Effects of Different Treatments on Postharvest Storage of Hongxiangsu Pear

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Abstract [**Objectives**] This study was conducted to effectively prolong the shelf life of Hongxiangsu pear and maintain its excellent quality. [**Methods**] The fruit of Hongxiangsu pear were treated with 1.5% sodium alginate, 0.4 g/L natamycin and 2% chitosan for 3 min, respectively. Taking soaking treatment as control, the effects of different treatments on the weight loss rate, firmness, color difference, soluble solid content, titratable acid content, catalase activity and peroxidase activity of Hongxiangsu pear fruit during postharvest storage were studied at 25 ℃. [**Results**] The results showed that compared with the control group, single or compound treatments all delayed the decline of fruit firmness and color difference, better inhibited the increase of weight loss rate, and maintained higher soluble solids and total acid content. Physiologically, single and compound treatments all maintained the activities of peroxidase and catalase. Among them, the compound treatment of three reagents could improve the storage and fresh-keeping ability of Hongxiangsu pear. After 15 d of storage, the weight loss rate of the fruit treated with three reagents was lower than that of the blank group by 2.47%, and the color difference was lower than that of the blank group by 3.79. In terms of soluble solids, firmness, and other qualities, the fruit treated with the combination of the three reagents was superior to that treated with singe reagent or two reagents in pair. [**Conclusions**] Different compound coating treatments all showed positive effects on the preservation of Hongxiangsu pear, but before practical application and promotion, it is necessary to further explore the appropriate coating methods and proportions.

Key words Hongxiangsu pear; Sodium alginate; Natamycin; Chitosan; Compound treatment

DOI:10.19759/j.cnki.2164 – 4993.2024.06.015

Hongxiangsu pear is a hybrid of Xinjiang Korla fragrant pear and Zhengzhou Eli pear. As a characteristic fruit with high nutritional value, delicious taste, and medicinal value[1], due to its thin skin, thick flesh, and crispy texture, it is susceptible to fungal invasion during storage, and is prone to problems such as yellowing of the skin, dewatering and softening, browning, and rotting at room temperature after harvesting[2], resulting in a sharp decline in commodity value and economic losses. How to effectively extend the shelf life of Hongxiangsu pear and maintain its excellent quality is particularly urgent.

At present, more and more attention has been paid to the physical and chemical preservation techniques, and the composite coating preservation technique based on bio-based materials has shown great potential. The advantages of biomaterials include environmental sustainability, biodegradability, reduction of resource consumption, reduction of carbon emissions, and being safe and friendly to human body and environment. These advantages make them an ideal choice for green and environmental protection[3]. Sodium alginate, as a natural polysaccharide from marine brown algae[4], shows good fresh-keeping effect in Gongli pear, Cuiguan pear, Huanghua pear and other pear varieties with its excellent biocompatibility, non-toxicity and excellent film-forming performance[5]. It can form an effective protective layer on the surface of Hongxiangsu pear, which can limit the evaporation of water, prevent the infiltration of oxygen and inhibit the occurrence of oxidation reaction, thus maintaining the fresh state of fruit.

Chitosan is a kind of natural macromolecular polysaccharide from crustacean shell, which has obvious antibacterial, antiseptic and antioxidant effects[6]. Ma[7] treated cantaloupe with 2% chitosan solution, which reduced the fruit weight loss, maintained the firmness and color, and significantly improved the antioxidant capacity of cantaloupe. In the coating treatment of Hongxiangsu pear, chitosan can not only inhibit the growth of various rot-causing microorganisms and prevent microorganism-induced rot, but also delay the physiological and biochemical changes by enhancing the activity of antioxidant enzymes in the fruit[8], thus effectively prolonging the storage period of Hongxiangsu pear.

