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Article

Evaluation of Biodegradable Gelatin and Gelatin–Rice Starch Coatings to Fresh Cut Zucchini Slices

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Abstract: Biodegradable packaging minimizes negative environmental impacts of synthetic materials and maintains product quality. Fresh cut vegetables and fruits such as zucchini were sensitive to degradation, which could be delayed by edible coatings. Mixtures of gelatin and other biopolymers were commonly used in novel food packaging preserving quality characteristics of foods. In this study, for first time, gelatin and a gelatin mixture with rice starch were applied to zucchini slices during 7 days of storage at 5 °C in order to evaluate weight loss, firmness, breaking force and color. Gelatin coating as a treatment type demonstrated superior ability to preserve the quality of sliced zucchini fruit and contributed to the maintenance of their texture characteristics similar to values of the control group. The addition of rice starch to the gelatin coating also maintained firmness and breaking force, but accelerated the increase of weight loss and decreased lightness compared to control samples. In conclusion, this study on coatings of gelatin and a gelatin–rice starch mixture enriches the knowledge within the food industry on biodegradable coatings, and gives useful information for zucchini slice storage at a low temperature.

Keywords: coating; zucchini; texture characteristics; color

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1. Introduction

Zucchini (*Curcubita pepo* L. *cv cylindrical*) has high respiration rate and is characterized as an immature fruit with a very thin cuticle. In previous studies, it was found that different levels of O_2 influence biochemical reactions in zucchini micro texture, resulting in the restriction of off-flavors and chilling injuries in zucchini [1–3].

Storage of vegetables and fruits at low temperatures plays an important role in reducing the rate of metabolism in order to delay decomposition [4]. At temperatures from 1 °C to 10 °C, horticultural crops undergo physiological and biochemical changes. There are also many factors which affect storage, such as the respiration rate, environmental factors, species and maturity at harvest. All these factors can be controlled, so food without treatment is preserved for longer.

Nowadays, the needs of food products with characteristics such as freshness, nutritiousness and convenience in handling have led to the development of alternative storage techniques. Edible films and coatings technologies are considered a novel approach in order to maintain quality properties, such as extending commercial shelf-life of coated products by modifying internal food environments, reducing microbial proliferation delaying weight loss, oxidation and respiration rate [5–8]. Additionally, gas permeability should be taken into consideration for films and coatings applied on fruit surfaces in order to maintain quality properties [9].

The edible coatings and films are made by biopolymers and/or industrial by-products [9,10]. Important functions of starch coatings applied on horticultural products include the decrease of oxygen permeability, but relatively high water loss [11,12]. All types of starch are abundant in nature, and therefore, they are inexpensive ingredients for many applications in the food industry. Rice starch, especially, among other botanical sources, has unique functional characteristics. Important properties of rice starch were bland taste, spreadability, and smooth texture [13–15]. On the other hand, when rice starch is used as coating or biofilm, it shows high water permeability and poor mechanical properties. Plasticizers and other food biopolymers are needed to repair these disadvantages. In previous studies, adding protein to rice starch produces a viscoelastic protein network. According to other authors, a combination of starch with biopolymers could provide extra functions in edible films and coatings and extra protection for crop quality characteristics [16–19].

A huge variety of films and coatings based on proteins also created networks with many and different functional properties [5,8,20]. Gelatin based coatings have many advantages such as high mechanical resistance and optical characteristics compared to other biopolymers. Coating from gelatin could also have disadvantages, for example low melting temperatures [20]. Gelatin is a product of collagen degradation, with unique functional properties and it is formed by the chemical denaturation of collagen gained from the skin, bone or tissues of animals [12,21]. Take into consideration that zucchini is a chilling-sensitive fruit [22], in the current study we investigate the coatings from gelatin and gelatin–rice starch applied on the surface of fresh cut zucchini slices. Both biopolymers have important characteristics.

The aim of this study is to enrich the knowledge on fresh cut zucchini slice preservation at a low temperature using biodegradable coatings of gelatin and a mixture of gelatin with rice starch. In order to investigate the coating effects, coatings were applied on fresh cut zucchini slices, and quality characteristics, such as hardness, breaking force, color and weight loss, were evaluated during storage over seven days and at cold storage.

