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Whey Protein Isolate-Based Edible Coatings Incorporated with Jojoba Oil as a Novel Approach for Improving the Quality of Fresh-Cut Root Parsley during Refrigerated Storage

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Abstract: In this paper, the effect of whey-protein-isolate-based edible coatings with the addition of jojoba oil at concentrations of 1 and 2% on the qualitative characteristics of fresh-cut root parsley was evaluated. Changes in hardness, color parameters, and the contents of polyphenols and flavonoids over 28 days of refrigerated storage, as well as changes in structure, were examined. It was observed that fresh-cut parsley, uncoated and coated with a protein solution, was characterized by a decrease in hardness, from 59.32 and 59.88 to 50.98 and 48.33 N, respectively, while parsley coated with whey protein isolate with the addition of jojoba oil showed an increase in hardness during storage, from 56.28 to 66.23 N and from 52.17 to 60.49 for 1% and 2% of jojoba-oil-containing formulations, respectively. The L*, a*, and b* color parameters and hue angle mostly remained at similar levels, which indicate the maintenance of the desired color, but changes in the values were observed during storage. Parameter L* was between 79.56 and 85.33 in the control samples and between 72.54 and 84.19 in the coated samples. It was shown that the use of whey protein coatings and storage time had a positive impact on the contents of polyphenols and flavonoids in the fresh-cut parsley. The highest changes in polyphenols, from 3.13 to 9.82 mg GAE/g d.m., were observed for the samples coated with the formulation containing 1% of jojoba oil. The highest increase in flavonoid content, from 23.65 to 40.60 mg QE/g d.m., was observed for the samples coated with the film-forming solution with 2% of jojoba oil. Scanning electron microscopy showed a smaller number of pores in the vegetable tissue as a result of the coatings, and this was the most noticeable for the samples without the jojoba oil. Storage deteriorated the quality of the fresh-cut parsley surface, and the drying effect was visible. The use of protein coatings incorporated with jojoba oil modifies the quality characteristics of fresh-cut parsley, and this can find application in reducing the waste of minimally processed vegetables during storage.

Keywords: edible coatings; root parsley; quality; color; polyphenols; flavonoids

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1. Introduction

Today, all over the world, there is growing consumer interest in a healthy and nutritious diet that includes fresh vegetables, which are perishable products [1]. In addition, fresh vegetables can easily be physically damaged and lose moisture, and as the rate of respiration increases, their shelf life is shortened, causing excessive softening and aging of the raw materials. The shortened shelf life may result from biochemical changes and the development of microorganisms affecting the loss of the desired quality. To extend the shelf life of vegetables and to maintain their quality after harvest, food coating technology is increasingly used [2]. The coating process, consisting of covering the surface of a product with a film-forming material, applied to whole or portioned raw materials, has found its greatest application in the case of vegetables and fruits [3,4]. After drying the product, a protective coating forms on its surface, influencing, e.g., the maintenance of qualitative characteristics by limiting the biochemical, chemical, and physical changes taking place. In addition, edible coatings give products an attractive and glossy appearance, improving

consumer acceptance and quality [5]. The use of coatings can also lead to a reduction in the exchange of gases, such as oxygen and carbon dioxide, as well as water vapor and other substances. The functionality of the coatings depends primarily on the properties of the film-forming materials, plasticizers, and other additives used in the preparation of the film-forming solutions. Moreover, coatings as integral food ingredients must meet legal requirements [6].

Carbohydrates, proteins, and lipids are most often used as film-forming substances, while water, ethanol, and acetone are used as solvents. Substances that can be added to films or coating solutions are, among others, essential oils, antioxidants, flavors, preservatives, vitamins, and antimicrobials [7]. The coating technique, due to the addition of biodegradable and cheap compounds, as well as its simplicity, is a method that attracts the interest of many researchers, especially due to the losses of food. Edible films prepared based on proteins (e.g., soy protein, wheat gluten, casein, and whey protein) are usually hydrophilic and sensitive to moisture [8], but these aspects can be easily modified by the incorporation of lipids [9]. Whey protein isolate is a hydrocolloid compound with good film-forming properties; this makes it possible to achieve coherent films with good mechanical properties, which are transparent, tasteless, odorless, and highly flexible [10,11]. However, the results of many studies show that, in the case of vegetable coatings, the transport of water vapor or gases enabling respiratory processes is necessary; therefore, the barrier properties of films obtained based on proteins should be constantly modified to achieve the best performing properties [12]. Therefore, different functional compounds are included in film-forming solutions to protect fresh-cut fruits and vegetables [6]. Among them, lipids are very popular as a good water vapor barrier. There are only few papers describing the usage of jojoba oil as a lipid-based compound in film-forming formulations, especially for fresh-cut vegetables. Cruz et al. [13] used different blends of jojoba oil, candelilla wax, gum arabic, and pomegranate polyphenols to improve the shelf-life quality of pears. However, Din et al. [14] showed that edible coatings based on corn starch, stearic acid, monoglycerides, and jojoba oil significantly increased the shelf life of kinnow. Jojoba oil, as a lipid obtained from the jojoba bush, is an ester of long-chain fatty acids and monovalent, long-chain alcohols, and it contains natural oxidants α, β, and δ tocopherols and, therefore, is resistant to oxidation [15]. Jojoba oil is a wax that is flowable at room temperature and has high thermal stability (up to 300 °C); thus, it has found a wide range of practical applications [16].

