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The influence of composite edible coating of Balangu gum and whey protein on strawberry storability

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ABSTRACT

The shelf-life of strawberry, as a valuable fruit, is short and it's highly perishable. Applying edible coatings is considered as a versatile approach to tackle this problem in order to preserve freshness, nutritional-sensory value of strawberry, and furthermore, to prevent losses. In the present study, the influence of Balangu gum and whey protein composite edible coatings with varying mixing ratios on physicochemical properties of strawberry has been investigated. The particle size of emulsions ranged between 3.2 and 4.8 µm and elevating the protein content increased the particle sizes. The surface of composite film with gum:protein ratio of 1:1 was smooth and dense and it had the least moisture content and water solubility, however, these parameters increased when the protein ratio was higher and film surface became irregular with cracks and water vapour permeability increased. Coating strawberries decreased the changes in weight loss, colour parameters, anthocyanin content, vitamin C, firmness, and soluble solids' content remained unchanged comparing uncoated samples. Concluding, applying coating effectively preserved the quality parameters of strawberry during storage by providing a barrier against moisture transmission and respiration. The results of the present study revealed that coating strawberry with composite Balangu gum and whey protein with 1:1 ratio can significantly enhance the storability and prevent the quality loss.

1-Introduction

Despite its valuable sensory and nutritional properties, strawberry is extremely perishable which is attributed to metabolic activity and microbial growth. Therefore, the shelf life of this fruit is very short and the simplest approach to prevent quality loss and waste is quick consumption, which is not practical in most occasions. Among different preservation methods for fresh products, especially perishable fruits, the use of edible coatings has gained special attention due to biodegradability, biocompatibility, and in some cases antioxidant and antimicrobial properties, and barrier characteristics to oxygen and moisture transfer [1, 2]. Proteins, polysaccharides, and lipids are biopolymers used to fabricate edible coatings. Because each of the mentioned materials has specific but limited properties, the use of composite coatings has received much attention in order to take advantage of the positive aspects of each [2]. The main compounds studied for coating strawberries to increase shelf life were hydrocolloids and proteins [3, 4].

Balangu Shirazi (*Lallemantia royleana*) seed gum is an arabino-galactan containing rhamnose, xylose, and glucose [5] which contains 62.9% acidic sugars (uronic acid) and is a weak gel-forming gum [6]. It has been reported that Balangu gum has also antioxidant and antimicrobial properties due to phenolic compounds [7]. Regarding functional and rheological properties of Balangu Shirazi gum, film forming [8] and coating possibility to coat fried potatoes [9], beef meat [10], and peaches [11] has been reported.

Whey protein, as water-soluble proteins obtained from the coagulation process of casein, is considered a byproduct of the dairy industry, which has received special attention for the production of value-added products due to its high production volume and nutritional value. Among the extensive applications of these proteins (in addition to texture modification, thickening, gel forming, foaming and emulsification), is the preparation of edible coatings with high nutritional value for coating fresh fruits and vegetables. Coatings made from whey protein are transparent and tasteless and have low permeability to oxygen, but due to their high solubility and permeability to water vapour, low flexibility and poor mechanical properties, they are not very desirable for sole utilisation [2]. For this reason, a practical solution to tackle these disadvantages is to combine it with polysaccharides. Whey protein coatings have been used alone or in combination with polysaccharides to preserve the quality of fruits such as apples [12], pears [13] or strawberries [14].

Considering the above mentioned notes, no published study has investigated the potential of using composites of Balangu gum and whey protein as a coating to preserve the quality and shelf life of strawberries. Therefore, the aim of this study was to develop a composite emulsion coating of Balangu gum and whey protein containing olive oil. In this regard, the physicochemical properties of the composite coating, including particle size, water vapour permeability, thickness, solubility, and structural changes, as well as the quality properties of strawberries coated with composite emulsion of Balangu gum and whey protein, including weight loss, colour, vitamin C, pH, acidity, anthocyanin content, and texture firmness, were investigated during one week of storage at refrigerate temperature.

2. Materials and methods

Balangu seed gum was extracted according to the optimised method of Mohammad Amini [15] and freeze-dried. Whey protein isolate with 92% protein was from Hilmar (Hilmar Ingredients, USA), olive oil from Behshahr Industrial Corporation, 2,6-dichlorophenol indophenol and ascorbic acid were purchased from Sigma-Aldrich (St. Louis, USA), and glycerol with other chemicals were from Merck (Darmstadt, Germany). Fresh strawberries with Camarousa variety were purchased from local market in Sanandaj.

