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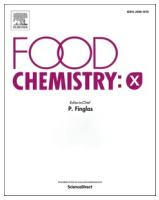

Effect of EVA film and chitosan coating on quality and physicochemical characteristics of mango fruit during postharvest storage

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ABSTRACT

Mango (*Mangifera indica L.*) is a major tropical fruit, but a short postharvest life hampers marketing. The objective of this work is to assess the influence of a novel nanocomposite poly (ethylene-*co*-vinyl acetate) (EVA) film and Chitosan (CTS) affect on mango postharvest quality while stored at 20 °C. The results showed that the film coating treatment reduced the decay rate and weight loss of mangoes, maintaining good postharvest quality of mango fruit. The film coating treatment increased the antioxidant capacity of mangoes by inhibiting PPO activity and increasing the activity of antioxidant enzymes. ACS, ACO, and ethylene release were all suppressed, as well as the expression of the ethylene receptors genes *ETR1*, *ETR2*, and *ERS2*, thus delaying mango aging. After harvest, the EVA treatment was superior to the CTS treatment in mango preservation.

1. Introduction

Mango (*Mangifera indica L.*) is a well-known tropical fruit with excellent nutritional content and flavor that is releshed consumers (Yu et al., 2021). However, mango is susceptible to various diseases during post-harvest treatment, transportation, and storage, resulting in a decline in mango quality, a shortened shelf life, and a large post-harvest loss of mango fruit (Ntsoane et al., 2019). Although there has been a lot of research on mango post-harvest preservation technology, such as controlled atmosphere storage (CA) (Niranjana et al., 2009), modified atmosphere packaging (MAP) (Ramayya et al., 2012), ultraviolet irradiation (UV) (Ruan et al., 2015), and ethylene treatment (Hu et al., 2019), the concept of environmentally friendly edible coatings has increasingly become a hot spot in the world of fruit and vegetable postharvest preservation technology.

Chitosan (CTS) is a straight-chain polymeric poly-saccharide generated by the deacetylation of chitin that has been used in post-harvest storage. Studies have shown that CTS can act as a physical barrier on the surface of fruits and vegetables, which has a certain effect on reducing the decay rate and extending the shelf life of fruits and vegetables (Shah & Hashmi, 2020). The use of chitosan coatings can reduce weight loss by up to 65 %, effectively extending the storage life of mango fruit and maintaining fruit quality during storage (Parvin et al., 2023). Coating treatment maintained the 2,2-Diphenyl-1-picrylhydrazyl (DPPH) scavenging capacity and ascorbic acid content of mango during storage at 25 °C (Jongsri et al., 2016). In addition, chitosan treatment can also enhances the phenolic, flavonoid, and antioxidant activities of mango fruits (Kumar et al., 2021), which improves the quality of mango fruits in postharvest storage.

A novel nanocomposite poly (ethylene-*co*-vinyl acetate) (EVA) film with high permeability and regulated medication release capabilities has been demonstrated to be useful in grape quality preservation (Xiao et al., 2020). It has been studied that low-density polyethylene is blended with EVA and then mixed with different kinds of essential oils to prepare food packaging modification films, which have certain antibacterial properties (Wattananawinrat et al., 2014). Studies have also shown that the membranes prepared by chitosan and EVA have excellent properties such as high form variables, high air permeability, self-repairability, water resistance, and antibacterial properties (Sessini et al., 2019).

'Tainong No.1' mangoes are metabolically vigorous after harvesting, easily ripening, turning soft, and have a short commercial cycle. Chitosan is known to have film-forming properties and antimicrobial functionality for successful use as a food packaging material, whereas

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low permeability, low tensile strength, and lack of antimicrobial activity limit the application of EVA as an active coating in fruits. (Xiao et al., 2020). Therefore, the inherent properties of polymer films, such as flexibility, antifungal ability, and high permeability, will become the target to meet the respiration metabolism of fruits. In this context, we propose to prepare composite films combining CTS and EVA to develop composite films with good mechanical properties, permeability, and antimicrobial ability, taking into account the advantages of both, is expected to obtain composite materials with excellent overall performance, which is of great practical significance to improve the quality and safety of mango fruits, reducing their decay rate, delaying ripening softening, maintaining freshness, and prolonging the commercial cycle of mangoes. The objective of this study was to investigate the effect of edible coatings of EVA and CTS composites on the storage and preservation of mango at 20 °C, to provide some theoretical basis for post-harvest storage and preservation technology of mango.

2. Materials and methods

2.1. Materials and treatments

The mango used in the test is called 'Tainong No.1′ and it was harvested in the Tianyang District, Baise City, Guangxi Zhuang Autonomous Region, China, mango base. It was picked at seven to eight points of ripeness, had a uniform individual size, had a fruit stalk, and was free of disease and mechanical damage. The mangoes were then transported right away to the lab and pre-cooled for 12 h at 12 to 13 °C. After the pre-cooling was completed, the selected mangoes were rinsed with water 3 times, dried, separated into three groups (each group containing 120 fruits), and subjected to the following treatments: 1 % CTS soaking for 5 min, EVA liquid film soaking for 5 min, with water treatment as the control (CK), the fruit was dried and stored in 20 °C and 80 % humidity. Physiological parameters were measured every 4 d for a total of 24 d. Each treatment took 20 fruits for the determination of decay rate and weight loss rate with 3 replicates. Samples of 5 fruits were taken at a time to determine other physiological indicators, and each index was repeated 3 times.

The chitosan (deacetylation degree ≥ 900) reagent was purchased from Solarbio Biotechnology Co., Ltd. The viscosity of EVA-707 emulsion is 2000–3000 cps, provided by Qisheng Chemical Reagent Co., Ltd. The following kits and manufacturers were used in this test: glutathione reductase (GR), ascorbate peroxidase (APX), peroxidase (POD), superoxide dismutase (SOD), and catalase (CAT) activities were measured using a microassay kit (Beijing Solarbio Technology Co., Ltd). Polyphenol oxidase (PPO) activity kit, ACC oxidase (ACO), and ACC synthase (ACS) ELISA kits (Shanghai Bioengineering Co., Ltd.) were used for the determination of PPO, ACO and ACS activities.

2.2. Preparation of EVA and CTS reagents

Preparation of EVA: First of all, the β-cyclodextrin (β-CD) modified polyethyleneimine (PEI) (β-CD-PEI) was synthesized to obtain an aldehyde-based polyethylene and vinyl alcohol copolymer, and then the Adamantane-modified chitosan (AD-chitosan) was synthesized. CTS was dissolved in 50 mL acetic acid (1 %, v/v), then poured into 50 mL EVA emulsion, and Tween-80 emulsifier was added, followed by magnetic stirring for 30 min. The mixture was then poured onto a flat glass plate air-dried at room temperature, and dried at 45 °C for 48 h. EVA liquid film was provided by Xiao Naiyu's group, School of Light Industry and Food, Zhongkai College of Agricultural Engineering following synthesis method of Xiao et al., 2020 (Xiao et al., 2020). Preparation of 1 % CTS: Chitosan was dissolved in 2 % acetic acid solution. Specifically, 1 g of chitosan was added to a small amount of 2 % acetic acid solution and dissolved. Then the acetic acid solution was further diluted to a total volume of 100 mL. Tween-80 emulsifier was added, homogenized, degassed, poured onto a glass plate, air-dried at room temperature, and dried at 45 °C for 48 h.

2.3. Determination of decay rate, weight loss, hardness, TSS content, TA content, SSC content

The decay rate was assessed concerning the following method (Zheng et al., 2007), which classified the fruit into five classes according to the size of the surface spots and the degree of decay, as shown in Table 1. The decay rate was calculated as follows: Decay rate (%) = (∑number of levels × number of fruit at that level) / (highest level × total number of fruit) × 100 %.

The weight loss rate was determined by weighing the quality before storage and the mass on the day of storage, averaging each treatment 3 times and calculated according to the following formula: Weight loss (%) = $(m_0 - m_i)/m_0 \times 100$ %, m_0 indicates the quantity of the fruit before storage; m_i indicates the quantity of the fruit on the day i of storage. Hardness was determined using a hand-held hardness tester FHT-15 (Guangzhou Lantai Instrument Technology Co.) at 3 points near the equator on both sides of the fruit, each treatment was repeated 3 times to take the average. The results of firmness were reported by Newton (N). Total soluble solids (TSS) content was determined with a Digital Handheld Brix Meter ATAGO PAL-1(ATAGO Co., Ltd, Japan). The mango was cut open and the TSS value of the mango juice liquid was determined using a sugar meter, the results were expressed in %, 3 fruits were determined at a time, and each fruit was repeated 3 times. Titratable acid (TA) content was determined by reference to the following method (Cao et al., 2007), which was performed by acid-base titration, and the results were expressed as % malic acid. Soluble sugar (SSC) content was determined by reference to the following method (Cao et al., 2007). The determination of SSC was performed by the anthrone reagent method, and the results were expressed in %.

