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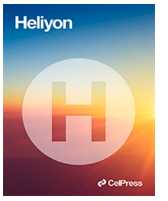

Research article

Preservative effects of *Osmanthus fragrans* flower flavonoids on fresh-cut Yuluxiang pear

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ABSTRACT

Osmanthus fragrans flower flavonoids (OFFF) possess superior antioxidant and antibacterial activities. However, scant information exists on the efficacy of these secondary metabolites as preservatives for fresh-cut fruits and vegetables. Here, OFFF were tested as a natural preservative for the first time in fresh-cut Yuluxiang pear (*Pyrus bretschneideri* Rehd.) to assess effects on fruit quality. OFFF-treated samples showed significant retention of firmness, titratable acid, soluble solid content, and weight. Moreover, OFFF maintained the original fruit color, inhibited the decline of total phenol, reducing power and 2,2-diphenyl-1-picrylhydrazyl radical scavenging power, and diminished polyphenol oxidase and peroxidase oxidase activities. Furthermore, OFFF treatment effectively inhibited microbial growth. OFFF-treated samples also displayed better sensory quality. Considering cost and effectiveness, the most suitable concentrations of OFFF extract for fresh-cut Yuluxiang pear preservation were 0.7 and 0.9 mg/mL. The results indicate that OFFF treatment may be a potent strategy to inhibit browning and enhance nutritional properties of fresh-cut pear fruit.

1. Introduction

Yuluxiang pear, which is one of the most widely grown pear cultivars in China, is a hybrid of 'kuerlexiangli (*Pyrus bretschneideri* Rehd.) × 'xuehuali' (*P bretschneideri* Rehd. cv. xuehua). This cultivar is superior as a fresh-cut fruit because of the large fruit size, high production values, excellent sensory quality, tolerance to unfavorable environmental factors, and strong disease resistance [1,2]. Fresh-cut produce is convenient for consumers, although the process shortens the shelf-life of fruits and vegetables. Fresh-cut fruits and vegetables, which also are termed microprocessed or minimum processed produce, are rapidly washed, sorted, peeled, cut, fresh-stored, and packaged. Fresh-cut produce maintains excellent freshness and is preferred by consumers globally because of the nutritional benefits, convenience of consumption, and other favorable characteristics [3]. However, fresh-cut processes for Yuluxiang pear, including cutting and slicing, produce wounds and affect tissue integrity which result in browning and a shelf life that may be lower than that of whole pear. Therefore, there is a need to enhance the storage life of fresh-cut Yuluxiang pear. Moreover, transfer of microbes from external surfaces to edible segments during fresh-cut processing is a potential transmission route for serious foodborne

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pathogens [3]. Microbes are able to grow at refrigerated temperatures on melon, apple, and mango [4], as well as on fresh-cut pear [5]. Heat treatment, radiation, or application of chemicals have been used to reduce microbial contamination of fresh-cut fruits and vegetables, but these harsh processes may affect the quality of the produce and also may leave residual toxic compounds. Thus, it is vital to innovate preservation methods that both maintain the quality of fresh-cut Yuluxiang pear and guarantee product safety.

Novel, natural preservatives with effective antioxidant and antibacterial properties are required to satisfy consumer demand for more natural, green, and safe fresh-cut products [6]. Natural extracts of flavonoids are new preservatives that extend storage time and maintain the original flavor of fresh-cut products. *Eleocharis tuberosa* (Chinese water-chestnuts) are rich in flavonoids and displayed antibacterial activity and medicinal properties [7]. *Sonchus oleraceus* L. extract showed elevated antioxidant capacity, effectively inhibited increases in malondialdehyde content, and efficiently controlled enzymatic activities in fresh-cut potato slices [8]. In addition, flavonoids extracted from hawthorn leaf enhanced antioxidant capacity, reduced activities of polyphenol oxidase (PPO) and peroxidase oxidase (POD), and extended fresh-cut potato shelf life [9].

Osmanthus fragrans is a member of the Oleaceae family that is cultivated extensively in Asia. The plant's fragrant flowers are used to produce tea, wine, cakes, candy, and beverages with pleasing aromas, and also are employed extensively in perfumes, fragrances, and cosmetics [10,11]. *O. fragrans* contains diverse flavonoids, phenolic acids, phenolic glycosides, and other bioactive components that contribute to the sensory properties of the flowers. Flavonoids are polyphenolic secondary metabolites synthesized in plants in which they form one of the main groups of bioactive compounds. Flavonoids exhibit antioxidant, antibacterial, and antitumor functions [12,13]. *O. fragrans* contains a plethora of flavonoids with antioxidant capacity [14,15]. Moreover, *O. fragrans* flower flavonoids (OFFF) effectively remove hydroxyl radical species and superoxide anions [13].

The capacity of OFFF to act as a natural preservative to enhance the quality of fresh-cut products, including Yuluxiang pear, has not been investigated to our knowledge, despite the numerous advantages that OFFF present for fruit preservation. Therefore, the main aim of this study was to dissect the effects of OFFF on weight retention, firmness, color, titratable acid (TA), soluble solids content (SSC), total phenol content, PPO and POD activities, microbial growth, antioxidant capacity, and sensory quality of fresh-cut Yuluxiang pears during storage. The data reveal that OFFF may be a viable approach to reduce browning and enhance the nutritional properties of fresh-cut pear fruit.

2. Materials and methods

2.1. Vegetal material

Seventy kilograms of Yuluxiang pears were harvested from Luoning County Xinguoyuan Ecological Agriculture Co., Ltd (Luoyang, China). The pears were selected for uniform ripeness, shape, color and size, and absence of visible defects, including diseases and pests. Fruits were transported to the Postharvest Physiology Laboratory of the Henan University of Science and Technology, College of Horticulture and Plant Protection and were stored at 4 °C before processing.