2. Materials and Methods

2.1. Preparation of Zucchini Slices

Zucchini fruits (*Cucurbita pepo* L. *cv cylindrica*) were obtained from a local market in Volos, Greece, at commercial maturity stage and stored at 5 °C. All samples had uniform size, shape and color without any physical and microbiological damage. Zucchini fruits were washed with distilled water, peeled and then carefully dried with absorbent paper. Then, zucchini were cut into slices. For the experiment, slices with specific dimensions—height 20 mm and diameter 31 mm—were used [23]. Sample analysis was performed in triplicate per treatment (3 slices) at each day of storage for each analysis.

2.2. Preparation of Gelatin and Gelatin–Rice Starch Edible Coatings

The gelatin edible coating (Gel) was prepared by 3% *w*/*w* gelatin [24,25] (AppliChem GmbH, Darmstadt, Germany) and 1.5% *w*/*w* glycerol (Sigma-Aldrich Co., St. Louis, MO, USA) [26]. The gelatin–starch (Gel-RS) coating was a mixture of 3% *w*/*w* gelatin with 5% *w*/*w* rice starch (Duchefa Biochemie B.V., Haarlem, The Netherlands) [27] and 1.5% *v*/*v* glycerol Anhydrous Glycerol was added to the mixture of the biopolymers as plasticizer. The biopolymers were dissolved by magnetic stirring and heating for 30 min at 85 °C in a water bath in order to denature the gelatin and complete rice starch gelatinization. Then, glycerol was added to the samples and the stirring was continued for 15 additional minutes. Finally, coatings were cooled to room temperature (~20 °C). Zucchini samples at the time of coating were also at 20 °C and each fruit fresh cut cylinder was subjected to treatment by dipping in the prepared edible coating, except for the control subjects, which were left untreated and considered as control (Ctr). Then, the samples were dried at room temperature for 1h to remove excess coatings from the fruit surface. The samples were placed in plastic disks and stored at 4 °C and their color and specific physicochemical properties were evaluated for a total 7-day storage period, and more specifically at day 0, 1, 2, 3, 4 and 7. All the experiments were conducted in triplicate. Zucchini samples (slices) at the time of coating were also at 20 °C and each fruit fresh cut cylinder was treated by dipping in the edible coating. Except for the control (Ctr) specimens, which were left untreated (only washed).

2.3. Weight Loss Measurements

The shelf-life study zucchini fruit cylindrical samples was undertaken over a period of total 7 days. At days 0, 1 2, 3, 4 and 7, zucchini slices coated with edible biopolymers and control fresh cut fruit cylinders were weighed using a laboratory scale high precision digital weighing balance according to the standard method of AOAC [28].

The weight loss was calculated as:

$$\text{Weight loss (\%)} = (\text{Wi} - \text{Wf})/\text{Wi} \times 100$$

where Wi (g) and Wf (g) are the initial and final sample weights, respectively. Results were expressed as a percentage (%). The measurements were performed in triplicate.

2.4. Texture Analysis

Texture analysis was performed on zucchini samples at 5 °C using an AdMet eXpert 5601 (AdMEt, Inc., Norwood, MA, USA) with a cylinder probe of 3.1 mm in diameter. The samples were slices—cylinders with dimensions of height 20 mm and diameter 31 mm. The instrumental measurements were performed at 70% compression of samples' initial height and the jog rate was 1mm/s. According to the texture attribute, firmness is defined as the highest force (Fmax) required to attain a given deformation, and breaking force is the force needed to break the samples [29]. For each treatment three replications were analyzed and averaged [30,31]. Results were expressed as Newton (N) units and the data were expressed as means ± standard errors of triplicate measurements.

2.5. Color Analysis

Color was measured at three points for each sample of the zucchini slices using a Hunter-Lab colorimeter (MiniScan XE Plus, Reston, VA, USA) in the CIELAB color space. The results were expressed as L* (luminosity, white-black), a* (green-red) and b* (yellow-blue). Color parameters were evaluated both on a scale of −60 to +60, in the Hunter scale, with the illumining D75 and observation angle of 10°, calibrated with a standard white plate.

Chroma (C*), or Chroma saturation index, was calculated by numerical values of L*, a* and b* parameters and was determined manually by the equation $\sqrt{(a^2 + b^2)}$.

HUE, or Hue angle, was calculated by the equation: arctangent (b*/a*).

Whiteness index (WI) was determined by the equation: $(\text{WI}) = 100 - [(100 - L^*)^2 + (a^*)^2 + (b^*)^2]^{\frac{1}{2}}$.

