Quality Characteristics of Semi-Moist Apricot-Cornflakes: Effect of Different Composite Coating Application and Storage Time

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Abstract: The effect of different composite coatings on quality of semi-moist apricot cubes mixed with cornflakes was investigated during 180 days of storage. The apricot cubes were osmotically dehydrated (OD) and coated before hot-air drying (HAD) at 60 °C. Chitosan-bees wax (CBW) and whey protein isolate-bees wax-oleic acid (WPI-BW-OA) coatings were applied after HAD and the samples were added to cornflakes. Application of OD and pectin-ascorbic acid (Pec-AA) coating (prior to HAD) and WPI-BW-OA coating (after HAD) led to significant retention of total phenol compounds, β-carotene and antioxidant activity in apricot cubes compared to uncoated and CBW-coated samples. WPI-BW-OA-coated samples gave significantly higher L* values (lighter color) and b* values (more creamy or yellowish color) and lower a* values (less reddish color) and browning values than control followed by CBW-coated apricots at any time of storage (p < 0.05). The rate of apricot moisture loss and cornflakes moisture gain was higher in uncoated apricot cubes, followed by CBW- and WPI-BW-OA-coated samples. Application of WPI-BW-OA coating was effective in retaining the crispness measured by lower firmness ($F_{max}$) values in cornflakes upon storage. Based on the obtained results, WPI-BW-OA coating allowed effectively preserving the quality characteristics of semi-moist apricot cubes and cornflakes components in the mixed state.

Keywords: osmotic dehydration; edible coating; dried apricot; breakfast cereals; food quality

1. Introduction

Dried apricots are nutritionally important due to their phenolic compounds, carotenoids and the high amount of iron as essential trace element [1]. In this regard, the addition of dried apricot to breakfast cereals produces health-promoting product with new taste, color and mouthfeel and rich in phenolic compounds, vitamins, minerals and fibre [2–4]. To produce dried apricots for inclusion in such system, most industries dry fruits to critical moisture content close to that of breakfast cereals [5,6]. This causes undesirable changes in physical and nutritional characteristics of the resulting dried fruits [7]. Applications of different pre-treatments prior or after hot-air drying (HAD) including osmotic dehydration and application of different edible coatings could solve this problem by obtaining semi-moist fruit pieces with desirable textural, nutritional and sensorial characteristics [8,9]. However, semi-moist apricot pieces should be physically, nutritionally and microbiologically stable when mixed with dry cereals in breakfast cereals applications [10,11]. In this regard, fruit samples can be coated with suitable film-forming materials to ensure their suitability for inclusion in multicomponent breakfast cereals system [12]. When dried apricots are mixed into breakfast cereals, there is a moisture transfer between the dried fruit,
the component with the highest water activity, and the cereals, until the system reaches a moisture equilibrium [13–15]. The moisture transfer could change physical, textural and sensorial attributes of dried fruit-cereals system, which would affect its quality, consumer acceptability and shelf-life [7,16].

The crispness or crunchiness of breakfast cereals is an essential quality criterion. It is lost when the water activity of the cereals exceeds to values of 0.60–0.68 [17]. On the other hand, dried apricots require higher moisture contents, ensuring right texture and mouthfeel properties for dried fruit-breakfast cereals product. The dried apricots become unacceptable when they reach water activity values lower than 0.3–0.5 [18]. This counterbalance can be solved by application of suitable coating to dried fruit samples as barrier, which can reduce the driving force of the moisture migration between the components of the breakfast cereal systems [13]. Talens et al. [7] showed suitability of chitosan-based edible coatings in dried pineapple samples for application in dry fruit-cereal products. They produced partially dehydrated pineapples by OD and vacuum impregnation. Other researchers also used edible coatings based on chitosan-oleic acid [19,20], caseinates-oleic acid-beeswax [21,22], caseinate-lysozyme [23] and caseinate-tung oil [24] mixtures for different applications.

In previous studies, the effect of osmotic dehydration (with and without sonication) and the use of pectin coatings (incorporating ascorbic acid or citric acid) on nutritional, chemical, sensory [8], physical, textural and microstructural properties [9] of HAD apricot cubes were investigated. To the best of our knowledge, there is no report on the application of semi-moist coated apricot cubes in breakfast cereal product. Thus, the objective of this study was to evaluate quality characteristics of HAD-apricot cubes coated by chitosan-beeswax (CBW) and whey protein isolate-beeswax (WPI-BW-OA) added to cornflakes during storage time.

2. Materials and Methods

2.1. Raw Material and Preparation of Fruit Samples

Mature apricot (Prunus armeniaca) fruits with approximate mass and diameter of 25 g and 3 cm, respectively, were purchased from local market and refrigerated before experiments. Fresh samples were sliced into 1 cm$^3$ cubes before each experiment.

2.2. Primary Coating Application before Hot-Air Drying (HAD)

In previous studies, fresh apricot cubes were treated by osmotic dehydration (OD) and ultrasonic-assisted osmotic dehydration (UOD) at 25 and 35 kHz for 30 and 45 min at 55 °C with sorbitol solution of 35° Brix concentration (sorbitol solution to apricot ration of 4:1 w/w) followed by application of edible coatings including pectin alone (Pec), pectin-citric acid (Pec-CA) and pectin-ascorbic acid (Pec-AA) prior to HAD at 60 °C with air velocity of 1.5 m/s to reach a moisture content of approximately 19%–20% (wet basis) [8,9]. It was concluded that OD treatment (without sonication) for 45 min and Pec-AA coating is regarded as optimal treatment and conditions to produce semi-moist apricot cubes with desired nutritional, sensory, physical and textural properties. Thus, these treatments were selected for subsequent coating application after HAD.

