Food Science and Engineering
http://ojs.wiserpub.com/index.php/FSE/

UNIVERSAL WISER PUBLISHER

Research Article

Soy Protein Isolate Edible Coating Incorporated with Pomegranate (*Punica granatum* L.) Peel Extract: Effect on Quality of Fresh-Cut Pineapples

Han Lyn Foong[1], Mohamad Soufi Ikhwan Nazeri[1], Jun Xian Wong[2], Nur Hanani Zainal Abedin[1,3*]

[1]Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia
[2]Department of Food Science, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia
[3]Halal Products Research Institute, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia
E-mail: hanani@upm.edu.my

Received: 8 October 2024; **Revised:** 6 January 2025; **Accepted:** 16 January 2025

Abstract: This study investigated the development of an edible coating using soy protein isolate (SPI) and pomegranate peel extract (PPE) to extend the shelf life of fresh-cut pineapple (FCP). Different dipping times (0, 2, 3, and 4 min) of the FCP in the coating solution were evaluated, and the samples were stored at 4 °C for 15 days, with analyses performed on days 0, 3, 8, 10, and 15. Results showed that the coated FCPs exhibited higher firmness and titratable acidity. Furthermore, the PPE-SPI coating also prevented weight loss as well as delayed the increase in pH and total soluble solids, suggesting slower senescence and enhanced preservation. Notably, a 4 min dipping time significantly ($p < 0.05$) reduced total plate count and yeast and mould count compared to control samples by 30% and 40%, respectively. The study suggests that longer dipping times enhance the effectiveness of the PPE-SPI coating in extending the shelf life of FCP, showcasing the potential of the PPE-SPI coating as an alternative to synthetic preservation methods for fresh-cut fruits.

***Keywords*:** pomegranate peel extract, soy-protein isolate, edible coating, fresh-cut pineapple, shelf life, dipping time

1. Introduction

Over the recent decades, the consumption of fresh-cut fruits has surged, driven by factors such as rapid preparation, convenience, and minimal processing that preserves their inherent nutritional qualities [1]. However, fresh-cut fruits have a relatively short shelf life, typically ranging from 5 to 7 days in chilled storage [2]. Primary spoilage factors encompass the physical processes of cutting and peeling, which expose the fruits and vegetables to cellular degradation and microbial contamination [3]. The deterioration of fresh-cut products impacts nutritious components, aroma, colour, moisture, and microbiological quality [4].

Pineapple (*Ananas comosus* (L.) Merr. (Bromeliaceae)) is widely consumed globally, and is prevalent in tropical regions such as Costa Rica, Philippines, Brazil, Thailand, and Malaysia [5]. The pineapple market is projected to grow significantly, with an estimated market size of USD 28.79 billion in 2024 and is expected to reach USD 39.13 billion by

DOI: https://doi.org/10.37256/fse.6120255850

2029 [6]. Apart from being consumed as fresh-cut fruits, pineapple is often processed into various value-added products such as jam, beverages, powder, and syrup [7]. Approximately 80% of pineapples sold are processed, with 48% of the processed amount used for concentrated juice and 30% for canned fruit [8]. Despite its popularity, pineapples are highly perishable, posing challenges for storing and packaging. The ideal storage temperatures of pineapples range from 4 to 12 °C [9-11] and higher storage temperatures can accelerate the conversion of starch into sugar, increasing the risk of microbial spoilage [7, 12]. Postharvest losses of pineapples can occur during various stages, including harvest, storage, and transport and these losses are estimated to range between 20% and 40%. The primary causes include mechanical injuries, decay, physiological disorders, and damage caused by fruit pests. Additionally, fresh-cut pineapples (FCPs), when exposed to high oxygen concentration, are susceptible to browning which is often caused by the enzyme polyphenol oxidase (PPO) [10]. This process can be delayed by coating the fruit to reduce the concentration of available oxygen.

Edible film or coating is a green approach, offering technical functions of enhancing appearance, providing antimicrobial and antioxidant properties, preventing browning, and serving as a barrier against moisture, gas, solute movement, and food aroma [10, 13]. Their significance extends beyond practicality, aligning with the growing emphasis on sustainability within the modern food industry [13]. Edible coating is typically developed using biopolymers such as protein, lipids, and polysaccharide or combination thereof [12, 14-15]. The incorporation of active ingredients has enhanced the functionality of edible coatings, extending their potential from improving barrier properties to providing antimicrobial and antioxidant effects [16]. However, maintaining the original organoleptic properties of food while ensuring safety for human consumption remains paramount [17, 18]. Recent studies have demonstrated the effectiveness of edible coatings in prolonging the shelf life of FCP. In a previous study, sodium alginate coating containing citral nanoemulsion effectively preserved colour, lowered respiration rates, and minimized microbial contamination in FCP for up to 12 days at 4 °C [11]. Similarly, an almond gum coating maintained sensory qualities and inhibited microbiological growth on FCP for ten days at 7 °C [19].

Soy protein isolate (SPI) is biopolymer extracted from soybean meal, consisting of over 95% protein content. It has gained popularity as a key ingredient in composite films due to its excellent compatibility with various polymers such as cellulose, gelatin, starch, and bio-active compounds [20]. SPI offers several benefits, including high availability, cost-effectiveness, low gas permeability, and excellent film-forming abilities, making it an ideal food packaging material [21, 22]. It is also highly soluble in water and safe for consumption, which makes SPI a suitable material for edible coatings [21, 23]. Due to its hydrophilicity, SPI possesses a poor moisture barrier, which necessitates interactions with other additives to enhance its functionality [24]. Various approaches have been used to improve the physical and functional properties of SPI films. Lipids such as soybean oil [25], rapeseed oil [26] and sunflower oil [24] have been incorporated to improve the elongation and moisture barrier of SPI films. On the other hand, plant-based extracts such as mango kernel [27], mangosteen peel [28], and liquorice residue [29], have been incorporated in SPI films and coatings to improve the functional properties such as antioxidant and antimicrobial activities.

Pomegranate (*Punica granatum* L.) peel contributes to a significant portion of fruit waste, representing approximately 50% of the total fruit mass [30]. Pomegranate peel is rich in phenolic compounds and flavonoids, including anthocyanins, punicalagin, ellagitannins, gallagic acid, and ellagic acid, making it a promising source of antimicrobial and antioxidant compound [31, 32]. Numerous studies have demonstrated the antioxidant and antimicrobial properties of pomegranate peel extract (PPE) in various food products such as fish burger [33], chicken nuggets [34], tomatoes [35], and alfalfa sprout [36].

To date, research on SPI and PPE-based edible coatings for preserving fresh-cut pineapple is limited. In a previous study, Yousuf and Srivastava [37] reported that the application of SPI coating incorporated with honey effectively prolonged the shelf life of pineapples for up to 16 days and with a higher retention of phenolic compounds. The combination of SPI's gas barrier property and PPE's antioxidants makes it a promising material for protecting fresh-cut fruit and delaying oxidative deterioration. Therefore, this study aimed to incorporate PPE into SPI to produce an edible coating. The effect of dipping time on the physicochemical changes and microbiological quality of fresh-cut pineapple was also investigated.

2. Materials and methods

2.1 *Materials*

All of the fresh pineapples were sourced on the same day from a local supermarket (Serdang, Malaysia) in the month of May 2023 for consistency. The samples were meticulously examined and chosen for uniform shape and absence of visual defects. Pineapples at stage 3 maturity, characterized by a half-yellowish-orange coloration on half of the surface, were selected according to guidelines outlined by the United Nations Economic Commission of Europe [38]. Pomegranate peel was collected from a local fruit juice franchise (Kuala Lumpur, Malaysia). Absolute ethanol, plate count agar, and potato dextrose agar were procured from Merck (Darmstadt, Germany). Soy protein isolate (SPI, 92% protein content), glycerol, sodium hydroxide pellets (NaOH), and calcium chloride ($CaCl_2$) were supplied by Sigma-Aldrich Co. (St. Louis, USA). All the chemicals and solvents used were of analytical grades.

2.2 *Preparation of pomegranate peel extract*

The pomegranate peel extract (PPE) was prepared according to the method of Nur Hanani et al. [39] and Han Lyn et al. [40]. The peel was cut into small pieces and washed using sterile distilled water. Immediately, the collected pomegranate peel was subjected to oven drying (Memmert Universal Oven UF110, Roth, Germany) at 40 ℃ for 48 h. The dried pomegranate peel was ground into a fine powder using an electronic blender (Tefal Blend-force 3071, Sarcelles, France). The extraction of pomegranate peel was done using the maceration method. Absolute ethanol was introduced to the peel at the ratio of 5 : 1 (w : v). The mixture was shaken using a digital orbital shaker (witeg Labortechnik GmbH, Wertheim, Germany) at 70 rpm for 24 h at room temperature (26 ± 1 ℃) in the dark. The filtrate was collected using a Whatman no. 4 filter paper (Maidstone, United Kingdom). The crude pomegranate peel extract (PPE) was obtained by evaporating the remaining solvent using a rotary evaporator (IKA® RV8, Staufen, Germany) at 40 ℃ and 150 rpm.