2.4. Determination of peel color, chlorophyll content, carotenoid content, anthocyanin content, flavonoids content, and total phenol content

Chromatic aberration L*, a*, b* was determined by washing the fruit and drying it, and three points near the equator on both sides of the fruit were determined by CR-10 chromatic aberration (Konica minolta optics, Japan), and each fruit obtained 6 sets of chromatic aberration. The chromatic aberration was calculated as follows: $\Delta E = [(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2}$. The determination of chlorophyll and carotenoid content was carried out as follows (Tang et al., 2004), and averaged each repeat three times. The results were expressed in mg/g. The determination of anthocyanins, flavonoids, and total phenol was carried out concerning the following methods (Cao et al., 2007). The absorbance values at 280 nm and 325 nm were determined for total phenols and flavonoids, respectively, and the anthocyanin contents were determined by the difference between the absorbance values at 530 nm and 600 nm. Results were expressed in milligrams of each substance per gram of fruit (mg/g).

2.5. Determination of MDA content, relative conductivity, GSH content, GSSG content, GR activity, APX activity

For malondialdehyde (MDA) content referred to the following methods (Cao et al., 2007). The MDA content was calculated as follows:

Table 1
Classification standard of fruit decay rate of mango.

Degree of decay	Evaluation criteria
1	Fruit surface free of disease spots
2	Small spots on the surface of the fruit
3	Surface decay of fruit ≤ 20 %
4	Fruit surface decay of 20 % to 50 % of the area
5	Surface decay of fruit ≥ 50 %

MDA content (μmol/g mF) = (C × V)/W × Vs × 1000.C indicates the concentration of MDA in the reaction mixture (μmol/L); V indicates the total volume of the extract (mL). Vs indicates the volume of sample extract taken for the determination (mL). W indicates the weight of the sample (g). Determination of relative conductivity referred to the following methods (Chen et al., 2010). The fresh sample was weighed 0.10 g, placed in a graduated test tube with 10 mL of deionized water, covered with a glass stopper, and soaked for 6.5 h at room temperature, and the conductivity of the extract was measured by a conductivity meter (R1). The extracts were then heated in a boiling water bath for 30 min, cooled to room temperature, shaken well and the conductivity (R2) of the extracts was measured again, and the average value was obtained by repeating 3 times. The relative conductivity was calculated as follows: Relative conductivity (%) = R1/R2 × 100 %.

Glutathione (GSH) and oxidized glutathione (GSSG) were determined by reference to the following methods (Cao et al., 2007). 5.0 g of fresh sample were weighed, added 5 mL of pre-cooled 50 g/L trichloroacetic acid solution at 4 °C, centrifuged at 9,500 g at 4 °C for 20 min and collected the supernatant. The determination of reduced glutathione and oxidized glutathione GSH and GSSG according to (Brehe & Burch, 1976). GR activity was assayed at 340 nm, and 1 μmol NADPH oxidation was catalyzed as one unit of enzyme activity per minute per gram of sample at 37 °C, pH 8.0. APX activity was measured at 290 nm, and 1 μmol AsA oxidized per gram of sample per minute was considered as 1 enzyme activity unit.

2.6. Determination of PPO activity, POD activity, SOD activity, CAT activity

A change of 0.01 in absorbance at 410 nm per minute per g of tissue per mL of reaction system was defined as one unit of PPO enzyme activity. POD unit is defined as one unit of enzyme activity per g of tissue per mL of reaction system per minute of 0.01 change in wavelength at 470 nm. SOD activity was measured at 560 nm. CAT units were defined as one unit of enzyme activity per g of tissue catalyzing 1 μmol of H_2O_2 degradation per minute.The results were expressed in $U \cdot g^{-1}$.

2.7. Determination of ethylene release, ACO activity, ACS activity, ETR1, ETR2, and ERS2 relative expression

Ethylene release was determined by selecting 3 fruits from each treatment (which were labelled and used for subsequent sampling fixation), approximately 0.4 kg, and placing each fruit in a 63 L sealed container for 1 h at room temperature, then collecting six separate tubes of gas using a 1 mL syringe. The collected gas samples were determined using an Agilent gas chromatograph. The column used was a PorapakQ (2 m × 3 mm (0 d)) stainless steel packed column with an oven temperature of 80 °C, an injector temperature of 180 °C, a detector temperature of 180 °C, a carrier gas N flow rate of 50 mL/min, a gas H flow rate of 50 m/min and an airflow rate of 136 mL/min. The determination of ACO and ACS activity was conducted using ACC oxidase (ACO) and ACC synthase (ACS) ELISA kits. The results were expressed in U/L.

Primer design was carried out with reference to the following methods (Li et al., 2018). The primer sequences used are shown in Table 2. Guotuo Biotechnology Co., Ltd. carried out the machine measurement.

Table 2
Primer sequence and Purpose.

Primer name	Primer sequence
Actin-q F	CTGGATTCTGGTGATGGTGTATCTC
Actin-q R	CCGTTCAGCAGTGGTGGTGA
ETR1-F	ACGCATGAGATCAGAAGCACTT
ETR1-R	CGGCATCCATAAGGCACACT
ETR2-F	GTTCTTGGAGCATTGAGAGCAT
ETR2-R	GCCATAGGTCCAGCCATTCA
ERS2-F	CGCCAGATTCACCAACATACTC
ERS2-R	ATTCAGGTCGCCAGTCTCTTG

2.8. Statistical analysis

The experimental data were statistically processed using SPSS 22.0 software, with Duncan's Multiple Range test (DMR) for significance analysis of differences between treatments. Results were graphically depicted using Pearson's analysis and Origin 2022b software.

3. Results

3.1. Effects on the flavor quality of mango

'Tainong No.1′ mangoes' decay rate increased steadily as storage duration grew (Fig. 1A). Indicating that the post-harvest EVA and CTS treatments could prevent the increase of mango decay rate and maintain the appearance quality of 'Tainong No.1′mangoes, the mango decay rates of the EVA and CTS treatments were lower than CK ($p < 0.05$). On 4, 8, 20, and 24 d of storage, the decay rate of EVA-treatment samples was 0.60 %, 0.36 %, 0.27 %, and 0.15 % lower than that of CTS-treatment ($p < 0.05$), demonstrating that EVA-treatment inhibits mango rot better than CTS treatment. The weight loss rate of 'Tainong No.1′ mangoes increased steadily as the period of storage increased (Fig. 1B). During storage, the weight loss rate of mangoes treated with EVA and CTS were consistently lower than that of CK mangoes. The results showed that post-harvest EVA and CTS treatments might reduce the weight in 'Tainong No.1′ mangoes while maintaining the intrinsic quality of 'Tainong No.1′. On 8, 12, and 24 d of storage, the weight loss rate of EVA-treatment mangoes was 0.17 %, 0.19 %, and 0.36 % lower than that of CTS-treatment ($p < 0.05$), illustrating that EVA-treatment mangoes were superior to CTS-treatment in terms of minimizing water loss of 'Tainong No.1′ mangoes. As storage time increased in the CK mangoes, the hardness of the 'Tainong No.1′ variety tended to gradually decline (Fig. 1C). On 8, 12, and 20 d of storage, the hardness of the EVA and CTS treatments were greater than that of the CK. According to the information above, CTS and EVA treatments may prevent 'Tainong No.1′ mangoes from losing their hardness. After 20 d of storage, the hardness of the CTS-treatment was 1.7 N higher than that of the EVA-treatment mangoes ($p < 0.05$), showing that the CTS-treatment was more successful in preventing the later-stage fall in hardness of 'Tainong No.1′ mangoes.

The TSS content of 'Tainong No.1′ mangoes in the CK group showed a tendency to initially increase and then gradually decline with the extension of the storage period (Fig. 1D). The CK attained its peak value of 18.6 % at the 16 d mark and then started to gradually decline to 18.0 % at the 24 d mark. TSS content was 4.8 % and 2.0 % lower in EVA-treatment and CTS-treatment than in CK at 13.8 % and 16.6 %, respectively ($p < 0.05$). The TSS content of the EVA-treatment fruit was 2.8 % lower after 16 d of storage than that of the CTS-treatment fruit, demonstrating that EVA-treatment was more successful at preventing the buildup of TSS in 'Tainong No.1′ mangoes. The TA content of CK 'Tainong No.1′ mangoes showed a trend of increasing and then decreasing as the storage time increased (Fig. 1E), peaking at 1.28 % on the 12th day of storage before starting to convert to sugar and subsequently decreasing. The TA content of the EVA-treatment didn't change throughout the first 16 d of storage; it only started to fall after that. The TA content of CTS-treatment didn't change much for the first 12 d of storage and started to drop after 16 d of storage. According to the results mentioned above, mangoes that have been EVA and CTS treatments are more likely to retain their TA content and 'Tainong No. 1′ flavor. From 16 to 24 d of storage, the TA content of the EVA-treatment was 0.36 %, 0.21 %, and 0.26 % greater than that of the CTS-treatment, respectively ($p < 0.05$), confirming that the EVA-treatment was more efficient in postponing the reduction in the TA content of the 'Tainong No.1′ mangoes. In 'Tainong No.1′ mangoes treated with CK, the SSC content