2.3. Secondary Coating Application after HAD

2.3.1. Chitosan-Bees Wax (CBW) Coating

High molecular weight chitosan solution of 1% (w/v) was prepared by dissolving chitosan in 100 mL of an aqueous solution of glacial acetic acid (1%, v/w) with continuous shaking at room temperature. After complete chitosan dissolution, 0.2 g of glycerol and 0.1 g of Tween-80 were added and stirred for 30 min. The obtained solution was then heated to 70 °C and beeswax was added at a ratio of 1:0.5 (w/w). The solution was homogenized at 70 °C for 1 min at 13,500 rpm using a rotor-stator homogenizer (Ultraturrax DI 25 basic-Yellowline, Janke and Kunkel, Staufen, Germany). The pH of coating emulsions was adjusted to 5.2 with NaOH 1 N.
2.3.2. Whey Protein Isolate-Bees Wax Oleic Acid (WPI-BW-OA) Coating

Pure whey protein isolate (5%, w/w) were dispersed in an aqueous solution of distilled water. In WPI-BW coating emulsion, the protein:glycerol ratio was 1:0.2 and the protein:lipid ratio was 1:0.5. The lipid fraction was composed of oleic acid:bees wax (70:30 mass ratio). After adding glycerol to aqueous solutions of WPI, all dispersions were heated and kept at 75 °C for 10 min to denature the protein fraction. Then, the required amount of beeswax was added while melted in the hot solution, and then homogenized at 75 °C for 1 min at 13,500 rpm. The emulsions were cooled at room temperature and oleic acid was added in the required amount. Coatings were applied by dipping semi-moist apricot cubes in film-forming solutions of CBW or WPI-BW-OA (solution: sample ratio of 20:1, w/w) at 25 °C for 10 min. Immersion of dried apricot cubes in composite edible coating solutions increased their moisture content to 30%–32% (wet basis). Hence, the coated samples were dried at 60 °C to reach to initial moisture content of dried apricot cubes (19%–20%). Uncoated apricot cubes, prepared from the same type of fruits, were used as a control.

2.4. Storage of the Dried Apricot-Cornflakes Product

To evaluate the effect of different coatings and pretreatments on quality of semi-moist apricot cubes-cornflakes system, coated and uncoated (control) apricot cubes were mixed at a fruit:cereal ratio of 30:70 (w/w) and stored in sealed polyethylene bags (water permeability of 1.2 g/m²/24 h) at a constant temperature of 25 °C. Then, nutritional and physical properties of dried apricot cubes and cornflakes in the mixed product were evaluated monthly during 180 days of storage. The experimental flowchart of processing fresh apricots to semi-moist coated apricot cubes to be incorporated into the breakfast cereal system is shown in Figure 1.
2.5. Sample Analysis

2.5.1. Total Phenolic Compounds (TPC)

To evaluate total phenolic compounds (TPC) of dried apricot samples, Folin-Ciocalteu procedure was applied. Polyphenols were extracted according procedure explained previously [9]. The results were expressed as mg gallic acid (GA)/100 g of dry matter (DM).

2.5.2. β-Carotene Content

β-Carotene extraction of dried apricot samples was done using procedure explained before [9] and absorbance was measured at 450 nm in a UV-visible spectrophotometer (Thermo Electron Corporation, Beverly, MA, USA). The total carotenoid content was represented as mg β-carotene/100 g of DM. Standard β-carotene (Fluka Biochemika, Honeywell, Charlotte, NC, USA) was used. The measurement was repeated triplicate for each sample.

2.5.3. Total Antioxidant Activity (TAA)

Total antioxidant activity of the dried apricot cubes was measured spectrophotometrically with the DPPH radical-scavenging method [8]. An aliquot of 50 µL of dried apricot extract was added to 3 mL of a 6.1 × 10^{-5} M methanol solution of DPPH. The decrease in absorption after 2.5 h at 517 nm was recorded using a UV-visible spectrophotometer (Thermo Electron Corporation, Beverly, MA, USA) at 25 °C. The percent inhibition of the DPPH radical was calculated using the Equation (1) [25]:

\[
TAA (\%) = \frac{Abs_{\text{control}} - Abs_{\text{sample}}}{Abs_{\text{control}}} \times 100
\]

where TAA (%) is the percentage of total antioxidant activity and \(Abs_{\text{control}}\) and \(Abs_{\text{sample}}\) are the absorbance values of the control and test sample, respectively.

2.5.4. Color Analysis

Color parameters of the coated-dried apricot cubes were analyzed according to the CIE (Commission Internationale de l’Eclairage or International Commission on Illumination) standard measuring \(L^*a^*b^*\) color values [26]. The total color change (\(\Delta E^*\)) and chroma (\(C_i^*, C_0^*, \Delta C^*\)) were then calculated using Equations (2)–(5):

\[
\Delta E^* = \sqrt{(L_i^* - L_0^*)^2 + (a_i^* - a_0^*)^2 + (b_i^* - b_0^*)^2}
\]

where \(L_i^*, a_i^*\) and \(b_i^*\) are the initial color values of fresh samples and \(L_0^*, a_0^*\) and \(b_0^*\) are the final color values of the dried samples.

\[
C_0^* = \sqrt{(a_0^* + b_0^*)^2}
\]

\[
C_i^* = \sqrt{(a_i^* + b_i^*)^2}
\]

\[
\Delta C = C_i^* - C_0^*
\]

2.5.5. Browning Value

Browning value of dried apricot samples was determined spectrophotometrically by measuring apricot extract absorbance at 420 nm using UV-visible spectrophotometer (Thermo Electron Corporation, Beverly, MA, USA) [27].