2.3 *Preparation of PPE-SPI coating solution*

Sterile distilled water was heated to 60 ℃ and 3.5% (w/v) of SPI was added. The solution was stirred for 30 min. An aliquot of glycerol (1%; w/v) and PPE (2%; w/v) were added into the solution and stirred at 50 ℃ for another 30 min. $CaCl_2$ (2%, w/v) was incorporated and the solution was stirred at 50 ℃ for another 30 min to induce crosslinking. The formula for preparing 100 mL of PPE-SPI coating solution is shown in Table 1.

Table 1. Formula for 100 mL of pomegranate-soy protein isolate (PPE-SPI) coating solution for fresh-cut pineapples

Materials	Sterile distilled water	SPI	Glycerol	PPE	$CaCl_2$
Amount	100 mL	3.5 g	1 g	2 g	2 g

2.4 *Coating treatment and pineapples storage*

The cutting board and knife were thoroughly washed and sanitized using a 0.1% (w/v) sodium hypochlorite solution (NaClO). Pineapple fruits were sliced into wedges which were approximately 2 cm wide. The fresh-cut pineapple (FCP) wedges were washed with distilled water for 2 min and the excess water was allowed to drip off. The FCP was divided into 4 batches (treatments): a control group without dip coating and three groups with different dipping times (2, 3, and 4 min) in the PPE-SPI coating solution. The maximum dipping time was limited to 4 min to prevent the FCP from becoming soggy. After dipping, all samples were allowed to drip off excess solution for 1 min. Subsequently, the dipped FCP wedges were immersed into $CaCl_2$ solution 2%, w/v) to induce cross-linking. Then, the samples were air-dried at room temperature (26 ± 1 ℃). The average time taken for the samples to dry was approximately 60 min. Subsequently, the samples were packaged according to their respective batches. Three FCP wedges from each

batch were placed in a polyethylene container with dimensions of 15 cm × 10 cm × 6 cm (length × width × height). The samples were arranged evenly, ensuring no contact between them. Both control and coated FCP samples were refrigerated (4 ± 1 °C) for 15 days in a commercial chiller (Midea, Guangdong, China). Physicochemical analyses were conducted at regular intervals (days 1, 3, 5, 8, 10, 12, and 15). Analysis was terminated after day 15 due to visible mould growth on all samples.

2.5 *pH, titratable acidity, and total soluble solids*

The control and coated FCP samples were homogenized and the residue was filtered using a Whatman no. 4 filter paper. Subsequently, the pH values of the filtrate were measured using a pH meter (Mettler Toledo F20, Ohio, United States).

Titratable acidity (TA) was determined according to the methods by Wang et al. [15] and Costa et al. [14] by mixing an aliquot (10 g) of the filtrate with 90 mL of sterile distilled water. The mixture was titrated along with 0.1 M NaOH solution until the end-point of pH 8.1 was reached. The TA value of the sample was expressed as the percentage (%) of citric acid and was calculated using the following formula:

$$\mathrm{TA}(\%) = \frac{w \times N \times v_{NaOH}}{v_{sample}} \times 100 \quad (1)$$

where, w is the weight of filtrate (g), N is the concentration of the sodium hydroxide (M), V_{NaOH} is the volume of the sodium hydroxide solution used in titration (mL), v_{sample} is the volume of the solution being titrated (mL).

Total soluble solids (TSS) of the samples were measured with a refractometer (Atago PAL-1, Maharashtra, India) based on the protocols of AOAC 942.15 [41] and Nazoori et al. [42]. The refractometer was calibrated using sterile distilled water. Then, a few drops of the filtrate were dispensed onto the prism and the value was recorded. All the TSS values were expressed as degree Brix (°Bx).

2.6 *Firmness*

The firmness of FCP was determined using a texture analyser (TA-XT2i, Stable Micro System, Surre, England) with reference to the method described by Jiang et al. [43] with minor modifications. To simulate biting and chewing, FCP sample (30 g) was positioned on the stage, and a stainless-steel cylindrical probe (2 mm diameter) with a 3.0 g load cell and a head speed of 0.50 mm/s was lowered onto the sample until it pierced through. The maximum firmness was recorded as peak force and expressed in newtons (N).

2.7 *Weight loss*

The weight of the samples was measured using a digital balance (Presica 4,000C, Zurich, Switzerland). The initial weight of all samples (day 0) was recorded and compared with weight at day 3, 8, 10, and 15. The weight loss is expressed in percent and calculated using the formula below [15]:

$$\text{Weight loss } (\%) = \frac{w_0 - w_1}{w_0} \times 100 \quad (2)$$

where w_0 is the sample weight (g) at day 0 and w_1 is the sample weight (g) after storage.

2.8 *Determination of colour change*

The colour changes of FCP samples during 15 days storage were evaluated using a colorimeter (Minolta CR-300, Konica Minolta Sensing, Tokyo, Japan). The instrument was calibrated using a standard white plate. Measurements were taken at three predetermined locations on each sample to ensure consistency and uniformity in the data. Visible yeast and mould growth was carefully removed before measurements were taken to ensure accuracy of data. The colour

of the samples was measured using CIE $L^*a^*b^*$ coordinates, where L^* represents lightness and darkness, a^* represents greenness or redness, and b^* represents blueness or yellowness.

2.9 *Microbiological analysis*

Total plate counts (TPC) and yeast and mould counts (YMC) were carried out on both coated and uncoated FCP samples on days 0, 3, 5, 8, 10, 12, and 15 of storage. To begin, FCP was aseptically transferred into a sterile stomacher bag and homogenized with saline (0.85%, w/v). The mixture was pummelled using stomacher (Interscience Bag Mixer® 400P, Saint Nom la Bretêche, France) for 1 min. Subsequently, serial dilutions were prepared and aliquots of the diluent (0.1 mL) were pipetted and spread onto agar media. Plate count agar (PCA) and potato dextrose agar (PDA) served as the growth media for TPC and YMC, respectively. Following inoculation, all plate cultures were incubated at 37 ℃ for 24 h (PCA) and 35 ℃ for 48 h (PDA). The analysis was carried out in triplicate and the number of colonies was enumerated and expressed as logarithmic colony-forming units per gram (log CFU/g).

2.10 *Statistical analysis*

All data were statistically analysed using one-way analysis of variance (ANOVA) and Tukey's comparison test to determine significant differences ($p < 0.05$) among the mean values at a 95% level of significance ($\alpha = 0.05$). The analysis was conducted using Minitab software (version 2018).

3. Results and discussion

3.1 *pH*

Figure 1 shows the pH values of FCP with various dipping times across different storage periods. Significant differences ($p < 0.05$) were observed between the coated samples and the uncoated (control) sample. On day 0, the difference of pH values among all samples were insignificant ($p \geq 0.05$). The pH decrease in the coated samples could be attributed to the acidity of the pomegranate extract [44]. From day 3 to day 15, a consistent increase in pH values was noted across all FCP samples, including those with the maximum coating time of 4 minutes, reflects the natural progression of ripening and senescence in fresh-cut pineapples [45]. This rise in pH could be attributed to the utilization of organic acids as substrates for respiration, leading to the conversion of acids into sugars and consequently elevating the pH [14].