Natamycin is a natural antifungal compound produced by *Streptomyces* fermentation, and its inhibitory effect on fungi is about 50 times stronger than that of potassium sorbate[9]. Natamycin changes the permeability of the cell membrane by binding to a special part of the cell membrane of fungi and causing the intracellular nutrients to ooze, thus achieving antibacterial effect[10]. At present, natamycin is mainly used in dairy products, meat products, fruits and vegetables, and beverages. Sun *et al.*[11] applied natamycin suspension on the surface of citrus, and the results showed that the optimal concentration of natamycin was 0.3 – 0.4 g/L. Incorporating natamycin into the coating formula can not only directly inhibit harmful microorganisms, but also construct a composite coating with comprehensive protection function together with sodium alginate and chitosan, which can completely resist all kinds of factors that are not conducive to the storage of Hongxiangsu pear.

Received: September 17, 2024 Accepted: November 25, 2024

Supported by Undergraduate Innovation and Entrepreneurship Training Program of Guangdong Province (S202010580073); Undergraduate Innovation and Entrepreneurship Training Program of Zhaoqing University (X202210580139, X202210580143); Zhaoqing Science and Technology Innovation Guidance Project (202304038003).

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However, although single materials achieve certain results in fruit preservation, the compound coating preservation technique is expected to achieve a more efficient preservation effect through the synergistic effect of various effective ingredients. Although the application of sodium alginate, chitosan and natamycin compound coating in fruit and vegetable preservation has been preliminarily studied, few systematic studies have been conducted on the particular fruit, Hongxiangsu pear, in China. In this study, the effects of sodium alginate, chitosan and natamycin on postharvest preservation and physiological metabolism of Hongxiangsu pear were investigated by single or compound coating experiments.

Materials and Methods

Experimental materials

Hongxiangsu pear fruit (origin: Linyi, Jiangxi) was bought in Xiangyang fruit trading market, Duanzhou District, Zhaoqing City, Guangdong Province, and immediately brought back in turnover baskets. The fruit with consistent size, color and maturity and free of rot, deterioration and mechanical damage was selected. The Hongxiangsu pear fruit to be treated was thoroughly washed with clear water to remove possible impurities and residues on the surface. After cleaning, the fruit was air-dried under natural ventilation at room temperature until the surface moisture evaporated completely.

Group setting

Eight different treatment groups were designed in the experiment including the control group. In the first group, the fruit was only used as a control group, and it was soaked in water for 3 min. In the second to fourth groups, the fruit was soaked in 1.5% sodium alginate solution, 0.4 g/L natamycin solution and 2% chitosan solution for 3 min, respectively, and then naturally dried. For the fifth and sixth groups, on the basis of the second group of fruit (soaked with sodium alginate), the fruit was further transferred to 0.4 g/L natamycin solution and 2% chitosan solution and soaked for 3 min, respectively, and then naturally dried. The seventh group was soaked in 0.4 g/L natamycin solution, and then transferred to 2% chitosan solution and soaked for 3 min. In the eighth group, the fruit was soaked in each solution for 3 min in the order of sodium alginate solution, natamycin solution and chitosan solution.

Data processing

Excel 2019 software was employed for data analysis. Origin Pro 2021 software was used for drawing. SPSS software was employed for significance analysis.

Determination methods of physiological indexes

Determination of weight loss rate The weight loss rate was determined by the weighing method[12]. During storage, the weight was measured by an electronic scale with a period of 3 d, and the weight loss rate was calculated according to the formula.

Weight loss rate (%) = (Fruit weight before storage − Fruit weight after storage)/Fruit weight before storage

Determination of peel color Referring to the research method of Liu[13], the L, a and b values of fruit were measured by an LS-173 color difference meter with a D65 light source, and the measurement diameter was 8.0 mm. The equatorial part of Hongxiangsu pear fruit was selected as the measurement area, and four relatively flat points were selected at the equatorial part and marked. The measurement was repeated for three times at each point to take the average. The total color change (ΔE) of Hongxiangsu pear was calculated according to the color difference of the marked points in different storage time.

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

Determination of fruit firmness Three relatively flat parts[14] were selected at the equatorial part of the fruit, and a 3.0 mm probe was selected as the hardness tester. During determination, the fruit was kept stable, a pressure was applied steadily with the probe perpendicular to the surface of the fruit until the probe penetrated 10 mm deep, and the reading was recorded.

