost and environmental friendly as compared to other treatments. Apart from that, several research evidences have been reported that the applications of edible coating prepared with chitosan, gums, agar, egg white protein, lecithin, monoesterate, gum arabic, CMC, sodium alginate/modified starch, alginate with silver nanoparticle, pectin, etc. (Cavusoglu et al., 2021; Jiang, 2013; Jiang et al., 2012; Minh & Hang, 2019; Samadpour et al., 2020; Sami et al., 2021; Sedaghat & Zahedi, 2012; Srivastava & Bala, 2016; Vaziri et al., 2019; Zhu et al., 2019) are potential to retarded the physiological loss weight in mushrooms during storage at different temperature due to create semi permeable layer between the surface of mushroom and external environment; which resulted reduction in the respiration rate and electrolytic leakage.

Respiration Rate

The changes in respiration rates of treated and control white button mushrooms are given in Fig. 2D for aloe vera edible coating without EOs and Fig. 3D for EO-incorporated aloe vera gel-based edible coating. In different concentrations of aloe vera gel-based coating, the mushrooms coated with AV 50 had a lower respiration rate than others even during the end day of storage at 4 °C. Uncoated mushrooms showed the highest oxygen consumption and highest carbon dioxide production, thus leading to rapid post-harvest quality of mushrooms during storage. During a high respiration rate, it creates anaerobic conditions inside the packaging material which favors the growth of spoilage microorganisms. The gas barrier property of aloe vera gel indicates that this edible coating can prolong the shelf life of mushrooms. Shahkoomahally and Ramezanian (2014) mentioned that the aloe vera coating on grapes reduced the weight loss and respiration rate twofold compared to the control (Fig. 2D). The respiration rate reduction has also been found in peach (Mohammadi et al., 2020), plum (Martinez-Romero et al., 2018), fresh cut papaya (Farina et al., 2020), and tomato fruit (Tzortzakis et al., 2019). Therefore, mushrooms coated with essential oil-enriched edible coating were found to have a significant reduction of the respiration rate of mushrooms throughout the storage period. Coating formulation F3 showed a lower respiration rate than the others even during the end day of storage at 4 °C. F3-treated mushrooms exhibited the lowest oxygen consumption and lowest carbon dioxide production, thus leading to delay in post-harvest quality loss of mushrooms during storage (Fig. 3D). During a high respiration rate, it creates anaerobic conditions inside the packaging material, which favors the growth of spoilage microorganisms. The concentration of orange peel essential oil significantly reduced ($p < 0.05$) the respiration rate of coated mushrooms. Similar results were observed in aloe vera-coated peach and plum fruit during the storage period (Guillén et al., 2013). Moreover, the results of the previous researcher, Huang et al. (2019), diminished the respiration rate of shitake mushrooms during the storage period by the application of composite coating prepared with chitosan and guar gum due to barrier properties of coating materials, which resulted inhibiting microbial populations as well as retarded dehydration (Xin et al., 2017). Similarly, in Cavusoglu et al. (2021), it reduced the respiration rate of mushroom at 4 ℃ during 15 days of storage period by applications of different coatings such as gum, agar, sodium alginate, egg protein, and lecithin, respectively. In addition, several researchers proved that the biopolymer such as cellulose, gellan gum, aloe vera, tragacanth, pectin, sodium alginate, CMC, and pectin-based edible coating turn delayed respiration rate in white button mushroom during the storage period at cold condition due to changes in redox state, respiratory pathway metabolism, and regulate rate of vinyl and oxygen from external environment (Criado et al., 2021; Mădălina Ples & Nour, 2022; Mohebbi et al., 2012).

Antioxidant Activity, Total Phenol Content, and Total Flavonoid Content

Antioxidant Activity

The results of antioxidant activity of the aloe vera-based edible coating with or without essential oil are shown in Fig. 4. The results showed that the control sample showed reduced antioxidant capacity during the storage period from 78 to 13%. The application of aloe vera gel on the mushroom surface significantly reduced ($p < 0.05$) its lowering tendency of antioxidant capacity during storage. AV 50-treated mushrooms retained the antioxidant capacity of fruit bodies 3 times higher compared to the control sample after the end of the storage period, with the values ranging from 78 to 45%. AV 10- and AV 30-treated mushrooms retained the antioxidant capacity 2 times higher compared with the control after 16 days of storage (Fig. 4A). Therefore, the DPPH activity of mushroom samples was retained higher with increasing concentration of orange peel essential oil in aloe vera (50%)-treated samples. The antioxidant activity of F3 (50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils)-treated samples was significantly affected ($p < 0.05$) by the concentration of orange peel essential oil (Fig. 4B). In conclusion, the mushrooms