2.5.6. Water Activity and Moisture Content

The measurement of dried apricot water activity was directly done using a hygrometer (LabMaster, Novasina AG, Lachen, Switzerland) at 25 °C with the accuracy of 0.003.
moisture content was evaluated by vacuum drying the samples to constant weight at 60 °C (method 20.013 AOAC, 1980).

2.5.7. Texture Analysis of Breakfast Cereals and Dried Apricot Cubes

Evaluation of texture of breakfast cereals was carried out by measuring the maximum tolerable force (N), the work required for 75% compression of cornflakes samples (N·mm) and the time required to reach the first maximum peak (S) using a compression tester (Hounsfieeld-H5ks, Instron, Norwood, MA, USA). The test parameters were set as follow: load cell, 5 N; test speed, 50 mm/min; and diameter of cylindrical flat-head probe, 2 cm.

2.6. Statistical Analysis

Statistical analysis of data was performed through analysis of variance (ANOVA) using SPSS (IBM SPSS statistic 16, New York, NY, USA). Normal distribution and homogeneity of variance were previously tested (Shapiro-Wilk). To evaluate the difference between mean values of responses, Duncan’s multiple range test was performed, and significant differences were defined at $p < 0.05$. The Pearson correlation test was also used to determine any correlations among responses. The measurement of each type of parameter was performed in triplicate.

3. Results and Discussion

3.1. Effect of Osmotic Dehydration and Active Pectin-Based Coating on Bioactive Compounds and Water Activity of Dried Apricot

Total phenolic compounds (TPC), β-carotene, total antioxidant activity (TAA) and aw of apricot cubes values obtained by OD(45) pre-treatment followed by Pec-AA coating, as optimum pre-treatment condition reported previously [9] before and after HAD, are shown in Table 1. The OD pre-treatment (45 min) of apricot cubes and application of Pec-AA coating prior to HAD at 60 °C significantly ($p < 0.05$) improved the preservation of TPC, β-carotene and TAA in samples compared to hot-air dried (HAD) samples with no pre-treatment. Higher TAA value of OD-coated dried samples compared to fresh apricot can be explained by the presence of ascorbic acid in those samples. Ascorbic acid is regarded as oxygen scavenger compound inhibiting polyphenol oxidase (PPO) catalyzed reactions. This increased the antioxidant capacity of the OD-coated dried apricots. These apricot samples had significantly lower aw than non-pretreated ones due to sugar gain during OD pre-treatment.

Table 1. Effect of osmotic dehydration (OD) and Pec-AA coating application prior to hot-air drying (HAD) on bioactive compounds, aw and browning value of dried apricot.

| Sample                  | TPC (mg GA/100 g d.m.) | β-Carotene (mg/100 g d.m.) | TAA (%) | aw  
|------------------------|------------------------|-----------------------------|---------|------
| Fresh apricot          | 210 * (3.1) a          | 25.1 (0.4) a                | 11.7 (0.02) b | 0.93 (0.003) a  
| OD-Pec_AA coated- HAD  | 109 (2.0) b            | 13.6 (0.3) b                | 23.3 (2.13) a | 0.55 (0.003) c  
| Non-pretreated- HAD    | 37 (1.7) c             | 12.2 (0.2) c                | 10.7 (3.50) c | 0.63 (0.004) b  

* Data are mean values of triplicate measurements and standard deviations are in parenthesis. a–c Different letters in each column correspond to significant ($p < 0.05$) differences due to pretreatments application. OD, osmotic dehydration; HAD, hot-air drying; TPC, total phenolic compounds; TAA, total antioxidant activity.

3.2. Effect of Composite Coating Type and Storage Time on Bioactive Compounds of Semi-Moist Apricots in Breakfast Cereals

The effect of composite coatings chitosan-bees wax (CBW) and whey protein isolate-bees wax-oleic acid (WPI-BW-OA) on the bioactive compounds of the dried apricot cubes mixed with breakfast cereals during 180 days of storage is shown in Table 2.
Table 2. Effect of different types of composite coating after HAD and storage time on bioactive compounds of semi-moist dried apricot.