Finally, the total color difference (ΔE) was calculated according to the Hunter–Scofield equation: $\Delta E = \sqrt{([(L^* - L_o^*)^2 + (a^* - a_o^*)^2 + (b^* - b_o^*)^2])}$. L_o^*, a_o^* and b_o^*, which indicates the color parameters of freshly cut control zucchini slices [32]. ΔE range could measure the difference between two samples in the following range: (a) ΔE = 0–0.5 trace level difference, (b) ΔE = 0.5–1.5 slight difference, (c) ΔE = 1.5–3.0 noticeable difference, (d) ΔE = 3.0–6.0 appreciable difference, (e) ΔE = 6.0–12.0 large difference and (f) ΔE > 12.0 obvious difference [33,34]. For all measurements three replications were obtained and averaged.

2.6. Statistical Analysis

All the experiments were repeated three times, each with three replicates (three slices for one replicate). The data were expressed as means ± standard errors of triplicate determinations. One-way analysis of variance (ANOVA) and Duncan's multiple range were carried out to assess the effect of independent variables, treatment and storage period on different quality parameters of fresh-cut zucchini for each sample on each day of analysis, using IBM SPSS Statistics 26 software. The significance of level was set at $p < 0.05$.

3. Results

3.1. Weight Loss

During storage, all crops, regardless of their species, lose weight due to water loss. The amount of water evaporated depends on the physiological and morphological characteristics of fruits and vegetables and it has great effect on their expected shelf life. In this research, the weight loss for fresh cut zucchini samples was evaluated under the different coating treatments, at a temperature of 5 °C (Figure 1) during a storage period of 7 days.

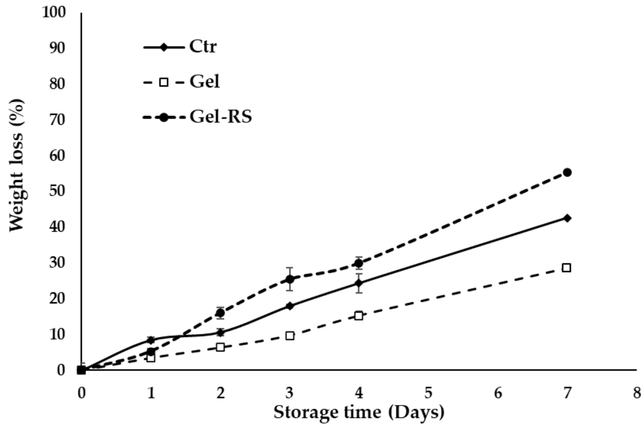

Figure 1. Daily weight loss (%) of coated fresh cut zucchini samples during a 7-day storage period at 5 °C. Sample analysis was in triplicate.

It was found that control samples (Ctr) showed a weight loss at first day of storage (8.48 ± 1.95%) and at the second day (10.6 ± 1.42%). After three days of storage the weight loss increased (18 ± 1.22%) and after four days it was almost doubled. Control samples after seven days of storage showed weight loss of 42.60 ± 2.68%. For samples of zucchini coated with gelatin, weight loss was almost stable during the first three days of storage, but on the fourth days onwards weight loss was increased. Weight loss of fresh cut zucchini slices coated with gelatin after seven 7 days of storage was 28.5 ± 0.36%. In general, this coating prevent zucchini slice weight loss as values were found to be statistically the smallest compared to the other treatments ($p < 0.05$) and less than the values measured for control samples. The addition of rice starch in the gelatin coating caused a further increase in water loss during the storage period of 7 days. Weight loss of fresh cut zucchini slices coated with gelatin–rice starch after 7 days of storage was 55.38 ± 2.27%. Zucchini slices coated with gelatin are protected from weight loss during storage at 5 °C, but the addition of rice starch accelerates this phenomenon.

3.2. Texture Analysis

The skin of some fruits and vegetable is eaten. The application of edible coatings affects skin texture and the overall hardness of final product. More clearly, firmness values of treated samples during seven days storage at 5 °C are presented in Figure 2a. As it is shown, no differences were noticed for control samples and zucchini slices with different treatments for each day of storage, because the p value of the statistical analysis was higher than 0.05 ($p > 0.05$). The greatest values for all treatments were recorded at day 3 and they were 214.05 ± 19.92, 220.59 ± 6.08 and 208.35 ± 19.06 N. When force is applied to plant tissue, it could break across cell walls or between cell walls and the required force is characterized as breaking force. Samples' breaking force was also presented in Figure 2b. The greatest breaking force values recorded for Gel-RS, Gel and control treatments were 155.27 ± 27.23, 156.9 ± 24.45 and 129.95 ± 1 4.05 N, respectively. No significant differences ($p > 0.05$) were noticed for each day of storage among the control samples and the samples with the coatings Gel and Gel-RS.