Determination of soluble solids After the fruit was squeezed by a juicer, the fruit juice was filtered. It was measured by a handheld sugar meter with automatic warming function[15]. The handheld sugar meter was calibrated by distilled water first, and then, a sample solution to be measured was dropped. The light source was aligned to record the reading, and the measurement was repeated for three times to take the average.

Determination of total acid content According to GB 12456-2021 *National food safety standard: Determination of total acid in foods*[16], the total acid content of Hongxiangsu pear was determined by acid-base titration.

Determination of catalase (CAT) activity The activity of CAT was determined according to the steps in the instruction of peroxidase kit.

Determination of peroxidase (POD) activity The activity of POD was determined according to the steps in the instruction of catalase kit.

Results and Analysis

Effects of different treatments on weight loss rate of Hongxiangsu pear

Weight loss rate is an index to measure the freshness of fruit, usually indicating the degree of water loss[17]. With the passage of time, the weight loss rate of Hongxiangsu pear under all preservation methods showed an upward trend. The weight loss rate of the control group was the highest, and rose to 3.14% on day 15 (Fig. 1). The reason might be that after 15 d of storage, the fruit without fresh-keeping treatment began to rot and deteriorate due to the lack of antibacterial ability, and the weight loss rate was greatly improved due to the loss of a large amount of water. It indicated that the water loss of Hongxiangsu pear was the fastest without fresh-keeping measures. The weight loss rate of fruit with fresh-keeping measures was significantly lower than that of the control group ($P < 0.05$), indicating that these fresh-keeping methods delayed the loss of water to some extent. The effects of different preservation methods varied. For example, the weight loss rate of the group combining natamycin with chitosan or sodium alginate was significantly higher than that of natamycin alone, which indicated that such combination had a certain effect on water conservation of Hongxiangsu pear. However, after the fresh-keeping treatment with two kinds of preservatives, the fruit weight loss rate was lower in the chitosan + natamycin group, with a weight loss rate only 0.32% higher than that of the compound treatment using three kinds of preservatives. Even though the weight loss rate of the sodium alginate + natamycin + chitosan group was not significant compared with the chitosan + natamycin group, there was still a significant difference compared with the single treatment groups or blank group. It showed that the synergistic effect of different reagents in the compound treatment groups could prolong the storage period of Hongxiangsu pear to a certain extent.

Effects of different treatments on color difference of Hongxiangsu pear

The color difference $\triangle E$ obtained through the calculation among L, a and b values can comprehensively reflect the change of fruit color. In this study, the change of fruit color was judged by calculating $\triangle E$, and the greater the value, the greater the color change. At the beginning of the fruit, the outside was bright and green, and with the extension of storage time, chlorophyll in the peel decomposed[18]. The fruit began to turn yellow gradually, the value of a decreased, and the value of b increased, which made the color difference larger and larger. As shown in Fig. 2, with the extension of time, the color difference of all treated fruit gradually became larger. Compared with the control group, the treatment groups had a better effect of maintaining fruit color difference. Among them, the effect of sodium alginate + natamycin + chitosan compound treatment was significantly higher than that of the blank group ($P<0.05$), indicating that the compound treatment of sodium alginate + natamycin + chitosan postponed the degradation of chlorophyll in fruit, and simultaneously delayed the deterioration time of Hongxiangsu pear, making the surface free from rot and blackening and reducing the color difference. Therefore, the compound treatment using three reagents could better maintain the appearance quality of Hongxiangsu pear.