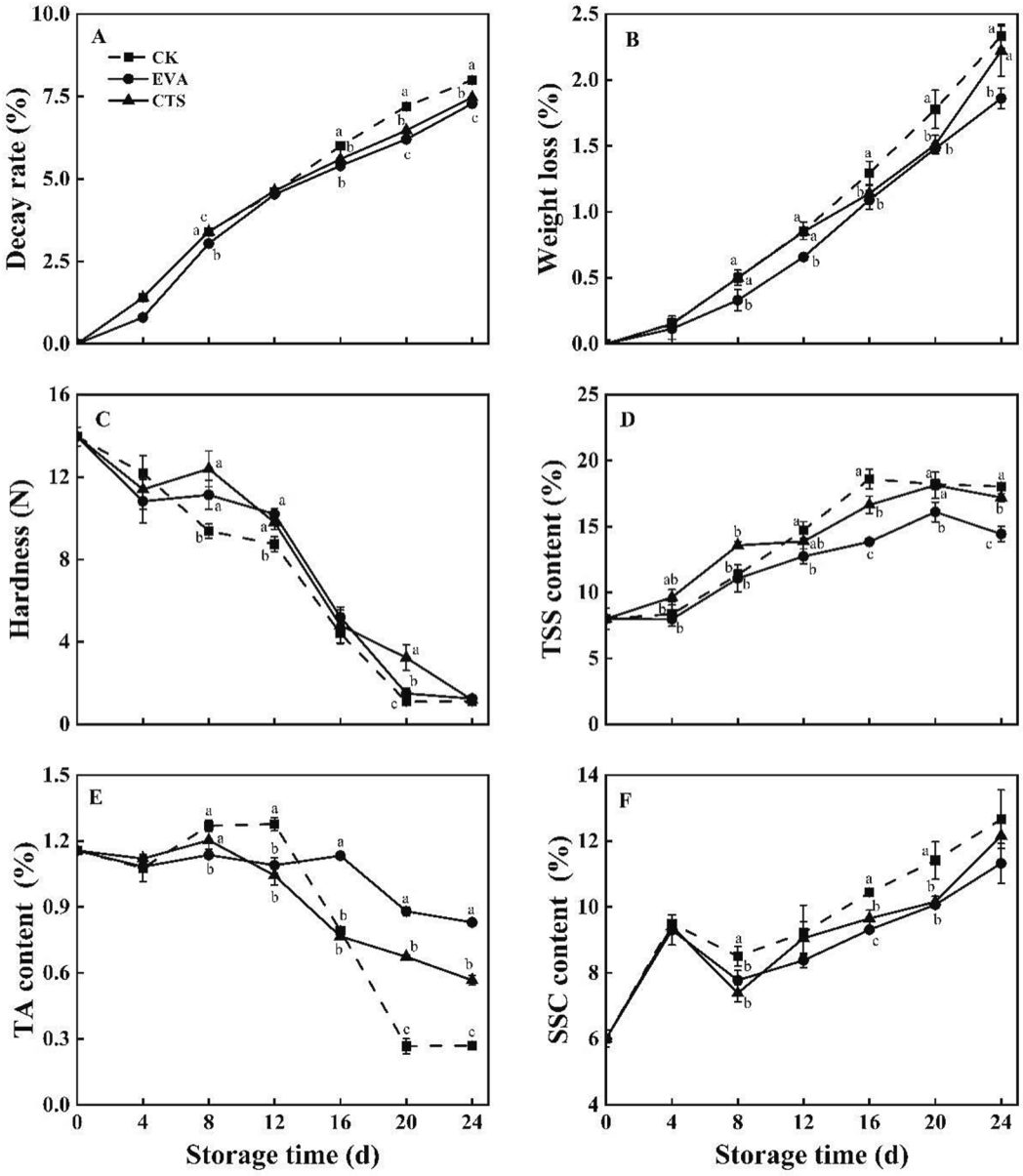

Fig. 1. Effect of post harvest film application treatments on mango decay rate (A), weight loss (B), hardness (C), TSS content (D), TA content (E), SSC content (F). a, b, c indicate significant differences between postharvest coating treatments ($p<0.05$).

grew steadily during the period of storage (Fig. 1F). The content was 12.7 % at the course of 24 d of storage. At 16 to 20 d of storage, the SSC concentration of CTS and EVA treatments were lower than that of CK. The results mentioned previously demonstrated that EVA and CTS treatments might prevent the buildup of SSC content in 'Tainong No.1′ mangoes and postpone the change in flavor. The lack of significance in the SSC content difference between EVA and CTS treatments during storage suggests that both treatments were equally effective at preventing the buildup of SSC content in 'Tainong No.1′ mangoes.

3.2. *Effects on postharvest mango ripeness*

CK 'Tainong No.1′ mango peel ΔE showed a continuous upward trend in storage (Fig. 2A). During storage, the EVA-treatment ΔE changed less than the CK. The ΔE change of CTS-treatment was lower than that of CK from 12 to 24 d of storage. According to the above justification, CTS and EVA treatments can prevent the change in the surface color of mango fruits and keep the 'Tainong No.1′ mango's aesthetic quality. The chlorophyll content of CK 'Tainong No.1′ mangoes showed a slow decline in the storage time (Fig. 2B). From 16 to 24 d of storage, CTS and EVA treatments had higher chlorophyll contents than CK. The evidence presented above suggested that CTS and EVA treatments could postpone the decline in mango chlorophyll content and, as a result, postpone the ripening of 'Tainong No.1′ mangoes. At 16 and 20 d of storage, the CTS-treatment had chlorophyll content that was 0.006 mg/g and 0.005 mg/g lower than those of the EVA-treatment, respectively, indicating that the EVA treatment was more effective in slowing down the decline of chlorophyll. 'Tainong No.1′ mangoes treated with CK had a consistently rising carotenoid concentration (Fig. 2C). At the 16 to 24 d of storage, the carotenoid content of the CK sample was higher than that of the EVA and CTS treatments. The above indicated that CTS and EVA treatments could inhibit the accumulation of carotenoid content in mangoes. The carotenoid content of EVA-treatment was 0.0003 mg/g and 0.004 mg/g lower than that of CTS-treatment on the 20 and 24 d of storage, respectively ($p < 0.05$), confirming that EVA-treatment was more effective in inhibiting the accumulation of carotenoids content in

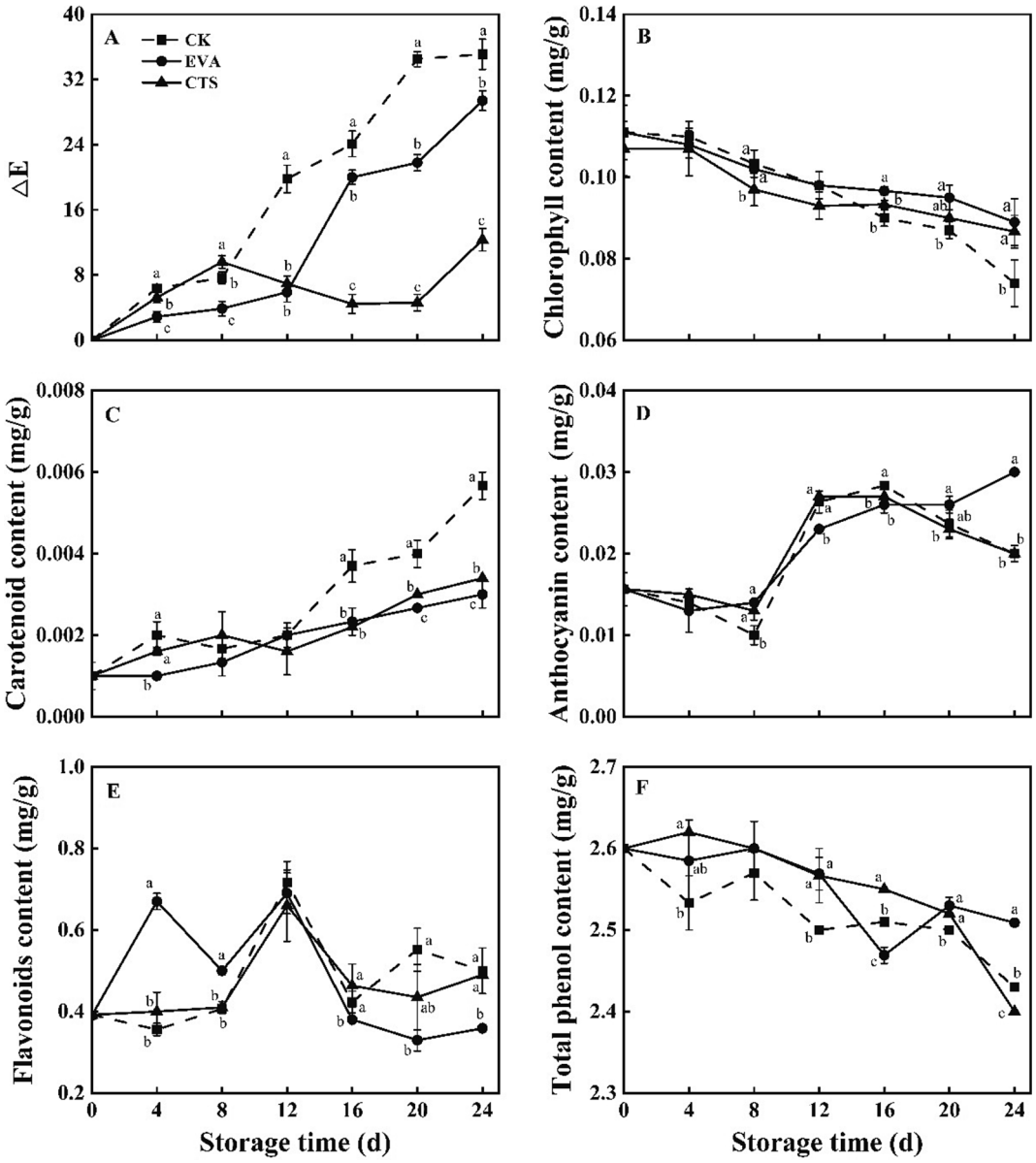

Fig. 2. Effect of postharvest film application treatments on mango ΔE(A), chlorophyll content (B), carotenoid content (C), anthocyanin content (D), flavonoids content (E), total phenol content (F). a, b, c indicate significant differences between postharvest coating treatments (p<0.05).