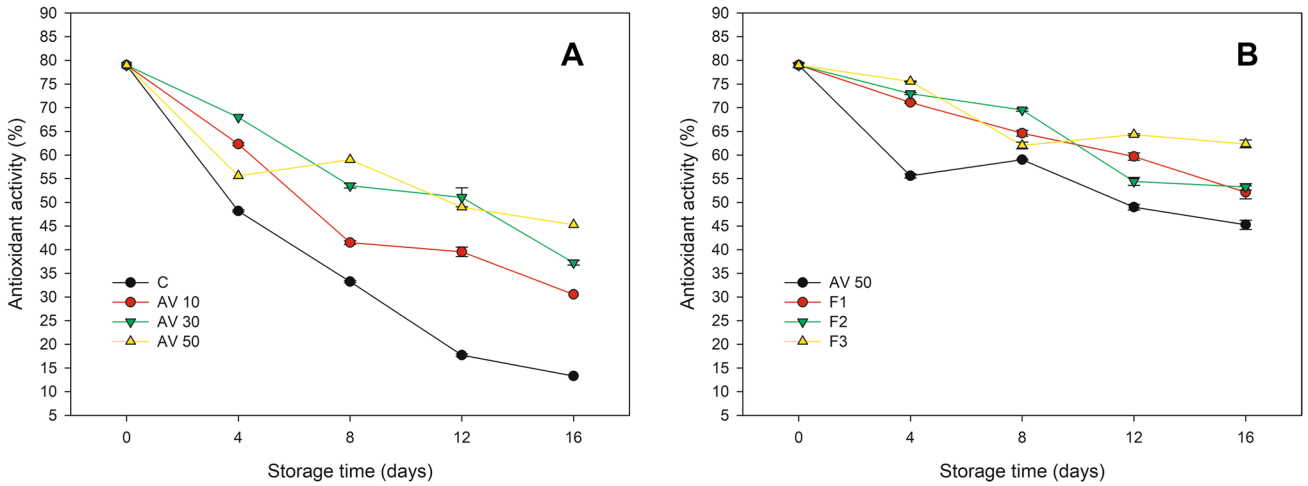

Fig. 4 Effects of aloe vera gel-based edible coating without EOs (**A**) and with EOs (**B**) on antioxidant activity of mushrooms. (AV 10, AV 30, AV 50 — 10%, 30%, and 50% aloe vera gel respectively; Av50 = AV gel; F1 = 50% AV gel + 10% (v/v) glycerol + 500 µL/L orange peel essential oils; F2 = 50% AV gel + 10% (v/v) glycerol + 1000 µL/L orange peel essential oils; F3 = 50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils)

treated with coating material incorporated with essential oil showed retention of higher antioxidant activity compared to other treatments. The results of current study are accordance with the previous findings of Mirshekari et al. (2019), who retained higher antioxidant activity of button mushroom using aloe vera gel-based edible coating. This might be possible due to increased phenylalanine ammonia lyase activity and maintained accumulation of phenolic fractions in mushrooms. Moreover, Hassanpour (2015) was also maintained the higher antioxidant activity in raspberry fruits by treatment of aloe vera gel. Therefore, the incorporation of essential oils in the edible coating may also improve the antioxidant capacity of coating materials of mushroom and others fruits and vegetables by retarding the oxidative degradation (Chaudhari et al., 2023; Yousuf et al., 2021). Previously, several researchers extended the antioxidant and phenolic content activity of button mushroom using different types of edible coatings such as chitosan nanoparticles (Chaudhari et al., 2023), nanosilica and oregano essential oils (Yan et al., 2023), and CMC, pectin, chitosan, and sodium alginate (Mădălina Ples & Nour, 2022) by producing free radical scavenging activity against free radical and oxidative degradation. In addition, Singla et al. (2012) investigated the effects of organic acid (malic acid) on the postharvest shelf life of white button mushroom during 5 days of storage period at 15 °C, and reported higher antioxidant activity (76%) in raw mushroom as compared to treated mushroom with 2% malic acid (69%) and 4% malic acid (71%) respectively. In our study, the antioxidant activity was maintained higher by the treatment of aloe vera gel-based edible coating enriched with orange peel essential oils throughout the storage period up to 16 days.

Total Phenolic Content (TPC)

The results of TPC of the aloe vera-based edible coating with or without essential oil are shown in Fig. 5. TPC of all samples was affected ($p < 0.05$) by the aloe vera gel concentration. The phenolic contents of AV 30 and AV 50 were greater than phenolic contents of AV 10 and control at the end of storage (Fig. 5A). The lower TPC of samples might be due to the utilization of polyphenols in the synthesis of brown pigment formation, thus resulting in increasing browning index and low polyphenol content. The same results have been observed in mushrooms with alginate-based coatings (Louis et al., 2021). The aloe vera (50%)-based edible coating enriched with different EOs significantly increased the TPC of mushrooms throughout the storage period, due to presence of phenolic groups of orange peel essential oil. Moreover, the phenolic contents of F3 (50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils)-treated mushroom samples were higher than the F2, F1, and other treatments (Fig. 5B). The results revealed that the increasing concentration of orange peel essential oils in 50% aloe vera gel-based edible coating of mushrooms significantly retained higher phenolic activity. The results of phenolic content are in line with the previous finding of Rehman et al. (2020) and Ali et al. (2019), those reported that the application of aloe vera gel-based edible coating maintained the higher phenolic components in treated guava and litchi fruits as compared to control fruits. These results are also consistent with the results reported by the previous scientist, those work extensively in the arena of phenolic fractions of fruits and vegetables (Chidtragool et al., 2011; da Silva et al., 2013). Our results are also better

