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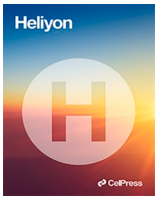

Research article

Effect of Balangu seed mucilage/gelatin coating containing dill essential oil and ZnO nanoparticles on sweet cherry quality during cold storage

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ABSTRACT

The current research focused on examining the effect of a coating made from Balangu seed mucilage (TSM-BM) and gelatin (Ge), with varying concentrations of dill essential oil (DEO) (0 %, 1 %, and 2 %) and zinc oxide nanoparticles (ZnO-np) (0 % and 0.5 %), on the quality characteristics of cherries stored at 4 °C over intervals of 0, 4, 7, 11, 18, and 25 days. The study noted that the application of this coating, particularly when combined with DEO and ZnO-np, significantly reduced the rate of changes in several parameters, including weight loss, firmness, titratable acidity, pH, total soluble solids, ascorbic acid, total anthocyanin content, total phenolic content, and antioxidant activity ($p<0.05$). During the storage period, the skin color of all treated fruits darkened. Significant reductions were also observed in the values of L^*, Chroma, and hue angle, with the coating slowing these changes ($p<0.05$). The BM-Ge coating's gas barrier properties contributed to a lower respiration rate in coated fruits than in uncoated controls, thereby delaying spoilage. The coating effectively prevented moisture loss from the stem and reduced browning over time. The incorporation of DEO into the BM-Ge coating enhanced its moisture barrier capabilities due to DEO's hydrophobic properties. BM-Ge coating containing 2 % DEO and 0.5 % ZnO-np was able to reduce changes of weight loss, firmness, titratable acidity, ascorbic acid, total soluble solids, total anthocyanin content, total phenolic content, and antioxidant activity by 71.23 %, 88.84 %, 60 %, 48.39 %, 30.05 %, 82.65 %, 50.77 %, and 55.46 % respectively. A significant correlation was also observed between the treated fruits' physical, chemical, and visual qualities.

1. Introduction

Edible coatings facilitate selective control over the exchange of essential gases such as oxygen, carbon, carbon dioxide, and ethylene, which play crucial roles in the respiration processes of food products [1–3]. Each type of edible coating possesses unique functional characteristics. For instance, polysaccharide-based coatings are hydrophilic and capable of gas transmission but exhibit limited moisture barrier properties [4]. Mucilage, a polysaccharide of non-glucose sugars, can significantly increase the viscosity of solutions even at low concentrations. These substances are chemically stable, cost-effective, biocompatible, non-toxic, odorless, and widely available [5–8]. Balangu seed mucilage (BM) is characterized as an anionic gum with a high molecular weight (1.294×10^6 Da)

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and a relatively flexible molecular chain, predominantly composed of carbohydrates. The significant presence of uronic acid, about 20 %, highlights its polyelectrolyte nature and indicates a substantial proportion of acidic polysaccharides within its structure [9–11]. The primary limitation of mucilage-based coatings is their weak vapor barrier properties. However, composite coatings that combine multiple components can enhance these coatings' physical, mechanical, and barrier properties [4,12,13]. Integrating proteins into mucilage-based coatings has been shown to reduce moisture loss [14,15]. Gelatin, derived from partial hydrolysis of collagen found in animal skin, bones, connective tissues, and fish skin, is rich in amino acids such as proline, hydroxyproline, lysine, and hydroxylysine [1,16,17]. Incorporating antimicrobial and antioxidant agents such as essential oils and plant extracts is expected to enhance the preservation capabilities of these coatings. These active coatings can significantly improve the safety and quality of food products [3, 18–20]. A variety of antimicrobial agents, including organic acids, nanoparticles, enzymes, bacteriocins, and essential oils, have been explored to boost the antimicrobial efficacy of these coatings [21–24]. Dill essential oil (DEO) from *Anethum graveolens* L., with a scent reminiscent of black cumin, contains around 70 compounds. Its major components include Carvone, Limonene, α-phellandrene, β-phellandrene, p-cymene, Eugenol, Dipentene, Isoeugenol, and Phenanthrene [22,25,26].

The simultaneous application of antimicrobial agents often results in greater efficacy due to synergistic interactions compared to when these compounds are used individually. Zinc oxide nanoparticles (ZnO-np) exhibit antimicrobial properties against Gram-positive and Gram-negative bacteria and fungi. These nanoparticles exert their antimicrobial effects by inducing oxidative stress in microbial cells, which involves the release of reactive oxygen species or ions that interact with and disrupt the cell membrane [27,28]. It is well-documented that applying coatings to fruits and vegetables enhances their quality and helps maintain it post-harvest. Sweet cherry (*Prunus avium* L.) is particularly noted for its rich content of phenolic compounds, fiber, carotenoids, vitamin C, and anthocyanins. This fruit ripens early and is highly valued and widely consumed for its superior quality [2,11,29–31]. However, it is vulnerable to environmental stressors, particularly temperature fluctuations. Quality deterioration in harvested cherries can manifest as skin bruising, softening, acidity reduction, stem drying and browning, and susceptibility to fungal infections such as those caused by *Monilinia fructicola*, *Botrytis cinerea*, and *Penicillium expansum* [2,30]. No studies have explored using a Balangu seed mucilage-gelatin (BM-Ge) blend as a coating or film. This research evaluates how adding DEO and ZnO-np to the BM-Ge coating affects the quality of cherries during cold storage.

2. Materials and methods

Balangu seed (*Lallemantia iberica* L.) and dill seed **(***Anethum graveolens***)** were purchased from a local market in Zanjan (Iran). Gelatin was sourced from Farmand CO. (Iran), while Gallic acid, 2,6-dichloroindophenol, and glycerol were supplied by Sigma Aldrich (USA). Other chemicals used were of laboratory-grade purity and were procured from Merck (Germany).

2.1. Balangu seed mucilage (BM) and dill essential oil (DEO) extraction

100 g of Balangu seeds (*Lallemantia iberica* L.) were mixed with 3500 mL of distilled water and kept at room temperature for 2 h. The mixture was then stored in a refrigerator at 4 °C for 8 h. Following this, the mixture underwent ultrasonic treatment for 20 min at 40 kHz and a power of 100 W (Backer, V9, Iran). The mucilage was separated using a centrifuge at 8000×*g* for 5 min. Afterward, the Balangu seed mucilage was concentrated using a rotary vacuum evaporator at 45 °C and then dried in a vacuum oven at 50 °C for 12 h [32,33]. To extract DEO, a hydro-distillation method was employed using a Clevenger apparatus, resulting in a DEO extraction yield of 1.35 % (v/w) [34–36].

2.2. Coating preparation, and cherry coating

Solutions of 1.5 % (v/w) BM and gelatin were prepared [9,16]. These were combined in a 1:1 ratio, to which 0.45 g of plasticizer (45 % w/w, based on the biopolymer weight) was added and mixed at 25 °C for 30 min. Subsequently, as per specified treatments (referenced in Table 1), varying amounts of Tween 80 (35 % v/v, based on the DEO concentration), DEO (0 %, 1 %, and 2 % v/v), and ZnO nanoparticles (0.5 % and 1.5 % v/w, based on the biopolymer weight) were incorporated into the blend and stirred at 25 °C for another 30 min. The final homogenization was performed using an ultrasonic homogenizer at 14000 RPM for 20 min (MTOPS., SR30, South Korea).

Sweet cherries were harvested from a garden in Zanjan, Iran, after species verification. Post-washing and drying off surface

Table 1
Balangu seed mucilage-gelatin coating forming treatments. EO: Dill essential oil (%). Zno: Zno nanoparticle.

Treatment	Zno (%)	Dill essential oil (%)
Ctrl	0	0
EO 0%-Zno 0 %	0	0
EO 1%-Zno 0 %	0	1
EO 2%-Zno 0 %	0	2
EO 0%-Zno 0.5 %	0.5	0
EO 1%-Zno 0.5 %	0.5	1
EO 2%-Zno 0.5 %	0.5	2

moisture, the cherries were dipped in the prepared coating solution at 25 °C for 5 min. After allowing the surface to dry, the cherries were placed in perforated polyethylene terephthalate containers and refrigerated at 4 °C for a duration of 25 days. Quality evaluations were conducted periodically on days 0, 4, 7, 11, 18, and 25. Total of 105 sweet cherries sample were studied throughout the experiment [31].