'Tainong No.1′ mangoes.

As storage time extended, the anthocyanin content of CK 'Tainong No.1′ mangoes exhibited a tendency of increasing and subsequently decreasing (Fig. 2D). The maximum anthocyanin content reached 0.020 mg/g on the 16 d of storage, and the anthocyanin content of EVA-treatment was 0.003 mg/g and 0.002 mg/g lower than that of CK from the 12 to 16 d of storage ($p < 0.05$). During storage, there was no discernible difference in the anthocyanin content of 'Tainong No.1′ mangoes treated with CTS-treatment and CK. This suggests that the CTS-treatment did not have an impact on the anthocyanin content buildup in 'Tainong No.1′ mangoes. As storage duration extended, the flavonoids content of CK 'Tainong No.1′ mangoes tended to increase before gradually declining (Fig. 2E), while that of EVA-treatment mangoes reached the maximum on the 12 d of storage. The flavonoids content of EVA-treatment was 0.31 mg/g and 0.09 mg/g higher than that of CK on the 4 to 8 d of storage ($p < 0.05$), showing that EVA-treatment could induce the increase of flavonoids content. On the 16 to 24 d of storage, the flavonoids content of the EVA-treatment mangoes was 0.04 mg/g, 0.22 mg/g, and 0.14 mg/g lower than that of the CK ($p < 0.05$), presenting that EVA-treatment decreased the mango flavonoids content at the later stage of storage. The flavonoids content of the CTS-treatement did not change considerably throughout storage. The total phenol content of CK 'Tainong No.1′ mangoes showed a slow decrease with the extension of storage time (Fig. 2F). After 12 d of storage, the total phenol level of the CTS-treatment and EVA-treatment didn't change. The above indicated that EVA and CTS treatments could delay the decline of total phenol content of mangoes and delay the browning reactions of mangoes, and the total phenol content of EVA-treatment was 0.11 mg/g higher than that of CTS-treatment on the 24 d of storage ($p < 0.05$), but at 16 d of storage, the CTS-treatment had 0.08 mg/g higher total phenol content significantly different than the EVA-treatment. The above showed that EVA-treatment and CTS-treatment could delay the decline of total phenol content and delay the browning of mangoes.

3.3. *Effects on membrane permeability and redox system of mango cells*

The MDA content of CK 'Tainong No.1′ mangoes showed a

continuous increase as the storage time increased (Fig. 3A). Following harvest, EVA and CTS treatments could suppress the increase of MDA content in 'Tainong No.1′ mangoes. On 8 and 20 d, the MDA content of EVA-treatment was 0.10 μmol/g and 0.26 μmol/g lower than that of CTS-treatment ($p < 0.05$), exhibiting that EVA-treatment was superior in limiting MDA accumulation. The relative conductivity of 'Tainong No.1′ mangoes increased and then decreased gradually as storage time increased (Fig. 3B), whereas the conductivity of the CK mangoes reached a maximum of 82.5 % on the 16th day of storage and then gradually decreased. On 12 to 16 d of storage, the conductivity of EVA-treatment and CTS-treatment were 9.4 %, 8.1 %, 20.3 %, and 16.7 % lower than that of CK, respectively ($p < 0.05$). From 12 to 16 d of storage, the difference in conductivity between EVA and CTS treatments was not significant, signifying that EVA and CTS had the same impact in suppressing the conductivity of 'Tainong No.1′ mangoes.

The GSSG content of 'Tainong No.1′ mangoes decreased steadily as storage time (Fig. 3C). From 12 to 24 d of storage, the GSSG concentration of EVA-treatment and CTS-treatment was higher than that of CK, showing that EVA-treatment and CTS-treatment might postpone the drop in GSSG content. The GSSG content of the EVA-treatment was significantly higher than that of the CTS-treatment during 12 to 20 d of storage, showing that the EVA-treatment had more of an impact on delaying the degradation of GSSG in mangoes. The GSH content of 'Tainong No.1′ mangoes rose and then diminished as the duration of storage increased (Fig. 3D). On the 8 to 24 d of storage, the GSH content of EVA-treatment and CTS-treatment was higher than that of CK mangoes. On 16 d of storage, the GSH content of EVA-treatment and CTS-treatment was 0.66 μmol/g and 0.39 μmol/g above that of CK mangoes, respectively ($p < 0.05$), revealing that EVA-treatment and CTS-treatment might boost GSH content accumulation in mangoes during storage. EVA-treatment had significantly greater GSH content than CTS-treatment, indicating that EVA was more effective in improving the antioxidation of 'Tainong No.1′ mangoes.

'Tainong No.1′ mangoes' AsA content tended of rising and then falling when storage time was extended (Fig. 3E). On the 16th day of storage, the CK 'Tainong No.1′ mangoes' AsA content peaked, and afterward a component of it began to decline. Mangoes treated with EVA and CTS had AsA contents that were at their highest on 20 d of storage. Mangoes that had been given the EVA and CTS treatments put off the lowering of AsA until later in the storage process, and the EVA treatment was better at delaying the oxidative senescence of mangoes. 'Tainong No.1′ mango GR activity exhibited a trend of increasing and then declining as storage time increased (Fig. 3F). The GR activity of the CK reached its maximum value at 16 d of storage. On 16 to 20 d of storage, the GR activity of the EVA-treatment was higher than that of the CK group. The GR activity of the CTS-treatment was 0.08 $U{\cdot}g^{-1}$ higher than that of the CK at 20 d of storage ($p < 0.05$). The above indicates that EVA and CTS treatments can induce GR activity in mangoes and improve the antioxidant capacity of mangoes. On 16 to 24 d of storage, the GR activity of EVA-treatment mangoes was significantly higher than that of CTS-treatment, indicating that EVA-treatment played a more significant role in improving the antioxidant capacity of 'Tainong No.1′ mangoes. The APX activity of 'Tainong No.1′ mangoes showed a slow increase with increasing storage time (Fig. 3G). On 8 to 24 d of storage, the APX activities of EVA and CTS treatments were higher than those of CK, illustrating that EVA and CTS treatments could induce APX activity and enhance the antioxidant capacity of mangoes. On 16 to 20 d of storage, the APX activity of EVA-treatment was significantly higher than that of CTS-treatment by 0.13 $U{\cdot}g^{-1}$ and 0.04 $U{\cdot}g^{-1}$, but at 8 to 12 d of storage, the APX activity of CTS-treatment was significantly higher than that of EVA-treatment by 0.12 $U{\cdot}g^{-1}$ and 0.10 $U{\cdot}g^{-1}$, displaying that EVA-treatment and CTS-treatment were not similar in improving the antioxidant capacity of 'Tainong No.1′ mangoes.

3.4. Effect on the activity of related enzymes

The PPO activity of 'Tainong No.1′ mangoes increased slowly with storage time (Fig. 4A). During the 24 d of storage, the PPO activity of the EVA-treatment and CTS-treatment groups was lower than that of the CK, indicating that the EVA-treatment and CTS-treatment could inhibit the PPO activity of mangoes and inhibit the browning reaction, and the PPO activity of EVA-treatment mangoes was significantly lower than that of CTS-treatment on 12 to 24 d of storage, suggesting that EVA-treatment had a better effect on inhibiting the browning reaction of mangoes. The 'Tainong No.1′ mangoes POD activity rose gradually with longer storage (Fig. 4B). The POD activity of 'Tainong No.1′ mangoes in the CK group was 155.3 $U{\cdot}g^{-1}$ on the 24 d of storage, whereas the POD activity of the EVA-treatment group was higher on 16 to 24 d of storage, reaching 173.0 $U{\cdot}g^{-1}$ at the 24 d of storage, 17.7 $U{\cdot}g^{-1}$ higher than that of the CK group ($p < 0.05$). This demonstrated that mangoes with an EVA-treatment could have increased POD activity and antioxidant capacity. At 24 d of storage, the POD activity of the CTS-treatment was 133.4 $U{\cdot}g^{-1}$, 21.9 $U{\cdot}g^{-1}$ lower than that of the CK ($p < 0.05$), exhibiting that the CTS-treatment inhibited the POD activity and reduced the antioxidant capacity of mangoes.