2.2. OFFF extraction

O. fragrans var. *thunbergii* powder (3 g dry weight) was soaked in a conical flask in ethanol (240 mL) (60 % v/v) at 25 °C for 12 h. The sample was sonicated at 80 W at 50 °C for 30 min in a KQ-500DE ultrasonic cleaner (Ultrasonic Instrument Co., Ltd., Kunshan, China), equilibrated for 15 min, and the extract was filtered through No. 103 qualitative filter paper. This procedure was repeated three times. The pooled extract was placed in a rotary evaporator (Heidolph Instruments Co., Schwabach, Germany) under vacuum at 50 °C to concentrate the solution five-fold and then was centrifuged at 3000 × *g* for 20 min. The supernatant was added slowly to a column of pre-treated H103 macroporous resin (Huanyu Biotechnology Co., Ltd., Beijing, China). The flavonoids were adsorbed on the resin and water-soluble material was eluted in duplicate with distilled water and discarded. The flavonoid-enriched extract was eluted with 80 % ethanol. Most of the ethanol and water in the extract was removed using a rotary vacuum evaporator until the extract mixture was reduced to approximately 5 mL. This extract procedure was repeated to produce sufficient flavonoid-enriched extract for the experiments. The extracts were pooled and stored at 4 °C before use. When required, the extract was diluted using sterile distilled water to standardized concentrations of 0.3, 0.5, 0.7, and 0.9 mg/mL and stored at 4 °C.

2.3. Determination of flavonoid content in OFFF extracts

Flavonoid content in OFFF extracts was determined by the sodium nitrite-aluminum nitrate method [16] with modifications. Briefly, 10 mg of OFFF extract and 1 mL of 5 % sodium nitrite were mixed, oscillated, and allowed to react for 6 min. 1 mL of 10 % aluminum nitrate was added, incubated for 6 min, followed by addition of 10 mL of 4 % sodium hydroxide, and adjustment of the final volume to 25 mL with water. The mixture was incubated for 10 min and absorbance values were measured at 510 nm with a UV-1800 spectrophotometer (Shimadzu Co., Columbia, MD, USA). 2, 4, 6, 8, and 10 mL of rutin (2 mg/mL) were used to construct standard absorbance curves.

2.4. Fresh-cut Yuluxiang pear preparation and treatments

Yuluxiang pears were sanitized by immersion in sodium hypochlorite (100 μL/L) for 5 min, washed with distilled water, peeled, and the cores were removed. Pears were sliced evenly into eight pieces and were divided into five groups. These fresh-cut pieces were

suspended in different concentrations of flavonoid solution (0.3, 0.5, 0.7, or 0.9 mg/mL) for 5 min and then drained on clean paper towels. Fruit treated with distilled water was used as a control. The treated slices were placed in a container covered with polyethylene plastic wrap and stored at 4 °C and 95 % relative humidity in a constant temperature and humidity incubator (Changzhou Runhua Electric Aappliance Co, Ltd., Changzhou, China). During storage, color, firmness, titratable acidity, SSC, total phenolic content, antioxidant capacity, peroxidase oxidase and polyphenol oxidase activities, and microbial contamination were measured at two day intervals. Three containers with 18 pear slices in each were used for every OFFF concentration. Experiments were performed as three replicates. Sensory analysis was done on days 2, 4, 6, and 8 with eight containers with 21 pear slices in each for each OFFF concentration. Each experiment for pear weight loss used a single container with eight pear slices in each at two day intervals. Experiments were performed in triplicate. Color change was recorded as images every two days using three containers with 8 pear slices in each for every OFFF concentration. All operations were performed at room temperature.

2.5. Measurement of weight loss, color, and firmness

The weight of fresh-cut Yuluxiang pears was determined and weight loss was calculated as：

$$Weight\ loss(\%) = \frac{Initial\ fruit\ weight - Final\ fruit\ weight}{Initial\ fruit\ weight} \times 100$$

Pear color was assessed with a CR-400 Chroma Meter (Konica Minolta Sensing, Inc., Tokyo, Japan). The L (lightness), a (red-green) and b (yellow-blue) values were measured by the reflectance index of color variation [17]:

$$\Delta E = \sqrt{(L^* - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)^2}$$

$$x = \frac{a^* + 1.75 \times L^*}{5.645 \times L^* + a^* - 3.012 \times b^*}$$

$$BI = \frac{(x - 0.31) \times 100}{0.172}$$

$$BI\ increase = \frac{BI_x - BI_0}{BI_0} \times 100$$

where L_0, a_0, and b_0 are the initial color values and L^*, a^*, and b^* are the color parameters at each storage period. BIx and BI_0 represent the browning index (BI) on day x and zero, respectively. The fruit firmness was measured by a TA-XT plus texture analyzer (Stable Micro Systems, Surrey, UK).

2.6. Measurement of titratable acidity and soluble solids content

The TA content was determined as described elsewhere [18] with minor modifications. Briefly, pears (10 g) were homogenized and were centrifuged at 5000 × *g* at 4 °C for 10 min. The supernatant (2 mL) was mixed with distilled water (15 mL) and titrated with 0.1 M NaOH to pH 8.1 terminal point. The TA content was calculated using the formula:

$$Titratable\ acidity(100) = \frac{V(NaOH) \times 0.1 \times 0.067}{m_{aliquote}} \times 100\%$$

where V (NaOH) is the volume (mL) of NaOH spent for titration, 0.1 is the molarity of the NaOH solution, 0.067 is the conversion factor for malic acid, and $m_{aliquote}$ is the mass of the aliquot sample taken for analysis. The SSC was measured with a refractometer (Atago Co. Ltd., Tokyo, Japan) by the method of Liu et al. [18], and these reading were expressed as percentage values.