Effects of different treatments on fruit firmness of Hongxiangsu pear

The fruit firmness of Hongxiangsu pear is one of the key parameters for evaluating its internal quality. As shown in Fig. 3, with the gradual increase of storage time, the fruit firmness of Hongxiangsu pear showed a slow decreasing trend. At the initial stage of storage, the hardness values of various groups were similar, but there were significant differences between the untreated blank group and the treatment groups on days 12 and 15 of storage ($P<0.05$). It showed that different treatment methods could effectively maintain the hardness of Hongxiangsu pear to some extent. Among them, the sodium alginate + natamycin + chitosan treatment group had a significant maintenance effect ($P<0.05$). Compared with the initial storage period, the fruit firmness of the group decreased by only 0.43 kg/cm after 15 d of storage, while that of the untreated control group decreased by 0.84 kg/cm. Although the sodium alginate + natamycin + chitosan group was better than the blank group in maintaining the hardness of Hongxiangsu pear, there was no significant difference in the hardness between the fruit treated with the combination of two reagents and the fruit treated with a single reagent. The reason might be that the natural change of hardness of Hongxiangsu pear within 15 d was low, or the synergistic effect of compound treatment of two reagents was low. Although these preservation methods do have certain effects in maintaining the hardness of Hongxiangsu pear, it is still worth exploring and researching optimization of specific treatment methods or concentration to improve the hardness index of Hongxiangsu pear.

Effects of different treatments on soluble solid content of Hongxiangsu pear

The soluble solids in the fruit of Hongxiangsu pear are mainly composed of soluble sugars, which are often used as respiratory substrates[19] and play an important role in evaluating fruit maturity. It could be found by observing Fig. 4 that the content of soluble solids in the fruit of Hongxiangsu pear after different treatments fluctuated to varying degrees with the passage of time. From the 3rd day after storage, there was a general downward trend. During storage, the decreasing trend of soluble solids in Hongxiangsu pear fruit might be related to the respiration of the fruit, as the organic matter inside the fruit gradually decomposed. After coating, the lenticels of Hongxiangsu pear were covered, which reduced the respiratory intensity and slowed down the decline of soluble solids. At the end of 15-day storage, the soluble solid content in the fruit of the blank control decreased to 8.65%, while the soluble solid content of the sodium alginate + natamycin + chitosan treatment group was 10.53%. After 15 d of storage, the content of soluble solids in the control group was significantly lower than that in the sodium alginate + natamycin + chitosan treatment group ($P<0.05$).

Effects of different treatments on total acid content of Hongxiangsu pear

The total acids in the fruit of Hongxiangsu pear are various titratable acids, among which malic acid is the most[20]. It has an important influence on the flavor of Hongxiangsu pear fruit. The total acid content of fruit in each group showed a downward trend during storage. As can be seen from Fig. 5, during the storage time, the total acid content of Hongxiangsu pear in each group decreased with the extension of the experimental time. After 15 d of storage, the total acid content of sodium alginate + natamycin + chitosan treatment was 1.27%, while that of the control group without coating treatment was 1.01%. The differences between various treatment groups and the blank control group were different, and the sodium alginate + natamycin + chitosan group, sodium alginate + chitosan group, sodium alginate + natamycin group and chitosan + natamycin group all reached the significant difference level. The reason might be that the fresh-keeping film on the surface of the fruit in the sodium alginate + chitosan treatment group was thicker and could effectively prevent the entry of air and oxygen compared with single film coatings, and hence, it could