Root parsley (*Petroselinum crispum* [Mill.] Nym. Ex A.W. Hill ssp. *Tuberosum* [Bernh.] Mart. Crov.) is a commonly cultivated vegetable in Poland and is also an important field crop in other countries in northern Europe [17]. In general, root vegetables, including root parsley, are characterized by antioxidant, anti-inflammatory, antibacterial, and antioxidant activities, and they are often consumed as an ingredient in soups or as an additive to vegetable dishes [18]. In addition, parsley has a pharmacological effect; therefore, it is used for various medicinal purposes in folk and traditional medicine. Parsley leaves are often used as a food flavor, an antitussive, and for gastrointestinal disorders. As an anticoagulant, they are also used, among others, for skin diseases, hypertension, kidney diseases, and urinary tract infections [19]. It is also possible to isolate apigenin from parsley leaves, a bioactive compound characterized by several beneficial properties for health, but with limited therapeutic application (low water solubility and bioavailability) [20]. Treating parsley can release nutrients, as well as shorten shelf life, by enhancing bacterial growth. To prevent this, non-thermal methods are used to extend the shelf-life of products, which include, among others, high hydrostatic pressure and the use of bacteriocins or food coatings [21]. This study aimed to determine the effect of edible coatings based on whey protein isolate incorporated with jojoba oil at concentrations of 1 and 2% on selected quality characteristics, namely, hardness, color, microstructure, and the content of polyphenols and flavonoids, of fresh-cut root parsley over 28 days of refrigerated storage.

2. Materials and Methods

2.1. Materials

The research material was parsley, harvested in 2014, of the Eagle variety from the supplier Cichowlas Polskie Warzywa (Środa Wielkopolska, Poland), purchased in the local market. For the preparation of film-forming solutions, whey protein isolate (BiPRO, Davisco Inc., La Sueur, MN, USA), glycerol (POCH S.A., Gliwice, Poland), and jojoba oil (Sigma Aldrich, Lima, Peru) were used. All other reagents were purchased from (Sigma Aldrich, Poznań, Poland).

2.2. Preparation of Film-Forming Solutions

Film-forming solutions were prepared according to the method presented in a previous study [22]. An 8% whey protein isolate solution was dissolved in distilled water under 250 rpm constant magnetic stirring using an RCT basic IKAMAG stirrer (IKA—Werke GmnH & Co., Staufen, Germany). The solution was heated to 80 °C for 30 min, and glycerol was used as a plasticizer in the amount of 50% relative to the protein isolate. In the same way, solutions of whey protein isolate with the addition of jojoba oil at concentrations of 1 and 2% were prepared. The solutions were homogenized with a homogenizer (IKA T25 DIGITAL Ultra Turrax, Staufen, Germany) for 3 min at a speed of 24,500 rpm.

2.3. Vegetable Coating

Before starting the tests, the parsley was thoroughly washed using tap water, dried, and cut into 1 cm slices in a slicer (CL50 Version D Robot Coupe, Vincennes, France). Then, using a cork borer, parsley rings with diameters of 2 cm were prepared. The obtained parsley discs were coated by immersion in distilled water (control test) or film-forming solutions for 2 min; then, the samples were dried on filter paper for 1 min and packed. The prepared controls and coated samples were placed and sealed with air in polyamide–polyethylene packaging PA/PE 70 T-flex 70 (Pakmar, Warsaw, Poland), with 10 discs each. Then, the samples were closed under an air atmosphere using a PP5.4 packing machine (TEPRO S.A., Koszalin, Poland). The samples were stored at 4 °C for 28 days with a high humidity of 80% in a climate chamber (standardized conditions, BINDER KBP 720 model, Tuttlingen, Germany).

2.4. Dry Matter

The determination of the dry matter content in the raw material and coated and uncoated parsley was carried out by drying samples in an oven (SUP 65 WG, WAMED, Warsaw, Poland) at 105 °C for 24 h with an accuracy of ±0.0001 g using an analytical balance (RADWAG PS 600/C/2, Radom, Poland). Measurements were made in 3 repetitions, and the dry matter was calculated according to the following equation:

$$d.m. = \frac{m_s - m}{m_p - m} \cdot 100\%$$

where:

m_1—sample mass before drying [g];
m_2—mass of the sample after drying [g];
m—mass of an empty glass [g].

2.5. pH Value

The pH was measured using a pH meter (SHOTT Instruments Lab 850, Mainz, Germany). The measurement was performed in 3 replicates at room temperature (23 ± 1 °C).

2.6. Hardness

The determination of the hardness parameter of the fresh raw material and coated and uncoated parsley was performed using a TA-XT2i texturometer (Stable Microsystems,

Surrey, UK) with Texture Expert software, having a 5 mm-thick stylus and a measuring table. The samples were placed on the measuring table and subjected to a 5 mm penetration test at a speed of 1 mm/s. Measurements were made after each storage step in 8 replicates.