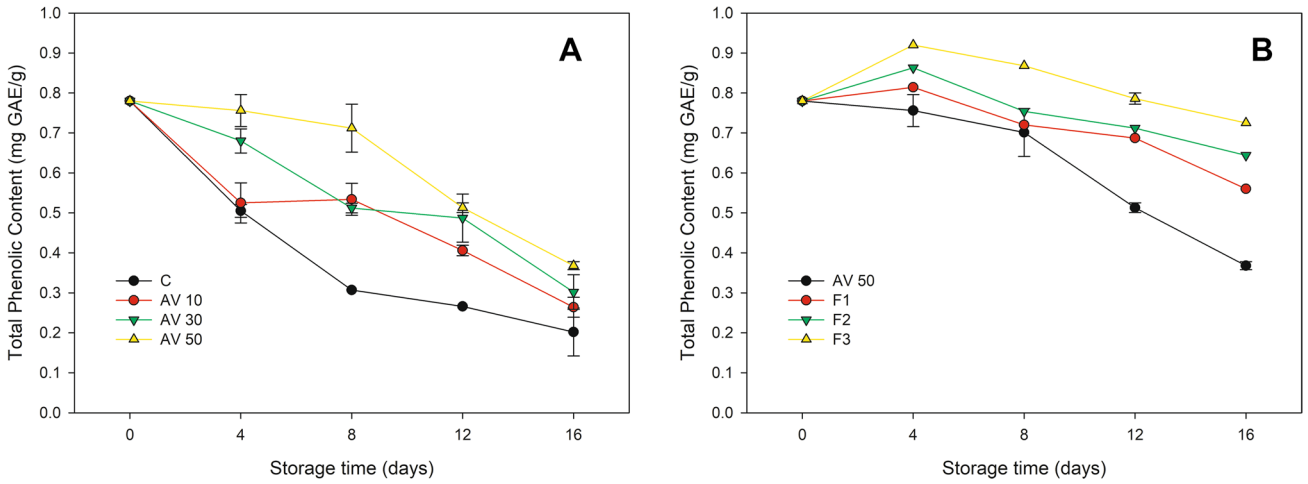

Fig. 5 Effects of aloe vera gel-based edible coating without EOs (**A**) and with EOs (**B**) on TPC of mushrooms. (AV 10, AV 30, AV 50 — 10%, 30%, and 50% aloe vera gel respectively; Av50 = AV gel; F1 = 50% AV gel + 10% (v/v) glycerol + 500 µL/L orange peel essential oils; F2 = 50% AV gel + 10% (v/v) glycerol + 1000 µL/L orange peel essential oils; F3 = 50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils)

in comparison with the previous finding of Zhu et al. (2019) who retained higher phenolic content in the mushroom treated with sodium alginate composite coating with thyme essential oil, L-cysteine, and nisin during the storage period up to 9 days at 4 °C. In addition, the effects of different concentrations (5–50 µL/L) of peppermint oil were also investigated by Qu et al. (2020) on the postharvest quality of white button mushrooms, their results showed that the increasing concentrations of essential oil significantly improve the anti-oxidant system of mushroom throughout the storage period at 4 °C up to 8 days. Therefore, the fumigation treatment of 50 µL/L of peppermint oil retained higher phenolic (1.49 fold) and flavonoid content (1.24 fold) respectively. Similar kinds of results have been also reported by Chaudhari et al. (2023), Jiang et al. (2012), and Mahshid Nasiri et al. (2017); they reported that the complex of chitosan with glucose, tragacanth gum enriched with Zataria *multiflora* essential oils, and cajuput-loaded chitosan coating had a potential effects on the phenolic content of button mushroom, which influenced higher antioxidant activity and minimized the risk of oxidation in button mushrooms.

Total Flavonoid Content

Flavonoids play a vital role in fruits and vegetables by exhibiting scavenging activity. This antioxidant activity of flavonoids was significantly affected ($p < 0.05$) by the concentration of aloe vera gel during the storage period of 16 days (Fig. 6A). Mushrooms coated with aloe vera gel retained higher flavonoid content than uncoated samples. AV 50-treated mushrooms contained the highest flavonoid content at the end of storage period. The same results were observed in the mushrooms coated with alginate-based coatings (Louis et al., 2021). Therefore, the essential oil incorporating aloe vera gel (50%)-based edible coatings were found to have the highest potential to retain a higher flavonoid content in mushroom samples throughout the storage period (Fig. 6B). The flavonoid content of coated mushrooms increased during the initial days of storage, peaking on the 4th day; rapidly, they started decreasing in flavonoid content. F3-coated mushrooms showed the highest flavonoid content at the end of the storage period. The results are in good agreement with the previous finding of Qu et al. (2020), who treated button mushrooms with peppermint essential oil and observed that higher flavonoid content activity of coated samples was retained. This might be due to the self-defense reaction of coated samples with increasing TPC and total anti-oxidant activities against the external stress created by orange peel essential oil which is present in the coating material. Meanwhile, the application of edible coating could be potential to inhibit rapid degradation of flavonoid content in treated mushroom as compared to control ones due to ability of aloe vera gel-based edible coating barrier against water and air from the external environment (Jati et al., 2022).