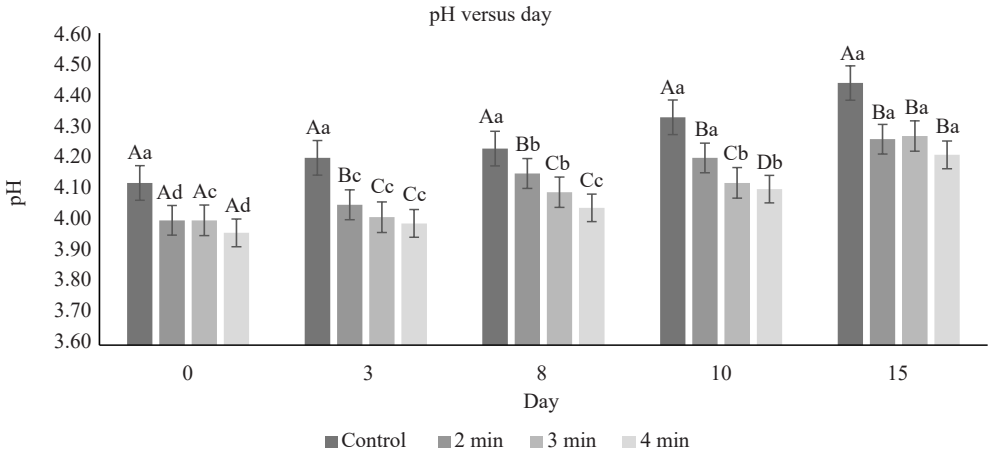

Figure 1. Effect of dipping times (0 (Control), 2, 3, and 4 min) of pomegranate peel extract-soy protein isolate coating on the pH of fresh-cut pineapple during a 15-day storage at 4 °C
[a, b]Means from the same dipping times which do not have a common superscript letter, are significantly different ($p < 0.05$)
[A, B]Means from the same day which do not have a common superscript letter, are significantly different ($p < 0.05$)

The coated samples showed significantly lower ($p < 0.05$) pH values compared to all coated samples. By day 15, the coated FCP with a 4-min dipping time demonstrated the lowest pH (pH 4.2) among other dipping periods. This shows that the PPE-SPI coating does not completely halt the metabolic processes associated with fruit ripening and senescence. Instead, it slows these processes by reducing oxygen availability and limiting the rate of respiration [21, 46]. These findings align with a study by Mantilla et al. [2], which indicated that a sodium alginate/cinnamaldehyde coating could delay the pH change in FCP for up to 15 days.

The lower pH observed in the coated samples may contribute to improved microbiological safety by inhibiting the growth of many spoilage microorganisms and foodborne pathogens, as acidic conditions are generally unfavourable for their proliferation. However, certain microorganisms, such as lactic acid bacteria, yeasts, and moulds, exhibit higher tolerance to acidic environments. Consequently, monitoring total plate counts and yeast and mould counts is essential to comprehensively evaluate the microbiological safety of the fruit throughout storage.

3.2 *Total soluble solids*

Figure 2 shows the TSS of the FCP during the storage period. Generally, an increasing trend of TSS was observed across the samples as the storage period increased. Uncoated samples exhibited the highest TSS levels compared to the coated FCP. The increase in TSS values suggests the occurrence of senescence, facilitating the breakdown of complex carbohydrates into simple sugars inside the fruit matrices [47].

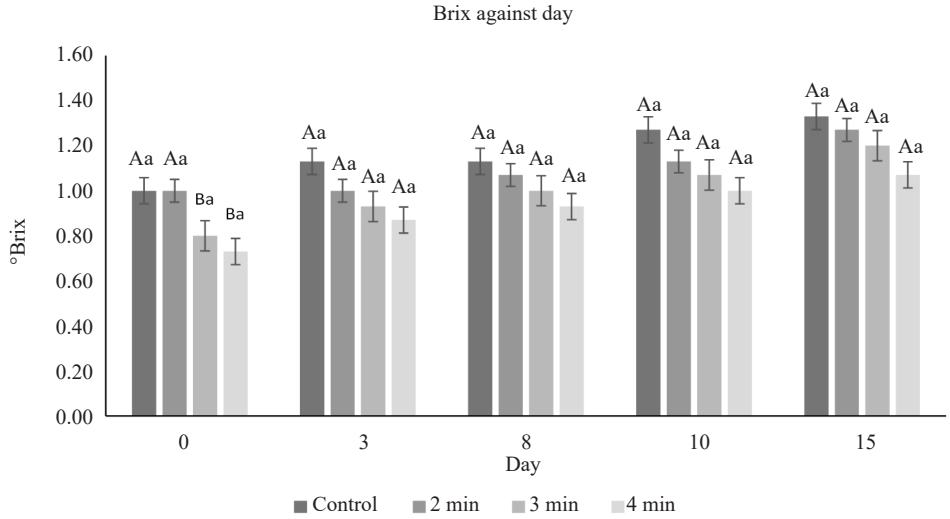

Figure 2. Effect of dipping times (0 (Control), 2, 3, and 4 min) of pomegranate peel extract-soy protein isolate coating on the total soluble solids of fresh-cut pineapple during a 15-day storage at 4 °C
[a, b]Means from the same dipping times which do not have a common superscript letter, are significantly different ($p < 0.05$)
[A, B]Means from the same day which do not have a common superscript letter, are significantly different ($p < 0.05$)

Interestingly, at the beginning of storage (day 0), the TSS values varied among the samples, despite all FCP being at the same maturity level. The uncoated FCP and those coated with a 2-minute dipping time exhibited comparable ($p \geq 0.05$) TSS levels. However, FCP subjected to 3- and 4-minute dipping times demonstrated significantly lower ($p < 0.05$) TSS values. This reduction is likely due to the formation of thicker coatings during prolonged dipping times, which may have introduced additional surface moisture. During homogenization, this moisture could have diluted the extracted juice, leading to a lower measured TSS.

Among the various coating periods on FCP, a 4-min dipping time resulted in the lowest TSS value, indicating its potential to effectively delay pineapple senescence by lowering respiration and maturity rates [42, 45]. Apart from providing physical barrier, the PPE in the coating, known for its antioxidant properties [40, 48-49], can indirectly lower the TSS through several ways such as slowing down the oxidation process during fruit ripening and reducing the activity

of enzymes such as amylase, which converts starches into sugars [50].

3.3 *Titratable acidity*

Titratable acidity (TA) is a crucial indicator of the storage lifespan of fruits, reflecting the concentration of organic acids in the fruits. TA values decrease over time when the organic acids are consumed during senescence and respiration of fruits, which often involves cellular breakdown [15, 51]. During this process, acids such as citric acid are metabolized into simpler compounds such as carbon dioxide, water, and energy, and intermediate metabolites, primarily through the tricarboxylic acid (TCA) or Krebs cycle, leading to a decrease in TA. Figure 3 shows the changes in TA of the FCP during storage.

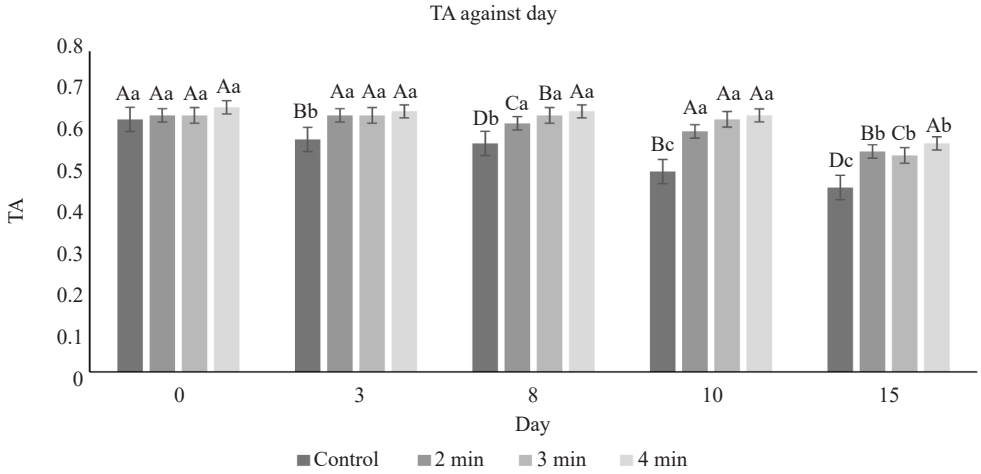

Figure 3. Effect of dipping times (0 (Control), 2, 3, and 4 min) of pomegranate peel extract-soy protein isolate coating on the titratable acidity of fresh-cut pineapple during a 15-day storage at 4 °C
[a, b]Means from the same dipping times which do not have a common superscript letter, are significantly different ($p < 0.05$)
[A, B]Means from the same day which do not have a common superscript letter, are significantly different ($p < 0.05$)

The coated samples exhibited significantly higher ($p < 0.05$) TA values compared to uncoated samples. The rapid decline in TA observed in the uncoated samples suggests accelerated fruit maturation and senescence [52], corroborating the trends observed in pH levels where the uncoated samples displayed higher pH levels compared to the coated samples. In some fruits, the TA content will increase with maturity before it starts to decrease [53, 54]. Notably, the samples with 4-min dipping time have the highest TA values among the coated samples throughout storage, which could indicate a lower respiration rate in the FCP. This is in good agreement with a study by Liao et al. [55], which showed that fresh-cut pineapples with a citric acid-enriched sodium alginate coating showed higher TA than non-coated pineapples in a chilled storage (4 °C), extending the shelf life for six days. In another study, the incorporation of PPE into chitosan and alginate coatings effectively delayed the ripening process in the guava fruits [56].