2.7. Color Measurement

The color of the fresh raw material and the coated and uncoated parsley was determined using a Minolta colorimeter CHROMA METER CR-5 (Minolta, Tokyo, Japan) in the CIE L*a*b* color system (where L* is the brightness, and a* and b* are the chromaticity coordinates). The color changes were analyzed with the use of the L* parameter and the H color tone angle, which was calculated based on the values of the a* and b* chromaticity coordinates [19]. Measurements were made in ten replicates after each storage step and calculated using the following equation:

$$H = \frac{\left[\left(\tan^{-1}\frac{b^*}{a^*}\right)\right] * 180}{\pi}$$

where:

H—color tone angle [°];
a* and b*—chromaticity coordinates [-].

2.8. The Content of Polyphenols

The polyphenol content was measured according to the Folin–Ciocalteu method described in our previous study [8]. A total of 5 g of the analyzed parsley sample was ground and weighed into 150 mL beakers; then, 25 mL of 80% ethanol was added and covered with a glass slide. The whole sample was homogenized with a homogenizer (Ika Ultra Turrax 25, Staufen, Germany) for 1 min and placed on the RCT basic IKAMAG magnetic plate (IKA—Werke GmnH & Co., Staufen, Germany) and, avoiding boiling the solutions, was brought to 100 °C. After this time, the contents of the beakers were filtered into 50 mL flasks, and the flasks were purged with 80% ethanol, not exceeding 50 mL in the flask. Then, 15 mL of distilled water, 0.75 mL of the sample extract, and 1.25 mL of the Folin–Ciocalteu solution were measured into 25 mL flasks and mixed thoroughly. After 3 min, 2.5 mL of a sodium carbonate solution was added, made up to 25 mL with distilled water, and placed in the dark for 1 h. After this time, the ABTS content of the obtained solutions was measured in 3 repetitions using a spectrophotometer (Thermo electron corporation Helios, Waltham, MA, USA). The content of polyphenols is expressed as mg of gallic acid equivalents per g of dry matter (mg GAE/g d.m.).

2.9. The Content of Flavonoids

The content of flavonoids was determined according to the modified Lamaison method [23]. A total of 5 g of parsley was ground and weighed into 150 mL beakers, and 25 mL of 80% ethanol solution was added and covered with a glass slide. The sample prepared in this way was homogenized for 1 min in a homogenizer (Ika Ultra Turrax 25, Staufen, Germany). The homogenate was rinsed thoroughly with a small amount of 80% ethanol using a Pasteur pipette. The beakers, covered with glass, were placed on the RCT basic IKAMAG magnetic plate (IKA—Werke GmnH & Co., Saufen, Germany), bringing the samples to a 100 °C. Then, the contents of the beakers were filtered into 50 mL flasks. To 2 mL of the obtained extract, 2 mL of 1% $AlCl_3x6H_2O$ solution was added, stirred, and left in the dark for 10 min. After the specified time elapsed, the absorbance at 430 nm was measured using a spectrophotometer (Thermo electron corporation Helios, Waltham, MA, USA) against the blank, i.e., 80% ethanol in water. Measurements were made in 3 replicates. The content of flavonoids is expressed as mg of quercetin equivalent per g of dry matter (mg QE/g d.m.).

2.10. Microstructure

Observations of the coated and uncoated parsley structure immediately after the coating process and after 28 days of storage were carried out using an FEI Quanta 200 scanning electron microscope (Brno, Czech Republic).

2.11. Statistical Analysis

A statistical analysis was performed using the Statistica 10.0 program, performing an analysis of variance in the system with repeated measurements and one-way analysis of variance (ANOVA) with the Tukey post hoc test, with a significance level at 0.05.

3. Results and Discussion

3.1. Characteristics of the Raw Material—Root Parsley

Table 1 presents the characteristics of the root parsley, with dry matter of 15.61%, sugars of 7.57°Bx, and pH of 5.75. A high hardness of the parsley root was observed, 89.09 N, which is rather typical of fresh root vegetables. The color parameters were as follows: L* 84.49 ± 2.41, indicating a high brightness; a* 1.29 ± 0.19; and b* 11.15 ± 1.34. Parameter b* indicates a color toward yellow. The color angle H was 83.21 ± 1.85, indicating a high degree of brightness of the tested vegetable. The obtained results show that the content of polyphenols in the parsley was 6.54 mg gallic acid/g d.m., and the content of flavonoids was 49.96 mg of quercetin/g d.m. Zlotek and Wójcik [24] obtained higher values of polyphenols in root parsley (23.4 mg/g d.m.); however, a different method was used, and the origin vegetable may also have an impact on the content of such bioactive compounds.

Table 1. Characteristics of the raw material—root parsley.