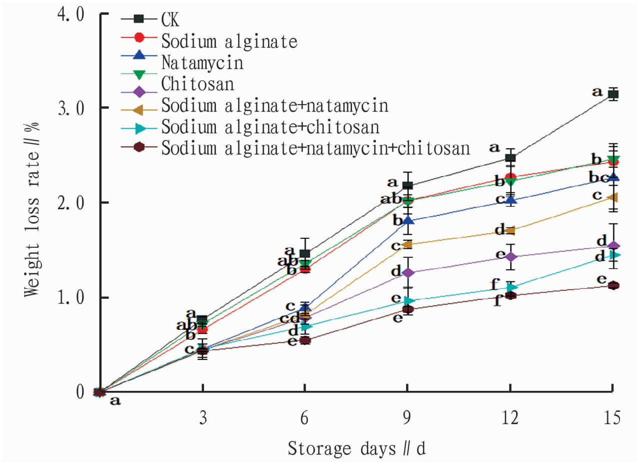

Fig. 1 Effects of different treatments on weight loss rate

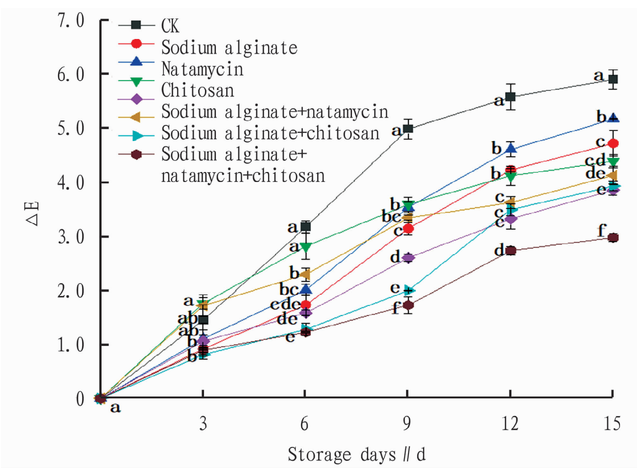

Fig. 2 Changing trend of peel color

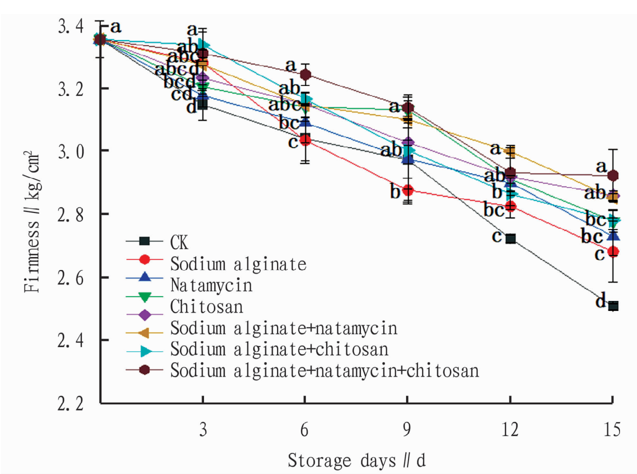

Fig. 3 Effects of different treatments on fruit firmness

slow down the respiration of the fruit and delay the loss of total acids caused by metabolism. However, after natamycin treatment, it could inhibit the growth of microorganisms and slow down the consumption of titratable acids in the fruit. After natamycin treatment, further treatment with sodium alginate or chitosan could attach a layer of film to the surface of the fruit, thus providing it with multi-layer protection.