<table>
<thead>
<tr>
<th>Storage (Days)</th>
<th>Samples</th>
<th>TPC (mg GA/100 g d.m.)</th>
<th>β-Carotene (mg/100 g d.m.)</th>
<th>TAA (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Control</td>
<td>109.3 (2.1) aA</td>
<td>13.5 (0.05) aA</td>
<td>23.2 (0.25) aA</td>
</tr>
<tr>
<td></td>
<td>WPI-BW-OA coating</td>
<td>104.5 (0.5) bA</td>
<td>13.5 (0.02) aA</td>
<td>21.9 (0.41) bA</td>
</tr>
<tr>
<td></td>
<td>CBW coating</td>
<td>103.9 (0.6) bA</td>
<td>13.5 (0.01) aA</td>
<td>21.7 (0.60) bA</td>
</tr>
<tr>
<td>30</td>
<td>Control</td>
<td>98.1 * (0.6) ab</td>
<td>13.4 (0.02) ab</td>
<td>21.4 (0.14) ab</td>
</tr>
<tr>
<td></td>
<td>WPI-BW-OA coating</td>
<td>86.1 (2.3) bB</td>
<td>12.7 (0.04) bB</td>
<td>19.4 (0.13) bB</td>
</tr>
<tr>
<td></td>
<td>CBW coating</td>
<td>82.1 (0.1) cb</td>
<td>12.1 (0.04) cb</td>
<td>18.2 (0.24) cb</td>
</tr>
<tr>
<td>60</td>
<td>Control</td>
<td>85.2 (0.3) ac</td>
<td>11.4 (0.04) ac</td>
<td>19.8 (0.13) ac</td>
</tr>
<tr>
<td></td>
<td>WPI-BW-OA coating</td>
<td>81.6 (2.1) bc</td>
<td>12.4 (0.04) bc</td>
<td>18.4 (0.42) bc</td>
</tr>
<tr>
<td></td>
<td>CBW coating</td>
<td>77.5 (1.9) cC</td>
<td>11.7 (0.08) cC</td>
<td>17.9 (0.06) cC</td>
</tr>
<tr>
<td>90</td>
<td>Control</td>
<td>71.6 (2.2) bd</td>
<td>10.9 (0.02) bd</td>
<td>16.3 (0.15) bd</td>
</tr>
<tr>
<td></td>
<td>WPI-BW-OA coating</td>
<td>77.6 (3.2) ad</td>
<td>12.0 (0.06) ad</td>
<td>17.5 (0.27) ad</td>
</tr>
<tr>
<td></td>
<td>CBW coating</td>
<td>70.5 (2.1) bd</td>
<td>11.2 (0.05) bd</td>
<td>17.0 (0.35) bd</td>
</tr>
<tr>
<td>120</td>
<td>Control</td>
<td>60.5 (0.7) be</td>
<td>10.3 (0.02) be</td>
<td>14.8 (0.26) be</td>
</tr>
<tr>
<td></td>
<td>WPI-BW-OA coating</td>
<td>71.5 (2.4) ae</td>
<td>11.8 (0.03) ae</td>
<td>15.9 (0.30) ae</td>
</tr>
<tr>
<td></td>
<td>CBW coating</td>
<td>60.3 (1.9) be</td>
<td>10.8 (0.06) be</td>
<td>15.4 (0.36) be</td>
</tr>
<tr>
<td>150</td>
<td>Control</td>
<td>52.1 (0.3) cf</td>
<td>9.8 (0.01) cf</td>
<td>12.3 (0.36) cf</td>
</tr>
<tr>
<td></td>
<td>WPI-BW-OA coating</td>
<td>68.0 (2.6) af</td>
<td>11.4 (0.04) af</td>
<td>14.3 (0.18) af</td>
</tr>
<tr>
<td></td>
<td>CBW coating</td>
<td>56.8 (2.1) bf</td>
<td>10.4 (0.04) bf</td>
<td>12.9 (0.30) bf</td>
</tr>
<tr>
<td>180</td>
<td>Control</td>
<td>40.8 (3.5) cg</td>
<td>9.2 (0.02) cg</td>
<td>11.0 (0.43) cg</td>
</tr>
<tr>
<td></td>
<td>WPI-BW-OA coating</td>
<td>59.5 (0.8) ag</td>
<td>11.1 (0.03) ag</td>
<td>13.2 (0.26) ag</td>
</tr>
<tr>
<td></td>
<td>CBW coating</td>
<td>49.1 (2.2) bg</td>
<td>10.1 (0.04) bg</td>
<td>12.2 (0.41) bg</td>
</tr>
</tbody>
</table>

* Data are mean values of triplicate measurements and standard deviations are in parenthesis. a–c Different letters in each column imply significant (p < 0.05) differences due to coating type. A–G Different letters in each column imply significant (p < 0.05) differences due to storage time effect. HAD, hot-air drying; TPC, total phenolic compounds; TAA, total antioxidant activity; WPI-BW-OA, whey protein isolate-bees wax-oleic acid; CBW, chitosan-bees wax.

There is a significant (p < 0.05) difference between total phenolic compounds (TPC), β-carotene and total antioxidant activity (TAA) of control versus CBW and WPI-BW-OA coated samples in all storage times. These results are consistent with those reported by Tseng and Zhao [28] in dried red grape pulp and Moraga et al. [29] in dried grapefruit. At the early storage time (Day 30) TAA, TPC and β-carotene contents of control was significantly (p < 0.05) higher than those in WPI-BW-OA coated sample followed by CBW coated samples. This is probably due to the existence of coating material at the surface of dried samples interfering measured components in total mass of the product. However, during storage Days 90–180, we can see a protective effect of coatings on the preservation of bioactive compounds in dried fruits. WPI-BW-OA coating significantly (p < 0.05) increased preservation of all bioactive compounds compared to CBW coating. This could be explained by lower oxygen and water vapor permeability of WPI-BW-OA compared to CBW coating. These results are consistent with those reported by Miller and Krochta [30] who compared the permeability of different edible coatings to oxygen and water vapor and found that whey protein isolate coating exhibited the lower permeability than chitosan coating. Likewise, protective effects of CBW coatings on vitamin C content of frozen peach slices [31], methylcellose-garlic oil coatings on anthocyanins and phenolic compounds of fresh strawberry [32] and arabic gum-sodium caseinate-cinnamon oil composite coating on vitamin C and phenolic compounds of guava fruit [33] have been reported during storage time.
3.3. Effect of Secondary Coating Type and Storage Time on Color Properties of Semi-Moist Apricots Cubes