Tested Feature	Mean ± Standard Deviation
Dry matter (%)	15.61 ± 0.09
pH	5.75 ± 0.02
Hardness (N)	89.09 ± 3.75
L*	84.49 ± 2.41
a*	−1.29 ± 0.19
b*	11.15 ± 1.34
Hue tone (°)	83.21 ± 1.85
Content of polyphenols (mg gallic acid/g d.m.)	6.54 ± 0.17
Content of flavonoids (mg quercetin/g d.m.)	49.96 ± 0.16

3.2. Effect of Coatings on the Hardness of Fresh-Cut Parsley during Storage

The changes in the hardness parameter of the parsley are presented in Table 2. It was observed that, during storage, in all tested samples, there were abrupt changes in the hardness parameter, and after 7 days of storage, in all the samples, there was an increase in hardness compared to the samples that were not stored. After 14 days of storage, all tests showed a decrease in the value of the hardness parameter, and after 21 days, an increase in the hardness was once again observed.

Parsley rings coated with whey protein isolate with the addition of jojoba oil at concentrations of 1 and 2% showed the ability to remain and increase hardness after 28 days. The highest value of the hardness parameter (72.28 ± 6.78 N) was achieved by the samples coated with a whey protein isolate with the addition of jojoba oil at a concentration of 2% after 21 days of storage, which could have been caused by an increase in the moisture barrier due to the content of hydrophobic jojoba oil belonging to lipid compounds.

Table 2. The hardness of samples uncoated (control) and coated with whey protein isolate (WPI) coatings incorporated with jojoba oil (JO) of fresh-cut root parsley during storage.

Storage Time (Days)	Hardness (N)			
	Type of Material			
	Control	WPI	WPI_JO_1%	WPI_JO_2%
0	$59.32 \pm 4.54^{ab,B}$	$59.88 \pm 4.41^{b,B}$	$56.28 \pm 4.26^{ab,AB}$	$52.17 \pm 5.43^{a,A}$
7	$64.34 \pm 4.52^{b,A}$	$63.73 \pm 6.78^{bc,A}$	$68.76 \pm 7.42^{c,A}$	$69.44 \pm 7.48^{bc,A}$
14	$60.84 \pm 7.97^{b,A}$	$58.82 \pm 5.86^{b,A}$	$63.82 \pm 8.78^{abc,A}$	$62.55 \pm 7.57^{b,A}$
21	$63.43 \pm 7.59^{b,AB}$	$71.05 \pm 7.66^{c,B}$	$55.22 \pm 6.19^{a,A}$	$72.28 \pm 6.78^{c,B}$
28	$50.98 \pm 4.39^{a,A}$	$48.33 \pm 5.29^{a,A}$	$66.23 \pm 8.48^{bc,B}$	$60.49 \pm 5.01^{ab,B}$

Mean values with standard deviations in brackets. Different superscript letters ($^{a–c}$) within the same column or (^{A,B}) within the lines indicate significant differences between the samples ($p < 0.05$).

The presence of a water barrier allows food products to be crunchy, and the use of edible coatings may delay the deterioration of vegetables by slowing down the loss of moisture. It was observed that the storage time significantly affected the changes in parsley hardness. Taking into account the type of coating used, no statistically significant differences were found between the uncoated sample and the sample coated with whey protein isolate, which is in contrast to the samples coated with the whey protein isolate with the addition of jojoba oil at concentrations of 1 and 2%, where these differences were statistically significant ($p < 0.05$). In general, the differences in the values of the hardness of root vegetables can be attributed to the anatomy of their roots and their two types of structures: xylem (the inner part) and phloem [25]. However, in the studies involving the coating of apples, potatoes, and carrots with whey protein/pectin/transglutaminase coatings, the hardness parameter of carrot samples after 10 days of storage was found to increase by about 34% compared to that of uncoated samples. The uncoated samples were characterized by a decrease in the hardness parameter from 190 ± 12 N to 130 ± 24 N. Moreover, the coating of carrot samples reduced the growth of microorganisms and retained the contents of phenols and carotenoids [26]. The increase in the hardness of the tested samples may be due to dehydrated tissues resulting from weight loss, which are characterized by a more fibrous structure during storage and, therefore, are of low quality [27].

3.3. Effect of Coatings on the Color of Fresh-Cut Parsley during Storage

Table 3 presents the parameters of the colors of the uncoated and coated fresh-cut root parsley. It can be observed that the analyzed parsley was characterized by a high color brightness stability, parameter L* changed slightly during storage, and the positive effect of the coating containing jojoba oil can be observed as a result of the emulsion-based character of the coatings [8].

When analyzing the changes in the color, the brightening of the parsley rings was noticed after 28 days of storage compared to day 0. Moreover, after 14 and 21 days of storage, a high proportion of the tested parsley samples was characterized by a yellow color (parameter b*). When examining the effect of the storage time on parameter changes a*, no statistically significant differences were found, except for in the case of the parsley coated with the whey protein isolate. However, in the remaining parsley samples, these differences were statistically significant. The statistical analysis showed that the protein coatings affected the changes in the value of parameter a*. During storage, no significant changes in the shade of the color were observed, which corresponds to the color tone, spanning the entire storage period at a level of approx. 86° in all tested samples. It was also shown that the type of edible coating used did not have a significant effect on the changes in the value of the color tone angle ($p < 0.05$), but it was found that the storage time significantly influenced the changes in the color tone angle. No statistically significant differences were observed in the samples coated with the whey protein isolate.

Table 3. L*, a*, and b* color parameters and hue tone of samples uncoated (control) and coated with whey protein isolate (WPI) coatings incorporated with jojoba oil (JO) of fresh-cut root parsley during storage.