2.7. Measurement of total phenolic content

The concentration of total phenolic compounds in pears was determined by the Folin-Ciocalteu method [19] with minor adjustments. First, 2.0 g of pear sample were homogenized in 13 mL ethanol (50 % v/v) for 5 min and then centrifuged at 5000 × *g* at 4 °C for 10 min. The supernatant (200 μL) was combined with 0.8 mL Na_2CO_3 (10 % w/v), 0.4 mL Folin-Ciocalteau's reagent, and 2.6 mL distilled water, and reacted for 1 h at room temperature in darkness. Absorbance was measured at 760 nm with a UV-1800 spectrophotometer and results were calculated as g/kg of fresh-cut Yuluxiang pears.

2.8. Measurement of antioxidant capacity

2.8.1. 2,2-Diphenyl-1-picrylhydrazyl radical scavenging activity

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity was established by the method of Liu et al. [20]. 2.0 g of pear material were homogenized in 13 mL of methanol (50 % v/v) for 5 min and centrifuged at 5000 × *g* at 4 °C for 10 min. The supernatant (80 μL) and 0.1 mM DPPH in methanol (3 mL) were mixed, incubated at room temperature for 30 min in darkness, and absorbance at

517 nm was measured. Control reactions contained all reagents except pear material. DPPH radical scavenging activity was determined by:

$$DPPH\ radical\ scavenging\ activity(\%) = \left(1 - \frac{A_1}{A_0}\right) \times 100$$

where A_0 is the absorbance of control samples and A_1 is the absorbance of the pear samples.

2.8.2. Reducing power

Reducing power was determined as described by Liu et al. [21]. Briefly, 2.0 g of pear were emulsified in 13 mL of methanol for 5 min, followed by centrifugation at 5000 × *g* at 4 °C for 10 min. Supernatant (80 μL), sodium phosphate buffer (0.2 M, pH 6.4) (1 mL) and 1 % potassium ferricyanide (1 mL) were mixed and incubated at 50 °C for 20 min. 0.4 mL of trichloroacetic acid (10 % w/v), 1.2 mL of distilled water, and 24 μL of 0.1 % ferric chloride were added to the mixture, reactions were incubated at room temperature for 30 min in darkness, and absorbance at 700 nm was measured by spectrophotometry.