2.1. Preparation and assessment of emulsion coating

In order to prepare sole emulsion coatings of Balangu gum and whey protein, their solution was prepared in distilled water and each was mixed with glycerol (50% by weight) while stirring, and then olive oil (50% by weight) was gradually added and homogenised for 5 minutes at 8000 rpm (Ultra-Turrax T18 digital, IKA, Germany). To prepare composite coatings, the required amount of Balangu gum and whey protein solution was mixed so that the concentration of the final mixture kept constant (1% w/w) in all mixing ratios of Balangu gum to whey protein (1:1, 1:3, and 1:5). The rest of the preparation steps were carried out exactly the same as for sole coatings. The particle size of the prepared coatings was measured by Zetasizer (Zetasizer Nano ZS, Malvern Panalytical, UK) and reported based on the volume average diameter [12]. The infrared absorption spectrum (FT-IR) of freeze-dried coating samples was recorded by a Bruker Vector 22 spectrometer (Bruker Corp., USA) in the wavenumber range of 4000 to 400 cm^{-1} and a resolution of 4 cm^{-1}.

2.2. Fabrication and characterization of film

A specified amount of the prepared coating was poured into polyethylene molds with a diameter of 15 cm and after dearation, dried under ambient conditions (average temperature and relative humidity of 28 °C and 19%, respectively) and separated from the mold as a film and stored in ziplock polyethylene bags and a cool environment until performing the experiments. The morphology of the films was assessed by MIRA3 FE-SEM scanning electron microscopy (TESCAN, Czech Republic) at 30 kV voltage after coating the samples with gold for 80 seconds. The thickness, water solubility and water vapour permeability (ASTM E96-00, 2000) of the film samples were determined according to Mohammad Amini and Razavi (2020) [16].

2.3. Coating the strawberries

First, healthy strawberries of the same approximate size and apparent ripeness were separated and washed with cold water. In order to accurately compare the characteristics of coated and uncoated fruits, each fruit was cut axially into two halves, and the stemless half was used as a control and the stemmed half was used for coating. After the surface of the fruit dried, it was immersed in the coating solution for one minute and repeated three times to completely cover its surface with the coating solution. After the surface of the fruits dried, the uncoated and coated fruit slices were stored in polyethylene bags at 5 °C until the experiments were performed. At least 10 fruit units were used for each coating sample.

2.4. Strawberry experiments

Moisture content of strawberry samples was measured based on standard gravimetric method (AOAC Method 930.15), and weight loss during time was calculated based on weight change compared to fresh samples. Total soluble solids (brix degree basis), pH, and titratable acidity (based on citric acid) of strawberry extract were measured using Atago Master 53α refractometer (Japan), AZ 86050 pH-meter (Taiwan), and titration with 0.1 N NaOH solution, respectively [17]. Vitamin C content of samples was assessed using 2,6-dichlorophenol indophenol method (AOAC Method 967.21). Anthocyanin content of strawberries was determined according to the reported method by Taghavi et al. (2020) using acidic chloroform-methanol mixture extraction and measurement of absorbance at 530 and 657 nm through UNICO UV-2100 spectrophotometer (USA) [18]. Colour parameters of strawberries in CIELAB colour space were obtained using TES 135a chroma meter (TES Electrical Electronic Corp., Taiwan) and Hue was calculated according to Equation 1.

Equation 1

$$Hue\,(^{\circ}) = \tan^{-1}\left(b^{*}/a^{*}\right)$$

Firmness of strawberry samples was reported as maximum force (N) at penetration test using QTS-25 texture analyser (CNS Farnell, UK) equipped with cylindrical probe (3 mm diameter), 50% strain and penetration speed of 1 mm/s [4].

2.5. Statistical analyses

The current research was performed in completely randomised design with factorial design in 3 replicates and the means were compared in 5% level using Toukey's test of Minitab version 21 software.

3. Results and discussion

3.1. Emulsion coating properties

3.1.1. Particle size

Based on the results (Table 1), it was found that the particle size of the emulsion sample containing Balangu gum (B) was significantly different from other samples except the composite sample with 1:1 ratio (BW-1). The smallest particle size belonged to B and BW-1, while for the whey protein coating (W) and the composite coating with 1:3 (BW-3) and 1:5 ratios (BW-5) it was almost in the same range and despite the increase in the protein ratio, no significant increase in particle size was observed. On the other hand, all the coating samples had an acceptable polydispersity index (PDI) except for the composite sample with 1:3 ratio which had a significant difference with other samples. The lowest PDI was observed in samples B, W and BW-5 ($p > 0.05$). Najaf Najafi et al. (2016), by exploring the emulsion prepared from the combination of Balangu gum (0 to 0.3%) and whey protein (0.5 to 3%), reported that the protein concentration had a significant effect on the particle size of the emulsion, so that with increasing protein concentration, the particle size decreased [19]. This difference in results is likely related to the amount of oil used in these researchers' study (20 to 50% of total emulsion) compared to the present study (0.5% of total emulsion) and the method of emulsion production.

The small particle size of emulsion B can be attributed to its stabilising effect by increasing the viscosity of the continuous phase and in emulsion BW-1 to the incompatibility between the gum and the negatively charged protein, which is probably due to the existing electrostatic repulsive forces, forming a more compact layer around the fat globules [20]. However, with increasing whey protein content, the concentration of free and unadsorbed protein in the continuous phase increased and the bonding between protein molecules (aggregation) replaced the gum-protein bonds, causing an increase in particle size [19].