3.4 *Firmness and weight loss*

Fruit firmness and weight are vital parameters in assessing fruits shelf life [57]. During harvesting, the high-water content of fruits (80-95%) contributes to their fresh appearance and crisp texture [10]. However, post-harvest, natural physiological process such as transpiration induce fruit senescence, resulting in softening and water loss [51]. Fruit softening primarily occurs due to the cell wall decomposition, particularly pectin dissolution and polymer dissociation [58], which are usually associated with enzymes such as polygalacturonase and pectin methyl esterase [15].

Based on the results presented in Figure 4, the firmness of uncoated FCP was approximately 17 N decreased along the storage period. Immediately following the coating treatment (day 0), the firmness of FCP was significantly ($p < 0.05$) higher with longer coating times, likely due to the thicker coating layer deposited on the FCP. Parreidt et al. [59]

reported similar results, where cantaloupe firmness increased with longer dipping times (4 min) in sodium alginate solution, compared to 2 min and 1 min. A sharp decrease in firmness was observed in samples with 3- and 4-min dipping time between day 0 and 3. The extended dipping time could have caused minor osmotic effects or enhanced enzymatic activities due to the interaction between the coating and the fruit tissue, leading to reduced firmness.

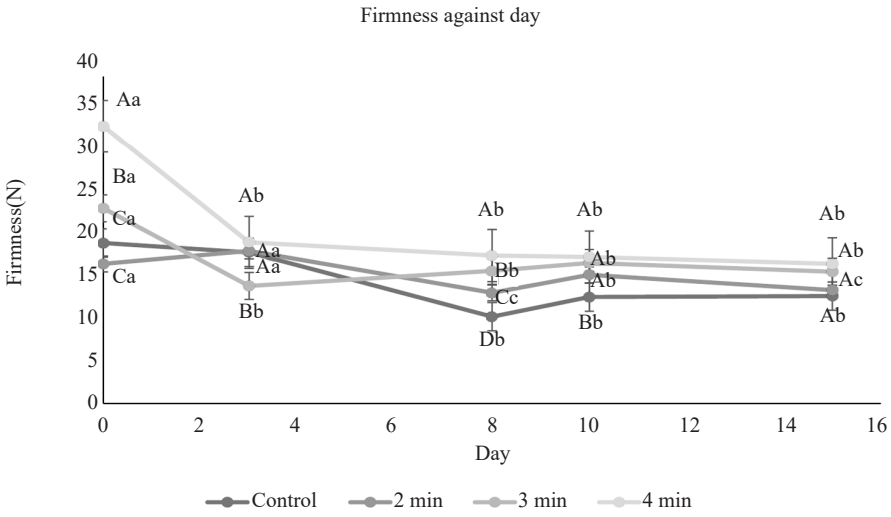

Figure 4. Effect of dipping times (0 (Control), 2, 3, and 4 min) of pomegranate peel extract-soy protein isolate coating on the firmness of fresh-cut pineapple during a 15-day storage at 4 °C
[a, b]Means from the same dipping times which do not have a common superscript letter, are significantly different ($p < 0.05$)
[A, B]Means from the same day which do not have a common superscript letter, are significantly different ($p < 0.05$)

The coated FCP samples exhibited significantly firmer ($p < 0.05$) texture compared to the control samples for up to ten days during storage. Previous studies have also shown that SPI and SPI-chitosan coatings can significantly reduce the softening rate of apricots [60]. The delaying in tissue softening may be attributed to the antimicrobial effect of ellagic acid and ellagitannins in PPE, known for their antioxidant, antimicrobial, and bio-preservative properties [31, 32]. Furthermore, Ca^{2+} ions in $CaCl_2$ may act as crosslinking agents, maintaining pectin structure stability in FCP while inhibiting the activities of cell wall degrading enzymes such as pectin methylesterase, polygalacturonase, β-galactosidase, and pectin lyase [58]. A transi ent reduction in firmness at day 8 could also result from localized microbial activity or variations in water loss during storage. By day 10, a stabilization or compensatory structural adjustment in the remaining tissues might explain the slight recovery in firmness, and all coated FCP demonstrated significantly higher ($p < 0.05$) firmness compared to the uncoated sample.

A slight weight loss observed on day 0 may be attributed to moisture evaporation from the PPE-SPE coating (Figure 5). Edible coatings help extend fruit shelf life by forming protective layers that cover the cell stomata, reducing water loss and cell shrinkage during transpiration [61, 62]. Similar to the firmness values, the samples with a 4-min dipping time demonstrated the least weight loss compared to other treatments until day 15. By day 15, FCP subjected to a 4-min dipping time experienced 29% less weight loss compared to the control sample. This finding is corroborated by Rajendran et al. [21], who reported that a 25% reduction in weight loss of avocados coated with a curcumin-incorporated SPI coating after 10 days. Similarly, SPI-chitosan coatings were shown to reduce weight loss percentage in apricots by 31% after 42 days [60]. However, SPI coatings are not excellent water barriers to prevent water loss, which may explain the lack of significant differences ($p \geq 0.05$) in weight loss between coated and uncoated samples.

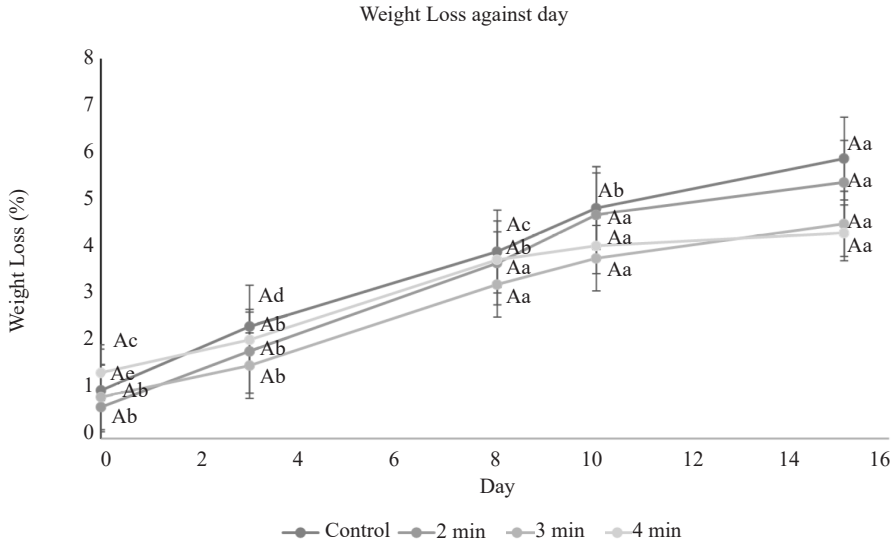

Figure 5. Effect of dipping times (0 (Control), 2, 3, and 4 min) of pomegranate peel extract-soy protein isolate coating on the weight loss of fresh-cut pineapple during a 15-day storage at 4 °C
[a, b]Means from the same dipping times which do not have a common superscript letter, are significantly different ($p < 0.05$)
[A, B]Means from the same day which do not have a common superscript letter, are significantly different ($p < 0.05$)

3.5 *Colour change*

Table 2 summarizes the colour changes in FCP during the storage period, expressed in L^*, a^*, and b^* coordinates. The colour of fresh-cut fruits is a pivotal indicator of quality and maturity, influencing consumer preferences. On day 0, both control and coated samples exhibited similar ($p \geq 0.05$) L^*, a^*, and b^* coordinates, suggesting minimal impact of the PPE-SPI coating on FCP appearance (Figure 6). Despite the yellowish hue of the PPE-SPI coating solution, it did not alter the visual aspect of the FCP once dried. A decreasing trend in L^* value was observed at day 0, possibly due to a thicker coating resulting from longer dipping times, consistent with findings by Mantilla et al. [2].