2.3. Quality analyzing

2.3.1. Physical properties

Weight loss was monitored by comparing the weight differences from the initial weight throughout the storage period. Firmness was assessed using a texture analyzer (SANTAM Co., STM5, Iran) equipped with a 3 mm plunger, operating at a penetration speed of 10 mm s^{-1} and to a maximum depth of 10 mm, with measurements depending on both storage duration and treatment conditions. The stem moisture content was determined by comparing the fresh weight of the stems against their weight post-drying in an oven set at 80 °C for 24 h [37,38].

2.3.2. Visual properties

Images in RGB format with a resolution of 1288 × 1936 and saved in TIFF were obtained using an image processing module. The color components L^*, a^*, and b^* were derived from these RGB images using ImageJ software (Version 13.0.6, USA). Chroma (C^*) and Hue angle (h*) were computed based on Equations (1) and (2), respectively:

$$C^* = \left(a^{*2} + b^{*2}\right)^{1/2} \tag{1}$$

$$h^* = arctan\left(b^*/a^*\right) \tag{2}$$

Volume alterations were determined utilizing the image processing tools available in MATLAB R2019a (Mathworks, USA) and ImageJ software (Version 13.0.6, USA). This procedure involved several steps: image segmentation, noise reduction using a median filter (Fig. 1-A), background subtraction via Otsu's method (Fig. 1-B), conversion to grayscale (Fig. 1-C), thresholding to create binary images (Fig. 1-D), removal of stems (Fig. 1-F), and image inversion (Fig. 1-G). The radius was measured from the binary images to estimate the volume of cherries as that of a sphere. Changes in cherry volume during storage were quantified by comparing initial and final volumes. Cherry volume changes (%) during the storage were calculated using the initial and final volumes [39]. The decay ratio was visually assessed by calculating the proportion of fruits exhibiting rot against the total fruit count. Rotten fruits were identified by at least one visible rot spot on their surface. The stem browning index (PBI) was determined by the ratio of fruits showing over 30 % browning of stems during storage to the total fruit count [37,38].

2.3.3. Chemical properties

Stem chlorophyll content (PCC) was computed based on Equation (3) after extracting chlorophyll from the peduncle using 80 % acetone and measuring absorbance at wavelengths of 645 nm (A_{645}) and 663 nm (A_{633}):

$$\text{PCC}\left(mg/kg\right) = 20.29\,A_{645} + 8.05\,A_{633} \tag{3}$$

Following juicing, cherry juice was centrifuged (12000×*g*, 20 min), after which the pH was recorded using a pH meter and total soluble solids (TS, degrees Brix) were determined with a refractometer. Titratable acidity (TA, g Maleic acid/kg fruit) was assessed by titrating 10 mL of cherry juice with a 0.1 M sodium hydroxide solution until reaching a pH of 1.8.The content of ascorbic acid (mg/100g fruit) was measured through the 2,6-dichloroindophenol titrimetric method after preparing the fruit extract by soaking in 3 % metaphosphoric acid (HPO_3) and titration until a stable pink color was achieved [2,31,40]. Total anthocyanin content (TAC) was evaluated using the pH differential method, relying on the absorption characteristics of Cyanidin-3-glucoside. A sample of 5 mg of cherries was mixed with 20 mL of methanol, ultrasonicated for 30 min, and then centrifuged. TAC was calculated considering the difference in absorbance at wavelengths 520 and 700 nm at pH values of 1 and 4.5, (A) taking into account factors such as the molecular weight (MW) of Cyanidin-3-glucoside, dilution factor (DF), path length (l), and molar extinction coefficient (ε) (Equation (4))

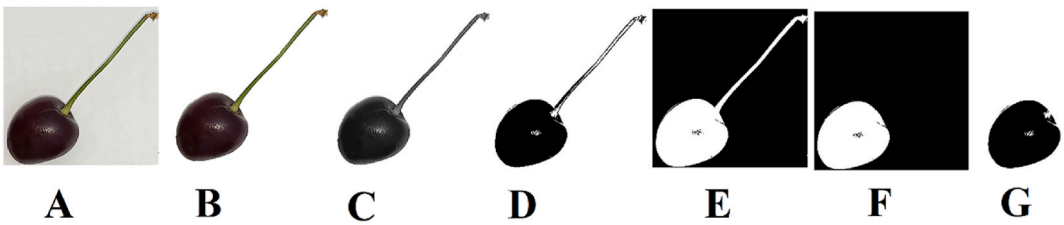

Fig. 1. (A) RGB image, (B) Images after background removal, (C) Grayscale images, (D) Binary images, (E) Image inversion, (F) images after stem removal, and (G) Image inversion.

[41]:

$$\text{TAC}\left(mg/kg\right) = (A \times MW \times DF \times 1000) \Big/ (\varepsilon \times l) \quad (4)$$

The evaluation of antioxidant properties was conducted using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay. In this method, 3.9 mL of DPPH solution was combined with 0.1 mL of methanolic extract from cherries. After an incubation period of 60 min, the absorbance levels were recorded by a UV–visible spectrophotometer (Lab Ram HR, Horiba, Japan) at 520 nm. For assessing the total phenolic content (TPC, expressed as mg GAE/100g of fruit), a mixture was prepared containing 0.1 mL of the cherry methanolic extract, 0.5 mL of Folin-Ciocalteu reagent, 2.9 mL of distilled water, and 2.0 mL of 20 % sodium carbonate solution. The absorbance of this mixture was then measured at 734 nm [15,30].

2.4. Correlation

The correlation between different variables was established using Pearson's correlation coefficient method, and the significance of these relationships was confirmed through the Kaiser-Meyer-Olkin test, with a significance level set at $p < 0.05$.

2.5. Statistical analysis

The effect of various treatments on quality and process parameters was analyzed by employing one-way ANOVA within a factorial randomized complete block design framework. Duncan's post hoc test was used to compare the means. Statistical analyses were performed using SPSS software (Version 26, USA), while graphical representations and error calculations were done using Excel (2019, USA). Each experimental condition was replicated at least three times.

3. Results and discussion

3.1. Physical properties

3.1.1. Weight loss (WL)

Weight loss (WL) in fruits and vegetables predominantly occurs due to transpiration and respiration. In cherries, the low diffusion resistance of the skin coupled with a high surface-area-to-volume ratio accelerates water loss [2,42–44]. Significant increases in WL were observed across all treatment groups during storage as shown in Fig. 2. The results demonstrated that the application of BM-Ge coating markedly reduces moisture transfer from cherries to their surrounding environment, achieving this by acting as a semi-permeable barrier to gases and water vapor. This leads to reduced rates of respiration and transpiration, minimized water loss, and decreased enzymatic browning [31]. WL was greater in the control (Ctrl) treatment, primarily due to heightened respiration and evaporation rates. This observation aligns with findings from several studies [2,37,38,42–46]. It was also noted that incorporating DEO markedly reduced WL throughout storage ($p < 0.05$). DEO improves the moisture barrier characteristics of biopolymer films, likely through the formation of a strengthened matrix between BM-Ge and DEO via hydrogen bonds, acting as a semi-permeable layer. The robust interaction and bonding between DEO and the hydroxyl groups in mucilage-gelatin may restrict these groups' ability to bond with water molecules, thereby forming a more effective coating that impedes water vapor release from the fruit surface [31,42]. Consequently, treatments that include DEO can diminish surface desiccation, wrinkling, and respiration rates in cherries during storage by creating an improved physical barrier [47].