Table 1- Formulation and particle size of coating emulsions

Sample code	Balangu gum (%)	Whey protein (%)	Particle size (µm)	PDI
B	1	-	3.2 ±0.4 ^{b}	0.15 ± 0.07 ^{b}
W	-	1	4.5 ± 0.3 ^{a}	0.14 ± 0.02 ^{b}
BW-1	0.5	0.5	3.8 ± 0.5 ^{ab}	0.18 ± 0.06 ^{ab}
BW-3	0.25	0.75	4.7 ± 0.4 ^{a}	0.35 ± 0.10 ^{a}
BW-5	0.167	0.833	4.8 ± 0.3 ^{a}	0.13 ± 0.03 ^{b}

B, W, BW-1, BW-3, and BW-5 are coating prepared by Balangu gum, whey protein, Balangu gum-whey protein composites with 1:1, 1:3, and 1:5 ratios.
The same letters in a column represent non-significant differences at 5% level.

3.1.2. FTIR spectroscopy of coatings

The FTIR spectra of the prepared coating samples are presented in Figure 1. In summary, the changes observed in the FTIR spectra of the coating samples indicate that in the composite samples, the interaction between the Balangu gum was probably through hydrogen bonds (elimination or decrease in the peak height at 3452 cm^{-1} (spectrum (a)) and 3416 cm^{-1} (spectrum (b)), the bond between carbonyl or carboxyl group with the amine groups of whey protein (increase in the peak height of 2856 cm^{-1}, 1747 cm^{-1}, 1545 cm^{-1} and decrease in the height or elimination of the peaks at 1650 cm^{-1}, 1160 cm^{-1}, 1109 cm^{-1} and 1060 cm^{-1} in the composite samples compared to the sole coatings), which was at its maximum in BW-1, however, with the increase in the amount of protein in the formulation, a number of free amine bonds remained in excess and no free functional groups from the gum remained to establish the bond, so the highest structural continuity in the sample BW-1 was observed and with increasing protein ratio, an aggregated and non-uniform structure has been emerged. Similar results regarding peak changes in the combination of gum and whey protein were reported by Najaf Najafi et al. (2016) [19].

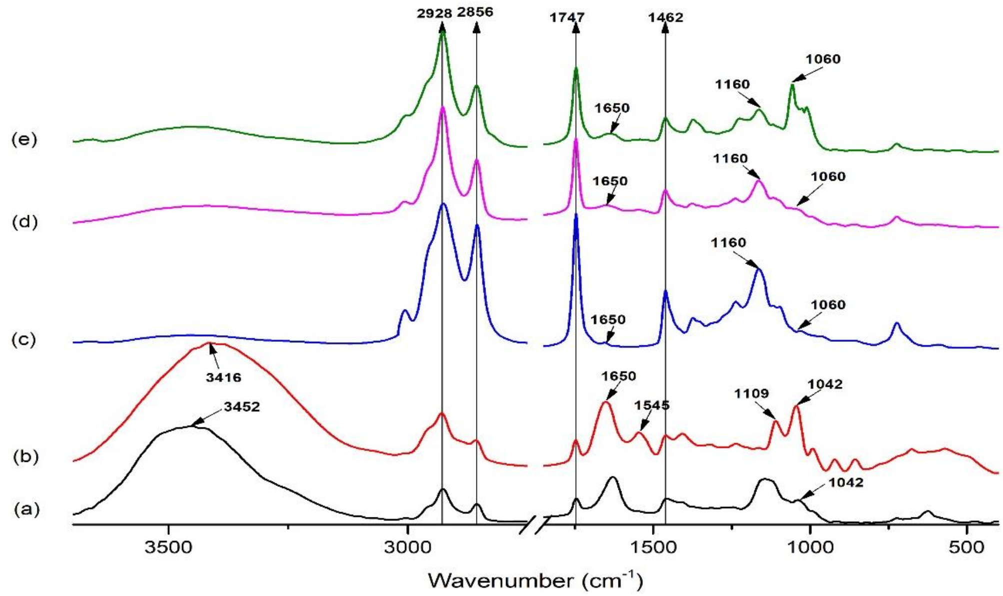

Fig. 1- FTIR spectra of coatings prepared from Balangu gum (a), whey protein (b), and their composite with gum to protein ratios of 1:1 (c), 1:3 (d), and 1:5 (e)

3.2. Physicochemical properties of films

3.2.1. Surface morphology of films

As can be seen in Figures 2a and 2b, film B has a rough surface and consists of irregularly arranged filaments, while film W has a relatively smoother surface (Fig. 2c) but spherical particles are visible on its surface (Fig. 2d). The microstructure images of film BW-1 (Figs. 2e and 2f) show a smooth and even surface, which indicates film compactness and the absence of any pores or fractures, probably indicating proper interaction and integration of Balangu gum and whey protein (Section 3.1.2). As the mixing ratio increased (Figs. 2g to 2j), evidence of surface roughness, the formation of particulate aggregate structure and a disrupted structure appeared. It is likely that the aggregations caused by protein-protein interaction caused the loss of structural integrity and the formation of cracks in the film surface. Similar results have been reported for the mixture of basil gum and whey protein [20].