The 'Tainong No.1′ mangoes SOD activity increased gradually during the period of storage (Fig. 4C). On the 4 d of storage, the SOD activity of the CK reached a maximum value of 95.4 $U{\cdot}g^{-1}$. The EVA-treatment SOD activity was higher than that of the CK group from 4 to 16 d of storage, and on the 4 d of storage, it was 109.7 $U{\cdot}g^{-1}$ higher than that of the CK by 13.4 $U{\cdot}g^{-1}$ ($p < 0.05$). On 8, 12, and 16 d of storage, the SOD activity of the CTS-treatment was 18.3 $U{\cdot}g^{-1}$, 11.9 $U{\cdot}g^{-1}$, and 69.5 $U{\cdot}g^{-1}$ higher than that of the CK, respectively ($p < 0.05$). The above indicates that EVA-treatment and CTS-treatment can induce SOD activity and improve the antioxidant capacity of mangoes. On 4, 8, and 16 d of storage, the SOD activity of EVA-treatment was significantly higher than that of CTS-treatment, indicating that EVA-treatment had a more significant effect on improving the antioxidant capacity of mangoes. The CAT activity of 'Tainong No.1′ mangoes showed a slow increase with increasing storage time (Fig. 4D). The CAT activity of the CK was 51.6 $U{\cdot}g^{-1}$ on the 24 d of storage, while the CAT activity of the EVA-treatment was higher than that of the CK group on 16 to 24 d of storage. On 16 and 20 d of storage, the CAT activities of the CTS-treatment were 50.5 $U{\cdot}g^{-1}$ and 67.0 $U{\cdot}g^{-1}$, respectively, which were 11.3 $U{\cdot}g^{-1}$ and 24.0 $U{\cdot}g^{-1}$ higher than those of the CK ($p < 0.05$). The above indicates that EVA-treatment and CTS-treatment can induce CAT activity and improve the antioxidant capacity of mangoes. On 16 to 24 d of storage, the CAT activity of EVA-treatment was significantly higher than that of CTS-treatment, indicating that EVA-treatment played a more significant role in improving the antioxidant capacity of mangoes.

3.5. Effects on the metabolism of mango ethylene

The ethylene release of 'Tainong No.1′ mangoes showed a trend of increasing and then decreasing as the storage time increased (Fig. 5A). The ethylene release from EVA and CTS treatments reached the maximum value on the 16 d of storage, which was 0.03 μL/kg·h and 0.04 μL/kg·h lower than those from CK respectively ($p < 0.05$). The CTS-treatment released 0.19 μL/kg·h and 0.24 μL/kg·h of ethylene respectively, which were 0.04 μL/kg·h and 0.02 μL/kg·h lower than those of the CK ($p < 0.05$). The above indicates that EVA and CTS treatments can inhibit the release of ethylene content in mangoes and play a role in inhibiting the senescence of mangoes. The differences in ethylene release between EVA and CTS treatments were not significant on 12 to 16 d of storage, indicating that EVA and CTS treatments were equally effective in delaying the ripening of mangoes. The ACO activity of 'Tainong No.1′ mangoes showed a trend of increasing and then decreasing as the storage time increased (Fig. 5B). The ACO activity of CK 'Tainong No.1′ mangoes reached the maximum value on the 16 d of storage. The ACO activity of mangoes from the EVA and CTS treatments

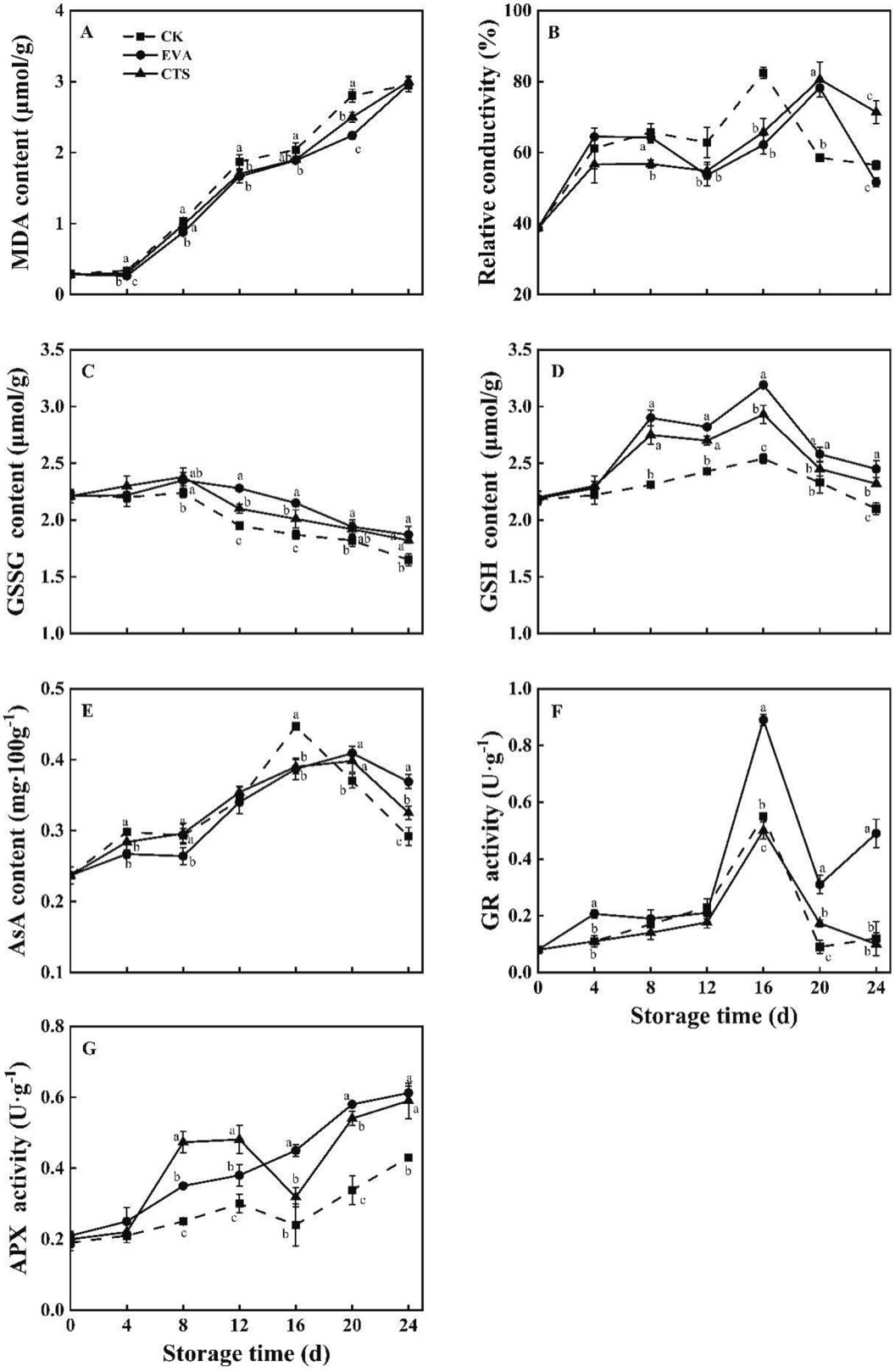

Fig. 3. Effect of postharvest film application treatments on mango MDA content (A), relative conductivity (B), GSS content (C), GSH content (D), AsA content (E), GR activity (F), APX activity (G). a, b, c indicate significant differences between postharvest coating treatments ($p<0.05$).

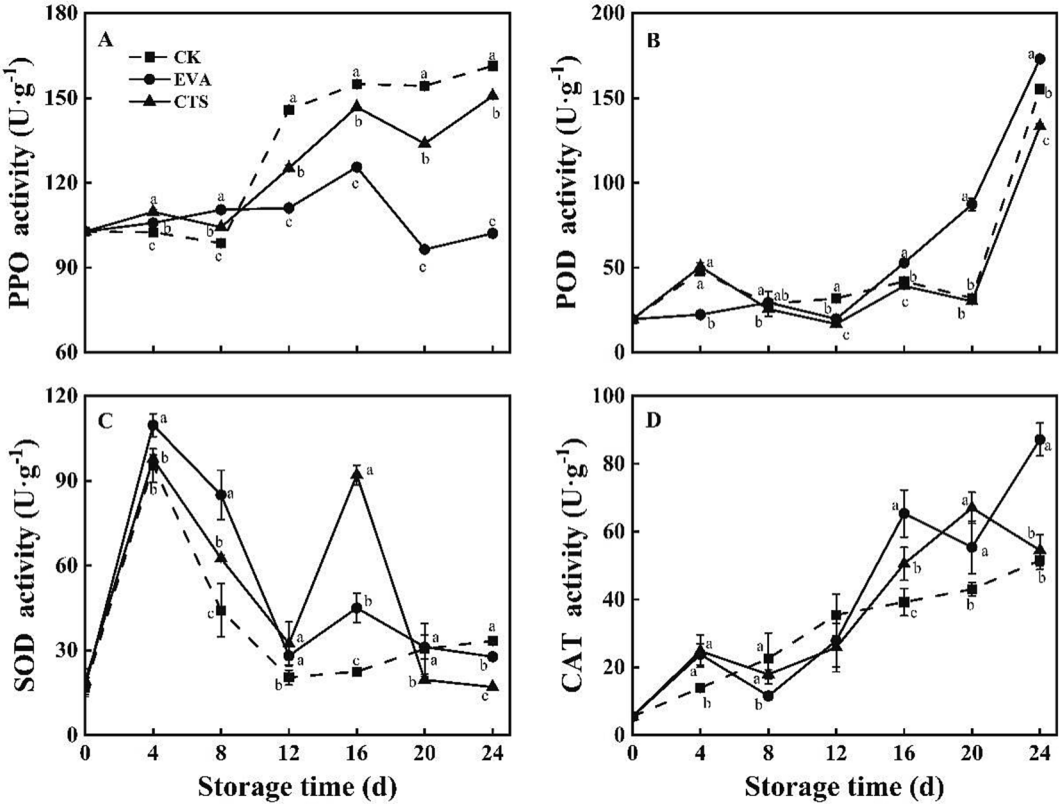

Fig. 4. Effect of postharvest film application treatments on mango PPO activity (A), POD activity (B), SOD activity (C), CAT activity (D). a, b, c indicate significant differences between postharvest coating treatments (p<0.05).