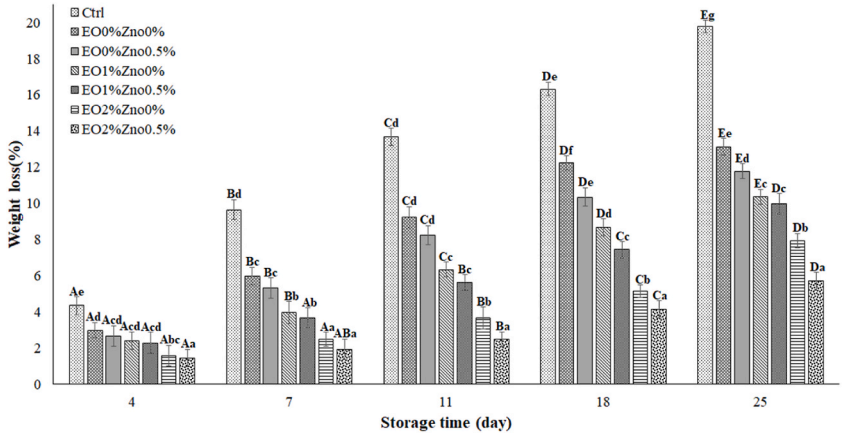

Fig. 2. Weight Loss (WL, %) of sweet cherry during cold storag. Numbers with similar lowercase letters in each storage time do not differ significantly (p>0.05). Numbers followed by different uppercase letters are statistically different (p>0.05).

Treatments containing zinc oxide nanoparticles (Zno-np) are crucial in significantly reducing WL during cold storage ($p < 0.05$). These coatings cut down mass transfer by 60 %, possibly through establishing a modified atmospheric condition around the fruit and its immediate environment, reducing carbon atom loss from respiration, and leveraging antimicrobial effects [48,49]. Agents like essential oils, nanoparticles, or their combinations serve as physical barriers against moisture loss while mitigating respiratory drawbacks [31,42]. Furthermore, the treatment combining 2 % DEO with 0.5 % Zno was found to be most effective in preserving cherry weight, highlighting the synergistic effect of DEO and Zno-np in maintaining cherry quality.

3.1.2. Firmness

Firmness is a critical measure of cherry ripening and quality [37,38]. The results indicated (Fig. 3) that firmness significantly declined in all treatments as storage duration increased ($p < 0.05$). During ripening, enzymes that degrade cell walls lessen cell adhesion and the structural integrity of the cell wall, converting protopectin into soluble pectin, thus reducing firmness [37,38]. The decrease in firmness was significantly ($p < 0.05$) more pronounced in the Ctrl treatment. The softening process is influenced by increased activities of enzymes such as polygalacturonase, beta-galactosidase, and pectin methylesterase, which are linked to the rate of fruit respiration during ripening. By managing internal oxygen and carbon dioxide levels, treatments capable of suppressing these enzyme activities can effectively maintain firmness [41,50].

The coating managed water loss and moisture migration through transpiration control, helping maintain fruit integrity and texture. This aligns with findings from other studies examining similar coatings for cherry preservation under cold storage conditions [37,38,41,43,50,51]. Adding DEO to the coatings significantly ($p > 0.05$) maintained firmness throughout storage compared to control treatments by forming a semi-permeable barrier that optimized internal atmospheric conditions and minimized water loss. Furthermore, treatments containing DEO were crucial in reducing fruit softening and inhibiting cell wall degradation [41]. Coatings that included ZnO-np were significantly ($p < 0.05$) more effective in maintaining firmness, potentially due to ZnO-np's role in lowering respiration rates and reducing ethylene and carbon dioxide production, which in turn decreased the activity of cell wall-degrading enzymes [37,38,48,49,52]. The combined use of DEO at 2 % and ZnO at 0.5 % demonstrated a synergistic effect, significantly preserving the firmness of the cherries. Similar outcomes have been documented in related research [37,38,41,43,44,48–54].

3.2. Chemical properties

3.2.1. Titratable acidity (TA) and pH

Titratable acidity (TA), expressed as a percentage of maleic acid, reflects the organic acid composition in fruits. A significantly ($p < 0.05$) decrease in TA was observed during cold storage, as illustrated in Table 2. In the control (Ctrl) group, the high respiratory activity of the fruits led to an increased use of organic acids as substrates for respiration, thereby hastening ripening. Coating treatments, however, were found to reduce both respiration and ethylene production rates. These findings align with previous studies [37,38,41,43,44,50–54]. The incorporation of ZnO nanoparticles (ZnO-np) and dill essential oil (DEO) significantly ($p < 0.05$) stabilized the TA levels. Adding DEO to the coating can reduce the rate of sugar decomposition and/or the consumption of organic acids by creating a modified internal atmosphere and delaying fruit respiration. DEO also reduces the respiration intensity, inhibits decaying, and reduces the fruit metabolic reactions [31]. By affecting the metabolic responses and reducing the microbial contamination, the addition of Zno-np caused a delay in the ripening process, decreased respiration intensity, and inhibition of cherry fruit rot. The EO 2%-Zno 0.5 % treatment showed the lowest TA changes during storage. In other words, the combination of DEO and Zno-np played a synergistic role in reducing TA changes due to their increased efficiency and antimicrobial properties.

In all the treatments, the pH values increased during the storage time, which is due to the consumption of organic acids in the enzymatic reactions during the respiration process (Fig. 4). At the end of the storage at 4 °C, the highest pH value was observed in the

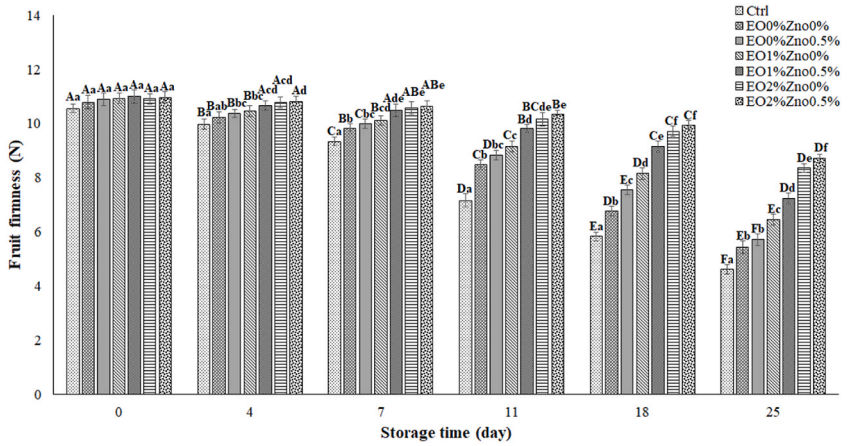

Fig. 3. Firmness (N) of sweet cherry during cold storage. Numbers with similar lowercase letters in each storage time do not differ significantly (p>0.05). Numbers followed by different uppercase letters are statistically different (p>0.05).

Table 2
Titratable acidity (TA) changes of sweet cherry during cold storage. Numbers with similar lowercase letters in each storage time do not differ significantly (p>0.05). Numbers followed by different uppercase letters are statistically different (p>0.05).

	0	4	7	11	18	25
Ctrl	0.85 ± 0.03^{Aa}	0.78 ± 0.02^{Bb}	0.56 ± 0.01^{Ce}	0.42 ± 0.03^{De}	0.37 ± 0.01^{Ef}	0.31 ± 0.02^{Ff}
EO 0%-Zno 0 %	0.89 ± 0.02^{Aa}	0.79 ± 0.01^{Bb}	0.63 ± 0.03^{Cd}	0.49 ± 0.02^{Dd}	0.44 ± 0.01^{Ee}	0.40 ± 0.03^{Ee}
EO 1%-Zno 0 %	0.87 ± 0.02^{Aa}	0.80 ± 0.02^{Bab}	0.64 ± 0.01^{Cd}	0.53 ± 0.03^{Dd}	0.48 ± 0.01^{Ed}	0.46 ± 0.02^{Ed}
EO 2%-Zno 0 %	0.88 ± 0.01^{Aa}	0.82 ± 0.02^{Bab}	0.69 ± 0.02^{Cc}	0.60 ± 0.02^{Dc}	0.53 ± 0.02^{Ec}	0.50 ± 0.03^{Ecd}
EO 0%-Zno 0.5 %	0.89 ± 0.01^{Aa}	0.81 ± 0.03^{Bab}	0.70 ± 0.03^{Cbc}	0.63 ± 0.02^{Dc}	0.56 ± 0.03^{Ec}	0.52 ± 0.02^{Ec}
EO 1%-Zno 0.5 %	0.87 ± 0.03^{Aa}	0.83 ± 0.02^{Aa}	0.74 ± 0.02^{Bab}	0.69 ± 0.02^{Cb}	0.61 ± 0.01^{Db}	0.59 ± 0.02^{Db}
EO 2%-Zno 0.5 %	0.87 ± 0.02^{Aa}	0.84 ± 0.02^{Aa}	0.76 ± 0.01^{Ba}	0.73 ± 0.01^{Ca}	0.66 ± 0.02^{Da}	0.64 ± 0.01^{Da}

Ctrl treatment and the lowest was observed for the samples coated with the BM-Ge coatings containing the highest amount of DEO. However, there was no significant difference between the coating treatments with different concentrations of DEO until the 18th day of storage ($p > 0.05$). The addition of DEO to the BM-Ge coating significantly ($p < 0.05$) decreased the rate of changes in the pH values during the cold storage. The addition of DEO to the coating could alter fruit respiration rates through interactions of DEO compounds with cell membranes that affect fruit metabolic patterns [42]. Moreover, the presence or absence of Zno-np had no significant effect on the changes in the pH values of cherries during storage ($p > 0.05$).