Storage Time (Days)	Type of Material			
	Control	WPI	WPI_JO_1%	WPI_JO_2%
L*				
0	$79.88 \pm 3.45^{a,AB}$	$79.29 \pm 2.50^{b,A}$	$82.71 \pm 2.04^{b,B}$	$81.33 \pm 2.39^{b,AB}$
7	$80.69 \pm 5.10^{a,A}$	$84.07 \pm 1.08^{c,A}$	$83.20 \pm 2.29^{b,A}$	$81.57 \pm 1.94^{b,A}$
14	$81.83 \pm 1.25^{ab,B}$	$74.71 \pm 4.29^{a,A}$	$82.99 \pm 2.51^{b,B}$	$82.40 \pm 2.72^{b,B}$
21	$79.56 \pm 3.01^{a,B}$	$73.44 \pm 5.33^{a,A}$	$76.61 \pm 1.90^{a,AB}$	$72.54 \pm 2.93^{a,A}$
28	$85.33 \pm 1.30^{b,C}$	$80.95 \pm 2.51^{bc,A}$	$84.19 \pm 1.54^{b,BC}$	$82.33 \pm 2.82^{b,AB}$
a*				
0	$-1.20 \pm 0.30^{a,A}$	$-1.24 \pm 0.16^{a,A}$	$-1.44 \pm 0.11^{a,A}$	$-1.43 \pm 0.35^{a,A}$
7	$0.43 \pm 1.07^{c,B}$	$-0.97 \pm 0.52^{a,A}$	$-0.66 \pm 0.25^{b,A}$	$-0.42 \pm 0.52^{b,A}$
14	$-0.01 \pm 0.53^{bc,A}$	$4.83 \pm 1.87^{b,B}$	$-0.81 \pm 0.13^{ab,A}$	$-0.75 \pm 0.33^{b,A}$
21	$0.51 \pm 1.06^{c,A}$	$6.07 \pm 3.29^{b,B}$	$4.52 \pm 1.23^{a,B}$	$6.50 \pm 0.81^{c,B}$
28	$-0.61 \pm 0.19^{ab,A}$	$0.83 \pm 1.18^{a,B}$	$-0.75 \pm 0.35^{ab,A}$	$-0.48 \pm 0.23^{b,A}$
b*				
0	$11.86 \pm 1.20^{a,A}$	$12.67 \pm 2.25^{a,A}$	$11.36 \pm 1.50^{a,A}$	$11.87 \pm 1.46^{a,A}$
7	$16.38 \pm 2.61^{b,B}$	$12.61 \pm 3.87^{a,A}$	$13.56 \pm 1.59^{b,AB}$	$13.22 \pm 2.93^{a,AB}$
14	$17.26 \pm 1.86^{b,B}$	$26.49 \pm 1.40^{c,C}$	$13.30 \pm 0.76^{b,A}$	$13.85 \pm 1.13^{a,A}$
21	$19.06 \pm 3.20^{b,A}$	$28.21 \pm 2.98^{c,B}$	$27.52 \pm 1.88^{c,B}$	$30.08 \pm 1.83^{b,B}$
28	$10.02 \pm 1.23^{a,A}$	$21.21 \pm 2.96^{b,C}$	$12.03 \pm 1.42^{ab,AB}$	$12.83 \pm 1.91^{a,B}$
H [°]				
0	$84.08 \pm 1.72^{a,A}$	$84.24 \pm 1.21^{b,A}$	$82.67 \pm 1.10^{b,A}$	$82.99 \pm 2.05^{b,A}$
7	$87.70 \pm 2.39^{bc,B}$	$84.79 \pm 1.66^{b,A}$	$87.12 \pm 1.28^{c,AB}$	$87.50 \pm 2.86^{c,B}$
14	$88.66 \pm 1.06^{c,B}$	$79.71 \pm 3.94^{a,A}$	$86.52 \pm 0.84^{c,B}$	$86.87 \pm 1.46^{c,B}$
21	$87.70 \pm 1.82^{bc,B}$	$78.25 \pm 5.70^{a,A}$	$80.79 \pm 2.07^{a,A}$	$77.81 \pm 1.40^{a,A}$
28	$86.47 \pm 1.18^{b,A}$	$87.21 \pm 2.08^{b,A}$	$86.33 \pm 1.73^{c,A}$	$87.77 \pm 1.21^{c,A}$

Mean values with standard deviations in brackets. Different superscript letters ($^{a–c}$) within the same column or ($^{A–C}$) within the lines indicate significant differences between the samples ($p < 0.05$).