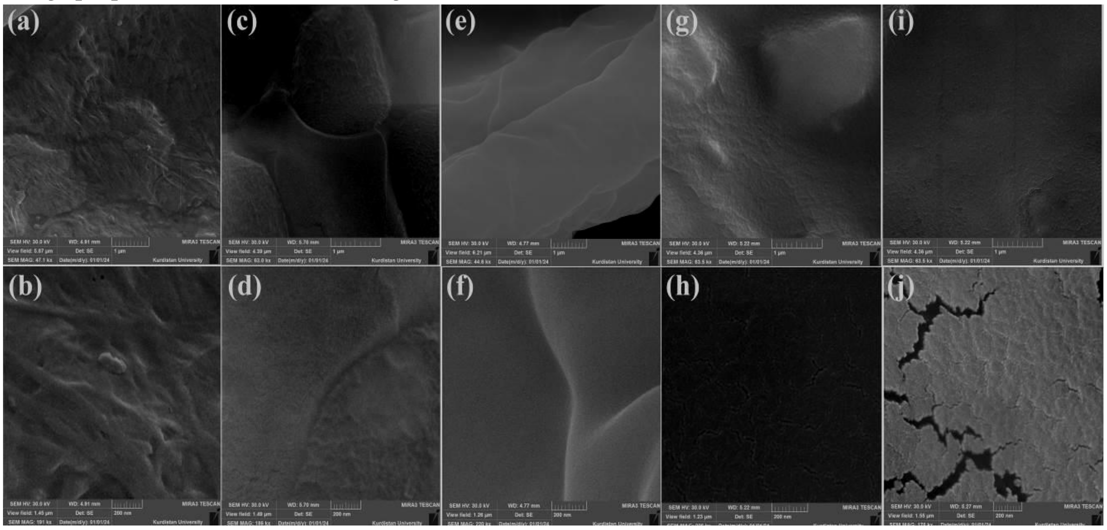

Fig. 2- Surface morphology of Balangu gum (a & b), whey protein (c & d), and their composite films with Balangu gum to whey protein ratios of 1:1 (e & f), 1:3 (g & h), and 1:5 (i & j) at 47kX (upper row) and 191kX (lower row) magnification.

3.2.2. Film thickness

The results of Table 2 showed that the highest film thickness was for sample W, while for film B, it was significantly lower. Interestingly, the thickness of BW-1 film was the lowest among all samples ($p < 0.05$), indicating a good interaction between gum and protein and the emergence of a dense and uniform structure in it, a result that was also observed in its microstructure. However, as the mixing ratio increased to 1:5, the thickness increased significantly. The reason for the low thickness of film B is probably related to its low flexibility and relative molecular rigidity [21], so that at low film humidity, intermolecular bonds increased and, as a result, a more ordered molecular arrangement was formed in it by reducing molecular mobility. In the presence of whey protein, interactions between Balangu gum and protein caused the creation of a regular and uniform structure, and therefore the molecular density increased and the film thickness decreased. As the amount of protein increased, there were fewer free groups of gum to bond with, and therefore the protein molecules interacted with each other, creating an irregular arrangement in the film structure (FTIR and SEM results).

Table 2- Physicochemical properties of films prepared with Balangu gum, whey protein, and their composites with different ratios

Sample	Thickness (µm)	Solubility (%)	Water vapour permeability ($\times 10^{-11} gm^{-1}s^{-1}Pa^{-1}$)
B	5.2 ± 0.8^{d}	10.1 ± 0.7^{d}	32.0 ± 4.3^{cd}
W	15.9 ± 0.9^{a}	19.2 ± 1.0^{a}	94.8 ± 5.1^{a}
BW-1	3.0 ± 0.8^{e}	9.3 ± 1.1^{d}	25.5 ± 3.7^{d}
BW-3	7.6 ± 0.5^{c}	12.6 ± 0.6^{c}	39.0 ± 4.7^{c}
BW-5	10.5 ± 0.4^{b}	15.1 ± 1.0^{b}	66.0 ± 2.9^{b}

B, W, BW-1, BW-3, and BW-5 are films prepared by Balangu gum, whey protein, Balangu gum-whey protein composites with 1:1, 1:3, and 1:5 ratios.
The same letters in a column represent non-significant differences at 5% level.

3.2.3. Film solubility

The water solubility of the films also followed a similar trend, with the solubility of W significantly higher than that of B (Table 2). BW-1 film had the lowest solubility ($p < 0.05$), while the moisture content increased significantly with increasing protein content. Considering the increase in film thickness with increasing whey protein content, it can be inferred that the decrease in the interaction between gum and protein molecules caused the loss of structural integrity and increased intermolecular distances, resulting in an open structure in the film, and the samples were easily broken up and dissolved in water. It is likely that the denser structure of BW-1 film and its uniform, non-porous surface caused the lowest water solubility of this film compared to the other samples.