3.2.2. Total soluble solids (TS) and TS/titratable acidity (TA)

Sweet cherry, as a climacteric fruit, exhibits an increase in total soluble solids (TS) over the storage period [41]. Consequently, there was a significant rise in TS during this time (Table 3). This increase is attributed to the hydrolysis of starch into monosaccharides via respiration and other catabolic activities. The rise in TS correlates with water loss and the fruit's ripening or softening, which is further influenced by heightened enzymatic activity and reduced turgor pressure [37,41,46].

The results indicated that the rate of TS changes in the Ctrl treatment was significantly ($p < 0.05$) higher than in the other treatments. The coatings develop a semipermeable layer around the cherries that slows the ripening and respiration rates by limiting gas exchange as well as ethylene production and delaying sugar consumption, which in turn delays the increase in soluble solids [1,14]. Researchers have shown that sugars are the primary components of TS in fruits or vegetables that are consumed during respiration [37]. Comparable outcomes were observed when cherries were coated with chitosan [41,44,46], chitosan-gelatin [37,38], gum arabic with almond [50], and guar gum [43]. The application of a 2 % essential oil and 0.5 % zinc oxide treatment showed the most significant prevention of total soluble solids (TS) alterations, likely due to reduced oxygen levels and/or elevated carbon dioxide levels, alongside inhibited ethylene production which diminishes starch breakdown into sugars [37,38,44,48,51,52]. The ratio of total soluble solids to titratable acidity (TS/TA) serves as a critical measure for assessing fruit quality, taste balance, and consumer preference [37,38,44]. All treatments exhibited lesser fluctuations in TS/TA during storage compared to the control group, attributed to delayed fruit ripening (Fig. 5). The inclusion of DEO and zinc oxide nanoparticles (Zno-np) significant reduced ($p<0.05$) the changes in TS/TA.

3.2.3. Ascorbic acid

Ascorbic acid, a potent free radical scavenger, helps prevent fruit spoilage during ripening. Throughout cold storage, ascorbic acid levels gradually declined in all treatments; however, the decline was more pronounced in the control group; Coating significantly slowed down this reduction in ascorbic acid levels ($p<0.05$) (Fig. 6). The reduction in Vitamin C content is primarily attributed to several factors that occur during the storage period. As storage time increases, the metabolic processes of the fruit continue, albeit at a

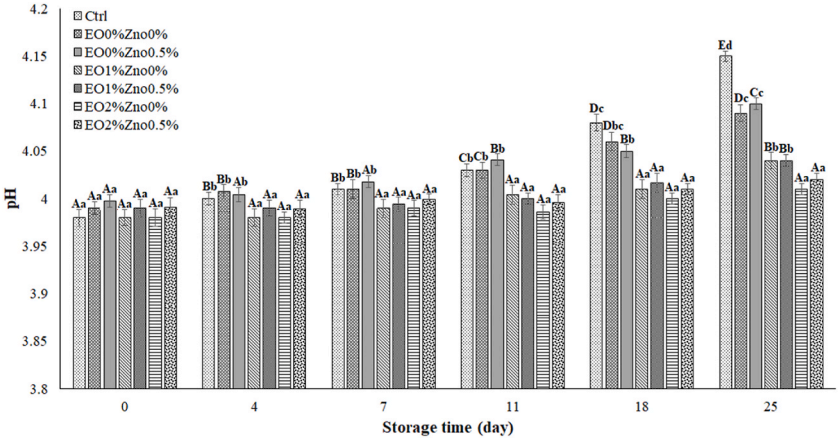

Fig. 4. pH changes of sweet cherry during cold storage. Numbers with similar lowercase letters in each storage time do not differ significantly (p>0.05). Numbers followed by different uppercase letters are statistically different (p>0.05).

Table 3
Total soluble solids (TS) changes of sweet cherry during cold storage. Numbers with similar lowercase letters in each storage time do not differ significantly (p>0.05). Numbers followed by different uppercase letters are statistically different (p>0.05).

	0	4	7	11	18	25
Ctrl	15.21 ± 0.54 ^{Aa}	18.94 ± 0.49 ^{Bc}	20.03 ± 0.39 ^{Cd}	22.45 ± 0.48 ^{De}	24.34 ± 0.62 ^{Ee}	25.42 ± 0.63 ^{Fd}
EO 0%-Zno 0 %	15.11 ± 0.39 ^{Aa}	17.21 ± 0.52 ^{Bb}	18.59 ± 0.46 ^{Cc}	19.45 ± 0.37 ^{Dd}	21.11 ± 0.56 ^{Ed}	21.08 ± 0.61 ^{Ec}
EO 1%-Zno 0 %	15.43 ± 0.62 ^{Aa}	17.01 ± 0.46 ^{Bb}	18.24 ± 0.54 ^{Cbc}	18.78 ± 0.36 ^{CDc}	19.43 ± 0.34 ^{DEc}	20.87 ± 0.51 ^{Ec}
EO 2%-Zno 0 %	15.19 ± 0.44 ^{Aa}	16.87 ± 0.52 ^{Bab}	17.45 ± 0.37 ^{Bab}	17.89 ± 0.47 ^{BCb}	18.65 ± 0.53 ^{CDb}	19.87 ± 0.35 ^{Db}
EO 0%-Zno 0.5 %	15.38 ± 0.43 ^{Aa}	16.66 ± 0.39 ^{Bab}	17.39 ± 0.43 ^{Ba}	17.44 ± 0.49 ^{BCab}	18.04 ± 0.36 ^{CDab}	18.69 ± 0.52 ^{Dab}
EO 1%-Zno 0.5 %	15.09 ± 0.37 ^{Aa}	16.04 ± 0.48 ^{Ba}	16.89 ± 0.51 ^{BCa}	17.01 ± 0.42 ^{BCab}	17.73 ± 0.51 ^{CDab}	18.32 ± 0.46 ^{Dab}
EO 2%-Zno 0.5 %	15.26 ± 0.40 ^{Aa}	16.01 ± 0.51 ^{Ba}	16.74 ± 0.43 ^{BCa}	16.98 ± 0.40 ^{BCa}	17.23 ± 0.52 ^{CDa}	17.78 ± 0.39 ^{Da}

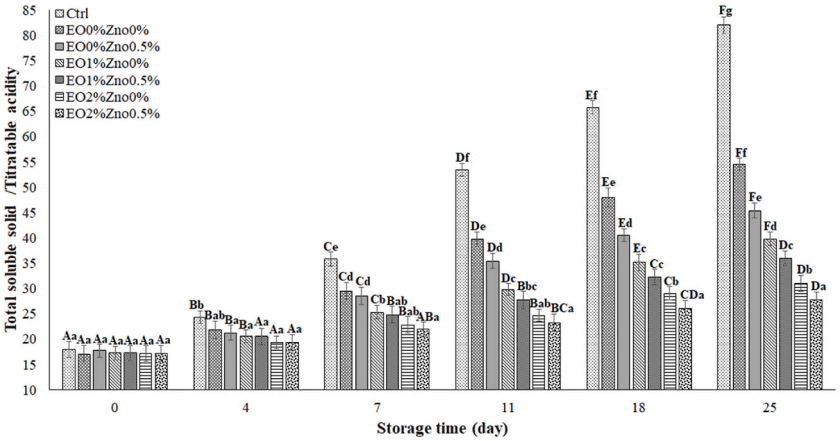

Fig. 5. Total soluble solids (TS)/Titratable acidity (TA) changes of sweet cherry during cold storage. Numbers with similar lowercase letters in each storage time do not differ significantly (p>0.05). Numbers followed by different uppercase letters are statistically different (p>0.05).