was lower than that of the CK during storage. This indicates that the EVA and CTS treatments could inhibit the ACO activity of mangoes and play a role in delaying the senescence of mangoes. On the 12 to 20 d of storage, the ACO activity of EVA-treatment was 129.0 U/L and 59.6 U/L lower than that of CTS-treatment ($p < 0.05$), indicating that EVA-treatment had a more obvious effect on delaying the senescence of mangoes. The ACS activity of 'Tainong No.1′ mangoes showed a trend of increasing and then decreasing with the extension of storage time (Fig. 5C), and the ACS activity of CK 'Tainong No.1′ mangoes reached the maximum value on the 16 d of storage. On 4, 12, and 16 d of storage, the ACS activity of EVA-treatment mangoes was 98.06 U/L, 165.0 U/L, and 220.2 U/L lower than that of CK mangoes respectively. The ACS activity of CTS-treatment was 55.8 U/L, 97.4 U/L, and 90.9 U/L lower than that of CK on the 4 to 12 d of storage, respectively ($p < 0.05$). The above indicates that EVA-treatment and CTS-treatment could inhibit the ACS activity of mangoes and delay their aging of mangoes. The ACS activity of EVA-treatment was 74.1 U/L and 220.2 U/L lower than that of CTS-treatment on the 12 to 16 d of storage ($p < 0.05$). The ACS activity of EVA-treatment reached its maximum value 4 d later than that of CTS-treatment, indicating that EVA-treatment had a more obvious effect on delaying the senescence of mangoes.

With the extension of storage time, the relative expression of *ETR1* in 'Tainong No.1′ mangoes treated with CK showed a trend of first increasing and then slowly decreasing (Fig. 5D). The relative expression level of *ETR1* in the CK reached its maximum on the 16 d of storage, the relative expression of *ETR1* in the EVA-treatment was significantly lower than that in the CK. The relative expression of *ETR1* in the CTS-treatment was also significantly lower than that in the CK during the 8 to 24 d of storage and reached a maximum on the 20 d of storage, which was 4 d later than that of CK. The above observations indicate that EVA and CTS-treatment can suppress the relative expression of *ETR1* in mango and delay the senescence of mango. On 4, 8, 16, and 24 d of storage, the relative expression of *ETR1* in EVA-treatment were 0.58, 0.21, 0.39, and 0.14 lower than that in CTS-treatment (Fig. 5D), indicating that EVA-treatment had a more significant effect on delaying the senescence of mangoes.

With the extension of storage time, the relative expression of *ETR2* in 'Tainong No.1′ mangoes treated with CK showed a trend of first increasing and then slowly decreasing (Fig. 5E), the relative expression level of *ETR2* in CK reached the maximum at 16 d of storage. The relative expression of *ETR2* in the CTS-treatment was significantly lower than that in the CK on 8, 16, 20, and 24 d of storage, and reached a maximum at 16 d of storage with a relative expression of *ETR2* of 1.85, which was 1.0 lower than that of CK. This indicates that EVA and CTS treatments can suppress the relative expression of *ETR2* in mangoes and play a role in delaying the senescence of mangoes. The relative expression of *ETR2* in EVA-treatment reached its maximum value on the 20 d of storage, which is 4 d later than that of CTS-treatment, indicating that EVA-treatment has a more obvious effect on delaying the senescence of mango.

With the extension of storage time, the relative expression of *ERS2* in 'Tainong No.1′ mangoes treated with CK showed a trend of first increasing and then slowly decreasing (Fig. 5F), and the relative expression level of *ERS2* in CK reached the maximum at the 16 d of storage. The relative expression of *ERS2* in EVA and CTS treatments were significantly lower than that of CK after the 12 d of storage, and the relative expression of *ERS2* reached the maximum on the 16 d of storage. The relative expression of *ERS2* in EVA-treatment was 2.63, 10.23, and 3.39 lower than that in CTS-treatment on the 16 to 24 d of storage ($p < 0.05$), indicating that EVA-treatment had a more significant effect on delaying the senescence of mangoes.

3.6. Pearson's correlation analysis of mango decay rate with various indicators

By analyzing the correlation of the indicators in different treatment

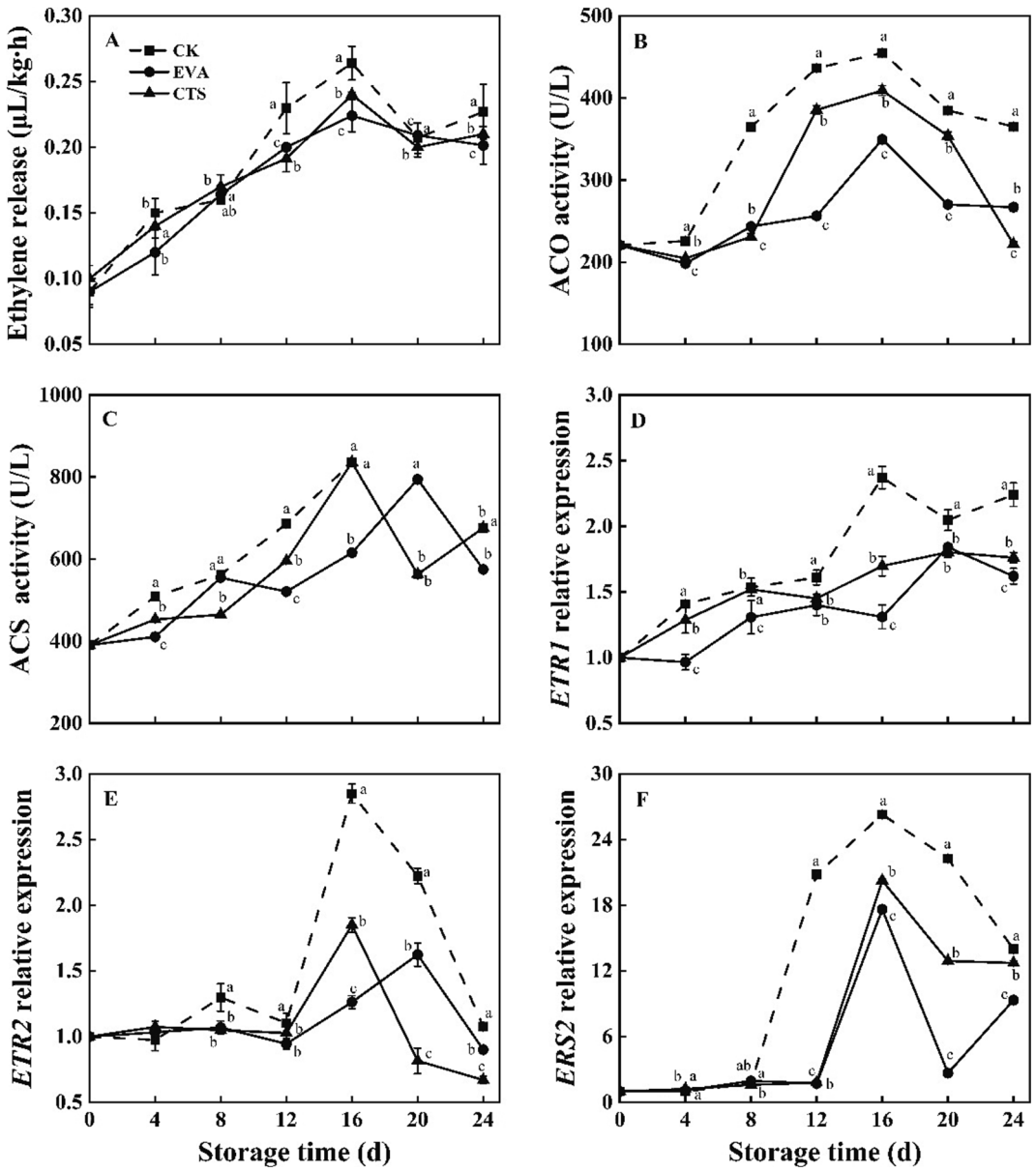

Fig. 5. Effect of postharvest film application treatments on mango ethylene release (A), ACO Activity (B), ACS Activity (C), *ETR1* relative expression (D), *ETR2* relative expression(E), *ERS2* relative expression (F). a, b, c indicate significant differences between postharvest coating treatments (p<0.05).

groups, it was found that the correlation of the indicators differed among different treatments of mangoes after storage. The decay rate of CK was high significantly correlated with weight loss, ΔE, carotenoid, TSS, SSC, MDA, PPO, CAT, and *ETR1* relative expression ($p < 0.01$). The decay rate was positively correlated with APX, ethylene release, ACO, and *ERS2* relative expression ($p < 0.05$). In addition, the decay rate of CK was highly significantly negatively correlated with hardness, chlorophyll, and GSSG ($p < 0.01$), and significantly negatively correlated with TA and total phenols ($p < 0.05$) (Fig. 6A). The decay rate of EVA-treatment showed highly significant positive correlations with weight loss, TSS, ΔE, carotenoids, anthocyanins, MDA, AsA, APX, ethylene release, and *ETR1* relative expression ($p < 0.01$), and significant positive correlations with SSC, POD, CAT, and ACS ($p < 0.05$). Moreover, the decay rate of EVA-treatment was highly significant and negatively correlated with hardness and chlorophyll ($p < 0.01$), and significantly negatively correlated with total phenols ($p < 0.05$) (Fig. 6B). The decay rate of CTS-treatment was highly significant and positively correlated with weight loss, TSS, carotenoids, MDA, relative conductivity, PPO, CAT, ethylene release, ACS, and *ETR1* relative expression ($p < 0.01$), and significantly positively correlated with SSC, AsA, and APX ($p < 0.05$). Furthermore, the decay rate of CTS-treatment was highly significantly negatively correlated with hardness and chlorophyll ($p < 0.01$), and significantly negatively correlated with TA, total phenols, and GSSG ($p < 0.05$) (Fig. 6C).