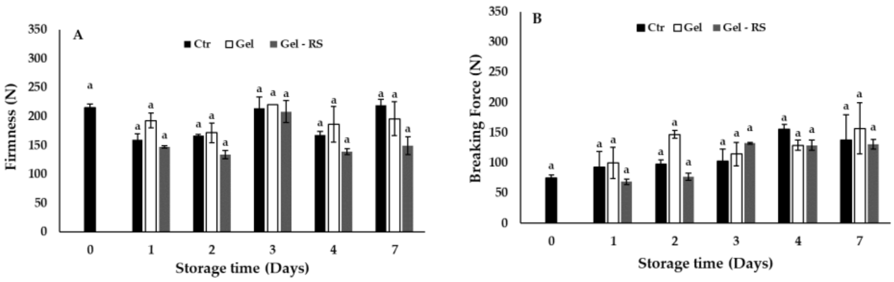

Figure 2. Firmness (N) (**A**) and Breaking Force (N) (**B**) of coated fresh cut zucchini samples during a 7-day storage period. Lack columns indicate Ctr treatment; white columns indicate Gel treatment and grey columns indicate Gel-RS treatment. Different letters indicate statistical differences. Different letters within the columns indicate significant differences ($p < 0.05$) among the different treatments on every sampling date. Sample analysis was in triplicate.

3.3. Color Analysis

3.3.1. Color Parameters

Color parameters L*, a*, b*, Chroma* and Hue* angle are presented in Table 1. During the storage period of 7 days at 5 °C, significant differences were found in L*, a* and b* parameter values among the untreated samples and the coated ones. L* parameter values were always found to be greater in control zucchini samples and the lowest values were observed in Gel-RS coated zucchini samples. The opposite was observed for a* and b* parameter values, for which the lowest values were observed for untreated samples.

Table 1. Color parameters L*, a*, b*, Chroma* and Hue* angle of coated fresh cut zucchini samples during a 7-day storage period at 5 °C. Sample analysis was in triplicate.

Day	Treatment	L*	a*	b*	Chroma*	Hue*
0	Ctr	89.98 ± 0.02 ^{a}	−1.13 ± 0.03 ^{c}	25.01 ± 0.01 ^{c}	25.04 ± 0.02 ^{c}	92.59 ± 0.07 ^{a}
	Gel	88.92 ± 0.05 ^{b}	−0.65 ± 0.01 ^{b}	25.62 ± 0.03 ^{b}	25.63 ± 0.05 ^{b}	91.45 ± 0.03 ^{b}
	Gel-RS	87.30 ± 0.06 ^{c}	−0.43 ± 0.01 ^{a}	27.26 ± 0.02 ^{a}	27.26 ± 0.03 ^{a}	90.90 ± 0.01 ^{c}
1	Ctr	90.48 ± 0.04 ^{a}	−0.86 ± 0.02 ^{c}	24.59 ± 0.02 ^{c}	24.61 ± 0.04 ^{c}	92.00 ± 0.06 ^{a}
	Gel	88.33 ± 0.07 ^{b}	−0.66 ± 0.03 ^{b}	26.82 ± 0.03 ^{b}	26.83 ± 0.05 ^{b}	91.40 ± 0.09 ^{b}
	Gel-RS	85.99 ± 0.01 ^{c}	−0.24 ± 0.03 ^{a}	32.02 ± 0.04 ^{a}	32.02 ± 0.07 ^{a}	90.43 ± 0.06 ^{c}
2	Ctr	89.55 ± 0.01 ^{a}	−0.65 ± 0.02 ^{c}	25.44 ± 0.02 ^{c}	25.45 ± 0.03 ^{c}	91.47 ± 0.05 ^{a}
	Gel	88.02 ± 0.08 ^{b}	−0.46 ± 0.01 ^{a}	26.85 ± 0.02 ^{b}	26.85 ± 0.04 ^{b}	90.98 ± 0.02 ^{b}
	Gel-RS	83.90 ± 0.11 ^{c}	0.50 ± 0.02 ^{b}	34.63 ± 0.02 ^{a}	34.63 ± 0.04 ^{a}	89.17 ± 0.04 ^{c}
3	Ctr	89.10 ± 0.05 ^{a}	−0.53 ± 0.02 ^{c}	24.61 ± 0.03 ^{c}	24.62 ± 0.05 ^{c}	90.61 ± 0.08 ^{a}
	Gel	87.72 ± 0.002 ^{b}	−0.43 ± 0.02 ^{b}	27.26 ± 0.03 ^{b}	27.26 ± 0.05 ^{b}	88.81 ± 0.03 ^{b}
	Gel-RS	83.51 ± 0.01 ^{c}	0.23 ± 0.03 ^{a}	33.82 ± 0.03 ^{a}	33.82 ± 0.05 ^{a}	89.62 ± 0.06 ^{c}
4	Ctr	88.15 ± 0.08 ^{a}	−0.28 ± 0.03 ^{c}	26.19 ± 0.03 ^{c}	26.19 ± 0.05 ^{c}	90.61 ± 0.08 ^{a}
	Gel	87.34 ± 0.00 ^{b}	0.61 ± 0.01 ^{b}	29.44 ± 0.03 ^{b}	29.45 ± 0.06 ^{b}	88.81 ± 0.03 ^{b}
	Gel-RS	81.57 ± 0.04 ^{c}	1.49 ± 0.02 ^{a}	31.31 ± 0.04 ^{a}	31.34 ± 0.07 ^{a}	87.28 ± 0.04 ^{c}
7	Ctr	87.15 ± 0.02 ^{a}	0.60 ± 0.01 ^{c}	29.44 ± 0.02 ^{c}	29.45 ± 0.03 ^{c}	88.84 ± 0.02 ^{a}
	Gel	85.76 ± 0.04 ^{b}	1.26 ± 0.02 ^{b}	33.07 ± 0.02 ^{b}	33.09 ± 0.03 ^{b}	87.82 ± 0.04 ^{b}
	Gel-RS	75.67 ± 0.06 ^{c}	2.33 ± 0.01 ^{a}	36.44 ± 0.02 ^{a}	36.51 ± 0.03 ^{a}	86.35 ± 0.02 ^{c}