reduced rate, which can lead to oxidative degradation of ascorbic acid. Environmental conditions, including temperature, humidity, and exposure to light, further exacerbate these losses. The ascorbic acid was significantly more susceptible to oxidation and degradation in the control group without any protective coating due to higher respiration rates and enzyme activity. This was less pronounced in coated fruits, where the coatings slowed down respiratory metabolism and enzyme activity, consequently preserving the ascorbic acid levels for a longer duration. Additionally, the antioxidant properties of DEO played a critical role in enhancing Vitamin C retention by mitigating oxidative stress within the fruit. This preservation of ascorbic acid in coated cherries is likely due to the coatings' low oxygen permeability and reduced respiration rate, which inhibit enzyme activity and prevent ascorbic acid oxidation. In summary, as the storage duration increases, various physiological and biochemical processes, including respiration, enzyme activity, and oxidative stress, contribute to the decline in Vitamin C content. The use of coatings can significantly influence these factors, thus

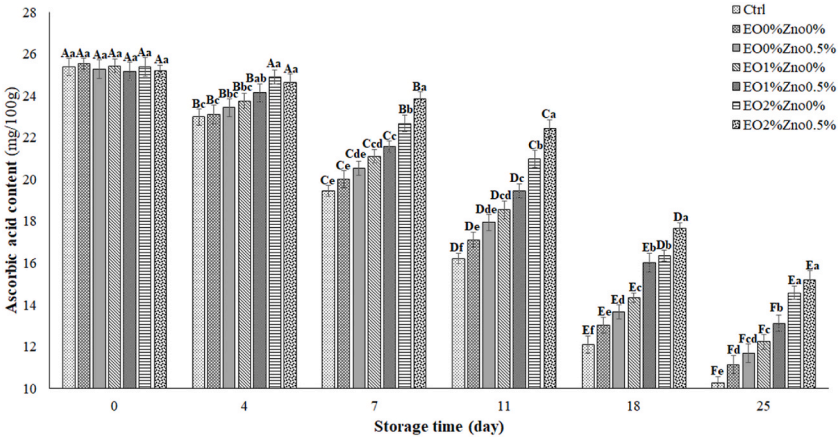

Fig. 6. Ascorbic acid changes of sweet cherry during cold storage. Numbers with similar lowercase letters in each storage time do not differ significantly (p>0.05). Numbers followed by different uppercase letters are statistically different (p>0.05).

preserving ascorbic acid levels more effectively than in untreated samples [43,44,46].

Similar effects of coatings with chitosan [41,44,55], guar [43], and alginate-chitosan containing olive leaf extract [46] have been documented. DEO addition significantly ($p<0.05$) enhanced ascorbic acid retention, attributable to DEO's antioxidant properties and the lower respiration rate in treated fruits [31]. While ascorbic acid levels in samples treated with Zno-np did not show significant differences at certain storage intervals compared to those without Zno-np ($p > 0.05$), the inclusion of Zno-np significantly ($p<0.05$) curtailed the rate of ascorbic acid degradation, likely due to altered internal atmosphere and decreased respiration rate [52].

3.2.4. Total anthocyanin content (TAC) and total phenolic content (TPC)

Anthocyanins, water-soluble phenolic compounds with high antioxidant capacity, are crucial for maintaining during storage [31,41]. A notable decline in total anthocyanin content (TAC) was noted across all treatments during cold storage (Table 4). This reduction is linked to diminished enzyme activities that affect anthocyanin synthesis, specifically phenylalanine ammonia-lyase and anthocyanidin synthase [41]. TAC was significantly higher ($p<0.05$) in coated cherries compared to the control group. The coating's barrier properties alter the internal atmosphere of the fruit, leading to reduced metabolic activities involved in anthocyanin degradation [31]. Incorporating DEO and Zno-np into the BM-Ge coating also stabilizes pH levels, which supports anthocyanin preservation while concurrently minimizing water loss and respiration rates [31].

The integration of essential oils into the coating enhances its antioxidant characteristics. This notable enhancement in the antioxidant capacity of cherries during storage can be linked to improved retention of phenolic and TAC contents. Similar observations have been documented in previous studies [31,41,50]. Phenolic compounds, as secondary metabolites, are crucial for augmenting fruit quality and nutritional value by enriching color, aroma, flavor, and taste [42,46,54]. Throughout the storage period, TPC demonstrated a significant ($p<0.05$) decline across all treatments (Table 4). This reduction in TPC is primarily due to cellular breakdown as the cherries ripen [55]. Although TPC consistently decreased across all treatments, the most significant reduction was observed in the control sample, with a lesser decline noted in the coated samples. This could be attributed to reduced oxygen permeability in the coated samples, likely lowering enzyme activity [46]. The results revealed that adding DEO to the BM-Ge coating significantly ($p<0.05$) slowed the rate of TPC degradation during cold storage. DEO's phenolic content inherently boosts the TPC of the product. The decline in TPC may result from the activities of polyphenol oxidase and phenylalanine ammonia lyase. DEO's aromatic ring potentially interacts with the active sites of these enzymes, inhibiting their role in oxidizing phenolic compounds [42]. Adding Zno-np helps slow down the rate of TPC reduction in cherries during storage. The combined application of DEO and Zno-np synergistically mitigates the degradation of phenolic compounds, reducing their breakdown rate.

3.2.5. Antioxidant capacity

Sweet cherries are rich in various phenolic substances and possess a high concentration of anthocyanins, enhancing their antioxidant capacity [51]. This antioxidant potential is likely due to synergistic effects among different phytochemicals [37]. During cold storage, antioxidant activity significantly ($p<0.05$) diminished across all treatments, although coating treatments helped slow this decline (Fig. 7). Key enzymatic antioxidants include superoxide dismutases, ascorbate peroxidases, and catalases, which are crucial in combating reactive oxygen species. The coating acts as a barrier against excessive oxygen transfer and reactive oxygen species production on the cherry surface. Certain mechanisms are instrumental in safeguarding cells from damage induced by free radicals [54]. Adding DEO and Zno-np to the BM-Ge edible coating significantly ($p<0.05$) increased the antioxidant activity in coated cherries, attributable to the suppressive impact of DEO and Zno-np on DPPH radicals during storage. The study findings confirm that both DEO-incorporated and Zno-np-incorporated BM-Ge coatings effectively preserve the antioxidant activity of cherries throughout storage.

Table 4
Total anthocyanin content (TAC) and Total phenolic content (TPC) changes of sweet cherry during cold storage. Numbers with similar lowercase letters in each storage time do not differ significantly ($p>0.05$). Numbers followed by different uppercase letters are statistically different ($p>0.05$).