All treatments showed highly significant or significant positive correlations between decay rate and weight loss, carotenoids, TSS, SSC, MDA, CAT, *ETR1* relative expression, APX, and ethylene release, suggesting that an increase in these indicators is an important factor in mango decay. Additionally, the decay rates of the three treatments were highly significant or significantly negatively correlated with hardness, chlorophyll, and total phenols, indicating that the decay rate of mango gradually increased with decreasing chlorophyll content (Fig. 6).

4. Discussion

4.1. Effect of coating treatments on the quality of mango fruits

With the prolongation of storage time, mango is prone to decay and

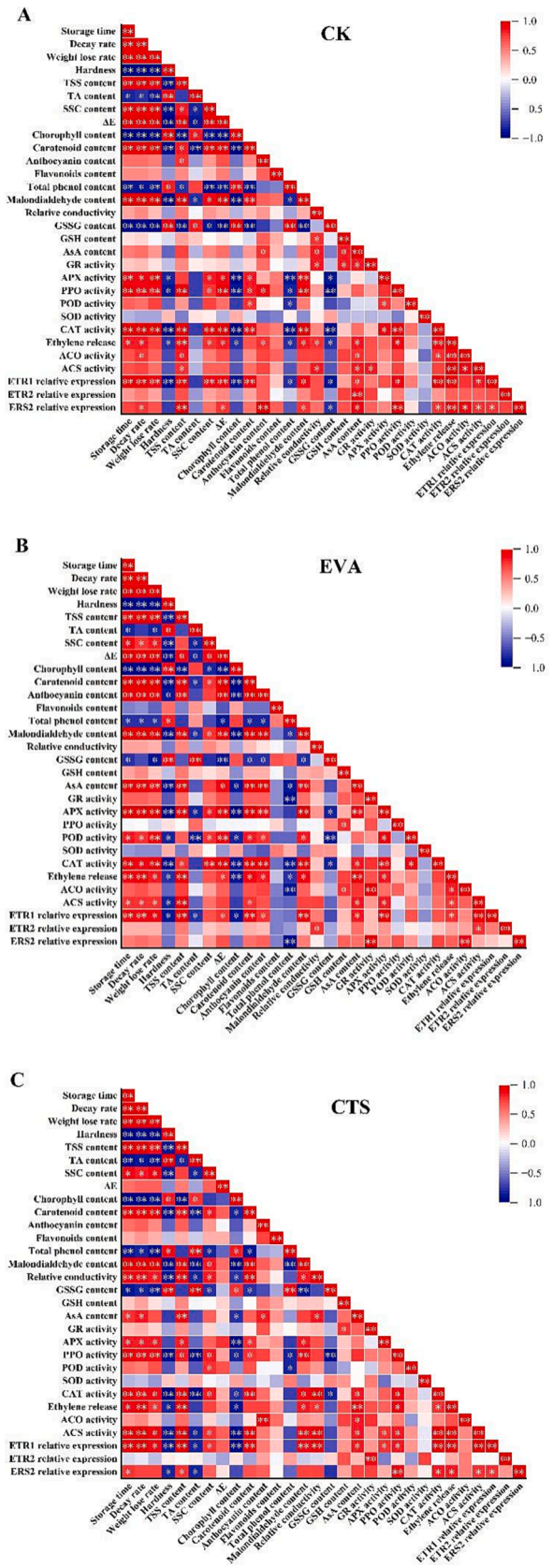

Fig. 6. Pearson's correlation matrix plots between metrics of postharvest CK (A), CTS-treatment (B) and EVA-treatment (C). * indicates significant differences between postharvest treatment indicators (*$p < 0.05$, **$p < 0.01$).

deterioration, so the decay rate is one of the most important physiological indicators to judge the fruit storage effect (Benatar et al., 2021). Studies have shown that chitosan coating can play a physical barrier role, which can significantly reduce the decay rate of green peppers and effectively extend the freshness period of green peppers (Adetunji et al., 2019). The weight loss rate is a crucial sign of fruit quality since the mango's surface rots and deteriorates and the fruit continues to lose water. The weight loss rate of 'Tainong No.1′ mango treated with coating by EVA and CTS decreased (Fig. 1B), which is likely due to the coating treatment preventing surface degradation of the fruit and slowing down water evaporation. During the fruit ripening the cellulose and raw pectin in the fruit body are hydrolyzed, the soluble pectin grows, the hardness of the fruit drops rapidly, and the mechanical strength of the cell expansion pressure, cell wall material, etc., in the fruit body gradually diminish (Xiao et al., 2020). In this study, the hardness (Fig. 1C) of the mango fruit treated with EVA and CTS treatments decreased relatively slowly, probably because the coating treatment could make the tissue structure of the mango more compact, increase the mechanical strength and intercellular binding force in the fruit, this is similar to the result of (Zheng et al., 2024).

Chlorophyll is an important substance for plant photosynthesis, carotenoids are fat-soluble pigments, and anthocyanins are water-soluble pigments, which play an important role in the coloring of fruits (Chen et al., 2022). When a fruit ages, chlorophyll progressively departs, and anthocyanins and carotenoids gradually develop, resulting in a change in the fruit's base color (Sudheeran et al., 2019). Therefore, the change in fruit color can be more intuitively judged by the ripeness of the fruit and the appearance quality of the fruit. The chlorophyll (Fig. 2B) content of the 'Tainong No.1′ mango continued to decline during storage, possibly because the postharvest fruit magnesium ion supply was cut off, resulting in obstruction of chlorophyll synthesis, or because the decline in the number of chloroplasts after harvest affected the synthesis of chlorophyll. EVA and CTS coatings delay the decline in chlorophyll content in mangoes, possibly owing to the degradation of mango chloroplasts. EVA and CTS coating treatments, the content of carotenoid (Fig. 2C) rose relatively slowly, possibly because it inhibited chlorophyll degradation. The increase in soluble sugar content can promote anthocyanin synthesis and promote grape coloration (Xia et al., 2021). The anthocyanin (Fig. 2D) content of the EVA-treatment rose relatively slowly, possibly because the coating treatment inhibited the accumulation of soluble sugar content in mangoes.

Changes in the sugar-acid ratio in mango directly affect the edible quality of the fruit, when the sugar-acid ratio is high, the fruit is sweet, while a lower sugar-acid ratio leads to soar fruits (Deng et al., 2021). The amount of soluble sugars and soluble solids in the fruit will rise as it ripens, while the amount of organic acids like titratable acid and ascorbic acid will fall. The soluble solids content (Fig. 1D) of CK 'Tainong No.1′ mango decreased slightly after storage 16 d, and the titratable acid content (Fig. 1E) decreased significantly after 12 d storage, possibly because the rate of sugar acid synthesis in mangoes stored for 12 to 16 d began to decline. Postharvest EVA and CTS coating treatment delayed the emergence of the peak of soluble solids of 'Tainong No.1′, inhibited the accumulation of soluble sugar content (Fig. 1F) in mango, and delayed the decline of titratable acid content, indicating that EVA and CTS coating film treatment can delay the ripening effect of mango by inhibiting the conversion of acids into sugars and the consumption of sugar acid, and further confirmed that the above EVA coating film can inhibit the synthesis of anthocyanins by inhibiting the soluble sugar content of mango. Using edible chitosan nanoparticle coatings can reduce soluble solids and lower sugar content in grapes, delaying titratable acidity decline, which is consistent with our findings(Castelo Branco Melo et al., 2018).

The above results indicate that the film treatment can better maintain the appearance and eating quality of mangoes, delay the change of fruit pigments, the conversion of mango sugars and acids, and the aging of fruit, preserving the nutritional quality of mangoes, thereby

extending the acceptance period of mangoes as commodities. Compared to CTS film treatment, the EVA film treatment shows more prominent effects in maintaining the quality of mangoes and slowing down mango senescence.