Changes in surface color of apricot cubes after HAD process and CBW and WPI-BW-OA coatings are shown in Figure 2. As is clear in this figure, WPI-BW-OA coated samples preserved the color of HAD apricot samples during storage months followed by CBW coated apricots. Control samples with no coating applied showed discoloration and browning during storage. The color properties ($L^*$, $a^*$, $b^*$, $C^*$ and browning value) of the dried apricot cubes mixed with breakfast cereals upon storage time are shown in Table 3. There is a significant ($p < 0.05$) decrease in $L^*$ and $b^*$ values and significant increase in $a^*$ values of both uncoated and coated apricot cubes upon storage. Moreover, WPI-BW-OA coated samples gave significantly higher $L^*$ values (lighter color) and $b^*$ values (more creamy or yellowish color) and lower $a^*$ values (less reddish color) than uncoated (control) samples followed by CBW coated apricots at any time of storage. This indicates that WPI-BW-OA coating due to its hydrophobic nature and oxygen/water vapor barrier properties was more effective than CBW coating in preserving color properties of HAD-coated samples mixed in breakfast cereal during storage time. Contrarily, according to Table 3, CBW-coated samples gave the weakest color attributes compared to all other samples. Color changes among treatments were also visually noticeable, as shown in Figure 2, since the color variations were above the just detectable difference reduced as 2.3 for $\Delta E$ reported by Mahy et al. [34].

![Figure 2](image-url)

**Figure 2.** Images of uncoated (control) and WPI-BW-OA- and CBW-coated samples during storage time (only Months 1, 3 and 6 are shown here). Samples for imaging were randomly selected from the apricot-cornflake mix system during storage times. The background of images was set in white for better clarity of color difference.
Table 3. Effect of different types of composite coating after HAD and storage time on color attributes of semi-moist dried apricot in breakfast cereals.

<table>
<thead>
<tr>
<th>Storage (Day)</th>
<th>Samples</th>
<th>$L^*$</th>
<th>$a^*$</th>
<th>$b^*$</th>
<th>C* (Chroma)</th>
<th>Browning Value (Abs/g d.m.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>Reference: OD45 + Pec-AA + HAD **</td>
<td>38.3 (1.8)</td>
<td>4.3 (0.2)</td>
<td>45.4 (1.2)</td>
<td>45.55 (0.4)</td>
<td>-</td>
</tr>
<tr>
<td>30</td>
<td>Control</td>
<td>27.5 (0.9) $^{bA}$</td>
<td>12.6 (0.2) $^{aE}$</td>
<td>37.2 (1.5) $^A$</td>
<td>39.3 (0.2) $^{cA}$</td>
<td>0.09 (0.00) $^{AF}$</td>
</tr>
<tr>
<td></td>
<td>CBW coating</td>
<td>33.8 (0.8) $^{aA}$</td>
<td>11.8 (0.4) $^{BE}$</td>
<td>39.9 (0.9) $^{bA}$</td>
<td>41.6 (0.3) $^{bA}$</td>
<td>0.08 (0.00) $^{bf}$</td>
</tr>
<tr>
<td></td>
<td>WPI-BW-OA coating</td>
<td>34.9 (0.9) $^{aA}$</td>
<td>9.4 (0.5) $^{CE}$</td>
<td>43.7 (0.6) $^{CA}$</td>
<td>43.7 (0.4) $^{aA}$</td>
<td>0.06 (0.00) $^{CF}$</td>
</tr>
<tr>
<td>60</td>
<td>Control</td>
<td>21.2 (0.1) $^{CB}$</td>
<td>16.6 (0.3) $^{AE}$</td>
<td>30.9 (0.1) $^{AB}$</td>
<td>35.1 (0.2) $^{bB}$</td>
<td>0.12 (0.01) $^{AE}$</td>
</tr>
<tr>
<td></td>
<td>CBW coating</td>
<td>25.3 (0.3) $^{BB}$</td>
<td>16.4 (0.3) $^{AD}$</td>
<td>33.2 (0.3) $^{bb}$</td>
<td>35.7 (0.4) $^{bB}$</td>
<td>0.09 (0.00) $^{bE}$</td>
</tr>
<tr>
<td></td>
<td>WPI-BW-OA coating</td>
<td>29.3 (0.2) $^{aB}$</td>
<td>13.6 (1.0) $^{BE}$</td>
<td>37.6 (0.9) $^{bb}$</td>
<td>40.0 (0.6) $^{ab}$</td>
<td>0.07 (0.00) $^{CF}$</td>
</tr>
<tr>
<td>90</td>
<td>Control</td>
<td>20.6 (0.1) $^{bC}$</td>
<td>18.4 (0.3) $^{AD}$</td>
<td>28.4 (0.4) $^{AC}$</td>
<td>33.8 (0.1) $^{cC}$</td>
<td>0.21 (0.02) $^{AD}$</td>
</tr>
<tr>
<td></td>
<td>CBW coating</td>
<td>22.0 (0.5) $^{bC}$</td>
<td>18.9 (0.5) $^{AC}$</td>
<td>30.4 (0.4) $^{AC}$</td>
<td>35.8 (0.3) $^{bB}$</td>
<td>0.17 (0.01) $^{bD}$</td>
</tr>
<tr>
<td></td>
<td>WPI-BW-OA coating</td>
<td>28.7 (0.6) $^{AC}$</td>
<td>13.3 (0.7) $^{BD}$</td>
<td>37.4 (0.4) $^{bc}$</td>
<td>39.7 (0.7) $^{ab}$</td>
<td>0.08 (0.00) $^{CD}$</td>
</tr>
<tr>
<td>120</td>
<td>Control</td>
<td>11.0 (0.3) $^{cD}$</td>
<td>20.0 (0.5) $^{AC}$</td>
<td>12.4 (0.4) $^{CD}$</td>
<td>23.5 (0.5) $^{CE}$</td>
<td>0.32 (0.03) $^{AC}$</td>
</tr>
<tr>
<td></td>
<td>CBW coating</td>
<td>16.9 (0.4) $^{bD}$</td>
<td>18.4 (0.3) $^{BC}$</td>
<td>23.1 (0.4) $^{ad}$</td>
<td>29.5 (0.6) $^{bc}$</td>
<td>0.19 (0.01) $^{bC}$</td>
</tr>
<tr>
<td></td>
<td>WPI-BW-OA coating</td>
<td>19.8 (0.4) $^{aD}$</td>
<td>18.6 (0.4) $^{BC}$</td>
<td>28.1 (0.4) $^{bd}$</td>
<td>33.7 (0.2) $^{ac}$</td>
<td>0.09 (0.00) $^{CC}$</td>
</tr>
<tr>
<td>150</td>
<td>Control</td>
<td>6.2 (0.4) $^{AE}$</td>
<td>24.3 (0.2) $^{bB}$</td>
<td>3.1 (0.4) $^{CE}$</td>
<td>24.5 (0.4) $^{be}$</td>
<td>0.34 (0.04) $^{AB}$</td>
</tr>
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<td></td>
<td>CBW coating</td>
<td>8.2 (0.2) $^{bE}$</td>
<td>21.2 (0.9) $^{bB}$</td>
<td>6.5 (0.1) $^{ae}$</td>
<td>22.2 (0.1) $^{ce}$</td>
<td>0.22 (0.02) $^{bB}$</td>
</tr>
<tr>
<td></td>
<td>WPI-BW-OA coating</td>
<td>21.9 (0.1) $^{cE}$</td>
<td>15.6 (0.1) $^{cB}$</td>
<td>24.7 (0.1) $^{be}$</td>
<td>29.2 (0.3) $^{ae}$</td>
<td>0.09 (0.00) $^{CD}$</td>
</tr>
<tr>
<td>180</td>
<td>Control</td>
<td>4.5 (0.4) $^{AF}$</td>
<td>25.9 (0.1) $^{aA}$</td>
<td>1.3 (0.4) $^{CE}$</td>
<td>26.0 (0.4) $^{bd}$</td>
<td>0.41 (0.06) $^{AA}$</td>
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<td></td>
<td>CBW coating</td>
<td>6.5 (0.3) $^{bF}$</td>
<td>25.1 (0.2) $^{ab}$</td>
<td>3.4 (0.2) $^{af}$</td>
<td>25.3 (0.1) $^{cd}$</td>
<td>0.28 (0.03) $^{bB}$</td>
</tr>
<tr>
<td></td>
<td>WPI-BW-OA coating</td>
<td>16.8 (0.2) $^{AF}$</td>
<td>18.2 (0.4) $^{CA}$</td>
<td>24.0 (0.1) $^{bf}$</td>
<td>30.1 (0.3) $^{ad}$</td>
<td>0.12 (0.01) $^{CA}$</td>
</tr>
</tbody>
</table>