Different letters within the columns indicate significant differences ($p < 0.05$) among the different treatments, on every sampling date.

Also, L* values were decreased, while a* and b* values were increased during the storage period for all samples tested. The greatest Chroma* values were observed for Gel-RS treated samples, and they were significant different ($p < 0.05$) compared to control and the other treatment for each day of storage. A gradual increase in Chroma* values during the storage time was observed for all the treatments. The greatest values were found on Day 7 and statistically significantly differed ($p < 0.05$) from the previous days.

Finally, Hue* angle values decreased during the storage of zucchini slices stored at a low temperature. For each day of storage, Hue* angle value of zucchini slices coated by Gel-RS had the lowest values compare to Ctr samples and to samples treated with Gel ($p < 0.05$) On the other hand, Ctr samples for each day of storage had the greatest values of Hue* angle values compared to the treated samples ($p < 0.05$).

3.3.2. Whiteness Index (WI)

In Figure 3, the Whiteness index of the samples tested is presented. We observed that WI values of the Gel treated samples (white color column) were higher ($p < 0.05$) compared to control samples (black color column) at every day of storage. Also, we found that WI values of Gel-RS coated samples (grey color column) were higher ($p < 0.05\%$) compared to Gel treated zucchini slices and to control samples each day of storage (Figure 3).

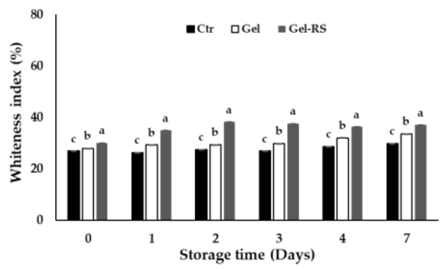

Figure 3. Whiteness Index (WI) of coated fresh cut zucchini samples during a 7-day storage period at 5 °C. Black columns indicate Ctr treatment, white columns indicate Gel treatment and grey columns indicate Gel-RS treatment. Different letters indicate statistical differences. Different letters within the columns indicate significant differences ($p < 0.05$) among the different treatments on every sampling date. Sample analysis was in triplicate.

3.3.3. Total Color Difference (ΔE)

Total color difference was determined for all zucchini samples Ctr, Gel and Gel-RS during the storage period of 7 days at 5 °C. As can be seen in Figure 4, from each treatment, ΔE values were the lowest at day 1 and the highest at day 7. Also, during all days of storage, the lowest values ΔE were measured for the control samples, followed by Gel coated zucchini slices and the highest were always for Gel-RS coated samples. ΔE values of different treatments were significantly different ($p < 0.05$) at the same day of storage.