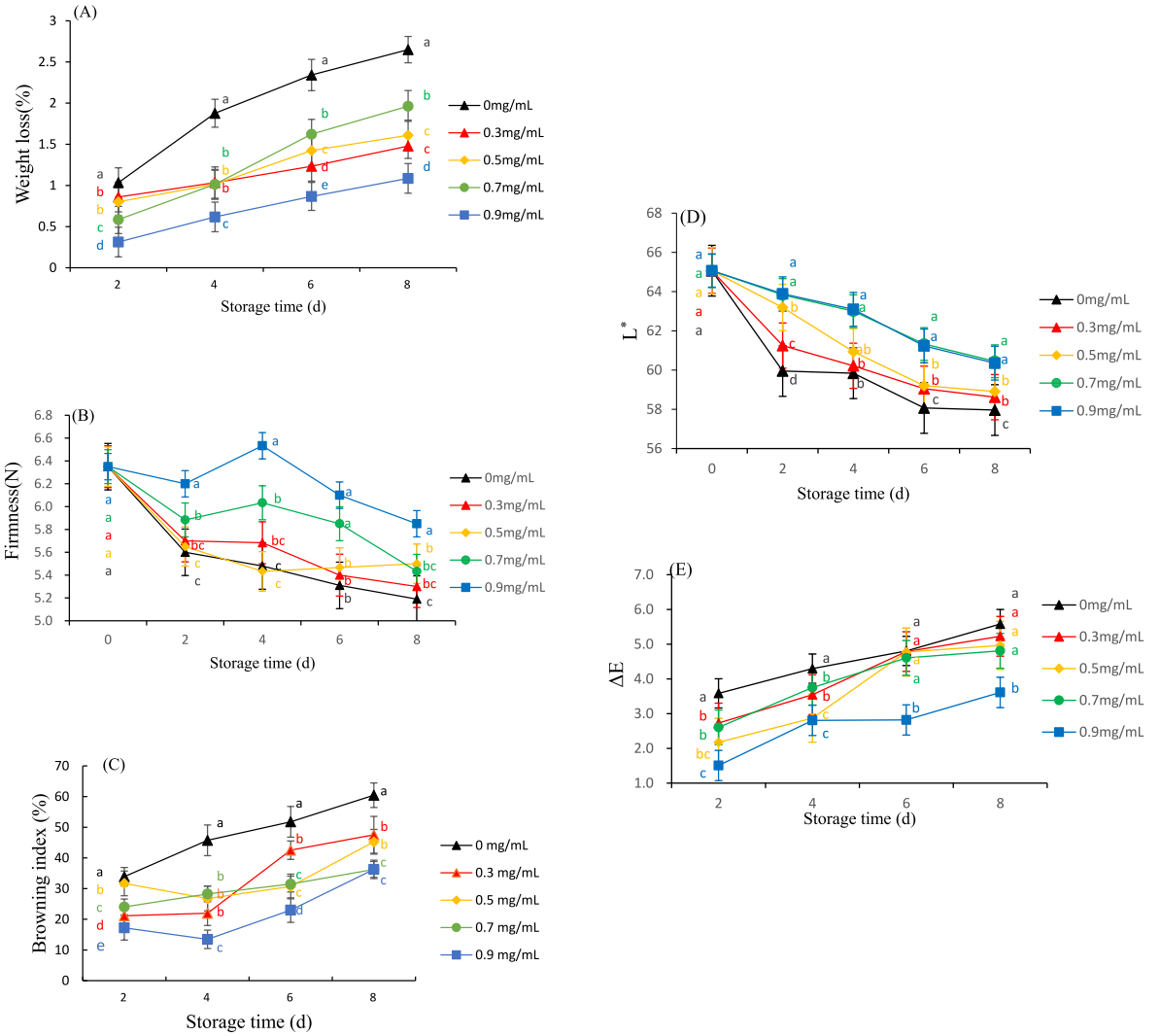


Fig. 1. Effects of OFFF treatment on (A) weight loss, (B) firmness, (C) BI, (D) L*, and (E) ΔE of fresh-cut Yuluxiang pear. Data are expressed as mean values with standard deviation from three replicates, and vertical bars represent the standard errors of the means. Different letters above the lines indicate significant differences ($p < 0.05$) for each sampling date.

2.9. Measurement of peroxidase oxidase and polyphenol oxidase activities

POD and PPO enzyme activities were assayed as outlined elsewhere [17]. For POD, 2.0 g of pear sample were ground in an ice bath in 10 mL polyvinylpolypyrrolidone and centrifuged at 7100 × *g* at 4 °C for 10 min. 2 mL of the supernatant were incubated with 2 mL guaiacol (8 mM) for 30 min at 30 °C. 1 mL H_2O_2 (2.5 mM) was added and mixed. Absorbance was measured at 460 nm. Results were expressed as U/g fresh weight, where U = 0.01 Δ460 nm per min. For PPO enzyme activity assay, 2 g of pear were blended with 10 mL of 0.1 M PBS (pH 6.4), and centrifuged at 7100 × *g* for 10 min at 4 °C. 2 mL of the supernatant were incubated with 6 mL of 0.1 M PBS (pH 6.4) and 2 mL of 0.2 M catechol for 10 min at 37 °C and the reaction was quenched at 95 °C for 5 min. Absorbance was determined at 420 nm. The result was stated as U/g fresh weight, where U = 0.01 Δ420 nm per min.

2.10. Measurement of microbial contamination

Total numbers of aerobic microorganisms in pears were determined during storage as described elsewhere [17] with some modifications. 2.5 g of pears were mixed with 22.5 mL of sterile water in a sterile beaker in a biosafety cabinet. Samples were diluted serially in sterile water, plated on nutrient agar medium, and incubated at 36 °C for 24 h. Colony numbers were assessed and expressed as $\log_{10}$ CFU/g.

2.11. Sensory analysis

Sensory analysis of treated and non-treated minimally processed pear was evaluated using a 9-hedonic scale test according to the method of Sharma and Rao [22] with modifications based on the methodology outlined above. Overall acceptability was assessed based on color, texture, taste, and odor at the commencement of OFFF treatment and during storage. Samples were presented at random to 21 non-expert panelists that comprised students and research scientists. Panelists classified samples by the following hedonic scale of 9 points: 9 = excellent, 7 = very good; 5 = good, 3 = unacceptable, and 1 = extremely unacceptable.This study was reviewed and approved by the Ethics Committee of the First Affiliated Hospital of Henan University of Science and Technology prior to sensory analysis on September 20, 2022(Approval number: 2022-09-B107).

2.12. Statistical analysis

All experiments, except sensory analysis, were conducted in triplicate and the data were expressed as mean ± standard deviation. Data were assessed by one-way analysis of variance (ANOVA) followed by the Duncan post hoc test using SPSS statistical analysis software. Differences of $p < 0.05$ were considered significant.

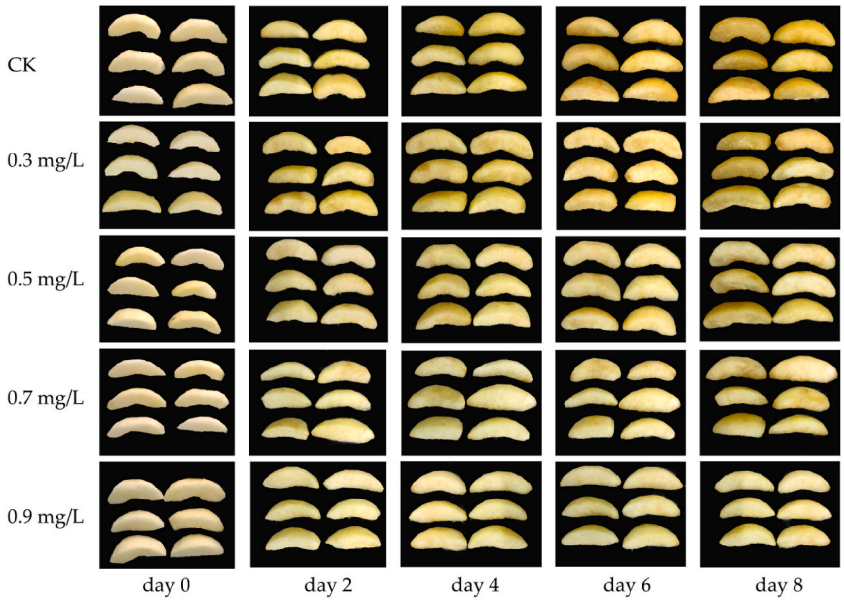


Fig. 2. Browning of fresh-cut Yuluxiang pear slices during storage at 4 °C.