Firmness

The firmness of all the samples gradually decreased with increasing time of storage. The edible coatings prepared with different concentrations of aloe vera gel without essential oils on mushrooms treated with AV 50 were significantly

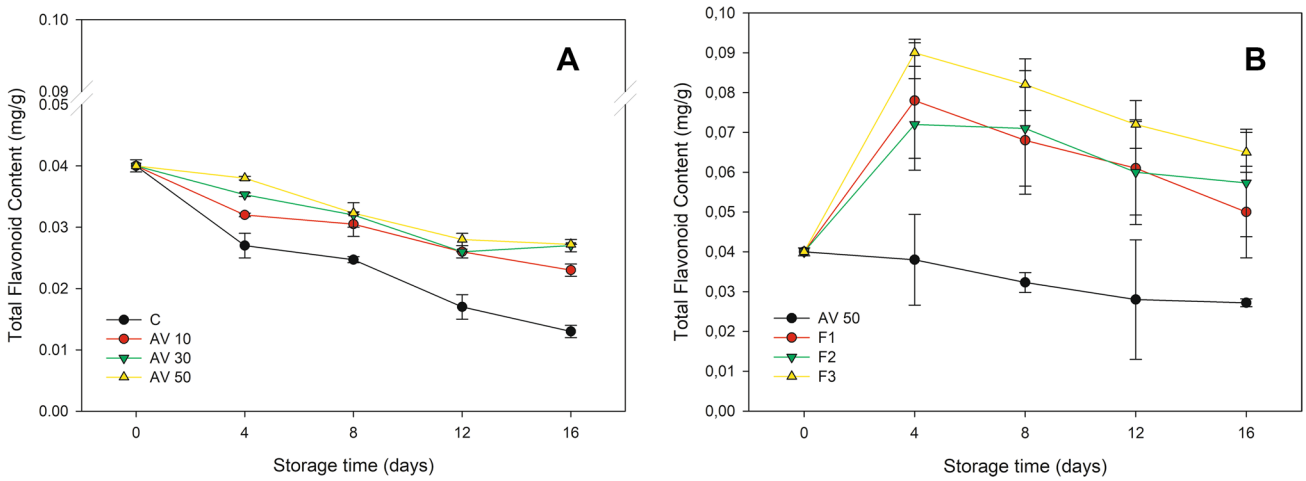

Fig. 6 Effects of aloe vera gel-based edible coating without EOs (**A**) and with EOs (**B**) on TFC of mushrooms. (AV 10, AV 30, AV 50 — 10%, 30%, and 50% aloe vera gel respectively; Av50 = AV gel; F1 = 50% AV gel + 10% (v/v) glycerol + 500 µL/L orange peel essential oils; F2 = 50% AV gel + 10% (v/v) glycerol + 1000 µL/L orange peel essential oils; F3 = 50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils)

firmer ($p < 0.05$) than others at the end of storage (Fig. 7A); the values ranged from 76 to 46 N. The firmness of the control sample reduced from 76 to 19 N during 16 days of storage. Aloe vera gel concentration significantly influences the firmness of coated mushrooms with increase in gel concentration. AV 10 and AV 30 treatments had a similar effect on firmness of mushroom. Therefore, the incorporation of orange peel essential oils in 50% aloe vera gel-based edible coating significantly ($p < 0.05$) retained the higher firmness of mushrooms as compared to the control and the sample without essential oils. Mushrooms treated with F3 were significantly firmer ($p < 0.05$) than the other treated mushrooms at the end of the storage (Fig. 7B); the values ranged from 76 to 69.2 N. The firmness of AV 50-treated samples decreased from 76 to 46.8 N, which showed the effect of essential oil incorporated in the aloe vera gel; the oil concentration significantly influenced the firmness of coated mushrooms with increase in oil concentration. F1 and F2 treatments had a similar effect on firmness of mushroom. The results are in line with the previous findings of Mohebbi et al. (2012), Martinez-Romero et al. (2018), and Farina et al. (2020); the firmness of button mushrooms and