* Data are mean values of triplicate measurements and standard deviations are in parenthesis. ** Different letters in each column imply significant ($p < 0.05$) differences due to coating type. A–F Different letters in each column imply significant ($p < 0.05$) differences due to storage time effect. WPI-BW-OA, whey protein isolate-bees wax-oleic acid; CBW, chitosan-bees wax. ** Hot-air dried (HAD) apricot samples pre-treated by osmotic dehydration (OD) followed by pectin + acid ascorbic (Pec-AA) coating application: as optimal pretreatment obtained by previous study [8].

The results of browning values of pretreated apricot cubes mixed in breakfast cereals measured by spectrophotometric method [9] are shown in Table 3. A significant ($p < 0.05$) increase in BV of both uncoated (control) and coated apricot samples was seen upon storage time. However, the extent of browning was greater for the uncoated samples due to possible oxidative or enzymatic browning reactions catalyzed by the presence of oxygen in these samples. Coating application introduces a protective layer over the surface of the product can inhibit moisture transfer from/to dried samples and restricts oxygen permeability leading to lower browning reactions during storage. Moreover, WPI-BW-OA coating gave significantly lower BVs than CBW coating at any time of storage, indicating the effectiveness of the hydrophobic WPI-BW-OA coating in preventing discoloration of apricot samples in breakfast cereals upon storage. Regarding the type of composite edible coatings, the results show that brownning value was significantly ($p < 0.05$) higher in the dried apricot coated by CBW compared to WPI-BW-OA coatings.