3.2.4. Permeability of films to water vapour

On the other hand, the results of water vapour permeability (WVP) of the films in Table 2 indicated that the lowest and highest values belonged to BW-1 and W films, respectively. In the composite samples, WVP also increased significantly with increasing protein content, whereas, it was still lower than the permeability of W. It is likely that the increase in protein content weakened the film structure and made its structure more open and permeable (SEM results), so it seems that due to the saturation of the interactions between gum and protein, there are no free sites of gum left to bond with protein.

3.3. Physicochemical properties of strawberries

3.3.1. Weight loss

Based on the results of measuring the weight loss of strawberries (Table 3), it was found that the uncoated samples lost about 6% of their weight by the third day and about 13.5% by the seventh day, while their corresponding coated samples had a lower weight loss. On the third day, the weight loss of the coated strawberries (except for the coating W) was significantly different from the corresponding uncoated sample, but the type of coating did not make a significant difference, so that only the sample with BW-1 coating had a significant difference. On the seventh day, a similar trend was observed, so that, except for the W and BW-5 coated samples, the existence of the coating caused a decrease in the weight loss of strawberries compared to the corresponding sample ($p < 0.05$). The weight loss due to the presence of the BW-1 coating was significantly lower than that of the other coated samples, which was similar to the results on the third day. According to the results obtained from the WVP of the films examined in this study (Table 2), a significant reduction in weight loss of the sample coated with BW-1 is expected because the highest film density and lowest permeability were observed in this coating. A similar trend has been observed in the literature regarding the reduction in weight loss of coated strawberries during storage [4]. The weight loss of strawberries over time is mainly attributed to moisture loss and its respiration process through the outer wall, therefore, placing the coating on this wall, which has low water vapour permeability, slows down the weight loss and increases the shelf life [1, 3, 4, 14].

3.3.2. Total soluble solids

The results of measuring the soluble solids of strawberries are given in Table 3. As can be seen from the results, the Brix of uncoated strawberries increased over time, but the presence of coating slowed down this process or even in some coated samples, the Brix has not changed significantly. Only the sample with BW-1 coating preserved soluble solids with a significant difference compared to other coatings. In other studies, an increase in strawberry Brix was observed by using coating [1, 3]. The increase in Brix is probably related to a decrease in moisture content of strawberries or the decomposition of some compounds and their conversion into soluble substances (such as the conversion of some polysaccharides to simple sugars) during fruit ripening [1, 14].

3.3.3. pH and titratable acidity

The pH of strawberry samples during storage for 7 days ranged from 3.24 to 4.07, and its changes showed an increasing trend, but no significant difference was observed between the coated and their corresponding uncoated samples or between different coatings; however, the results indicated that the presence of the coating caused better preservation of the pH of strawberries during storage compared to its uncoated counterpart. The observed results are similar to various studies on the effect of coatings on slowing the increase in pH of different strawberry varieties during storage [4].

The range of acidity values of strawberry samples was from 0.75 to 0.44%, which showed that the titratable acidity of strawberry samples decreases during storage, so that, like the pH parameter, no significant difference was observed between coated and uncoated samples. On the other hand, the type of coating also had no significant effect on the acidity value, but among them, the sample with BW-1 coating had the least change ($p > 0.05$). The decreasing trend of acidity in strawberries coated with different materials during storage has also been reported in other studies [1, 3]. Changes in pH and acidity of strawberries during storage are related to increased respiration and decomposition of organic acids during it after the decomposition of carbohydrates in the fruit ripening process [1, 3, 4, 14].

Table 3- Physicochemical properties of coated and non-coated strawberries during storage at 5 °C.