4.2. Effect of coating treatment on lipidation reactions and cell membrane permeability of mangoes

Malondialdehyde (MDA) is the end product of membrane lipid peroxidation, which causes crosslinking and polymerization of living macromolecules such as decaying and nucleic acids, which will aggravate membrane damage (Mirshekari et al., 2020). During the storage process, the MDA content increases with the prolongation of storage time, and the aging of the fruit is aggravated, so the MDA content is a common indicator in the study of fruit aging physiology and resistance physiology. The chitosan/zein-cinnamaldehyde (CHI/zein-cma) nanocomposite film coating treatment significantly slowed down the rate of MDA accumulation. It was effective in creating a micro-modified atmosphere to improve the quality of mangoes (Xiao et al., 2021). The EVA and CTS treatments MDA content (Fig. 3A) rose relatively slowly, possibly because it inhibited the production of O_2^-, OH^-, and H_2O_2 peroxide substances, which had a protective effect on the phospholipid molecules in the cell membrane. Relative conductivity plays an important role in maintaining the microenvironment of cells and normal metabolism, under normal circumstances, cell membranes have selective permeability to substances. When cells are stressed by adversity, the cell membrane is broken, increasing membrane permeability, electrolytes are extravasated, and the relative conductivity of the plant cell extract increases, so relative conductivity is a basic indicator reflecting the permeability of plant cell membranes (Anisimov & Suslov, 2021). It has been shown that edible coating and air conditioning techniques can inhibit the increase in relative conductivity, slow down the fruit senescence process, and inhibit the increase in cell membrane permeability (Wei et al., 2021). EVA and CTS treatments inhibited the increase in the relative conductivity (Fig. 3B) of mango, possibly because it had a protective effect on cell membranes. Chitosan coatings supplemented with chitosan-montmorillonite nanocomposites can delay the increase of banana electrolyte leakage, and reduce the damage to fruit cell membranes, which is consistent with our research results (Wantat et al., 2022). Both EVA and CTS film treatments have certain effects in inhibiting the increase of mango malondialdehyde and relative conductivity, suppressing mango lipolysis reaction, and maintaining mango cell permeability.

4.3. Effect of coating treatment on the redox system of mangoes

The ascorbic acid-glutathione (AsA-GSH) cycle is an important component of the non-enzymatic antioxidant system that directly removes H_2O_2 from plants. GR can catalyze GSSG to GSH, GSH can reduce DHA to AsA, and AsA has the effect of directly eliminating H_2O_2 (Cheng et al., 2020). In this study, the GSSG content (Fig. 3C) of mango continued to decline, the GSH content (Fig. 3D) and AsA content (Fig. 3E) increased first and then decreased, probably because the fruit was just harvested from the mother body in the early stage of storage, and the stress of adapting to the adverse environment in the early stage, the GSH content and AsA content began to decline in the late storage period, GSH and AsA cleared the active oxygen species in the plant, and the oxidation occurred on its own, and the content decrease. The relatively high activities of GR (Fig. 3F) and APX (Fig. 3G) in postharvest EVA and CTS treatments indicate that they help to accelerate the clearance of reactive oxygen species in mangoes and slow down the aging of mangoes. Our results are similar to chitosan treatment in regulating the reactive oxygen metabolism of apples (Ackah et al., 2022).

Total phenol substances are the key substrates for enzymatic browning and are an important factor in causing enzymatic browning in fruits and vegetables (Kumpoun et al., 2015). PPO is a reactive enzyme that promotes enzymatic browning (Rastegar et al., 2020). When fruits and vegetables are damaged, the membrane system is destroyed, a serious browning reaction occurs between the phenolic substrate and the PPO, and in the later stage of storage, the consumption of phenolic substances in the early stage leads to a decrease in content, enzymes lose activity, and PPO activity decreases significantly. EVA and CTS treatments delayed the decline of total phenol content (Fig. 2F) in the fruit and reduced the consumption of mango total phenols, the trend of coating sweet cherries with chitosan of varying deacetylation degrees is similar (Zheng et al., 2024). The activity of PPO (Fig. 4A) is relatively low, inhibiting the activity of PPO, it is indicated that it can delay the aging of mango by reducing the substrate required for the browning reaction and inhibiting the enzymatic activity of the browning reaction.

Flavonoids are antioxidants metabolized by plants that have antioxidant effects that can combat the aging of fruits (Chen et al., 2022). In this study, the EVA and CTS treatments promoted the accumulation of flavonoid content (Fig. 2E) in mangoes, and the EVA-treatment induced an increase in flavonoid content in the early storage stage, possibly because the EVA and CTS treatments induced an increase in flavonoid content in mangoes and improved the antioxidant capacity of the fruit. CAT, POD, and SOD is an important antioxidant enzymes in the plant enzymatic reaction system, and the activities of POD (Fig. 4B), SOD (Fig. 4C), and CAT (Fig. 4D), in mango treated with EVA and CTS treatments, are relatively elevated, it may be because it protects the intact structure of the cell membrane and maintains the reactive oxygen species balance in mango. This is in line with the results of a study on the use of exogenous melatonin to improve the scavenging capacity of reactive oxygen species during cold storage of mango fruit, thereby increasing the antioxidant capacity of mango fruit and maintaining fruit quality (Njie et al., 2022).

As shown by the results, the coating treatment has enhanced the AsA-GSH cycle and antioxidant metabolism of mangoes. Compared to CTS film treatment, the EVA film treatment shows more significant enhancement in mango AsA-GSH cycle and antioxidant capacity of active oxygen metabolism.

4.4. Effect of coating treatments on ethylene metabolism in mangoes

Mango is a typical respiratory transition type of fruit, ethylene in the postharvest storage and shelf during a large number of synthetic releases is an important hormone to promote fruit maturity and aging, inhibit the production of endogenous ethylene in the fruit, to slow down the aging of mango has great significance (Khedr, 2022). ACS and ACO are two key rate-limiting enzymes for ethylene synthesis. Ethylene in plants is synthesized via the methionine pathway, in which ACS catalyzes the synthesis of ACC from S-adenosylmethionine, which is finally oxidized by ACO to ethylene (Liu et al., 2023). The EVA and CTS coating treatment inhibited ACO activity (Fig. 5B) and reduced the ethylene release in mango, possibly because the coating inhibited the synthesis of the ethylene (Fig. 5A) precursor substance methionine. Similarly, the use of chitosan coatings supplemented with chitosan-montmorillonite nanocomposites also reduced the production of ethylene when treating bananas (Wantat et al., 2022). CTS-treatment inhibited the activity of mango ACS (Fig. 5C) before the peak of mango ethylene release, possibly because the coating treatment slowed down the release of ethylene, and EVA-treatment not only inhibited the activity of mango ACS, but also delayed its activity peak by 4 days, which may not only inhibit the release of ethylene, but also inhibit its synthesis speed. It has been reported that the ripening and softening of peach fruits are regulated through the *SEP1* gene by down-regulating *ACS2*, *ACO1*, *ETR2,* and other related genes (Li et al., 2017) which is consistent with our findings.

Five ethylene receptors have been identified and characterized in *ETR1*, *ERS1*, *ETR2*, *ERS2*, and *EIN4* (Ish-Shalom et al., 2011). Based on phylogenetic analysis, ethylene receptors can be divided into two subfamilies with identical structural features. Subfamily 1 contains *ETR1*

and *ERS1*, and subfamily 2 contains *ETR2*, *ERS2*, and *EIN4*. *ETR1*, *ETR2*, and *ERS2* are important fruit ethylene receptor genes (Winterhagen et al., 2016). It has been suggested that 1-MCP treatment can effectively prevent ethylene-induced maturation and senescence by regulating ethylene biosynthesis and the expression of ethylene receptor genes (*MiETR1* and *MiERS1*) (Li et al., 2020). In this study, EVA and CTS treatments showed lower ethylene release than CK (Fig. 5A), and the relative expression of *ETR1* (Fig. 5D), *ETR2* (Fig. 5E), and *ERS2* (Fig. 5F) genes was relatively reduced, suggesting that they can reduce ethylene release from mangoes by inhibiting the expression of the mango ethylene receptor genes, *ETR1*, *ETR2*, and *ERS2*, and thus delay mango senescence. Consistent with our findings, down-regulation of genes involved in ethylene perception and signaling (such as *ETR1*, and *ERS1*) was observed in the late ripening stage of mango (Busatto et al., 2022). Compared to CTS-treatment, EVA-treatment has a more pronounced effect on inhibiting mango ethylene metabolism and delaying ripening.

5. Conclusion

In conclusion, postharvest EVA and CTS coating treatments can boost mango antioxidant capacity and decrease mango decay, water loss, delay mango color conversion, and sugar acid conversion. As part of the AsA-GSH cycle, the oxidation metabolism system is improved to remove dangerous compounds from reactive oxygen species, prevent ethylene oxidation anabolism, postpone fruit aging, extend shelf life, and enhance the mango freshness effect. Besides, weight loss, carotenoids, TSS, SSC, MDA, CAT, APX, ethylene release, and relative expression of *ETR1* were all extremely significant or significantly positively linked with decay rates in all treatments. The EVA coating treatments have a more significant effect on improving the preservation of mangoes, providing a new method for the post-harvest preservation of mangoes and has a wide range of applications in the field of mango post-harvest storage and preservation. However, the mechanism of the effect of the oxidative-reductive system during the post-harvest ripening process of mangoes is not well understood and further research can be done at the molecular level to reveal its intrinsic mechanism. In the future, the application of EVA film treatment can also be considered for other types of fruit post-harvest preservation, further promoting the development of the field of fruit post-harvest preservation.

CRediT authorship contribution statement

Xi Pang: Data curation, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing. **Yumi Huang:** Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization. **Naiyu Xiao:** Conceptualization, Methodology, Resources. **Qing Wang:** Formal analysis, Resources, Supervision. **Bihong Feng:** Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Validation, Writing – review & editing. **Munsif Ali Shad:** Formal analysis, Resources, Supervision.

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.

Data availability

Data will be made available on request.

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