Similar findings were reported by Ubeyitogullari and Cekmecelioglu [35], who studied the effect of hemicellulose edible coating extracted from hazelnut shells and chitosan prior to drying on color properties of dried apricots. They stated that the chitosan edible coating was not able to retain color characteristics of dried apricots compared to hemicellulose edible coating. Non-enzymatic browning (Maillard) and enzymatic browning reactions due to oxidation of polyphenols, β-carotene and ascorbic acid is responsible for discoloration of dried apricot samples [36]. Moisture migration from dried apricot samples to cornflakes can enhance samples discoloration, as Pearson’s statistical correlation showed a negative and significant correlation between moisture content and browning value of dried apricot cubes ($r = −0.567, p < 0.01$). Acevedo et al. [37] also observed a negative correlation between the browning rate of dehydrated potato and its water content.
Variation of BVs are in line with color changes in terms of $\Delta E^*$, $\Delta L^*$, $\Delta b^*$ and $\Delta C^*$, as shown in Figure 3 (only results on storage Days 30, 90 and 180 are reported). $\Delta E^*$ as an indication of total color change of apricot samples [38] was significantly ($p < 0.05$) increased upon storage for all samples. The same trend was seen for $\Delta L^*$, $\Delta b^*$ and $\Delta C^*$. It is clear that coating application regardless of coating type did not help in in suppressing color changes of semi-dried fruit samples mixed with cornflakes during storage, but it could decrease discoloration rate in coated ones. These results are in line with those reported by Ubeyitogullari and Cekmecelioglu [35] in application of chitosan-based edible coatings before hot-air drying of apricots.

3.4. Effect of Composite Coating Type and Storage Time on Moisture Changes of Semi-Moist Apricot Cubes and Cornflakes in the Apricot-Cereal System

Figure 4 shows moisture variation (changes in percent) in cornflakes (Figure 4A) mixed with uncoated or coated apricot cubes with CBW and WPI-BW-OA (Figure 4B) in apricot-cereal system throughout the storage time.

The changes corresponded to the water gain of dry cornflakes and the water loss of semi-moist apricot samples. In this study, the initial moisture contents of cornflake and processed apricot cubes were 2.34% and 20% (on wet basis), respectively, which were used for the calculations presented in Figure 4. An increase in both parameters was observed in all the samples evaluated as the storage period increased. An asymptotic development of weight loss and weight gain was generally observed. Faster changes in moisture content of both components in breakfast cereal system at the beginning of the storage was seen, due to the highest differences in the water activity values of semi-moist fruit samples and dry cereals, which implies a higher driven force for the water transfer. However, throughout the storage time, there is a progressive decrease in this driven force in line with decrease of the differences of their moisture contents. The rate of moisture changes (moisture loss in apricot samples and moisture gain in cereals) was faster with system comprising uncoated apricot cubes (control) followed by CBW-coated and WPI-BW-OA-coated samples. This indicates that the water barrier effect of WPI-BW-OA coating and the interactions developed with the product surface (affected by the coating type) greatly determine the coating effectiveness to control the water migration in this kind of systems [39,40]. It could be related to less permeability of whey protein-based coating to water vapor than chitosan-based coating [41]. It was shown that the protein-based films and coatings have better barrier properties than the polysaccharide-based films [7,42]. These results are in agreement with those reported for pineapple weight loss and can be attributed to the lower water vapor permeability of whey protein based coatings (WPI-BW-OA) in comparison to chitosan-based coatings [19,21]. Likewise, Talens et al. [7] showed that composite chitosan-based coatings are less effective to limit water vapor transfer from dried pineapple to cereal in a pineapple-cereal system.

3.5. Effect of Composite Coating Type and Storage Time on Firmness of Semi-Moist Apricot Cubes and Cornflakes in the Apricot-Cereals System

Figure 5 shows firmness ($F_{\text{max}}$) values of uncoated (control) and CBW and WPI-BW-OA coated apricot cubes (Figure 5A) mixed with cornflakes in the apricot–cereal system throughout the storage time. In addition, variation in the firmness of cornflakes time is shown in Figure 5B. There is a significant increase in $F_{\text{max}}$ values of uncoated apricots mixed in cereals until Day 90 of storage followed by a plateau trend. This can be explained by moisture loss of apricot and moisture gain by dry cereals as shown in Figure 4. Pearson’s statistical correlation analysis showed a positive and significant correlation between moisture content and maximum force of cornflakes ($r = 0.940$, $p < 0.01$). Katz and Labuza [43] found that an increase in $a_{\text{wo}}$ of cornflakes from 0.1 to 0.4 caused a significant increase in the firmness of popcorn. Our results show that the highest $F_{\text{max}}$ values in apricot samples were obtained when their moisture content reaches to 10%–11%. Similar results were reported by Roudaut et al. [44], who studied texture properties of crispy
bread as a function of water content using compression test. They indicated plasticizing effects of water content on the product at moisture contents of 9%–11%.

**Figure 3.** Effect of secondary coating type and storage time ((A) 30 days; (B) 90 days; and (C) 180 days) on variation of color changes ($\Delta E^*$, $\Delta L^*$, $\Delta b^*$ and $\Delta C^*$) in apricot cubes mixed with cereal breakfast. Data are mean of triplicate measurements. Error bars indicate SD values. CBW, chitosan bees wax coating; WPI-BW-OA, Whey protein isolate-bees wax-oleic acid coating.
Figure 4. Effect of composite coating type and storage time on moisture changes of uncoated and coated semi-moist apricot cubes and cornflakes in apricot-cereals system: (A) cornflakes; and (B) semi-moist apricot cubes. Data are mean of triplicate measurements. Error bars indicate SD values. CBW, chitosan bees wax coating; WPI-BW-OA, whey protein isolate-bees wax-oleic acid coating.