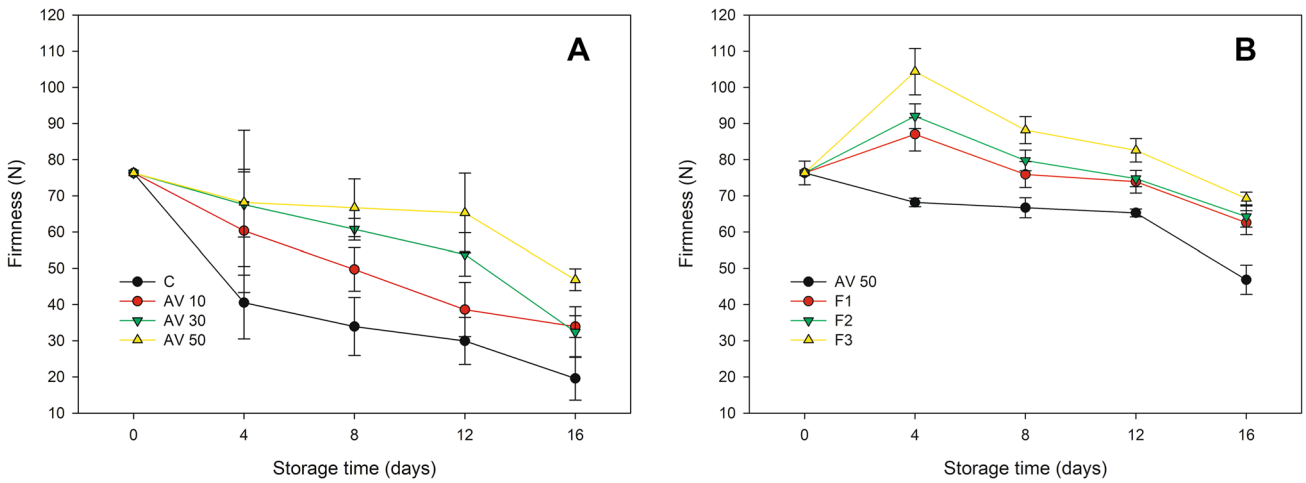

Fig. 7 Effects of aloe vera gel-based edible coating without EOs (**A**) and with EOs (**B**) on firmness of mushrooms. (AV 10, AV 30, AV 50 — 10%, 30%, and 50% aloe vera gel respectively; Av50 = AV gel; F1 = 50% AV gel + 10% (v/v) glycerol + 500 µL/L orange peel essential oils; F2 = 50% AV gel + 10% (v/v) glycerol + 1000 µL/L orange peel essential oils; F3 = 50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils)

fresh cut papaya was maintained using aloe vera gel and tragacanth gum-based edible coatings. Moreover, the previous findings of Jiang et al. (2012) and Zhu et al. (2019) were also maintained the firmness of mushroom at 4 °C throughout storage period using chitosan edible coating enriched with thyme essential oils and sodium alginate edible coating by reducing the weight loss and respiration rate. The significantly higher firmness 716.9 g was reported by Sedaghat and Zahedi (2012) after 10 days of storage in mushroom treated with gum arabic edible coating as compared to other treated and uncoated samples. Similarly, Jiang (2013) reported losses about 26% of firmness in control samples as compared to alginate coating [1% (17%), 2% (11%), and 3% (12.8)]-treated samples under modified atmosphere. The effects of chitosan/zein based edible films enriched with α-tocopherol was also investigated by Zhang et al. (2020) on white button mushrooms during the storage at 4 ℃ up to 12 days. Those reported that the treatment of composite coating of chitosan/zein with with α-tocopherol was most potential to maintained higher firmness of mushroom throughout the storage period as compared to alone chitosan, chitosan/zein, and control mushrooms due to lower degradation of polysaccharide and protein in mushroom, demolition of central vacuoles, and contraction of mycelium.

Open Cap Percentage

The percentage of opened caps in stored mushrooms increased in all samples (Fig. 8). Control (C) and AV 10-coated samples showed a higher percentage than other treatments. For AV 30 and AV 50, the values were in the range 82 to 64% (Fig. 8A). The leading of cap opening of the mushroom during storage increments the higher water loss. AV 50-treated cap opening of mushrooms was lower. Therefore, the incorporation of higher concentration of orange peel essential oils in 50% aloe vera gel-based edible coating showed a lower open cap percentage as compared to the control and non-essential oil-based edible coating (Fig. 8B). The edible coating F3 had a lower open cap percentage of mushrooms (49%) followed by F2 (52%) as compared to F1, control, and other non-essential-based edible coatings. Similar results were observed in button mushrooms coated with tragacanth gum-enriched *Satureja khuzistanica* essential oil and *Zataria multiflora* Boiss. essential oils, which reduced the senescence of samples and browning (Nasiri et al., 2018; Mahshid Nasiri et al., 2019). Moreover, Jiang (2013) also reported that the treatments of alginate (1%, 2%, 3%)-based edible coatings are effective to reduce the percent cap opening of mushroom as compared to uncoated samples throughout the storage period by reducing the moisture loss and maintained the gaseous environment. The increasing trends of cap open percentage were also reported in all treated mushroom with sodium alginate-based edible coating combined with thyme essential oils (1% v/v), L-cysteine, and nisin and untreated (control) samples. However, the higher cap open percentage of mushroom was reported in control samples at 4 °C up to 9 days of storage due to major loss of water content (Zhu et al., 2019).