	0	4	7	11	18	25
Total anthocyanin content (TAC)						
Ctrl	95.70 ± 1.02^{Aa}	87.30 ± 1.13^{Bb}	80.11 ± 0.95^{Cd}	67.21 ± 0.89^{Dd}	59.43 ± 1.15^{Ec}	44.90 ± 0.99^{Eg}
EO 0%-Zno 0 %	87.30 ± 1.10^{Aa}	93.78 ± 0.98^{Ba}	88.56 ± 1.18^{Cc}	79.93 ± 0.97^{Dc}	74.45 ± 1.04^{Dd}	60.87 ± 1.08^{Ef}
EO 1%-Zno 0 %	95.73 ± 0.94^{Aa}	94.03 ± 1.11^{Aa}	90.23 ± 0.97^{Bb}	81.87 ± 1.13^{Cc}	76.28 ± 1.12^{Dd}	63.89 ± 0.87^{Ee}
EO 2%-Zno 0 %	96.31 ± 0.93^{Aa}	95.11 ± 0.87^{Aa}	92.54 ± 1.19^{Ba}	84.73 ± 0.96^{Cb}	80.11 ± 1.19^{Cc}	71.07 ± 0.95^{Dd}
EO 0%-Zno 0.5 %	95.80 ± 1.23^{Aa}	94.65 ± 0.95^{ABa}	93.11 ± 1.09^{Ba}	86.43 ± 1.11^{Cb}	84.78 ± 1.02^{Db}	75.49 ± 1.02^{Dc}
EO 1%-Zno 0.5 %	96.20 ± 1.02^{Aa}	94.89 ± 0.86^{ABa}	93.74 ± 1.13^{Ba}	88.94 ± 0.93^{Ca}	86.32 ± 1.19^{Dab}	78.13 ± 1.11^{Db}
EO 2%-Zno 0.5 %	96.03 ± 1.28^{Aa}	95.40 ± 1.02^{Aa}	94.21 ± 0.97^{Aa}	89.92 ± 1.09^{Ba}	86.93 ± 1.16^{Ca}	82.01 ± 1.16^{Ea}
Total phenolic content (TPC)						
Ctrl	19.43 ± 0.55^{Aa}	17.65 ± 0.49^{Bb}	15.46 ± 0.52^{Cc}	13.98 ± 0.48^{Dd}	11.43 ± 0.54^{Ec}	10.32 ± 0.42^{Ed}
EO 0%-Zno 0 %	19.52 ± 0.53^{Aa}	17.77 ± 0.57^{Bb}	16.23 ± 0.47^{Cc}	14.78 ± 0.56^{Dcd}	13.23 ± 0.59^{Eb}	11.67 ± 0.54^{Ec}
EO 1%-Zno 0 %	19.37 ± 0.52^{Aa}	17.98 ± 0.62^{Bb}	17.05 ± 0.59^{Bc}	15.67 ± 0.59^{Cc}	13.54 ± 0.42^{Db}	12.05 ± 0.52^{Ec}
EO 2%-Zno 0 %	20.31 ± 0.60^{Aa}	19.67 ± 0.45^{Aa}	18.40 ± 0.54^{Bb}	17.14 ± 0.53^{Cb}	15.73 ± 0.60^{Da}	14.04 ± 0.44^{Eb}
EO 0%-Zno 0.5 %	20.17 ± 0.52^{Aa}	19.24 ± 0.54^{ABa}	18.67 ± 0.49^{Bab}	17.66 ± 0.41^{Cab}	15.68 ± 0.56^{Da}	14.98 ± 0.49^{Dab}
EO 1%-Zno 0.5 %	20.06 ± 0.53^{Aa}	19.98 ± 0.40^{Aa}	19.04 ± 0.52^{Aab}	17.84 ± 0.49^{Bab}	16.45 ± 0.44^{Ca}	15.21 ± 0.58^{Da}
EO 2%-Zno 0.5 %	20.28 ± 0.41^{Aa}	20.11 ± 0.52^{Aa}	19.67 ± 0.59^{Aa}	18.23 ± 0.47^{Ba}	16.43 ± 0.53^{BCa}	15.56 ± 0.55^{Ca}

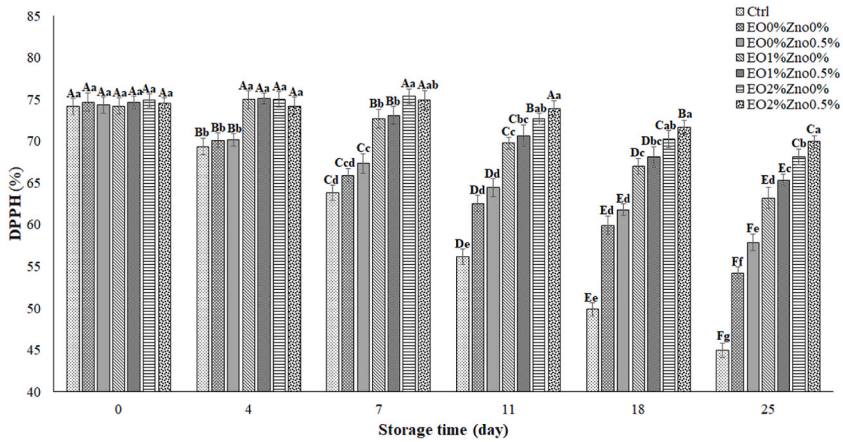

Fig. 7. DPPH (%) changes of sweet cherry during cold storage. Numbers with similar lowercase letters in each storage time do not differ significantly (p>0.05). Numbers followed by different uppercase letters are statistically different (p>0.05).

3.3. Visual properties

Cherry skin color serves as a quality and ripeness indicator for this fruit [37]. Throughout storage, skin color in all treatments darkened, with significant reductions in L^*, Chroma, and hue angle values ($p<0.05$). These changes in hue angle and Chroma reflect the progression of fruit ripening [44,51]. Sweet cherries contain different types of phenolic substances and a high concentration of anthocyanins. Phenolic and anthocyanin compounds decrease with the onset of fruit aging due to the breakdown of cell structures [38]. Coating cherry fruit with BM-Ge coating reduced the rate of color changes (Fig. 8). Edible coatings were able to reduce the rate of TPC changes and maintain higher antioxidant activity during cherry storage. Edible coatings reduce the amount of oxygen used for fruit metabolic activities, thereby inhibiting respiration and the activity of polyphenol oxidase and peroxidase and reducing the activity of phenylalanine ammonia lyase and flavanone synthase [38]. Similar results of the coating effect on color changes have been reported by other researchers [37,38,44,50,51]. The addition of DEO and Zno-np significantly ($p<0.05$) decreased the rate of changes in the color indicators. Moreover, the simultaneous combination of DEO and Zno-np with a synergistic effect reduced the rate of changes in these color indicators in cherries during storage. DEO and Zno-np decrease membrane oxygen permeability as well as enzyme activity, which decreases the degradation rate of phenolic and anthocyanin compounds. The higher values of hue angle and Chroma in the coated fruits compared to the uncoated fruits can be related to less water loss during storage [51]. At the end of the storage period in all the

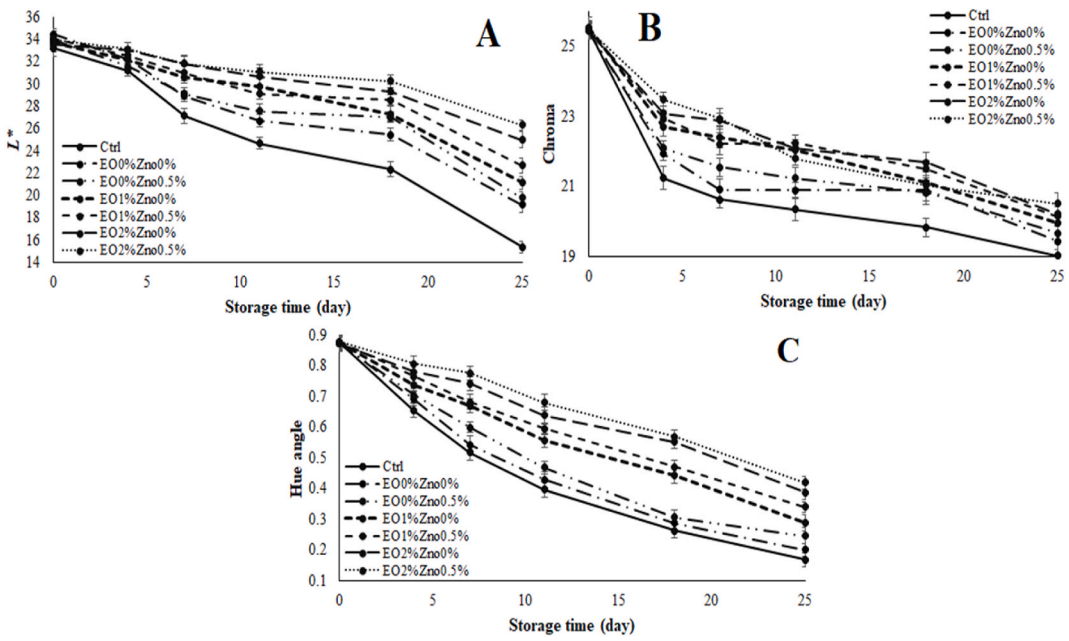

Fig. 8. (A) L^*, (B) Chroma, and (C) Hue angle changes of sweet cherry during cold storage.

treatments, the lowest values of L^*, Chroma, and hue angle were observed in the BM-Ge coating containing 2 % DEO and 0.5 % Zno.