Parameter	Coating type	Storage time (day)				
		0	3		7	
			Non-coated	Coated	Non-coated	Coated
WL (%)	B	-	6.14 ± 0.27 a	4.13 ± 0.17 bc	13.48 ± 0.68 a	10.96 ± 0.42 b
	W	-	6.22 ± 0.28 a	5.47 ± 0.57 abc	13.22 ± 0.57 a	11.86 ± 0.71 ab
	BW-1	-	6.13 ± 0.18 a	3.57 ± 0.14 d	13.35 ± 0.78 a	8.37 ± 0.44 c
	BW-3	-	6.33 ± 0.53 a	4.69 ± 0.55 bc	13.36 ± 1.02 a	11.18 ± 0.88 b
	BW-5	-	6.26 ± 0.65 a	5.09 ± 0.42 bc	13.46 ± 1.15 a	12.64 ± 0.91 ab
Brix (°)	B	9.9 ± 1.1	10.3 ± 0.4 abc	10.0 ± 0.7 abc	14.5 ± 0.8 ab	12.2 ± 0.3 bcd
	W	10.8 ± 0.6	11.1 ± 1.1 abc	11.0 ± 0.3 abc	15.6 ± 1.0 a	15.4 ± 1.1 a
	BW-1	9.2 ± 0.4	9.5 ± 0.8 abc	9.2 ± 0.9 a	13.2 ± 0.6 abc	10.6 ± 0.7 d
	BW-3	9.1 ± 0.7	9.4 ± 1.3 ab	9.3 ± 1.2 a	13.4 ± 0.9 abc	11.0 ± 1.3 cd
	BW-5	11.6 ± 0.8	11.9 ± 1.5 c	11.8 ± 1.0 bc	15.6 ± 1.4 a	14.3 ± 1.7 ab
AC (mg/100g)	B	48.0 ± 1.3	37.2 ± 1.7 abcde	43.3 ± 1.4 bc	21.7 ± 2.8 a	39.7 ± 4.0 b
	W	45.1 ± 0.6	36.8 ± 1.6 abcde	41.9 ± 2.8 abc	20.4 ± 1.9 a	38.1 ± 2.3 b
	BW-1	54.7 ± 2.1	31.1 ± 2.0 d	53.1 ± 3.8 e	18.9 ± 2.4 a	51.5 ± 2.1 c
	BW-3	51.6 ± 2.6	40.6 ± 2.1 abc	46.0 ± 2.4 c	24.5 ± 2.5 a	39.0 ± 2.8 b
	BW-5	43.8 ± 1.7	31.9 ± 2.6 de	39.6 ± 3.6 ab	24.6 ± 3.2 a	36.7 ± 2.6 b
L*	B	37.29 ± 1.41	28.45 ± 1.88 de	35.86 ± 2.83 a	20.83 ± 3.10 ab	30.03 ± 1.94 e
	W	35.51 ± 0.84	26.10 ± 1.64 cde	34.29 ± 1.41 ab	20.14 ± 4.04 ab	28.12 ± 1.27 cde
	BW-1	40.59 ± 2.69	33.82 ± 2.47 ab	38.17 ± 1.55 a	22.67 ± 3.81 abc	36.50 ± 1.77 f
	BW-3	31.80 ± 1.98	21.78 ± 1.81 c	29.40 ± 3.11 bcde	11.25 ± 3.39 d	22.31 ± 1.86 abc
	BW-5	38.04 ± 2.86	23.87 ± 2.12 cd	34.49 ± 2.96 ab	15.67 ± 2.31 abcd	23.25 ± 3.75 bc
Hue (°)	B	24.7 ± 1.6	16.3 ± 1.2 b	23.2 ± 1.3 a	7.0 ± 2.5 a	18.6 ± 1.6 c
	W	25.3 ± 0.7	17.4 ± 1.4 bc	22.4 ± 0.8 a	9.3 ± 0.7 ab	16.9 ± 0.8 c

	BW-1	28.5 ± 1.2	21.2 ± 1.1 abc	27.7 ± 2.2 d	10.8 ± 1.1 ab	25.1 ± 1.3 d
	BW-3	26.6 ± 1.8	19.4 ± 1.8 abc	21.8 ± 2.3 abc	10.3 ± 1.7 ab	12.2 ± 1.0 b
	BW-5	30.9 ± 0.6	22.0 ± 2.0 a	15.3 ± 3.3 b	9.6 ± 2.0 ab	10.0 ± 2.9 ab

WL and AC stand for weight loss and anthocyanin content, respectively.

B, W, BW-1, BW-3, and BW-5 represent coatings prepared from Balangu gum, whey protein isolate, and composites of Balangu gum-whey protein isolate at 1:1, 1:3, and 1:5 ratios, respectively.

The data are mean of at least five replicates ± standard deviation and different letters infer significant difference at 5% level.

3.3.4. Anthocyanin content

Based on the results (Table 3), it was found that the anthocyanin content of strawberries decreased during storage, but in the coated samples, this decrease was slower than in the uncoated samples ($p > 0.05$). On the third day of storage, the anthocyanin content of BW-1 and BW-5 samples was significantly different from the corresponding uncoated samples, while the other coatings did not make a significant difference. On the seventh day, all the coated samples had a significant difference in anthocyanin content from the uncoated samples, but among the coated samples, only BW-1 had the least change compared to the corresponding uncoated sample ($p < 0.05$). In the literature, there are reports of both a decreasing trend in anthocyanin content during storage and reports of its increasing trend [3]. Given that anthocyanin content depends on cultivar, storage temperature, and oxygen concentration, differences in reported results are expected. However, ripe fruits that have reached maximum anthocyanin synthesis experience a decrease in concentration due to the lack of new anthocyanin synthesis and degradation due to environmental factors [4].

3.3.5. Colour parameters

In order to investigate the effect of coating on the colour changes of strawberry samples over time, the parameters of brightness (L*) and Hue were used. Based on the results of Table 3, it can be seen that the L* value of strawberries decreased with storage time up to 7 days, which was very significant in uncoated samples. By applying the coating, the brightness of strawberries changed to a lesser extent than the corresponding uncoated samples ($p > 0.05$), so that coatings B and BW-1 significantly maintained the L* of strawberries.