Table 2. Effect of dipping times (0 (Control), 2, 3, and 4 min) of pomegranate peel extract-soy protein isolate coating on the colour of fresh-cut pineapple during a 15-day storage at 4 °C

		Day 0	Day 3	Day 8	Day 10	Day 15
L^* values	Control	63.97 ± 5.60^{Ab}	64.19 ± 1.49^{Ab}	56.69 ± 3.59^{Bc}	65.59 ± 0.60^{Ca}	54.06 ± 2.79^{Ad}
	2 min	61.85 ± 1.82^{Ac}	65.99 ± 2.06^{Ab}	60.45 ± 1.60^{Ad}	69.19 ± 1.58^{Aa}	58.83 ± 1.95^{Ad}
	3 min	61.28 ± 1.93^{Aa}	65.14 ± 3.29^{Aa}	61.41 ± 0.67^{Aa}	65.74 ± 1.02^{Ba}	51.40 ± 5.61^{Ab}
	4 min	61.61 ± 0.88^{Aa}	67.12 ± 0.94^{Aa}	53.75 ± 2.09^{Cb}	64.20 ± 1.82^{Ca}	55.66 ± 3.85^{Ab}
a^* values	Control	0.85 ± 0.29^{Ad}	1.27 ± 0.20^{Ac}	3.12 ± 0.87^{Aa}	2.50 ± 0.52^{Ab}	3.09 ± 0.62^{Aa}
	2 min	1.21 ± 0.30^{Ad}	1.37 ± 0.19^{Ad}	1.93 ± 0.15^{Cc}	2.58 ± 0.36^{Ab}	3.27 ± 0.51^{Aa}
	3 min	1.51 ± 0.14^{Ad}	1.79 ± 0.12^{Ad}	2.09 ± 0.08^{Bc}	2.52 ± 0.50^{Ab}	2.96 ± 0.08^{Aa}
	4 min	1.26 ± 0.29^{Ac}	1.50 ± 0.34^{Ac}	1.89 ± 0.11^{Cb}	2.29 ± 0.29^{Aa}	2.58 ± 0.27^{Aa}
b^* values	Control	15.09 ± 2.55^{Aa}	13.98 ± 0.09^{Aa}	13.14 ± 5.05^{Ba}	14.95 ± 0.80^{Da}	9.54 ± 1.84^{Ca}
	2 min	11.87 ± 2.07^{Ad}	16.03 ± 1.10^{Ab}	13.4 ± 0.14^{Bc}	20.14 ± 1.99^{Aa}	14.22 ± 0.67^{Ac}
	3 min	12.49 ± 3.14^{Ab}	14.47 ± 3.40^{Ab}	16.37 ± 1.10^{Aa}	18.79 ± 1.01^{Ba}	9.22 ± 2.65^{Cc}
	4 min	9.53 ± 1.16^{Ac}	12.79 ± 1.36^{Ab}	9.04 ± 2.09^{Cd}	15.55 ± 1.06^{Ca}	10.74 ± 0.98^{Bc}

[a, b]Means within a row which do not have a common superscript letter, are significantly different ($p < 0.05$)
[A, B]Means within a column which do not have a common superscript letter, are significantly different ($p < 0.05$)

Figure 6. Effect of dipping times (0 (Control), 2, 3, and 4 min) of pomegranate peel extract-soy protein isolate coating on the appearance of fresh-cut pineapple during a 15-day storage at 4 °C

From day 3 to day 8, all coated samples exhibited higher lightness values compared to the control group. Concurrently, the a^* values for all samples increased significantly ($p < 0.05$) over time, indicating an increase in redness. This observation could be associated with browning caused by the oxidation of phenolic compounds to their corresponding o-quinones [43, 63]. Notably, coated samples with a 4-min dipping time exhibited the lowest a^* values. This can be ascribed to the gas barrier property of SPI, which restricts oxygen penetration into the FCP. Reduced oxygen levels have been reported to impede enzymatic browning [64]. Additionally, antioxidants in PPE may delay FCP oxidation, as demonstrated by Nair et al. [56], who found that the incorporation of 1% PPE in chitosan and sodium alginate coatings delayed browning in guavas.

The coated samples exhibited lower a^* values until day 8, after which the differences became insignificant ($p \geq 0.05$). This trend may be attributed to the progression of advanced enzymatic browning and oxidative processes, likely indicating a depletion of the antioxidant activity in the PPE-SPI coating over time.

3.6 *Microbiological changes*

Due to large exposed surface area, high moisture content, and rich nutrient composition, cut fruits are especially susceptible to microbial growth [3]. Table 3 shows the microbiological changes in coated and uncoated FCP samples over a 15-day storage period, based on total plate count (TPC) and yeast and mould count (YMC).

Table 3. Effect of dipping times (0 (Control), 2, 3, and 4 min) of pomegranate peel extract-soy protein isolate coating on the total plate count and yeast and mould count of fresh-cut pineapple during a 15-day storage at 4 °C

	Day 0	Day 3	Day 5	Day 8	Day 10	Day 12	Day 15
				Total plate count (log CFU/g)			
Control	0.00 ± 0.00^{Af}	3.25 ± 0.10^{Ae}	5.38 ± 0.04^{Ad}	6.06 ± 0.04^{Ac}	6.75 ± 0.42^{Ac}	7.33 ± 0.03^{Ab}	8.63 ± 0.04^{Aa}
2 min	0.00 ± 0.00^{Ae}	2.66 ± 0.32^{Bd}	3.92 ± 0.15^{Bc}	4.31 ± 0.09^{Bc}	4.99 ± 0.06^{Bb}	5.19 ± 0.04^{Bb}	6.15 ± 0.06^{Ba}
3 min	0.00 ± 0.00^{Af}	2.46 ± 0.28^{Ce}	3.89 ± 0.11^{Bd}	4.30 ± 0.04^{Bc}	4.96 ± 0.06^{Bb}	5.21 ± 0.05^{Bb}	6.10 ± 0.05^{Ca}
4 min	0.00 ± 0.00^{Af}	2.40 ± 0.17^{Ce}	3.66 ± 0.10^{Bd}	4.16 ± 0.09^{Bc}	4.94 ± 0.08^{Bb}	5.13 ± 0.04^{Bb}	6.03 ± 0.03^{Da}
				Yeast and mould count (log CFU/g)			
Control	0.00 ± 0.00^{Ae}	1.33 ± 1.15^{Ad}	1.43 ± 1.25^{Ad}	2.86 ± 0.24^{Ac}	3.01 ± 0.21^{Ac}	4.28 ± 0.16^{Ab}	5.10 ± 0.53^{Aa}
2 min	0.00 ± 0.00^{Ac}	0.67 ± 1.15^{Ab}	1.49 ± 1.32^{Ab}	1.69 ± 1.47^{Aa}	1.73 ± 1.53^{Ab}	2.30 ± 0.30^{Bb}	3.04 ± 0.17^{Ba}
3 min	0.00 ± 0.00^{Ac}	0.00 ± 0.00^{Ac}	1.33 ± 1.15^{Ab}	1.59 ± 1.38^{Ab}	1.67 ± 1.46^{Ab}	2.33 ± 0.35^{Bb}	3.19 ± 0.31^{Ba}
4 min	0.00 ± 0.00^{Ac}	0.00 ± 0.00^{Ac}	0.67 ± 1.15^{Ac}	1.33 ± 1.15^{Ab}	1.49 ± 1.31^{Ab}	2.20 ± 0.35^{Bb}	3.10 ± 0.13^{Ba}

[a, b]Means within a row which do not have a common superscript letter, are significantly different ($p < 0.05$)
[A, B]Means within a column which do not have a common superscript letter, are significantly different ($p < 0.05$)

Microbial growth increased gradually from day 0 to 15 in all samples. Throughout the storage period, coated FCP samples consistently exhibited significantly lower ($p < 0.05$) TPC and YMC values. By day 15, there was a notably 30% reduction in TPC and a 40% reduction in YMC in the coated samples (4 min) compared to the uncoated samples. The TPC in the control sample reached 6 log CFU/g by day 8 of storage. According to the regulation by European Commission Regulation 2073/2005, the TPC and YMC of fresh-cut produces should be below the maximum tolerance limits of 7 log CFU/g and 5 log CFU/g, respectively [65]. For the coated FCP, the maximum TPC and YMC were 6.15 and 3.19 log CFU/g, which were below the threshold. The antimicrobial effect of the coating can be attributed to the presence of phenolic compounds in PPE, such as chlorogenic acid, epicatechin, and ellagic acid [66, 67], along with antifungal compounds such as gallic acid and punicalagin [68, 69]. However, the storage and analyses were terminated due to visible mould growth on all samples (Figure 6).

Several studies have explored the postharvest shelf life extension in fruits and vegetables using antimicrobial coating. Chitosan films incorporated with PPE (10 g/L) have demonstrated effective antibacterial activity against *Staphylococcus aureus* and *Escherichia coli* [70]. In another study, Basumatary et al. [12] demonstrated that chitosan coating incorporating eugenol and aloe vera gel preserved the quality and overall acceptability of whole pineapples for up to 20 days under ambient storage conditions, compared to control samples which exhibited signs of fruit rot by day 12. While chitosan is commonly used in the development of edible coatings due to its antimicrobial properties, it is only soluble in acids [12, 71], potentially affecting the taste of the fruits. The results suggest that PPE-SPI coating shows promising potential as an antimicrobial and antioxidant edible coating to replace synthetic preservatives in maintaining pineapple quality during storage.