The results indicated that the maximum relative prediction error in volume estimation with the help of image processing was 5.43 %. According to the results of the estimation of volume changes, the volume changes in the sweet cherries in all the treatments significantly increased ($p<0.05$) during the cold storage period (Fig. 9). WL plays the main role in the volume change of the sweet cherries during the storage period, resulting in the shrinkage of the stored cherries. Coating significantly ($p<0.05$) reduced volume changes during the storage. The use of coating can reduce the amount of WL and thus the volume changes. As the amounts of DEO and Zno-np increased, the volume changes significantly decreased ($p<0.05$). The increased amount of DEO due to its hydrophobic property increases the water vapor barrier property and improves the coating's physical properties. The antioxidant effects of DEO, along with improving physical, and barrier properties, reduce physical, chemical, and metabolic changes (respiration), and thus the moisture loss [37,38,44,50,51].

3.4. Quality and decay properties

The decay rate is closely related to the respiration rate of the fruit. Cherry has a high respiration rate and is susceptible to various types of fungal decay [38]. Table 5 shows that the decay rate significantly increased ($p<0.05$) for all the treatments during the storage. Results also indicated that the decay ratio of the Ctrl treatment was significantly ($p<0.05$) higher than that of the other treatments. The respiration rate of the coating treatments is lower than that of the Ctrl treatment due to the water vapor barrier property of the BM-Ge coating. The coating also limits the entry of oxygen to the fruit and inhibits its respiration rate, ultimately delaying the fruit's decay. The addition of DEO to the coating resulted in lower levels of fruit rot, especially at higher concentrations of DEO. DEO develops a waterproof layer on the outermost surface of the cherry, which prevents the adhesion, invasion, germination, and reproduction of pathogenic fungi and bacteria. The Zno-np-contained BM-Ge coating also delayed the decay rate of the cherry. The rot rate of the Zno-np-coated groups was significantly ($p<0.05$) lower compared to the other treatments, which may be related to the antimicrobial properties of Zno-np. Zno-np prevents decay and makes the cell wall-less exposed to degrading enzymes produced by pathogens, thereby improving cell stability. Green and juicy stems indicate the sweet cherries' freshness. The browning and wrinkling of the stem is caused by its drying. Transpiration through stems in an unsaturated atmosphere is one of the causes of drying [37]. The pores on the fruit epidermis are the main channel of its transpiration, and its condition and quantity are closely related to the moisture loss of the fruit after harvesting. Various studies have shown that the stomatal density on the surface of the cherry stem is 40 times higher than on the surface of the fruit, and the permeability of the surface of the stem is higher than that of the surface of the fruit. The surface coating of the stem is the main limiter of its moisture loss rate during storage [37].

The stem browning in all the coating treatments was significantly ($p<0.05$) lower than in the Ctrl treatment (Fig. 10). The browning of the tissue of fruits and vegetables during the post-harvest storage is due to the formation of quinones from phenolic substances under the effect of polyphenol oxidase. The coatings have good oxygen barrier properties and limit the entry of oxygen into the stem, leading to the decreased activity of polyphenol oxidase and suppressing stem browning [37].

The addition of DEO and Zno-np also significantly ($p<0.05$) reduces the stem browning rate, which is probably due to the limitation of polyphenol oxidase activity by DEO and Zno-np. PMC significantly decreased ($p<0.05$) during cold storage time in all the treatments, and the use of the BM-Ge coatings containing DEO and Zno-np significantly ($p<0.05$) decreased the rate of moisture loss (Fig. 10). The coating creates a moisture barrier, and on the other hand, the addition of DEO to the coating improves its moisture barrier properties due to its oily nature. Although the addition of Zno-np caused a significant decrease ($p < 0.05$) in the rate of moisture loss, no significant difference was observed in the decrease of PMC rate in the presence of DEO ($p > 0.05$). Although PCC significantly decreased ($p<0.05$) in all the treatments during cold storage time.

Results also indicated that the coating significantly ($p<0.05$) decreased the rate of PCC changes (Fig. 11). Moreover, the addition of Zno-np to the coating did not have a significant effect on PCC ($p > 0.05$); however, the addition of DEO to the coating had a significant effect ($p > 0.05$). These changes may be related to the decomposition of chlorophyll and the oxygen barrier properties of the BM-Ge coating. Coating delayed the degradation rate of PCC.

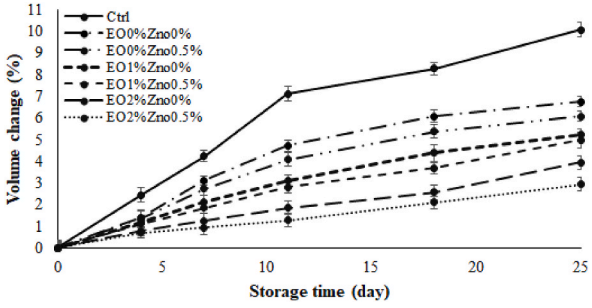

Fig. 9. Volume changes of sweet cherry during cold storage.

Table 5
Decay ratio (%) and stem browning index (PBI, %) changes of sweet cherry during cold storage. Numbers with similar lowercase letters in each storage time do not differ significantly (p>0.05). Numbers followed by different uppercase letters are statistically different (p>0.05).

	0	4	7	11	18	25
Decay ratio (%)						
Ctrl	0 ± 0^{Aa}	0 ± 0^{Aa}	1.97 ± 0.54^{Bb}	8.94 ± 0.46^{Cc}	25.48 ± 1.22^{Df}	57.93 ± 1.65^{Eg}
EO 0%-Zno 0 %	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	1.21 ± 0.32^{Bb}	5.68 ± 0.93^{Ce}	16.43 ± 1.06^{Df}
EO 1%-Zno 0 %	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	4.48 ± 1.03^{Bd}	13.98 ± 0.97^{Ce}
EO 2%-Zno 0 %	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	2.65 ± 0.76^{Bc}	10.11 ± 0.82^{Cd}
EO 0%-Zno 0.5 %	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	1.65 ± 0.45^{Bb}	8.98 ± 0.54^{Cc}
EO 1%-Zno 0.5 %	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	6.32 ± 0.89^{Bb}
EO 2%-Zno 0.5 %	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	3.21 ± 0.67^{Aa}
stem browning index (PBI, %)						
Ctrl	0 ± 0^{Aa}	8.11 ± 1.78^{Bc}	18.98 ± 2.11^{Cf}	37.21 ± 2.34^{Dd}	50.16 ± 0.54^{Ef}	68.51 ± 2.03^{Ff}
EO 0%-Zno 0 %	0 ± 0^{Aa}	3.54 ± 1.35^{Bb}	9.57 ± 1.83^{Ce}	24.31 ± 1.76^{Dc}	34.11 ± 2.05^{Ee}	47.65 ± 1.99^{Fe}
EO 1%-Zno 0 %	0 ± 0^{Aa}	2.87 ± 1.21^{Bb}	8.24 ± 2.21^{Cde}	22.45 ± 2.18^{Dc}	29.78 ± 2.21^{Ee}	38.67 ± 2.35^{Fd}
EO 2%-Zno 0 %	0 ± 0^{Aa}	1.11 ± 0.87^{Bb}	5.21 ± 1.74^{Ccd}	15.34 ± 2.16^{Db}	25.45 ± 1.98^{Ed}	32.11 ± 2.11^{Fc}
EO 0%-Zno 0.5 %	0 ± 0^{Aa}	0 ± 0^{Aa}	4.78 ± 1.65^{Bbc}	13.56 ± 1.98^{Cb}	20.15 ± 2.16^{Dc}	29.43 ± 2.32^{Ebc}
EO 1%-Zno 0.5 %	0 ± 0^{Aa}	0 ± 0^{Aa}	2.11 ± 1.29^{Bb}	5.89 ± 2.07^{Ca}	13.23 ± 1.89^{Db}	24.31 ± 2.07^{Ea}
EO 2%-Zno 0.5 %	0 ± 0^{Aa}	0 ± 0^{Aa}	0 ± 0^{Aa}	3.11 ± 1.79^{Ba}	7.26 ± 2.32^{Ca}	20.12 ± 2.18^{Da}