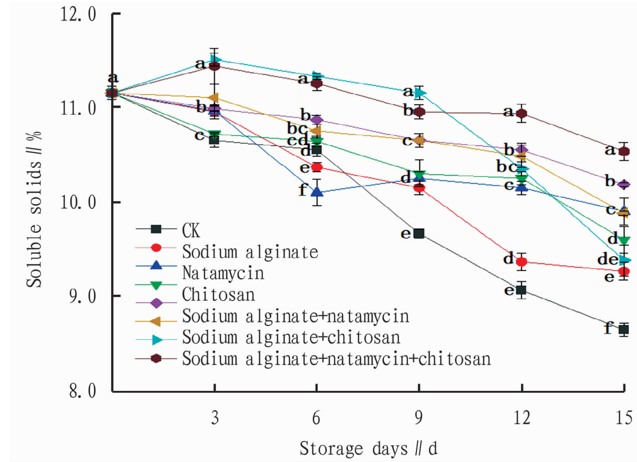

Fig. 4 Effects of different treatments on soluble solids of Hongxiangsu pear

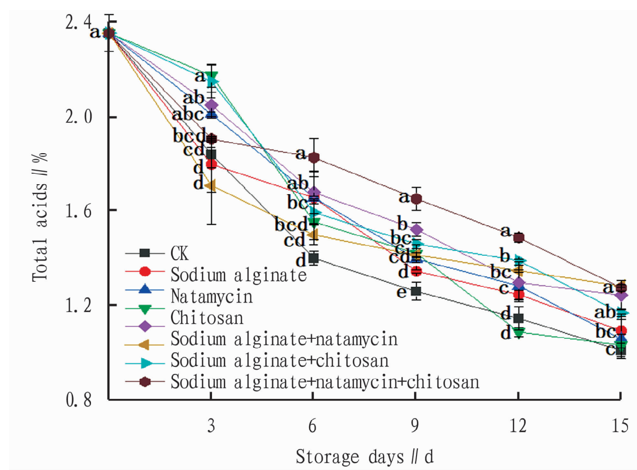

Fig. 5 Effects of different treatments on total acid content of Hongxiangsu pear

Effects of different treatments on catalase (CAT) activity of Hongxiangsu pear

CAT can directly remove H_2O_2 and decompose H_2O_2 into H_2O and O_2 when the fruit is under stress. The increase of CAT activity is an adaptive feature to overcome the damage of excess H_2O_2 to metabolic tissues[21]. As can be seen from Fig. 6, during the storage period of 15 d, the CAT activity of Hongxiangsu pear first increased and then decreased. The enzyme activity of the blank control group and sodium alginate group reached a peak after 3 d of storage, and then decreased all the time. However, the CAT activity of other treatment groups increased in the first 6 d, reached a peak on day 6, and decreased from day 6 to day 15. Among them, the group of sodium alginate + natamycin + chitosan kept the CAT activity at a high level. After 15 d of storage, the activity of CAT was 51.09 U/(g · min), while that of the control group was 15.35 U/(g · min). The results showed that the compound coating treatments could improve the activity of CAT in Hongxiangsu pear during storage, and maintain the activity of CAT in Hongxiangsu pear at a high level, and the maintenance effect was significant ($P<0.05$). The compound treatment group with three reagents had the best effect, and the coating treatment groups with two reagents showed the second effect, while the single reagent treatment groups exhibited the worst effect.

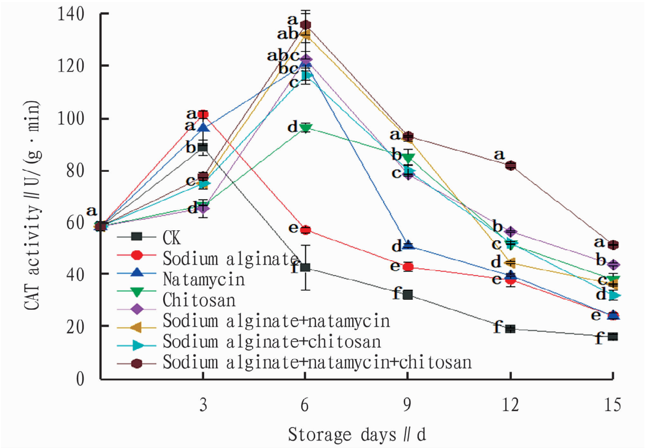

Fig. 6 Effects of different treatments on catalase (CAT) activity of Hongxiangsu pear

Effects of different treatments on peroxidase (POD) activity in Hongxiangsu pear

POD is an oxidoreductase, which plays an important role in the growth and development of plants and enzymatic browning[22]. During postharvest storage of the fruit, the POD activity firstly increased and then decreased. On the 6th day of storage, the POD activity of the fruit under all treatments reached a highest point, and the enzyme activity of the compound treatment group with three reagents was 1.14 times that of the control group, reaching a significant level ($P<0.05$). After storage for 15 d, the POD activity of the fruit treated with different reagents was higher than that of the control group in different degrees. Among them, the treatment group of sodium alginate + chitosanthe showed a higher POD activity of 14.97 U/(g · min), followed by the treatment group of sodium alginate + chitosan + natamycin. The single reagent treatments all could delay the decrease of POD activity, but the effect was significantly lower than that of compound treatments, and the compound treatments of two reagents could maintain the POD activity in the fruit better (Fig. 7).