4. Conclusion

In this study, the application of PPE-SPI coating demonstrated significant improvements in the quality and shelf life FCP during chilled storage. The coating effectively prolonged the shelf life to 10 days, surpassing the unacceptable quality threshold observed in uncoated control samples by day 7. Samples coated with a 4-minute dipping time exhibited the least variation in pH, titratable acidity (TA), firmness, weight loss, and browning (Figure 7), indicating delayed senescence and improved preservation. The reduced weight loss and maintained firmness were likely due to the moisture

barrier properties of the PPE-SPI coating, which delayed water loss and mitigated cellular degradation. The antioxidant activity of PPE contributed to the slower increase in pH and sustained TA levels, which, in turn, inhibited microbial proliferation. The antimicrobial activities of the PPE-SPI coating were evidenced by significant ($p < 0.05$) reductions in total plate count and yeast and mould counts, by 30% and 40%, respectively, compared to uncoated samples. Future studies should include sensory evaluations to assess consumer acceptance and further validate the practical applicability of this coating. In conclusion, the PPE-SPI coating represents a promising and sustainable alternative to synthetic preservatives, effectively extending the shelf life of fresh-cut fruits while reducing packaging waste.

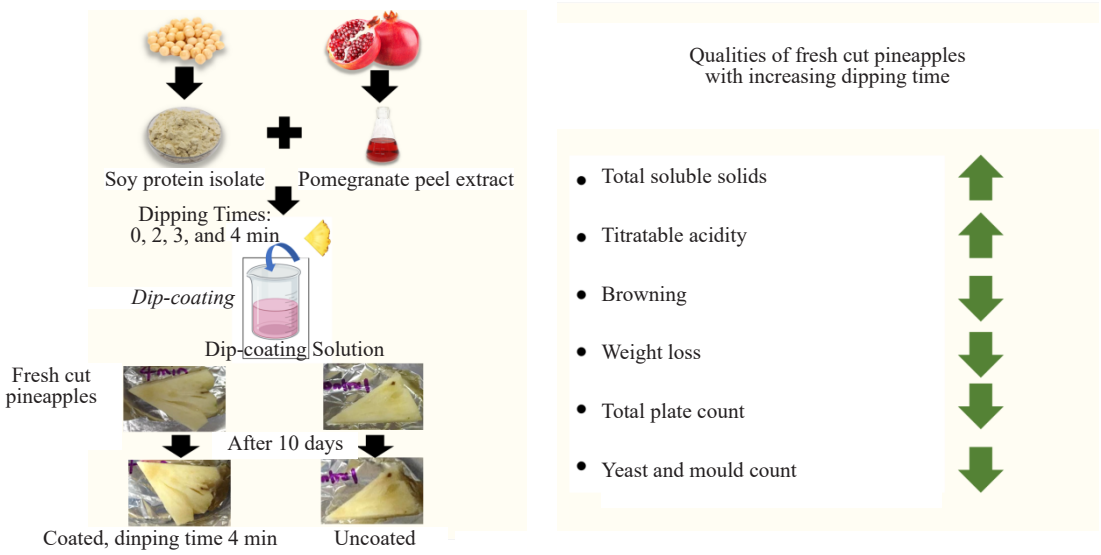

Figure 7. A summary of the study

Acknowledgments

The authors would like to thank Universiti Putra Malaysia (UPM) for the facilities provided.

Conflict of 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.

References

[1] Saha T, Roy DKD, Khatun MN, Asaduzzaman M. Quality and shelf life of fresh-cut pineapple (*Ananas comosus*) coated with aloe vera and honey in the refrigerated condition. *Journal of Agriculture and Food Research*. 2023; 14: 100709. Available from: doi:10.1016/j.jafr.2023.100709.

[2] Mantilla N, Castell-Perez ME, Gomes C, Moreira RG. Multilayered antimicrobial edible coating and its effect on quality and shelf-life of fresh-cut pineapple (*Ananas comosus*). *LWT-Food Science and Technology*. 2013; 51(1): 37-43. Available from: doi:10.1016/j.lwt.2012.10.010.

[3] Nikhanj P, Singh MP, Saini S, Kaur G, Kumari J. Fresh cut fruits and vegetables disinfection pretreatment: A novel approach to extend fresh cut's shelf life. In: *Food Processing and Packaging Technologies-Recent Advances*. London, United Kingdom: InTech Open, Limited; 2022. p.1-24.

[4] Yousuf B, Qadri OS, Srivastava AK. Recent developments in shelf-life extension of fresh-cut fruits and vegetables

by application of different edible coatings: A review. *LWT-Food Science and Technology*. 2018; 89: 198-209. Available from: doi:10.1016/j.lwt.2017.10.051.
[5] Lasekan O, Hussein FK. Classification of different pineapple varieties grown in Malaysia based on volatile fingerprinting and sensory analysis. *Chemistry Central Journal*. 2018; 12(1): 140. Available from: doi:10.1186/s13065-018-0505-3.
[6] Mordor Intelligence. *Pineapple Market Size (2024-2029)*. Available from: https://www.mordorintelligence.com/industry-reports/global-pineapple-market/market-size#:~:text=The%20Pineapple%20Market%20size%20is,period%20(2024%2D2029) [Accessed 3rd December 2024].
[7] Abraham RA, Joshi TJ, Abdullah S. A comprehensive review of pineapple processing and its by-product valorization in India. *Food Chemistry Advances*. 2023; 3: 100416. Available from: doi:10.1016/j.focha.2023.100416.
[8] Chaudhary V, Kumar V, Singh K, Kumar R, Kumar V, Vipul Chaudhary C. Pineapple (*Ananas cosmosus*) product processing: A review. *Journal of Pharmacognosy and Phytochemistry*. 2019; 8(3): 4642-4652.
[9] Janick J. *Horticultural Reviews*. Toronto, Canada: John Wiley & Sons, Inc; 2010.
[10] Md Nor S, Ding P. Trends and advances in edible biopolymer coating for tropical fruit: A review. *Food Research International*. 2020; 134: 109208. Available from: doi:10.1016/j.foodres.2020.109208.
[11] Prakash A, Baskaran R, Vadivel V. Citral nanoemulsion incorporated edible coating to extend the shelf life of fresh cut pineapples. *LWT-Food Science and Technology*. 2020; 118: 108851. Available from: doi:10.1016/j.lwt.2019.108851.
[12] Basumatary IB, Mukherjee A, Katiyar V, Dutta J, Kumar S. Chitosan-based active coating for pineapple preservation: Evaluation of antimicrobial efficacy and shelf-life extension. *LWT-Food Science and Technology*. 2022; 168: 113940. Available from: doi:10.1016/j.lwt.2022.113940.
[13] Jurić M, Bandić LM, Carullo D, Jurić S. Technological advancements in edible coatings: Emerging trends and applications in sustainable food preservation. *Food Bioscience*. 2024; 58: 103835. Available from: doi:10.1016/j.fbio.2024.103835.
[14] Costa BP, Carpiné D, Ikeda M, Pazzini IAE, da Silva Bambirra Alves FE, de Melo AM, et al. Bioactive coatings from non-conventional loquat (*Eriobotrya japonica* Lindl.) seed starch to extend strawberries shelf-life: An antioxidant packaging. *Progress in Organic Coatings*. 2023; 175: 107320. Available from: doi:10.1016/j.porgcoat.2022.107320.
[15] Wang LY, Peng HH, Liu CY, Li CC, Qu JM, Geng XQ, et al. Effect of chitosan-ascorbic acid composite coating on postharvest quality of Custard apple (*Annona squamosa*). *Process Biochemistry*. 2023; 129: 76-85. Available from: doi:10.1016/j.procbio.2023.03.013.
[16] Odetayo T, Tesfay S, Ngobese NZ. Nanotechnology-enhanced edible coating application on climacteric fruits. *Food Science & Nutrition*. 2022; 10(7): 2149-2167. Available from: doi:10.1002/fsn3.2557.
[17] Iturralde-García RD, Cinco-Moroyoqui FJ, Martínez-Cruz O, Ruiz-Cruz S, Wong-Corral FJ, Borboa-Flores J, et al. Emerging technologies for prolonging fresh-cut fruits' quality and safety during storage. *Horticulturae*. 2022; 8(8): 731. Available from: doi:10.3390/horticulturae8080731.
[18] Chawla R, Sivakumar S, Kaur H. Antimicrobial edible films in food packaging: Current scenario and recent nanotechnological advancements-a review. *Carbohydrate Polymer Technologies and Applications*. 2021; 2: 100024. Available from: doi:10.1016/j.carpta.2020.100024.
[19] Rasool F, Zahoor I, Ayoub WS, Ganaie TA, Dar AH, Farooq S, et al. Formulation and characterization of natural almond gum as an edible coating source for enhancing the shelf life of fresh cut pineapple slices. *Food Chemistry Advances*. 2023; 3: 100366. Available from: doi:10.1016/j.focha.2023.100366.
[20] Liu C, Yu B, Tao H, Liu P, Zhao H, Tan C, et al. Effects of soy protein isolate on mechanical and hydrophobic properties of oxidized corn starch film. *LWT-Food Science and Technology*. 2021; 147: 111529. Available from: doi:10.1016/j.lwt.2021.111529.
[21] Rajendran N, Runge T, Bergman RD, Nepal P, Pottackal NT, Rahman MM. Economic and environmental analysis of producing soy protein-cellulose-based bionanocomposite fruit coating. *Industrial Crops and Products*. 2024; 211: 118213. Available from: doi:10.1016/j.indcrop.2024.118213.
[22] Yavari Maroufi L, Shahabi N, Fallah AA, Mahmoudi E, Al-Musawi MH, Ghorbani M. Soy protein isolate/kappa-carrageenan/cellulose nanofibrils composite film incorporated with zenian essential oil-loaded MOFs for food packaging. *International Journal of Biological Macromolecules*. 2023; 250: 126176. Available from: doi:10.1016/j.ijbiomac.2023.126176.
[23] Zhang T, Yun Y, Chu M, Bai X, Sun J, Zhang Y, et al. Coating of fruit with an edible soybean protein isolate film