Microbiological Quality

The results of total plate count and yeast and mold of treated and control mushrooms were determined at 8 and 16 days of storage respectively. The results of total plate

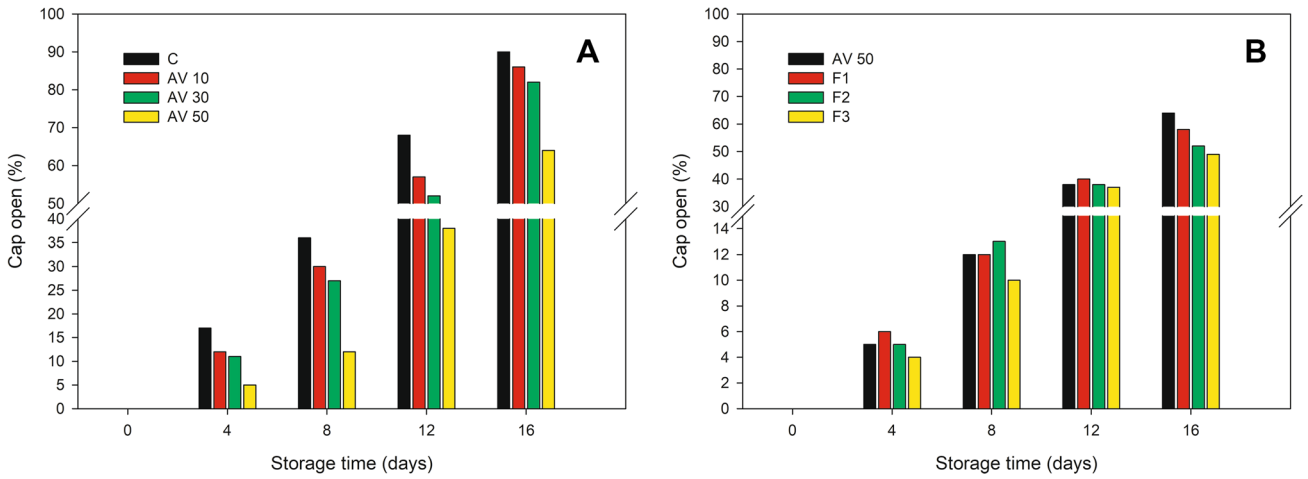

Fig. 8 Effects of aloe vera gel-based edible coating without EOs (**A**) and with EOs (**B**) on open cap percentage of mushrooms. (AV 10, AV 30, AV 50 — 10%, 30%, and 50% aloe vera gel respectively; Av50 = AV gel; F1 = 50% AV gel + 10% (v/v) glycerol + 500 µL/L orange peel essential oils; F2 = 50% AV gel + 10% (v/v) glycerol + 1000 µL/L orange peel essential oils; F3 = 50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils)

count (mesophiles) and total yeast and mold count of mushroom coated with different concentrations of aloe vera gel and 50% aloe vera gel-based edible coating enriched with orange peel essential oils are depicted in Table 5. In samples without essential oil rich edible coating, 50% aloe vera gel-treated mushrooms had a lower microbial count in terms of total plate count (4.87 log cfu/g) and yeast and mold count (3.44 log cfu/g) due to its antimicrobial activity as compared to other aloe vera gel at 16 days of storage due to natural antimicrobial activity of aloe vera (Al-Ahbabi et al., 2016). Therefore, the 50% aloe vera gel-based edible coating enriched with different concentrations of orange peel essential oils significantly ($p < 0.05$) inhibited the growth of mesophiles, yeast, and mold in mushrooms as compared to those treated with or without EO edible coatings. The F3 (50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils)-treated mushrooms had a lower microbial count than the other treated samples. In the present study, the effectiveness of aloe vera gel in inhibiting the growth of microorganisms (antimicrobial activity) increased with the increase in orange peel essential oil concentration in treated fruit bodies. The results of yeast and mold counts at the end of storage were 3.88 log cfu/g and 2.86 log cfu/g respectively in F3-treated mushrooms, which are significantly lower as compared to other treated mushrooms. The results of microbial analysis are in good agreement with the findings reported by Passafiume et al. (2020), who developed aloe vera gel-based edible coating with lemon essential oil and combined with other polymers and their applications on kiwifruits. Their results showed that the aloe vera combined with essential oil and other polymer was effective to reducing microbial growth on fruits by inhibit water and gas transpiration. Moreover, Mohebbi et al. (2012) stated that the development of edible coating with natural preservative like essential oils may be reduced respiration rate and inhibit enzymatic browning (Khorram & Ramezanian, 2021).