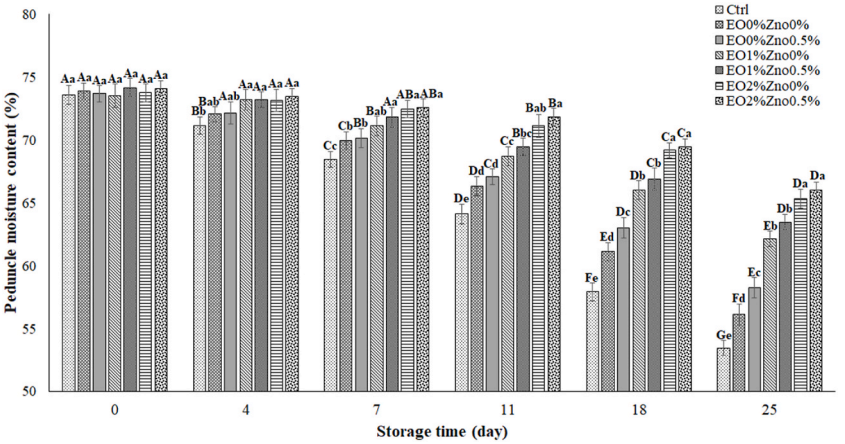

Fig. 10. Peduncle moisture content (PMC, %) of sweet cherry during cold storage. Numbers with similar lowercase letters in each storage time do not differ significantly (p>0.05). Numbers followed by different uppercase letters are statistically different (p>0.05).

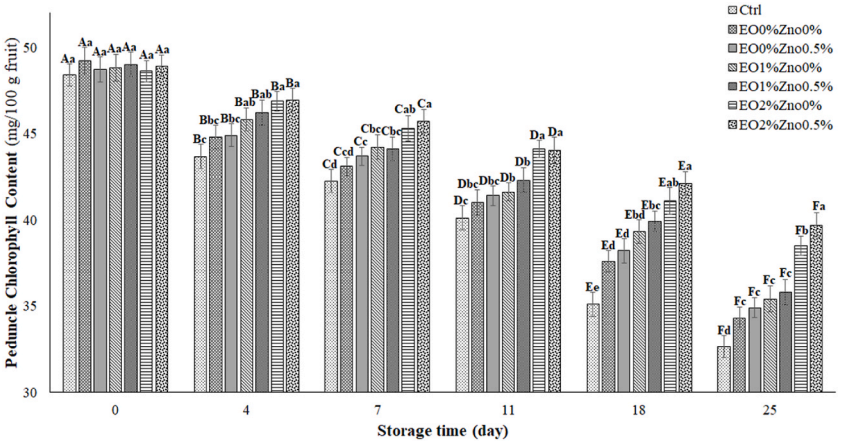

Fig. 11. Stem chlorophyll content (PCC, %) of sweet cherry during cold storage. Numbers with similar lowercase letters in each storage time do not differ significantly (p>0.05). Numbers followed by different uppercase letters are statistically different (p>0.05).

3.5. Correlation

The results of the present study showed that there is a high correlation between the changes in the cherry fruit color and ripening. There is a significant negative correlation ($p<0.01$) between WL and firmness. Also, there is a significant positive correlation ($p<0.05$) between WL with color intensity (Chroma), hue angle, and TS indicators, which is due to the strong relationship between color changes and physical and chemical activities in fruits and vegetables. The results indicated that there is a highly significant positive correlation ($p<0.01$) between firmness and TS. Also, there is a significant negative correlation ($p<0.05$) between the WL and TA of cherry. There is also a highly significant positive correlation ($p<0.01$) between hue angle and Chroma. Examining pH shows that the pH values are significantly correlated ($p<0.01$) with TA and ascorbic acid. Moreover, there is a significant positive correlation ($p<0.05$) between the pH values and TPC, TAC, and antioxidant activity, which, along with the significant correlation ($p<0.05$) of TA with the other chemical variable, indicates the coordinated changes in the chemical properties of cherries in all the treatments during cold storage. As can be seen in Table 6, the other chemical properties, except TS, have a strong correlation with each other.

4. Conclusion

The results of the present study indicated that BM-Ge coating can delay the moisture migration from sweet cherries to the environment, which subsequently decreases WL, volume changes, and firmness of the fruit during the cold storage period. Moreover, the addition of DEO and Zno-np significantly ($p < 0.05$) limited WL and firmness. The decreased TA and the increased TS in the Ctrl treatment compared to the coating treatments indicated that the coating has delayed respiration by providing a semipermeable cortical layer. The ascorbic acid content, color indices, TPC, and TAC decreased in all the treatments during the cold storage period, and the coating delayed the rate of changes significantly ($p<0.05$), which could be attributed to the low oxygen permeability of the coating and the decreased respiration rate leading to the decreased activity of enzymes. DEO contains phenolic compounds that alone increase TPC. According to the results, the coating treatment, especially in the presence of DEO and Zno-np, can result in a decrease in the percentage of cherry rot and PBI during the cold storage period. The respiration rate of the coating treatments is lower than that of the Ctrl treatment due to the barrier property of the coating, which inhibited the activity of polyphenol oxidase by limiting the entry of oxygen and reducing the respiration rate. Also, the EO 2%-Zno 0.5 % treatment had the most significant effect in preventing the process of quality reduction changes.

CRediT authorship contribution statement

Yashar Shahedi: Writing – original draft, Resources, Methodology, Investigation. **Mohsen Zandi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mandana Bimakr:** Writing – review & editing, Supervision, Investigation.

Ethics approval and consent to participate

Not applicable.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Code availability

Not applicable.

Funding

Not applicable.

Table 6
Correlation matrix for physical, chemical, and visual properties of sweet cherry during storage.

	WL	F	L^*	h^*	C^*	pH	**TA**	TS	AA	TAC	TPC	DPPH
WL	1											
F	−0.978**	1										
L^*	0.119^{ns}	0.104^{ns}	1									
h^*	0.412*	-0.162^{ns}	-0.261^{ns}	1								
C^*	0.305*	0.239^{ns}	-0.198^{ns}	0.898**	1							
pH	0.251^{ns}	-0.196^{ns}	0.173^{ns}	0.153^{ns}	0.232^{ns}	1						
TA	-0.139^{ns}	−0.403*	0.194^{ns}	0.101^{ns}	0.176^{ns}	−0.965**	1					
TS	0.671*	0.765**	-0.103^{ns}	0.223^{ns}	-0.165^{ns}	0.931**	0.165^{ns}	1				
AA	-0.198^{ns}	0.163^{ns}	0.165^{ns}	0.219^{ns}	0.102^{ns}	0.902**	0.866**	0.176^{ns}	1			
TAC	0.221^{ns}	-0.157^{ns}	0.231^{ns}	0.144^{ns}	0.263^{ns}	0.452*	−0.339*	0.231^{ns}	−0.703**	1		
TPC	-0.263^{ns}	0.199^{ns}	-0.201^{ns}	0.137^{ns}	-0.183^{ns}	0.398*	0.578*	0.158^{ns}	0.749**	−0.967**	1	
DPPH	-0.154^{ns}	0.231^{ns}	0.132^{ns}	0.129^{ns}	-0.224^{ns}	0.408*	0.654*	-0.254^{ns}	0.568**	−0.783**	0.893**	1

Value with one asterisk (*) indicates significant differences ($p < 0.05$), value with two asterisks (**) indicates significant differences ($p < 0.01$), and value with ns indicates no statistically significant difference).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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