doped with hydroxypropyl methyl cellulose for improved preservation. *Bioresources*. 2022; 17(2): 2563-2575. Available from: doi:10.15376/biores.17.2.2563-2575.
[24] Erdem BG, Kaya S. Characterization and application of novel composite films based on soy protein isolate and sunflower oil produced using freeze drying method. *Food Chemistry*. 2022; 366: 130709. Available from: doi:10.1016/j.foodchem.2021.130709.
[25] Tirgarian B, Farmani J, Milani JM. Edible oleofilms with high vegetable oil content obtained from novel soy protein isolate/gelatin/chitosan nanofiber emulgels. *Food Hydrocolloids*. 2023; 134: 108082. Available from: doi:10.1016/j.foodhyd.2022.108082.
[26] Galus S. Functional properties of soy protein isolate edible films as affected by rapeseed oil concentration. *Food Hydrocolloids*. 2018; 85: 233-241. Available from: doi:10.1016/j.foodhyd.2018.07.026.
[27] Maryam Adilah ZA, Jamilah B, Nur Hanani ZA. Functional and antioxidant properties of protein-based films incorporated with mango kernel extract for active packaging. *Food Hydrocolloids*. 2018; 74: 207-218. Available from: doi:10.1016/j.foodhyd.2017.08.017.
[28] Huang X, Zhou X, Dai Q, Qin Z. Antibacterial, antioxidation, UV-blocking, and biodegradable soy protein isolate food packaging film with mangosteen peel extract and ZnO nanoparticles. *Nanomaterials*. 2021; 11(12): 3337. Available from: doi:10.3390/nano11123337.
[29] Han Y, Yu M, Wang L. Preparation and characterization of antioxidant soy protein isolate films incorporating licorice residue extract. *Food Hydrocolloids*. 2018; 75: 13-21. Available from: doi:10.1016/j.foodhyd.2017.09.020.
[30] Karakuş E, Ayhan Z, Haskaraca G. Development and characterization of sustainable-active-edible-bio based films from orange and pomegranate peel waste for food packaging: Effects of particle size and acid/plasticizer concentrations. *Food Packaging and Shelf Life*. 2023; 37: 101092. Available from: doi:10.1016/j.fpsl.2023.101092.
[31] Smaoui S, Hlima HB, Mtibaa AC, Fourati M, Sellem I, Elhadef K, et al. Pomegranate peel as phenolic compounds source: Advanced analytical strategies and practical use in meat products. *Meat Science*. 2019; 158: 107914. Available from: doi:10.1016/j.meatsci.2019.107914.
[32] Ordaz-Rodríguez SB, López-Hernández LH, Mendoza-Sánchez M de J, Escobar-Ortiz A, Abadía-García L, García-Pérez J, et al. Green extract of pomegranate peel (*Punica granatum* L.) obtained by ultrasound assisted extraction and its preservative properties on raw chicken burgers. *Food and Humanity*. 2023; 1: 1046-1054. Available from: doi:10.1016/j.foohum.2023.08.020.
[33] Panza O, Conte A, Del Nobile MA. Zero-waste approach applied to pomegranates for prolonging fish burger shelf life. *Foods*. 2022; 11(4): 551. Available from: doi:10.3390/foods11040551.
[34] Bashir S, Arshad MS, Khalid W, Nayik GA, Al Obaid S, Ansari MJ, et al. Effect of antimicrobial and antioxidant rich pomegranate peel based edible coatings on quality and functional properties of chicken nuggets. *Molecules*. 2022; 27(14): 4500. Available from: doi:10.3390/molecules27144500.
[35] Saeed M, Azam M, Ahmad T, Akhtar S, Hussain M, Nasir S, et al. Utilization of pomegranate peel extract as antifungal coating agent against fusarium oxysporum on tomatoes. *Journal of Food Processing and Preservation*. 2022; 46(12): e17157. Available from: doi:10.1111/jfpp.17157.
[36] Cruz-Valenzuela MR, Ayala-Soto RE, Ayala-Zavala JF, Espinoza-Silva BA, González-Aguilar GA, Martín-Belloso O, et al. Pomegranate (*Punica granatum* L.) peel extracts as antimicrobial and antioxidant additives used in alfalfa sprouts. *Foods*. 2022; 11(17): 2588. Available from: doi:10.3390/foods11172588.
[37] Yousuf B, Srivastava AK. Impact of honey treatments and soy protein isolate-based coating on fresh-cut pineapple during storage at 4 °C. *Food Packaging and Shelf Life*. 2019; 21: 100361. Available from: doi:10.1016/j.fpsl.2019.100361.
[38] UNECE. *UNECE Standard on the Marketing and Commercial Quality Control of Pineapples*. Geneva, Switzerland: United Nations Economic Commission for Europe; 2013.
[39] Hanani ZAN, Yee FC, Nor-Khaizura MAR. Effect of pomegranate (*Punica granatum* L.) peel powder on the antioxidant and antimicrobial properties of fish gelatin films as active packaging. *Food Hydrocolloids*. 2019; 89: 253-259. Available from: doi:10.1016/j.foodhyd.2018.10.007.
[40] Han Lyn F, Nor Adilah A, Gun Hean C, Nur Hanani ZA. Effect of pressure on the supercritical solvent impregnation of pomegranate peel extract into low-density polyethylene films. *Journal of Food Engineering*. 2023; 357: 111646. Available from: doi:10.1016/j.jfoodeng.2023.111646.
[41] AOAC. Chemical methods. In: Blake C (ed.) *Official Methods of Analysis of AOAC International*. New York, USA: Oxford University Press; 2023. Available from: doi:10.1093/9780197610145.003.243.
[42] Nazoori F, Mollai S, Sobhani F, Mirdehghan SH, Sahhafi SR. Carboxymethyl cellulose and carnauba wax treatments kept the pomegranate fruit (*Punica granatum* L.) quality during cold storage via improving enzymatic