According to the conducted research, the highest value of the L* parameter was achieved for the control sample (85.33) after 28 days of storage, although there were no large differences in the measurement values of the other parsley samples tested. Taking into account the samples coated with the whey protein isolate with the addition of jojoba oil at concentrations of 1 and 2%, in contrast to the uncoated samples and those coated with the isolate alone, the storage time was characterized by no statistically significant differences ($p < 0.05$). The type of applied coating significantly influenced the brightening of the parsley rings, as evidenced by the performed statistical analysis. The value of the L* parameter is an important indicator of the attractiveness of vegetables and fruits. Low values of this parameter indicate a pale and "stale" appearance of the product. With the lightening of the parsley discs after 28 days of storage, the b* chromaticity index increased compared to the measurements from day 0 in the coated samples, and the parameter a* also increased, which proves the proportion of the red color. After 14 and 21 days of storage, it was observed that the coated samples showed a very high increase in the parameter a* value, which decreased after 28 days. Changes in the b* parameter during storage showed no statistically significant differences ($p < 0.05$) in the uncoated and coated samples with whey protein isolate and 2% jojoba oil. The type of coating used had a significant effect on the color changes from blue to yellow (b*). Shon and Choi [28] showed that sliced carrots, coated with whey protein isolate and a control, turned paler with time, while onion slices showed no changes in the L* parameter over time. The brightness of the control onion slices was 87.9, while the value of the L* parameter of the onion slices covered with a coating obtained based on whey protein isolate had similar values—88.9 and 88.3. The data obtained showed that the coatings obtained from whey protein isolate are an effective alternative in controlling the oxidative browning that occurs in sliced vegetables and fruits. In addition, the coated apple and potato slices were greener, which made them appear

fresher than the control slices. In the case of the carrot slices, there was no significant change in the value of parameter a* for both the coated and control samples.

3.4. Effect of Coatings on the Content of Polyphenols of Fresh-Cut Parsley during Storage

The content of polyphenols in the uncoated (control) and coated fresh-cut root parsley is presented in Table 4. After 7 days of storage, an increase in the content of polyphenols was observed, except for in the control sample. It was also observed that, after 14 days of storage (except for the sample coated with whey protein isolate), their value decreased, and after 21 days of storage, all samples showed an increase in polyphenol content compared to the samples from the previous measurement days. Comparing the samples to those stored for 14 days, it was concluded that they were characterized by an increase in the content of polyphenols: for the control sample, from 3.72 mg/g d.m. to 8.6 mg/g d.m.; for the test coated with the whey protein isolate, from 6.03 mg/g d.s. to 7.55 mg/g d.m.; for the test coated with the isolate with the addition of jojoba oil at a concentration of 1%, from 6.95 mg/g d.m. to 9.38 mg/g d.m.; and for the test coated with the isolate with the addition of jojoba oil at a concentration of 2%, from 6.72 mg/g d.m. to 7.41 mg/g on d.m. After 28 days of storage, in the samples coated with the whey protein isolate with the addition of jojoba oil at concentrations of 1 and 2%, an increase in the content of polyphenols (by 0.44 and 0.36 mg/g d.m., respectively) was observed, and in the sample coated with the whey protein isolate and the control, a decrease in the content of polyphenols was observed. Vegetables are a good source of phenols and flavonoids, contributing as antioxidants to reducing the risk of contracting many diseases. During the ripening of vegetables, the content of these compounds is reduced, which results from the vegetable's metabolic rate. The modification of metabolism and the impact of the production of secondary metabolites are possible due to the use of edible coatings, and the use of coatings containing 10% gum arabic maintains the polyphenol content in tomatoes for a longer time than uncoated tomatoes, delaying the aging process [29].

Table 4. Polyphenol content of samples uncoated (control) and coated with whey protein isolate (WPI) coatings incorporated with jojoba oil (JO) of fresh-cut root parsley during storage.

Storage Time (Days)	Polyphenols (mg GAE/g d.m.)			
	Type of Material			
	Control	WPI	WPI_JO_1%	WPI_JO_2%
0	$4.32 \pm 0.26^{a,B}$	$3.61 \pm 0.21^{a,A}$	$3.13 \pm 0.37^{a,A}$	$5.97 \pm 0.13^{a,C}$
7	$4.02 \pm 0.57^{a,A}$	$5.11 \pm 0.32^{b,A}$	$7.21 \pm 0.22^{b,B}$	$7.56 \pm 1.17^{ab,B}$
14	$3.72 \pm 0.17^{a,A}$	$6.03 \pm 0.35^{c,B}$	$6.95 \pm 0.05^{b,C}$	$6.72 \pm 0.13^{ab,C}$
21	$8.60 \pm 0.13^{c,B}$	$7.55 \pm 0.37^{d,A}$	$9.38 \pm 0.47^{c,B}$	$7.41 \pm 0.39^{ab,A}$
28	$5.59 \pm 0.05^{b,A}$	$5.81 \pm 0.09^{bc,A}$	$9.82 \pm 0.09^{c,C}$	$7.77 \pm 0.51^{b,B}$

Mean values with standard deviations in brackets. Different superscript letters ($^{a–d}$) within the same column or ($^{A–C}$) within the lines indicate significant differences between the samples ($p < 0.05$).