Hue parameter, as one of the three dimensions of colour that expresses the visual sensation that can be perceived and recognized by humans (such as red, green, blue, etc.), can be used to monitor changes in the colour of foods [22]. Based on the results (Table 3), it was found that the coatings significantly slowed down the downward trend in the Hue of strawberries during 7 days of storage compared to the corresponding uncoated samples, except for sample BW-3 at all times and BW-5 on the seventh day ($p > 0.05$). As can be seen from the results, the least Hue change was observed in the strawberry sample with BW-1 coating, which was also significantly different from the other coated samples. Similar results have been reported regarding the reduction in brightness [3, 4] and Hue [3] of coated strawberries during storage at different temperatures for periods of up to 15 days.

3.3.6. Vitamin C

The results of measuring the vitamin C content of strawberry samples are presented in Figure 3. As can be seen, in all types of uncoated and coated strawberries, their vitamin C content decreased with storage time, so that there was no significant difference between the vitamin C content of uncoated samples over time, but the presence of a coating improved the vitamin C retention compared to them ($p < 0.05$). The least change was observed in the BW-1 sample. Similarly, a decreasing trend was reported for the vitamin C content of various coated strawberries [1, 3]. The decrease in vitamin C content is probably related to increased respiration in strawberries and oxidative reactions [3, 4, 14], but on the other hand, the increase in vitamin C content could be related to increased biosynthesis during storage for strawberries that were not fully ripe at the time of harvest [1].

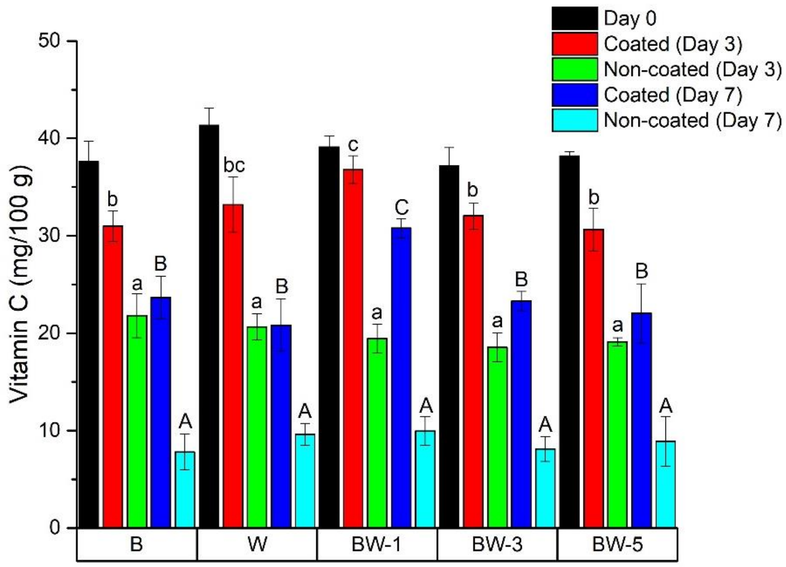

Figure 3- Vitamin C content of coated and non-coated strawberries during storage at 5 °C. B, W, BW-1, BW-3, and BW-5 represent coatings prepared from Balangu gum, whey protein isolate, and composites of Balangu gum-whey protein isolate at 1:1, 1:3, and 1:5 ratios, respectively. Different letters represent significant difference at 5% level (lowercase letters for day 3 and uppercase letters for 7th day).

3.3.7. Firmness

Based on the results of the firmness assessment (Figure 4), it was found that the texture of strawberry samples deteriorated and the firmness value decreased during storage for up to 7 days. On the third and seventh days of storage, the firmness of coated samples was higher than their uncoated counterparts ($p < 0.05$), but no significant difference was observed between coated samples on the third and seventh days, except for sample BW-1, which had the highest firmness among all samples ($p < 0.05$). Similarly, it has been reported in the literature that strawberry firmness decreases over time and that coating is effective in slowing it down. This is probably related to changes in cell wall polysaccharides, especially pectin, which gradually increases the amount of water-soluble pectin and softens the fruit texture due to respiration and the role of pectolytic enzymes (ester elimination and depolymerization) [1, 3, 4].