3. Results and discussion

3.1. Effects of OFFF treatment on fresh-cut Yuluxiang pear weight loss, firmness, and color

The effects of OFFF treatment on weight change, firmness, and color of fresh-cut Yuluxiang pear samples were analyzed on alternate days during an eight day period using 0.3, 0.5, 0.7, and 0.9 mg/mL of extract, as well as an untreated control (Fig. 1). Weight loss of all samples increased during the treatment process, although loss was most pronounced in the untreated samples at all time periods. Moreover, the weight reduction of OFFF-treated samples was significantly less than the control group ($p < 0.05$), specially for the samples treated with 0.9 mg/mL extract (Fig. 1A). The firmness of fresh-cut Yuluxiang pears decreased progressively during the test period, although firmness of pears treated with OFFF (0.7 and 0.9 mg/mL extract) was significantly higher than the untreated control ($p < 0.05$) from day 2 (Fig. 1B). Treatment with 0.9 mg/mL extract exerted the best effect on maintenance of fruit firmness. The enhanced weight loss and diminished firmness of fresh-cut pears may be caused mainly by increased water loss during storage. Damaged cell membranes may promote metabolite release to extracellular spaces which results in a flaccid pear texture. In addition, cell walls that were wounded during fresh-cut processing may affect the actions of cell wall hydrolases due to leakage of electrolytes

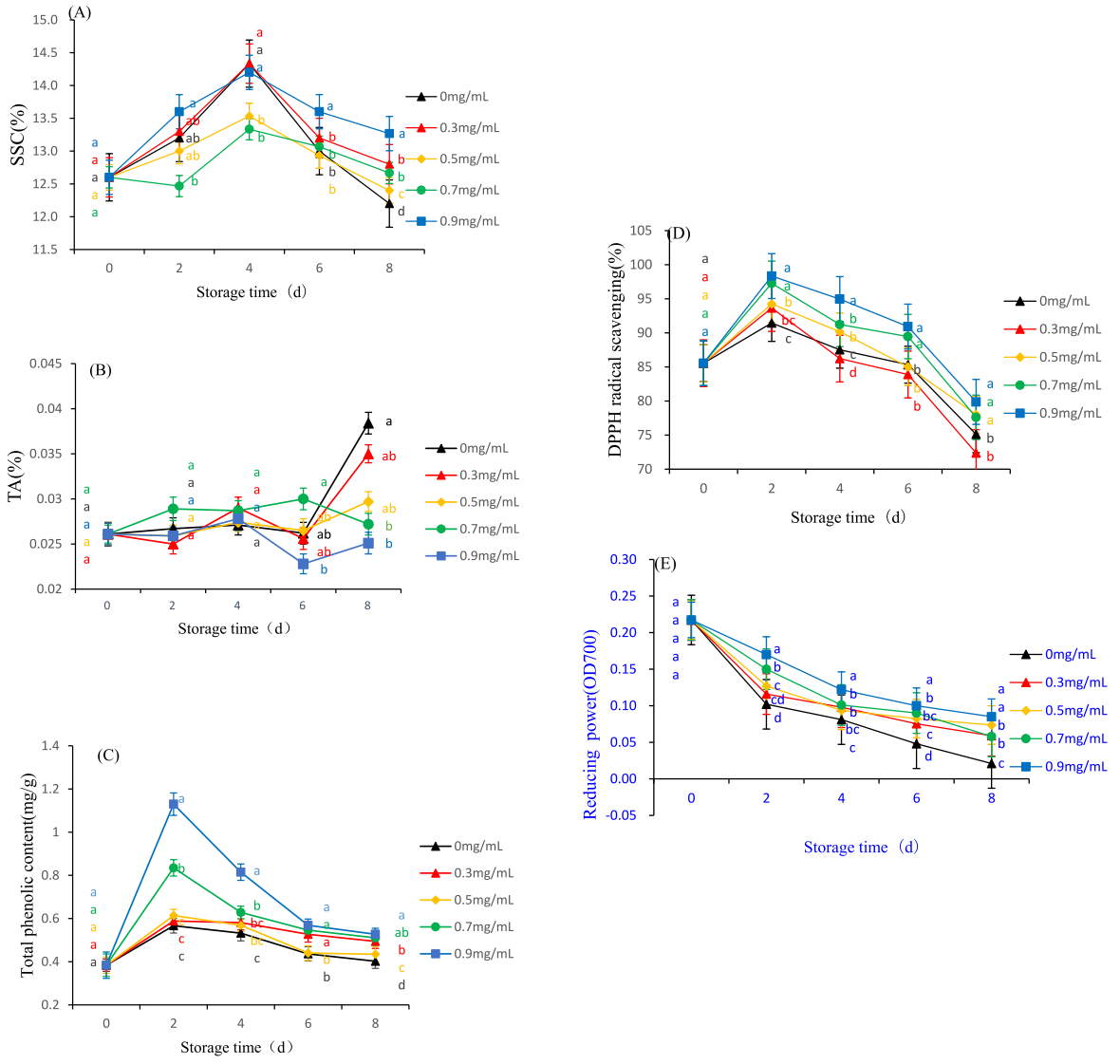


Fig. 3. Effects of OFFF treatment on (A) SSC content, (B) TA, (C) total phenolic content, (D) DPPH free radical scavenging ability, and (E) reducing power of fresh-cut Yuluxiang pear. Data are expressed as mean values with standard deviation from three replicates, and vertical bars represent the standard errors of the means. Different letters above the lines indicate significant differences ($p < 0.05$) for each sampling date.

that promoted the rapid decline of fruit integrity [23,24]. The decreased firmness during storage may reflect damage of cell vacuoles which consequently may promote water diffusion and subsequent water loss from the fruit [25]. The results indicate that OFFF treatment may have preventative effects on water loss and cell wall hydrolase activities, as well as positive effects on cell membrane integrity.