The statistical analysis shows that the storage did not significantly affect the changes in the content of polyphenols in the control sample until day 14, from 7 to 14 days of the research in the trial examining the sample coated with the jojoba oil isolate at a concentration of 1%, and from 7 to 21 days in the trial examining the sample coated with the isolate with jojoba oil at a concentration of 2%. No statistically significant differences were observed between the samples of parsley coated with the isolate alone and the isolate with the addition of jojoba oil at a concentration of 1% on the first measurement day (0 days), and no statistically significant differences were observed between the uncoated parsley discs and those coated with whey protein isolate after 7 days of storage. The change in the content of polyphenols and statistically significant differences between uncoated parsley samples and those coated with the whey protein isolate alone were observed after 14 days of storage. However, after 21 days in the tested trials, no significant statistical differences were noted between the protein coating and the coating obtained with the addition of

2% jojoba oil, and no significant differences ($p < 0.05$) were observed between the control sample and the coating with the addition of 1% jojoba oil. Złotek and Wójcik [24] coated fresh-cut parsley roots of 0.5 cm-thick rings with coatings based on 0.1% chitosan and 1% citric acid. The coated samples were stored for 4 weeks at 4 °C. The authors showed similar decreasing and increasing trends in the total content of polyphenols during storage. The increase in the total content of polyphenols occurred after 1 week of storage from 23.4 mg/g d.m. up to 32.8 mg/g d.m. in the control sample, 35.1 mg/g d.m. for controls containing citric acid, and 28.9 mg/g d.m. in trials of chitosan-coated parsley. The content of polyphenols decreased after 2 weeks and increased again after 3 and 4 weeks of storage under refrigerated conditions. However, Pen and Jiang [30], analyzing the effect of a chitosan coating on chestnut fruit during a storage period of 2 weeks, noticed an increase in the content of polyphenols after a week of storage and a decrease in their content after 2 weeks. The delayed increase in the polyphenol content was probably related to the inhibition of the enzyme that influences the regulation of the phenolic compound biosynthetic pathway. Also in these studies, the authors did not observe any significant effect of the chitosan coating on the total phenol content during storage.

3.5. Effect of Coatings on the Content of Flavonoids of Fresh-Cut Parsley during Storage

From the data presented in Table 5, it can be concluded that there was an increase in the content of flavonoids in all tested samples up to 14 days of storage. The greatest increase in the content of flavonoids occurred in the coated samples and, above all, in the samples coated with a film-forming material based on whey protein isolate with the addition of jojoba oil at a concentration of 2%. A reduction in the content of flavonoids was noted after 21 days of storage, but an increase in their content was observed after 28 days.

Table 5. Flavonoid content of samples uncoated (control) and coated with whey protein isolate (WPI) coatings incorporated with jojoba oil (JO) of fresh-cut root parsley during storage.

Storage Time (Days)	Flavonoids (mg QE/g d.m.)			
	Type of Material			
	Control	WPI	WPI_JO_1%	WPI_JO_2%
0	$22.61 \pm 0.32^{a,B}$	$21.08 \pm 0.06^{a,A}$	$26.22 \pm 0.04^{a,D}$	$23.65 \pm 0.24^{a,C}$
7	$24.72 \pm 0.52^{b,A}$	$25.40 \pm 0.12^{b,B}$	$27.16 \pm 0.33^{a,C}$	$34.00 \pm 0.22^{b,D}$
14	$37.91 \pm 0.15^{e,A}$	$40.81 \pm 0.13^{e,B}$	$43.27 \pm 0.14^{d,C}$	$48.43 \pm 0.07^{e,D}$
21	$33.80 \pm 0.30^{c,A}$	$32.36 \pm 0.11^{c,A}$	$39.55 \pm 1.37^{c,C}$	$37.28 \pm 0.17^{c,B}$
28	$35.53 \pm 0.19^{d,A}$	$39.73 \pm 0.03^{d,C}$	$36.89 \pm 0.58^{b,B}$	$40.60 \pm 0.16^{d,D}$

Mean values with standard deviations in brackets. Different superscript letters ($^{a–e}$) within the same column or ($^{A–D}$) within the lines indicate significant differences between the samples ($p < 0.05$).

Złotek and Wójcik [24] observed a decrease in the content of flavonoids after 2 weeks of storage in the fresh-cut root parsley coated with chitosan coatings and an increase in the content of flavonoids after further storage. Based on the performed statistical analysis, statistically significant differences were observed in the content of flavonoids in parsley, which resulted from the storage time. Considering the type of coatings used, i.e., isolate, 1% jojoba oil isolate, and 2% jojoba oil isolate, or the uncoated sample, significant differences were also observed in the content of flavonoids.

3.6. Microstructure of Fresh-Cut Parsley during Storage

A microscopic observation of the structure of the examined parsley was carried out immediately after the coating process and after 28 days of refrigerated storage (Figure 1). It was observed that the parsley discs immediately after coating and the uncoated ones had numerous open pores. In addition, the film-forming solution was inside the pores of the tissues. The samples coated with the whey protein isolate showed the most drying on their surface after 28 days of storage. The exception was the parsley rings coated with the whey protein isolate with the addition of jojoba oil at a concentration of 2%. The loss of texture

and the integrity of fresh produce is due to enzymatic degradation and is associated with a decrease in consumer acceptability [31]. The softening of fruits and vegetables is related to the activity of enzymes. The higher the activity, the faster it can be noticed. Visible changes in the structure on the surface of freshly cut vegetables and fruits also result from the loss of water, which reduces the firmness of cells [29]. Hasan et al. [32] mentioned that the use of chitosan coatings reduced the loss of texture in green beans, zucchini, and strawberries. The addition of stabilizers (xanthan, pectin, and whey protein isolate) to nanoemulsions has a positive effect on maintaining the appropriate structure, preventing water loss, resulting in a cross-linked network, and increasing mechanical strength. Kowalczyk et al. [33] observed that freeze-dried carrots were characterized by an uneven surface coverage, revealing empty areas of cells, while other researchers observed that the use of UV radiation on coatings made based on chitosan allows for the preservation of a better cell structure in which less intercellular space is visible and damage is reduced [34].