Figure 5. Effect of different composite coatings and storage time on firmness ($F_{\text{max}}$) of uncoated and coated semi-moist apricot cubes mixed with cornflakes in apricot-cereals system: (A) semi-moist apricot cubes; and (B) cornflakes. Data are mean of triplicate measurements. Error bars indicate SD values. CBW, chitosan bees wax coating; WPI-BW-OA, whey protein isolate-bees wax-oleic acid coating.
WPI-BW-OA-coated apricots had the lowest firmness values. As explained above, moisture loss in apricot samples was slowest in WPI-BW-OA-coated samples followed by CBW-coated and uncoated apricot (control). This relates to water barrier effect of WPI-BW-OA coating, which greatly determines its effectiveness in controlling the water migration from semi-moist fruits to cereals [45,46]. As a result, firmness of apricots was lowest in such system. Katz and Labuza [43] reported that an increase in puffed corn and popcorn water activity to 0.4 increased its firmness. They indicated that texture properties of cereals are a function of their water activity. As is shown in Figure 5B, there was a significant difference ($p < 0.05$) between $F_{\text{max}}$ of cornflakes mixed with the WPI-BW-OA- and CBW-coated apricots during storage time. The lowest and highest crispness belong to cornflakes mixed with control and WPI-BW-OA-OA-coated apricots, respectively. Less moisture uptake by cornflakes mixed with WPI-BW-OA-OA-coated apricots during storage (as shown in Figure 4B) results in the obtained lower firmness values of these samples. Our findings confirm the effectiveness of the application of both composite edible coatings on dried apricot cubes, maintaining the crunchy texture of the dry cereals in the semi-moist apricot-breakfast cereal system.

4. Conclusions

Reducing the harshness of heat processing treatments (i.e., hot air frying, HAD) by application of suitable edible coatings could be an interesting strategy to preserve the technological and nutritional quality of heat-sensitive food products, while saving fossil energy resources. Application of OD pre-treatment and pectin-AA primary coating before HAD produced semi-moist apricot samples with improved nutritional ($\beta$-carotene) and bioactivity in terms of total antioxidant activity (TAA) and total phenolic content (TPC). In this study, secondary coatings comprising whey protein isolate-bees wax-oleic acid (WPI-BW-OA) and chitosan-bees wax (CBW) were applied to preserve the quality of HAD apricot samples mixed with dry cereals (cornflakes) during storage time. The WPI-BW-OA coating—compared to CBW-coated and uncoated samples (as control)—significantly preserved the color attributes (higher $L^*$ and $b^*$, lower $a^*$ and lower browning values), textural properties (lower firmness values), nutritional value ($\beta$-carotene) and bioactivity (total phenolic content and total antioxidant activity) of mixed semi-moist apricot samples with cornflakes upon six months of storage. Furthermore, cornflakes mixed with the apricots coated by different composite edible coatings retained more crispness compared to the cornflakes mixed with uncoated apricots. Coating of dried apricot by WPI-BW-OA coating effectively inhibited moisture migration from dried apricot to cornflakes during storage. This effect was due to lower oxygen and water vapor permeability of WPI-BW-OA compared to CBW coating. Overall, the successfulness of active coating application in preserving the quality characteristics of both semi-moist apricot cubes and dry cereals components in the mixed state was proven.

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References


7. Talens, P.; Pérez-Masia, R.; Fabra, M.J.; Vargas, M.; Chiralt, A. Application of edible coatings to partially dehydrated pineapple for use in fruit-cereal products. J. Food Eng. 2012. [CrossRef]

8. Sakooei-Vayghan, R.; Peighambardoust, S.H.; Hesari, J.; Peressini, D. Effects of osmotic dehydration (with and without sonication) and pectin-based coating pretreatments on functional properties and color of hot-air dried apricot cubes. Food Chem. 2020, 311, 125978. [CrossRef]


16. Peighambardoust, S.J.; Peighambardoust, S.H.; Pournasir, N.; Mohammadzadeh-Pakdel, P. Properties of active starch-based films incorporating a combination of Ag, ZnO and CuO nanoparticles for potential use in food packaging applications. Food Packag. Shelf Life 2019, 22, 100420. [CrossRef]


22. Fabra, M.J.; Talens, P.; Chiralt, A. Microstructure and optical properties of sodium caseinate films containing oleic acid-beeswax mixtures. Food Hydrocoll. 2009. [CrossRef]


24. Pereda, M.; Aranguren, M.I.; Marcovich, N.E. Caseinate films modified with tung oil. Food Hydrocoll. 2010. [CrossRef]


27. Ebrahimi, Y.; Peighambardoust, S.J.; Peighambardoust, S.H.; Karkaj, S.Z. Development of antibacterial carboxymethyl cellulose-based nanobiocomposite films containing various metallic nanoparticles for food packaging applications. *J. Food Sci.* 2019, 84, 2537–2548. [CrossRef]

28. Tseng, A.; Zhao, Y. Effect of different drying methods and storage time on the retention of bioactive compounds and antibacterial activity of wine grape pomace (Pinot Noir and Merlot). *J. Food Sci.* 2012. [CrossRef]


35. Ubeyitogullari, A.; Cekmecelioglu, D. Optimization of hemicellulose coating as applied to apricot drying and comparison with chitosan coating and sulfitation treatment. *J. Food Process Eng.* 2016. [CrossRef]


38. Dehghani, S.; Peighambardoust, S.H.; Peighambardoust, S.J.; Hosseini, S.V.; Regenstein, J.M. Improved mechanical and antibacterial properties of active LDPE films prepared with combination of Ag, ZnO and CuO nanoparticles. *Food Packag. Shelf Life* 2019, 22. [CrossRef]


42. Cao, N.; Fu, Y.; He, J. Preparation and physical properties of soy protein isolate and gelatin composite films. *Food Hydrocoll.* 2007. [CrossRef]