defense system and bioactive compounds. *Scientia Horticulturae*. 2023; 309: 111645. Available from: doi:10.1016/j.scienta.2022.111645.
[43] Jiang Y, Wang X, Li X, Wang Z, Wang H, Li W, et al. Combination of 1-methylcyclopropene and phytic acid inhibits surface browning and maintains texture and aroma of fresh-cut peaches. *Postharvest Biology and Technology*. 2023; 200: 112328. Available from: doi:10.1016/j.postharvbio.2023.112328.
[44] Abdelmigid HM, Morsi MM, Hussien NA, Alyamani AA, Alhuthal NA, Albukhaty S. Green synthesis of phosphorous-containing hydroxyapatite nanoparticles (nHAP) as a novel nano-fertilizer: preliminary assessment on pomegranate (*Punica granatum* L.). *Nanomaterials*. 2022; 12(9): 1527. Available from: doi:10.3390/nano12091527.
[45] Al-Hilifi SA, Al-Ali RM, Al-Ibresam OT, Kumar N, Paidari S, Trajkovska Petkoska A, et al. Physicochemical, morphological, and functional characterization of edible anthocyanin-enriched aloevera coatings on fresh figs (*Ficus carica* L.). *Gels*. 2022; 8(10): 645. Available from: doi:10.3390/gels8100645.
[46] Upadhyay A, Kumar P, Kardam SK, Gaikwad KK. Ethylene scavenging film based on corn starch-gum acacia impregnated with sepiolite clay and its effect on quality of fresh broccoli florets. *Food Bioscience*. 2022; 46: 101556. Available from: doi:10.1016/j.fbio.2022.101556.
[47] Moreira SP, de Carvalho WM, Alexandrino AC, de Paula HCB, Rodrigues M do CP, de Figueiredo RW, et al. Freshness retention of minimally processed melon using different packages and multilayered edible coating containing microencapsulated essential oil. *International Journal of Food Science and Technology*. 2014; 49(10): 2192-2203. Available from: doi:10.1111/ijfs.12535.
[48] Kumar N, Daniloski D, Cunha NMD, Naumovski N, Petkoska AT. Pomegranate peel extract-A natural bioactive addition to novel active edible packaging. *Food Research International*. 2022; 156: 111378. Available from: doi:10.1016/j.foodres.2022.111378.
[49] Gosset-Erard C, Zhao M, Lordel-Madeleine S, Ennahar S. Identification of punicalagin as the bioactive compound behind the antimicrobial activity of pomegranate (*Punica granatum* L.) peels. *Food Chemistry*. 2021; 352: 129396. Available from: doi:10.1016/j.foodchem.2021.129396.
[50] Huang X, Bian Y, Liu T, Xu Z, Song Z, Wang F, et al. Antioxidant potential and in vitro inhibition of starch digestion of flavonoids from *Crataegus pinnatifida*. *Heliyon*. 2022; 8(10): e11058. Available from: doi:10.1016/j.heliyon.2022.e11058.
[51] Subramaniyan V, Sellamuthu PS, Sadiku ER, Jarugala J. Effect of flax seed mucilage and guar gum coating enriched with postbiotics on postharvest storage of fig fruits (*Ficus carica* L.). *South African Journal of Botany*. 2024; 166: 636-647. Available from: doi:10.1016/j.sajb.2024.01.071.
[52] Li X, Li C, Sun J, Jackson A. Dynamic changes of enzymes involved in sugar and organic acid level modification during blueberry fruit maturation. *Food Chemistry*. 2020; 309: 125617. Available from: doi:10.1016/j.foodchem.2019.125617.
[53] Moneruzzaman KM, Hossain ABMS, Sani W, Saifuddin M. Effect of stages of maturity and ripening conditions on the biochemical characteristics of tomato. *American Journal of Biochemistry and Biotechnology*. 2008; 4(4): 336-344. Available from: doi:10.3844/ajbbsp.2008.336.344.
[54] Priyankara GGDS, Karunarathne CLSM, Sarananda KH, Ariyaratne M, Lanka S. Effect of maturity stage on ripening and quality characters of four tomato (*Solanum lycopersicum* L.) varieties of Sri Lanka. *Tropical Agricultural Research*. 2017; 28(4): 496-502.
[55] Liao X, Xing Y, Fan X, Qiu Y, Xu Q, Liu X. Effect of composite edible coatings combined with modified atmosphere packaging on the storage quality and microbiological properties of fresh-cut pineapple. *Foods*. 2023; 12(6): 1344. Available from: doi:10.3390/foods12061344.
[56] Nair MS, Saxena A, Kaur C. Effect of chitosan and alginate based coatings enriched with pomegranate peel extract to extend the postharvest quality of guava (*Psidium guajava* L.). *Food Chemistry*. 2018; 240: 245-252. Available from: doi:10.1016/j.foodchem.2017.07.122.
[57] Poongavanam SS, Subramaniyan V, Rajendra AB, Sellamuthu PS, Jarugala J, Sadiku ER. Physiochemical analysis of *Manilkara zapota* (Sapota) coated with aloe vera gel and enriched with ajwain and oregano essential oils. *Coatings*. 2023; 13(8): 1358. Available from: doi:10.3390/coatings13081358.
[58] Zhang Y, Kong Q, Niu B, Liu R, Chen H, Xiao S, et al. The dual function of calcium ion in fruit edible coating: Regulating polymer internal crosslinking state and improving fruit postharvest quality. *Food Chemistry*. 2024; 447: 138952. Available from: doi:10.1016/j.foodchem.2024.138952.
[59] Parreidt TS, Schmid M, Müller K. Effect of dipping and vacuum impregnation coating techniques with alginate based coating on physical quality parameters of cantaloupe melon. *Journal of Food Science*. 2018; 83(4): 929-936.

Available from: doi:10.1111/1750-3841.14091.
[60] Zhang L, Chen F, Lai S, Wang H, Yang H. Impact of soybean protein isolate-chitosan edible coating on the softening of apricot fruit during storage. *LWT-Food Science and Technology*. 2018; 96: 604-611. Available from: doi:10.1016/j.lwt.2018.06.011.
[61] Yadav A, Kumar N, Upadhyay A, Sethi S, Singh A. Edible coating as postharvest management strategy for shelf-life extension of fresh tomato (*Solanum lycopersicum* L.): An overview. *Journal of Food Science*. 2022; 87(6): 2256-2290. Available from: doi:10.1111/1750-3841.16145.
[62] Nasrin TAA, Rahman MA, Arfin MS, Islam MN, Ullah MA. Effect of novel coconut oil and beeswax edible coating on postharvest quality of lemon at ambient storage. *Journal of Agriculture and Food Research*. 2020; 2: 100019. Available from: doi:10.1016/j.jafr.2019.100019.
[63] Ismail HA, Richard I, Ramaiya SD, Zakaria MH, Lee SY. Browning in relation to enzymatic activities and phytochemical content in terap peel (*Artocarpus odoratissimus* Blanco) during postharvest ripening. *Horticulturae*. 2023; 9(1): 57. Available from: doi:10.3390/horticulturae9010057.
[64] Rux G, Bohne K, Huyskens-Keil S, Ulrichs C, Hassenberg K, Herppich WB. Effects of modified atmosphere and sugar immersion on physiology and quality of fresh-cut 'Braeburn' apples. *Food Packaging and Shelf Life*. 2021; 29: 100726. Available from: doi:10.1016/j.fpsl.2021.100726.
[65] Piano AMP, Castillo-Israel KAT. Physico-chemical quality and microbial safety evaluation of ready-to-eat freshcut watermelon and pineapple sold in Imus, Cavite, Philippines. *Food Research*. 2019; 3(6): 684-692. Available from: doi:10.26656/fr.2017.3(6).139.
[66] Pirzadeh M, Caporaso N, Rauf A, Shariati MA, Yessimbekov Z, Khan MU, et al. Pomegranate as a source of bioactive constituents: A review on their characterization, properties and applications. *Critical Reviews in Food Science and Nutrition*. 2021; 61(6): 982-999. Available from: doi:10.1080/10408398.2020.1749825.
[67] Salim A, Deiana P, Fancello F, Molinu MG, Santona M, Zara S. Antimicrobial and antibiofilm activities of pomegranate peel phenolic compounds: Varietal screening through a multivariate approach. *Journal of Bioresources and Bioproducts*. 2023; 8(2): 146-161. Available from: doi:10.1016/j.jobab.2023.01.006.
[68] Foss SR, Nakamura CV, Ueda-Nakamura T, Cortez DA, Endo EH, Dias Filho BP. Antifungal activity of pomegranate peel extract and isolated compound punicalagin against dermatophytes. *Annals of Clinical Microbiology and Antimicrobials*. 2014; 13(1): 32. Available from: doi:10.1186/s12941-014-0032-6.
[69] Fan G, Xu Z, Liu X, Yin W, Sun L, Wu D, et al. Antifungal efficacy of gallic acid extracted from pomegranate peel against Trichophyton rubrum: In vitro case study. *Natural Product Communications*. 2023; 18(1): 1-9. Available from: doi:10.1177/1934578X221148607.
[70] Yuan G, Lv H, Yang B, Chen X, Sun H. Physical properties, antioxidant and antimicrobial activity of chitosan films containing carvacrol and pomegranate peel extract. *Molecules*. 2015; 20(6): 11034-11045. Available from: doi:10.3390/molecules200611034.
[71] Tagrida M, Nilsuwan K, Gulzar S, Prodpran T, Benjakul S. Fish gelatin/chitosan blend films incorporated with betel (*Piper betle* L.) leaf ethanolic extracts: Characteristics, antioxidant and antimicrobial properties. *Food Hydrocolloids*. 2023; 137: 108316. Available from: doi:10.1016/j.foodhyd.2022.108316.