Sensory Evaluation and Visual Appearance

The results of sensory characteristics of the mushrooms treated with different concentrations of aloe vera gel and 50% aloe vera gel-based edible coating enriched with different concentrations of orange peel essential oils are shown in Fig. 9A and B. The results indicate that the overall acceptability or intent to purchase of all mushroom samples gradually decreased with increasing time of storage. The sensory characteristics including color, texture, odor, and appearance of mushrooms were significantly reduced during storage. In mushrooms without EO edible coating, the control

Table 5 Total plate count and yeast and mold count of control and treated mushrooms with or without essential oil aloe vera gel-based edible coatings

Total plate count = log CFU/g			
Treatments	**Days of storage**		
	0	**8**	**16**
Control	ND	4.46 ± 0.10^{a}	5.06 ± 0.03^{a}
AV 10	ND	4.38 ± 0.06^{ab}	4.99 ± 0.05^{b}
AV 30	ND	4.32 ± 0.19^{abc}	4.92 ± 0.03^{c}
AV 50	ND	4.27 ± 0.32^{cd}	4.87 ± 0.01^{d}
F1	ND	4.19 ± 0.02^{cde}	4.80 ± 0.23^{de}
F2	ND	4.07 ± 0.10^{f}	4.27 ± 0.12^{f}
F3	ND	3.58 ± 0.03^{g}	3.88 ± 0.15^{g}
Total yeast and mold count = log CFU/g			
	0	**8**	**16**
Control	ND	3.08 ± 0.01^{a}	3.78 ± 0.06^{a}
AV 10	ND	2.98 ± 0.17^{b}	3.67 ± 0.22^{ab}
AV 30	ND	2.94 ± 0.09^{bc}	3.65 ± 0.01^{abc}
AV 50	ND	2.82 ± 0.04^{bcd}	3.44 ± 0.03^{d}
F1	ND	2.75 ± 0.03^{e}	3.40 ± 0.98^{de}
F2	ND	2.70 ± 0.07^{ef}	2.93 ± 0.02^{f}
F3	ND	2.48 ± 0.02^{g}	2.86 ± 0.03^{g}

Mean ± SD, where: superscript a,b,c…n indicated the significant differences between the sample. AV 10 = 10% aloe vera gel; AV 30 = 30% aloe vera gel; AV 50 = 50% aloe vera gel; F1 = 50% AV gel + 10% (v/v) glycerol + 500 µL/L orange peel essential oils; F2 = 50% AV gel + 10% (v/v) glycerol + 1000 µL/L orange peel essential oils; where, F3 = 50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils

and AV 10-treated mushrooms were not acceptable at the end of the storage period. Moreover, AV 30 and AV 50 did not show any unsuitable attributes and received an overall acceptability ranging from 3 to 4 points, thus proving that AV 50 has the ability to delay the spoilage of mushrooms. The visual appearance of the control mushrooms and those treated with different concentrations of aloe vera gel-based coating supports these results. Based on this, AV 50 treatment is selected for the incorporation of orange peel essential oil to improve the antimicrobial efficiency of coating materials for extending the shelf life of mushrooms. Therefore, the mushrooms treated with 50% aloe vera gel-based edible coating enriched with orange peel essential oils have the most potential to retain higher consumer acceptability of mushrooms throughout the storage period. The mushroom sample treated with F2 (50% AV gel + 10% (v/v) glycerol + 1000 µL/L orange peel essential oils) and F3 (50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils) showed higher overall consumer acceptability between the 3 and 4 point range, thus proving that a higher concentration of essential oil has the ability to delay the spoilage of mushrooms. The effects of aloe vera gel-based coating enriched with orange peel essential oils on the visual appearance of button mushrooms throughout the 16 days of storage at 4 °C. The overall results demonstrate the effectiveness of the combined essential oil and aloe vera gel in delaying mushroom appearance deterioration. It is evidently proven by the previous researchers that the application of edible coating is useful to extending shelf life of fruits and vegetables by maintaining their postharvest quality attributes and organoleptic properties including color, reducing browning, maintaining higher texture, appearance, reducing browning, and others due to creating barrier properties against water loss and gas transpiration throughout the storage period (Maroufi et al., 2022). For example, Lai et al. (2013) and Pan et al. (2013) retained higher sensory properties of different fruits such as fresh cut apple and carrot throughout the storage period by reducing color browning, weight loss, respiration rate, etc. The results of present study are in good agreement with the previous findings reported by Mohammadi et al. (2021), who retained higher consumer acceptability of the button mushrooms using aloe vera-based edible coating enriched with basil essential oils. The button mushroom shelf life was also extended by Chen et al. (2022) using poly (butylene sdipate-co-terephthalate/poly (butylene succinate)-based packaging film incorporated with polyethylene oxide (15%) by maintained postharvest characteristic and organoleptic characteristics of button mushroom during storage. The results are also in good agreement with the recent findings of Chaudhari et al. (2023); this research maintained the higher sensorial attributes such as flavor, color, and uniformity of white button mushroom using cajuput essential oil-loaded chitosan films. This might be possible due to retardation of microbial contamination, lower weight loss, minimize oxidation, and retention of higher levels of antioxidant enzymes such as catalase and superoxide dismutase.