Color is a major sensory property of fruit. Browning of fruit due to oxidation of phenolic compounds to brown pigments diminishes nutritional quality and product value. OFFF treatment enhanced natural color retention and reduced browning of fresh-cut Yuluxiang pears (Fig. 2). The BI increased gradually during storage of the pears for up to eight days (Fig. 1C). However, OFFF treatment reduced browning compared with the untreated control throughout the storage period. For example, the BI values of pears treated with all concentrations of OFFF were significantly lower ($p < 0.05$) than the control samples after eight days (Fig. 1C). The initial L* value of 65.07 decreased to 58.62, 58.91, 60.45, and 60.35 for samples treated with 0.3, 0.5, 0.7, and 0.9 mg/mL OFFF, respectively. In comparison, the L* of untreated samples decreased to 57.96 (Fig. 1D). Changes in flesh color (ΔE) of untreated fresh-cut Yuluxiang pears and of pears treated with OFFF increased during the test period (Fig. 1E). However, the increase in ΔE values was reduced significantly in samples treated with all concentrations of OFFF compared with the untreated sample in the first four days. Increases in BI and loss of natural color are common characteristics of fresh-cut fruit. Tissue damage caused by slicing places the cut surface in rapid contact with air which results in oxidation and enzymatic and nonenzymatic browning reactions that promote the loss of natural color [26,27]. However, flavonoids may inhibit the activity of PPO and thereby ameliorate the rate of enzymatic browning [28]. Thus, the results here with fresh-cut Yuluxiang pears suggest that increases in BI values may be due to the formation and accumulation of brown compounds caused by nonenzymatic browning during storage. In addition, the decreases in L* values and the increases in ΔE levels are indicative of browning [29]. However, treatment with OFFF consistently improved BI, L*, and ΔE values which suggest that application of flavonoids partially offsets the decline in sensory properties of fresh-cut Yuluxiang pears during storage.

3.2. Effect of OFFF treatment on soluble solid content and titratable acid of fresh-cut Yuluxiang pear fruit

In view of the preceding observations that OFFF reduced weight loss and improved the firmness and color characteristics of fresh-cut Yuluxiang pears during storage compared to untreated fruit, SSC and TA parameters also were assessed. These parameters are indicators of fruit flavor and maturity. SSC of fresh-cut pear fruit increased in the first four days for both untreated samples and samples treated with 0.3, 0.5, 0.7, or 0.9 mg/mL OFFF, and declined subsequently. Nevertheless, the SSC content of fresh-cut pears treated with OFFF was significantly higher ($p < 0.05$) on day 8 compared with untreated fruit (Fig. 3A). Moreover, the TA for OFFF-treated fresh-cut pear was lower than the control group on day 8, with 0.7 mg/mL and 0.9 mg/mL concentrations of extract exerting the most significant effects ($p < 0.05$) (Fig. 3B). The increase in SSC content during early storage may indicate the conversion of starch to sugars, whereas the subsequent decrease may be due to the consumption of sugar substrates by respiration [30]. In addition, the decrease in SSC may be caused by the effect of the extracts on carbohydrate metabolism [21]. Changes in TA content during storage may be more complex. First, water loss in the samples increases with increased storage time which may be reflected in the upward trend in TA content in the early stages. Second, increased microbial invasion and an accelerated decay rate towards the end of storage may cause the accrual of certain acidic compounds that significantly boost the TA content of both untreated and OFFF-treated samples. Nevertheless, this increase may be counterbalanced by the consumption of organic acids through respiration so that the TA content decreases [31].

3.3. OFFF treatment impacts antioxidant capacity and total phenolic content of fresh-cut Yuluxiang pear fruit

Phenols in fruits possess antioxidant capacity which is implicated in enzymatic browning. The total phenol content of fresh-cut Yuluxiang pears increased in the first two days for both untreated and OFFF-treated samples, followed by a decline on days 4, 6, and 8. However, the content of total phenol in samples treated with OFFF was significantly higher ($p < 0.05$) than the control on day 8 (Fig. 3C). DPPH radical scavenging ability and reducing power reflect antioxidant activity in fruits. DPPH radical scavenging ability increased in the first two days in all pear samples, and then declined. However, the DPPH radical scavenging activity of pears treated with OFFF was significantly higher ($p < 0.05$) than untreated samples at day 8, except in the case of treatment with 0.3 mg/mL OFFF (Fig. 3D). The effect of OFFF on reducing power in fresh-cut pears also was assessed. The reducing power in samples treated with 0.3, 0.5, 0.7, and 0.9 mg/mL OFFF decreased from a starting value of 0.217 to 0.059, 0.074, 0.058, and 0.085, respectively (Fig. 3E). In comparison, reducing power in untreated samples decreased to 0.021. Thus, the reducing power in fresh-cut pear treated with all concentrations of OFFF was significantly higher ($p < 0.05$) in comparison with control samples during eight days of storage. These results indicate that OFFF treatment exerts a beneficial effect on maintaining the total phenol content in fresh-cut pears. The total phenol content increased up to day 2 due to water loss and softening of fruit during storage [24]. The subsequent decrease in total phenol content reflects reactions between phenolic substrates and PPO with consequent browning, destruction of cell membrane structure, and decomposition of cell intima [32]. The decline in antioxidant activity in pear samples during storage may be due to cellular senescence and decay. In addition, as the phenol content decreased and the degree of browning increased, the antioxidant activity in the fruit decreased significantly [33].