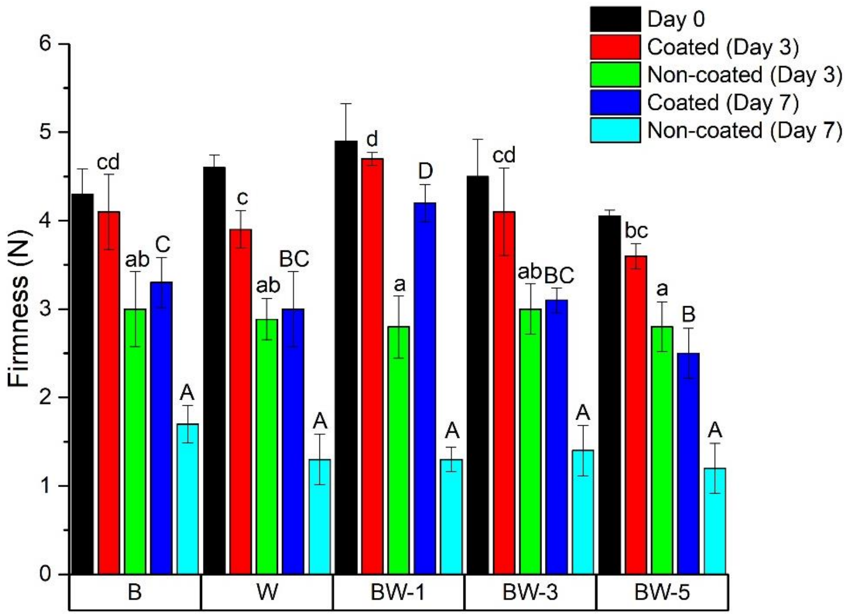

Figure 4- Firmness of coated and non-coated strawberries during storage at 5 °C. B, W, BW-1, BW-3, and BW-5 represent coatings prepared from Balangu gum, whey protein isolate, and composites of Balangu gum-whey

protein isolate at 1:1, 1:3, and 1:5 ratios, respectively. Different letters represent significant difference at 5% level (lowercase letters for day 3 and uppercase letters for 7th day).

4. Conclusion

Based on the results of the present study, it was found that the Balangu seed gum interacted appropriately with whey protein in a 1:1 mixing ratio and formed a highly effective emulsion coating to maintain the quality characteristics of strawberries during cold storage for 7 days. The investigation of the coating properties showed that hydrogen bonds and interactions between the carbonyl and carboxyl groups of the Balangu gum with the side groups of the amino acids of whey protein resulted in a uniform and dense coating with a particle size of less than 4 microns and a suitable particle dispersion that had much lower solubility, moisture content, and thickness than sole or composite coatings with protein mixing ratios of 1:3 and 1:5. The very low permeability of this coating was a very effective solution to delay moisture loss and tissue softening, chemical and enzymatic reactions of strawberries during storage, so that fruit quality parameters such as vitamin C, anthocyanins, acidity, and colour were largely preserved until the seventh day. Overall, the composite coating investigated in this study can effectively increase the shelf life of strawberries for fresh consumption and reduce waste of this perishable product.

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مقاله علمی_پژوهشی

اثر پوشش خوراکی تلفیقی صمغ بالنگو و پروتئین آب پنیر بر ماندگاری توت فرنگی

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چکیده

توت‌فرنگی به عنوان یک میوه ارزشمند، عمر ماندگاری کوتاه داشته و بسیار فسادپذیر است. از جمله راهکارهای مؤثر برای رفع این مشکل، استفاده از پوشش‌های خوراکی است که علاوه بر حفظ تازگی و ارزش تغذیه‌ای و حسی، از ضایعات آن هم می‌توان جلوگیری نمود. در این تحقیق، اثر پوشش خوراکی امولسیونی تکی و تلفیقی صمغ بالنگو و پروتئین آب پنیر با سه سطح نسبت اختلاط در قالب طرح کاملاً تصادفی بر ویژگی‌های فیزیکوشیمیایی توت‌فرنگی مورد بررسی قرار گرفت. اندازه ذره امولسیون‌ها در محدوده ۳/۲ تا ۴/۸ میکرون متغیر بود و با بیشتر شدن مقدار پروتئین، اندازه ذره‌ها افزایش یافت. سطح فیلم تلفیقی با نسبت صمغ به پروتئین ۱:۱ کاملاً صاف و متراکم بود و کمترین محتوای رطوبت و حلالیت در آب را داشت، در حالی که با افزایش مقدار پروتئین، مقدار آنها بالا رفت و سطح فیلم‌ها ناهموار و گسیخته شد و مقدار نفوذپذیری به بخار آب افزایش یافت. پوشش دادن توت‌فرنگی سبب کاهش تغییرات افت وزنی، پارامترهای رنگی، محتوای آنتوسیانین، ویتامین C، سفتی بافت و ثابت ماندن مقدار مواد جامد محلول نسبت به نمونه‌های بدون پوشش شد. بطور کلی، پوشش دادن توت‌فرنگی از طریق ایجاد مانعی در مقابل تبادل رطوبت و تنفس بطور مؤثری سبب حفظ پارامترهای کیفی توت‌فرنگی طی نگهداری شد. نتایج این تحقیق نشان داد پوشش دادن توت‌فرنگی با پوشش تلفیقی صمغ بالنگو و پروتئین آب پنیر در نسبت ۱:۱ می‌تواند بطور کارآمدی ماندگاری را افزایش داده و از افت کیفیت و ایجاد ضایعات آن جلوگیری نماید.