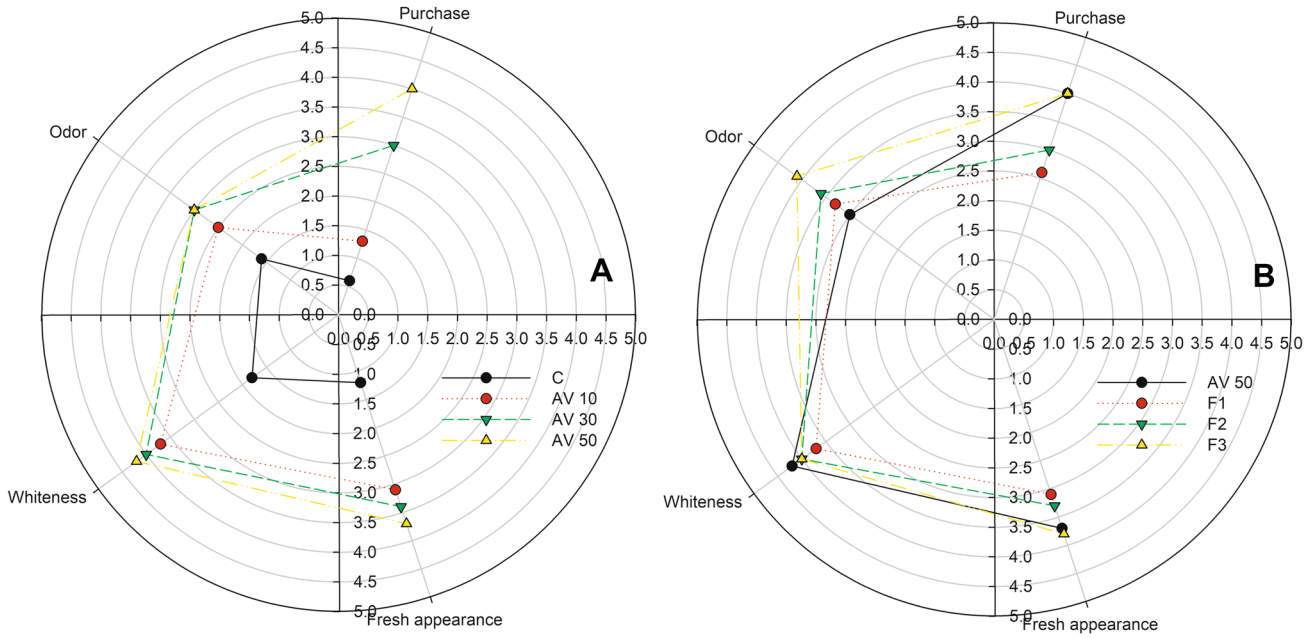

Fig. 9 Effects of aloe vera gel-based edible coating without EOs (**A**) and with EOs (**B**) on sensory characteristics of mushrooms. (AV 10, AV 30, AV 50 — 10%, 30%, and 50% aloe vera gel respectively; Av50 = AV gel; F1 = 50% AV gel + 10% (v/v) glycerol + 500 µL/L orange peel essential oils; F2 = 50% AV gel + 10% (v/v) glycerol + 1000 µL/L orange peel essential oils; F3 = 50% AV gel + 10% (v/v) glycerol + 1500 µL/L orange peel essential oils)

Conclusion

In present study, the shelf life of white button mushroom was successfully extended by maintaining their postharvest quality and sensory attributes at 4 °C throughout 16 days of storage period using aloe vera-based edible coating with or without incorporation of different concentrations of orange peel essential oil. The physic-chemical characterization of coating materials showed that the increasing concentration of orange peel essential oils in aloe vera gel-based edible coatings significantly improved rheological behavior and increased the TSS and particle size of the matrix while reducing their stability and PDI of the coating materials due to the hydrophobic nature of EOs.

Furthermore, the application of aloe vera gel-based edible coatings with incorporation of orange peel essential oil on white button mushrooms has the potential to slow down the respiration rate, inhibiting the browning index and moisture loss. The firmness, total phenolic content, antioxidant activity, and total flavonoid content of the coated mushrooms were maintained better than in the control sample. The aloe vera gel incorporated with orange peel essential oil (50% aloe vera gel + 1500 µL/L EOs) was found effective in retarding microbial load and received higher consumer acceptability of mushrooms throughout the storage period as compared to the control and other coating treatments. So, it is concluded that the bilayer edible coating, i.e., aloe vera gel incorporated with orange peel essential oil, can be an alternative and cheaper method to prolong post-harvest shelf life of mushrooms up to 16 days when compared with an uncoated sample (12 days). Further research should be performed to develop a nano and smart packaging system using aloe vera gel to improve gas and water barrier properties for longer storage of mushrooms with retention of higher quality attributes.

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Author Contribution Shenbagam A.: data curation, methodology, investigation, and writing—original draft. Nishant Kumar: conceptualization, methodology, formal analysis, investigation, project administration, and writing—review and editing. Kumar Rahul: validation, methodology, software, formal analysis, software, and data curation. Ashutosh Upadhyay: methodology, formal analysis, and investigation. Małgorzata Gniewosz: writing—review and editing. Marek Kieliszek: resources, funding acquisition, writing—review and editing, and supervision.

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Data Availability The data obtained during the study are available from the corresponding author upon reasonable request.

Declarations

Competing Interests The authors declare no competing interests.

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