3.4. Effect of OFFF treatment on POD and PPO activities of fresh-cut Yuluxiang pear fruit

POD and PPO catalyze the conversion of phenols to quinones and therefore play key roles in the browning process in fruit [34]. In particular, surface browning of fresh-cut pears is exacerbated by an increase in POD activity accompanied by a reduction in total phenol content. POD activity increased on day 2 and diminished during extended storage of both untreated and OFFF-treated pear

samples (Fig. 4A). PPO activities in the untreated control sample and in fruit treated with 0.5 mg/mL OFFF increased during the first four days and then decreased. Other OFFF treatments were accompanied by gradual increases in PPO activity during the first six days with a subsequent decrease (Fig. 4B). Overall, PPO activity in OFFF-treated fruit decreased significantly from day 6 to day 8 compared with the control group. PPO and POD are the key enzymes that instigate enzymatic browning and the increase in the activities of these proteins may reflect tissue damage in the fresh-cut pears in the early stage of storage [35].

3.5. OFFF treatment reduces the microbial load of fresh-cut Yuluxiang pear

The microbial status of fresh-cut pear fruit is a critical parameter for assessing storage quality. Therefore, the impact of OFFF treatment on total aerobic microorganisms on the surfaces of fresh-cut Yuluxiang pears was assessed. The total microbial count at the beginning of the trial was 1.67 log10 CFU/g. These numbers increased to 2.51 log10 CFU/g, 2.44 log10 CFU/g, 2.31 log10 CFU/g, 2.25 log10 CFU/g, and 2.13 log10 CFU/g for untreated samples and samples treated with 0.3, 0.5, 0.7, and 0.9 mg/mL OFFF, respectively, during eight days of storage (Fig. 4C). Thus, the microbial load in both control and flavonoid-treated fresh-cut pear fruit increased gradually during the storage period. However, OFFF treatment significantly inhibited ($p < 0.05$) the growth of surface

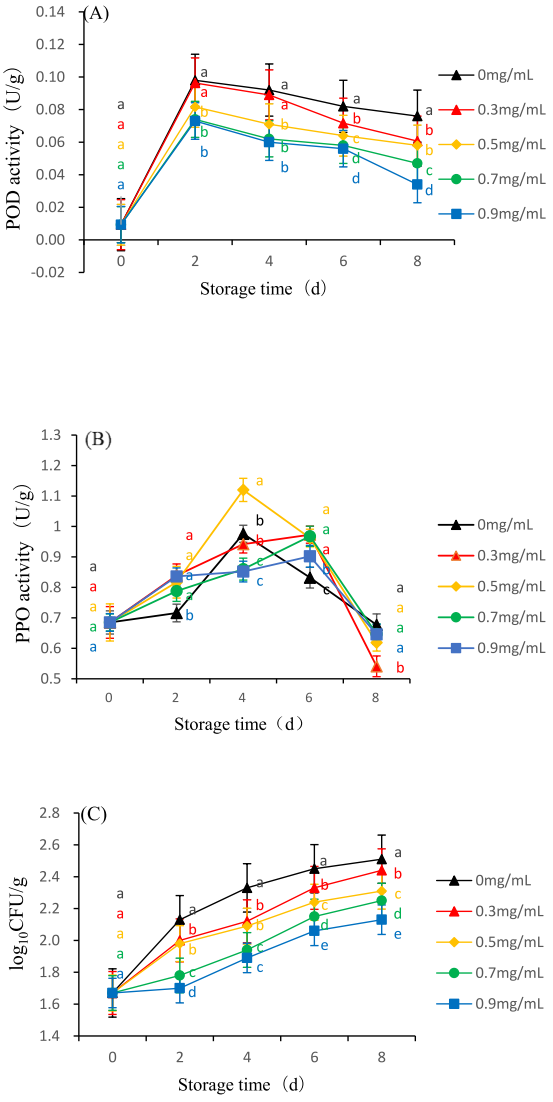
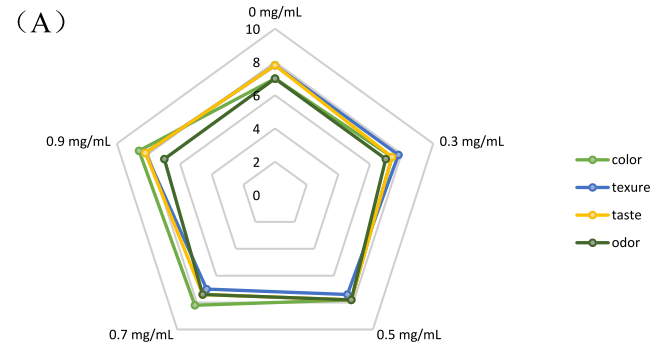
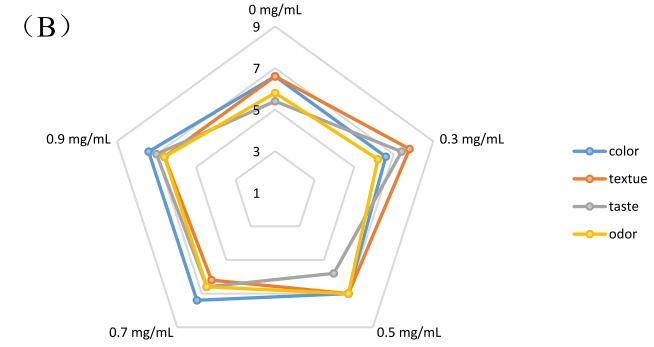
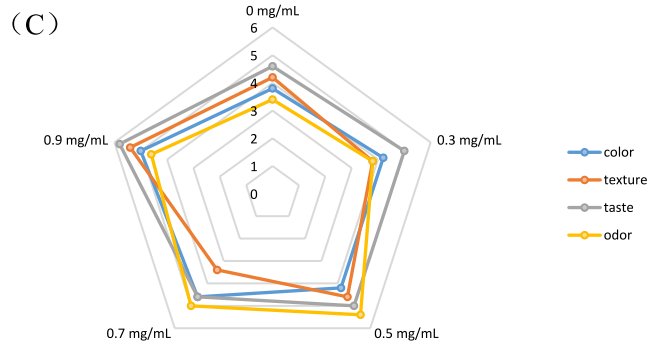


Fig. 4. Effects of OFFF treatment on the activity of (A) POD, (B) PPO, and (C) bacterial counts of fresh-cut Yuluxiang pear. Data are expressed as mean values with standard deviation from three replicates, and vertical bars represent the standard errors of the means. Different letters above the lines indicate significant differences ($p < 0.05$) for each sampling date.