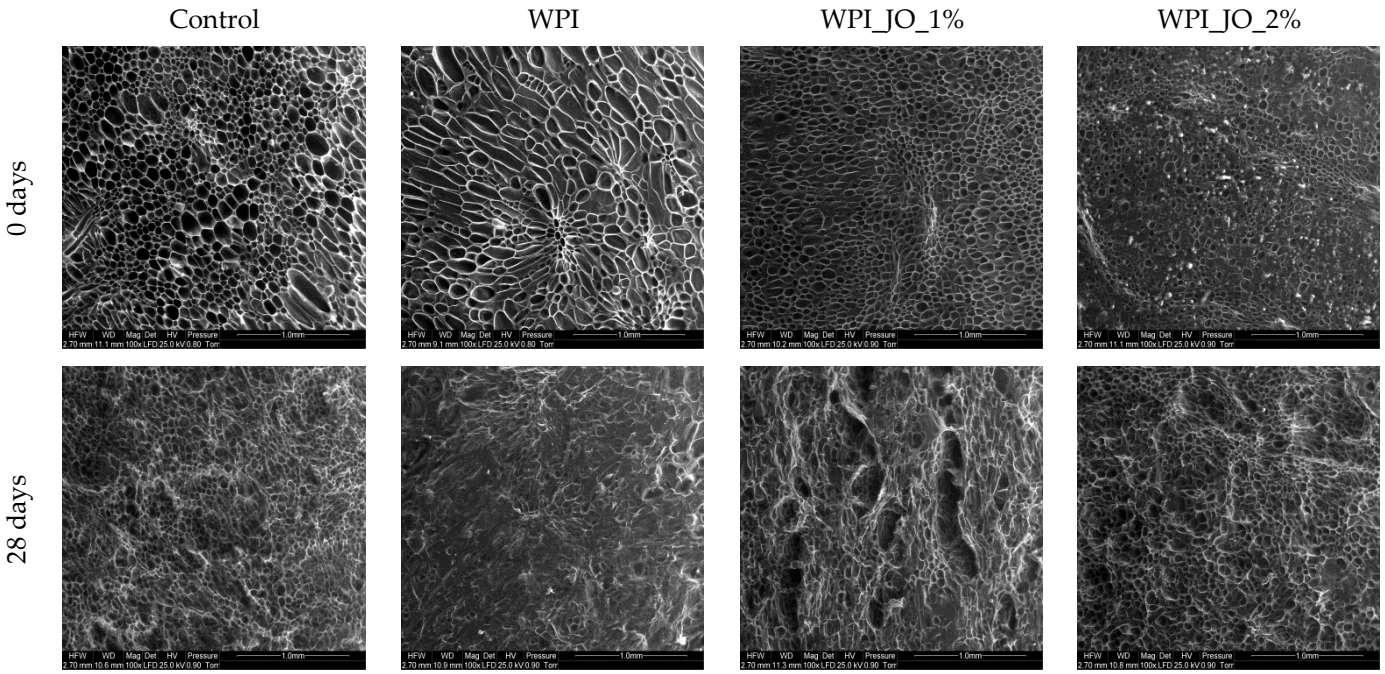

Figure 1. Scanning electron micrographs of samples uncoated (control) and coated with whey protein isolate (WPI) coatings incorporated with jojoba oil (JO) of fresh-cut root parsley at 0 and 28 days of storage (magnification 100×).

4. Conclusions

Edible films and coatings as a non-invasive technology play a very important role in maintaining the quality of fresh vegetables. A whey-protein-isolate-based edible coating incorporated with jojoba oil was used to protect fresh-cut root parsley by an immersion process. Samples of fresh-cut parsley uncoated (control) and coated with whey protein film-forming solution were characterized by a decrease in hardness, while parsley coated with whey protein isolate with the addition of jojoba oil showed higher values in hardness during storage. The L*, a*, and b* color parameters and hue angle mostly remained at similar levels, which indicate the maintenance of the desired color, but changes in the values were observed during storage. The research shows that the use of whey protein coatings and the storage time had a positive impact on the contents of polyphenols and flavonoids in fresh-cut parsley. Scanning electron microscopy showed a smaller number of pores in the vegetable tissue as a result of the whey protein coatings. The storage deteriorated the quality of the fresh-cut parsley surface, and the drying effect was visible. The use of protein coatings incorporated with jojoba oil modifies the quality characteristics of fresh-cut parsley, which can find application in reducing the waste of minimally processed vegetables

during storage. The research shows that the technology of edible coatings based on whey protein isolate and jojoba oil is a promising technology for improving fresh-cut parsley roots; however, more research is needed, especially a sensory analysis and a study on storage stability.

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