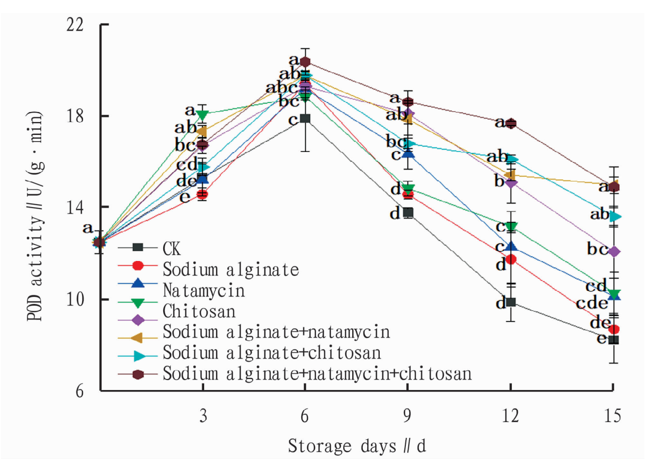

Fig. 7 Effects of different treatments on peroxidase (POD) activity in Hongxiangsu pear

Conclusions and Discussion

The results of this study showed that compared with the control group, both single and compound treatments could effectively delay the decline of firmness and color change and the increase of weight loss rate during storage, and maintain high soluble solids and total acid content, demonstrating good preservation effect. Especially when sodium alginate, natamycin and chitosan were used in combination, the best fresh-keeping performance was achieved. At the end of storage, the weight loss rate of Hongxiangsu pear in the compound treatment group was 1.89% lower than that in the blank control group, and the color difference value decreased by 3.94, and the quality parameters such as firmness and soluble solids were also better than the fruit in treatments of single reagent or two reagents in pair. When the three reagents were used in combination, the activities of peroxidase and catalase in the fruit of Hongxiangsu pear could be maintained, which was very important for resisting oxidative stress and delaying the fruit aging process. When sodium alginate and natamycin were used together, the color difference, hardness, soluble sugar content and CAT activity of the fruit were well maintained. The combination of sodium alginate and chitosan could maintain the total acid content and POD activity of the fruit, while the combination of natamycin and chitosan could better prevent the loss of fruit water, thereby delaying the increase of fruit weight loss rate.

However, this study also revealed some areas that need to be improved. Although the compound coating treatments showed superior preservation efficiency, there were still differences between different treatment methods, suggesting the possibility of further optimizing the treatment conditions and proportions. In addition, although this study confirmed the feasibility of the compound application of three biomaterials in the preservation of Hongxiangsu pear, the in-depth analysis of specific mechanisms, such as the interaction between different components, needs to be strengthened.

To sum up, this study not only verified the positive role of sodium alginate, natamycin and chitosan compound coating treatment in the preservation of Hongxiangsu pear, but also reflected their key role in maintaining fruit quality and physiological and metabolic stability. However, before practical application and popularization, it is necessary to further explore the appropriate coating methods, proportions and long-term storage effect.

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Editor: Yingzhi GUANG Proofreader: Xinxiu ZHU

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are suitable for cultivation in coastal saline-alkali areas in China.

Table 3 Traits of different asparagus cultivars under salt environment

No.	Cultivar	Plant height cm	Number of stalks	Mean spear weight//g	Total yield kg/hm^2
1	Grande	167	5.5	15.5	3 125
2	Eposs	175	5.1	14.2	3 875
3	European male	161	4.8	13.2	2 798
4	Uc157	174	5.3	13.7	2 875
5	Apllo	168	5.1	14.4	3 087
6	Taramec	157	5.0	14.5	3 545
7	Pacific green	157	5.5	14.1	2 985
8	Jinglv1	158	4.3	12.6	3 565
9	Pacific2000	147	6.2	13.9	2 075
10	Vittorio	149	4.6	11.6	3 541
11	Jinglv3	162	5.2	11.8	2 797
12	Feicuimingzhu	135	4.7	14.8	3 470
13	JX1502	178	5.5	16.2	5 040
14	Jersey knight	174	6.2	17.5	4 874
15	Jinggang701	154	4.1	12.8	3 580
16	Potron	137	4.9	12.8	3 568
17	Jinguan	170	4.8	14.5	3 520
18	T30	162	4.1	19.5	2 010
19	Guanjun	176	4.5	15.9	2 965
20	Jiyulvlu3	154	5.1	15.7	3 471

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