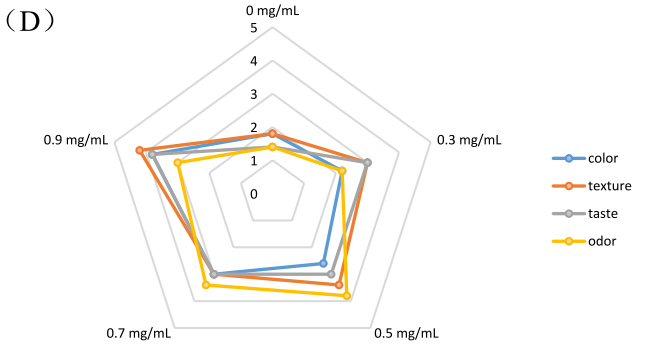


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Fig. 5. Effect of OFFF treatment on part sensory quality of fresh-cut Yuluxiang Pear on (A) day 2, (B) day 4, (C) day 6, and (D) day 8. Data are expressed as mean values.

microorganisms. Plants are rich in flavonoids that exhibit antibacterial activity [36]. Moreover, flavonoid compounds extracted from milk banana peel effectively controlled bacterial growth [37]. In addition, different flavonoid monomers in OFFF exert different antibacterial activities. Therefore, it is necessary to analyze further the specific compounds in OFFF that possess antimicrobial activity to pinpoint which one of these compound(s) is implicated.

3.6. OFFF treatment on fresh-cut Yuluxiang pear fruit sensory quality

Consumers often choose food products for the first time based on appearance, whereas taste, texture, color, odor, and other sensory factors encourage repeat purchases. According to the preceding data, a panel of 21 non-trained individuals was used here to ascertain whether treatment of fresh-cut Yuluxiang pear with OFFF (0.3, 0.5, 0.7, and 0.9 mg/mL) influenced consumer opinion. The application of OFFF had no notable impact on sensory qualities such as color, taste, texture, and odor during two days of treatment (Fig. 5). Indeed, untreated samples received lower color scores (>5) than OFFF-treated samples until day 6 of the storage period (Fig. 5C and D). The sensory quality scores for treated samples were significantly higher than scores for untreated samples on day 8. Thus, the results indicate that OFFF treatment has a positive impact on the sensory quality of fresh-cut pear fruits.

4. Conclusions

The purpose of this study was to explore the effects of OFFF on physical, physicochemical, microbiological, and sensory parameters of fresh-cut Yuluxiang pears during the course of eight days storage at 4 °C. The results revealed that OFFF treatment exerted significant positive effects on fresh-cut Yuluxiang pear freshness and suggest that OFFF may be a promising approach to improve fresh-cut pear shelf life. OFFF reduced the weight loss of pears during storage, delayed fruit softening, maintained color and firmness, and reduced the loss of TA, SSC, and the total phenolic content. Moreover, OFFF showed a potent antioxidant ability that prevented pear tissue from oxidation and also effectively reduced microbial growth thereby ensuring quality and maintaining shelf life. OFFF also maintained pear sensory quality. Overall, 0.9 mg/mL OFFF exerted the best effect on pear characteristics, although 0.7 mg/mL OFFF also was effective and is slightly more economical. The combined results suggest that OFFF treatment may be a promising strategy to enhance the storage quality of fresh-cut Yuluxiang pears. In addition, in view of the growing demand for green and safe fresh-cut fruits and vegetables and the high antioxidant activity and potent antimicrobial activity exhibited by OFFF, these flavonoids may be used to develop new natural preservatives that have broad applications in maintaining fresh-cut produce freshness.

Ethics statement

This study was reviewed and approved by the Ethics Committee of the First Affiliated Hospital of Henan University of Science and Technology, with an approval number: 2022-09-B107. An informed written consent to participate in the study was obtained from each participant.

We confirm that the study complies with all established regulations and ethical guidelines. Before conducting the study, we informed the sensory panels and ensured that the proper protocols were followed to protect the rights and privacy of all participants. These protocols included:

(1) No Coercion: Participants were not subjected to any form of coercion to participate in the study.
(2) Full Disclosure: We provided a comprehensive disclosure of the study's requirements and associated risks to the participants.
(3) Informed Consent: Participants were required to provide written consent, ensuring that they were fully aware of their participation in the study.
(4) Data Protection: We guaranteed that participant data would not be released without their explicit knowledge and consent.
(5) Withdrawal Option: Participants had the freedom to withdraw from the study at any point without facing any consequences.
(6) Vulnerable populations were not included in our study.

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Data availability

Data will be made available on request.

CRediT authorship contribution statement

Dixin Chen: Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Qian Wang:** Writing – original draft, Methodology, Data curation. **Yingjun Yang:** Formal analysis. **Yang Zhang:** Validation, Data curation. **Peijie Zuo:** Validation. **Yujie Guo:** Methodology, Data curation. **Zhiguo Shen:** Supervision, Funding acquisition, Data curation.

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e29748.

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