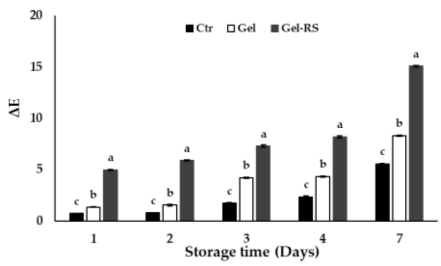

Figure 4. ΔE values of coated fresh cut zucchini samples during a 7-day storage period at 5 °C. Black columns indicate Ctr treatment; white columns indicate Gel treatment and grey columns indicate Gel-RS treatment. Different letters indicate statistical differences. Different letters within the columns indicate significant differences ($p < 0.05$) among the different treatments on every sampling date. Sample analysis was in triplicate.

More specifically for Ctr samples, only after 3 days of storage were ΔE values (1.70 ± 0.07) higher than the perception threshold. Fresh cut zucchini slices coated with gelatin showed a noticeable difference in color on the second day of storage (1.538 ± 0.07) and on the seventh day of storage were 8.31 ± 0.03 and characterized as showing a large difference in total color. The addition of rice starch to the gelatin coating resulted in the acceleration of color difference in coated zucchini slices. Even from the first day of storage, the ΔE value showed an appreciable difference ($p < 0.05$) (4.94 ± 0.05). ΔE values for Gel-RS continued to increase during storage with very obvious differences on the 7th day (15.07 ± 0.09). Finally, Gel-RS coatings decreased the time of appearance of color change during storage of the fresh cut zucchini.

4. Discussion

Summarizing, in this study, two types of biodegradable gelatin coatings have been applied to fresh cut zucchini slices and evaluated for 7 days' storage at 5 °C. Samples coated with gelatin protected the fresh cut slices from weight loss, but the addition of rice starch to the coating accelerated the increase of weight loss values and gelatin lost its protective role. In addition, no significant differences were found for untreated and treated samples with gelatin and gelatin–rice starch coatings in the texture parameters of firmness and breaking force. Additionally, color analysis showed that the specific coatings decrease L* of fresh cut zucchini slices during all days of storage, and at the same time increase a* and b* color parameters. The gelatin–rice starch coating also presented significantly higher values of a* and b* compared to untreated and gelatin-treated samples. In addition, coated samples exhibited the highest values on the Whiteness Index (WI) and accelerated the total color change (ΔE) during the storage of the fresh cut zucchini slices. Our results were based on the following observations.

Firstly, vegetables and fruits during peeling, slicing and coating had been subjected to severe physical stress as protective epidermal cells have been removed. Coatings could provide a protective layer for fresh cut zucchini tissues, as water vapor permeability and respiration rates had changed [35] and low water loss was often desired [36]. In this study gelatin coating applied on fresh cut zucchini slices appears to slow down water release, probably by creating a compact macromolecular network. Mixing gelatin with rice starch showed opposite properties by increasing weight loss during all the 7 days' storage at low temperature (5 °C). It is well known that gelatin builds a macromolecular network with less permeability to vapors and gases compared to control samples, and this is different to the functional characteristics of many protein coatings, which are highly effective oxygen blockers but allow relative humidity [37]. For example, coatings of concentrated solutions of pea protein had no significant influence on the water loss of Cavendish bananas [38]. On the other hand, a decrease in water vapor permeability was found for edible films prepared from cassava starch and soy protein blends, due to the creation of a dense network between protein and starch with a small free volume, therefore inhibiting diffusion [39]. According to other studies, rice starch is compatible with glycerol and although the mixture glycerol with gelatin creates homogeneous, very viscous coatings [40], due to addition of rice starch, its crystalline region ratio to the amorphous region decreases because of glycerol's presence [41]. Consequently, intermolecular spacing increased values of water loss. Also, rice starch high hydrophilicity could speed up the entire phenomenon. In the coating mixture of gelatin with rice starch, the presence of gelatin does not have predominant behavior in water loss characteristics, but gelatin on its own could protect fresh cut zucchini from water loss.

Secondly, the texture in fruits and vegetables is affected by composition of the cell wall, biochemical constituents, chemical composition and moisture content. Consumers know what to expect when they perceive fresh food, as food texture is considered a dominant characteristic, [42]. It is well known that zucchini fruit has thin cuticle, and the way it breaks during the mastication process is a characteristic that influences the organoleptic textural sensation. It is widely known that the application of biodegradable coatings could influence control over the deformation profile and general textural characteristics. Our data showed that both treatments of gelatin and gelatin–rice starch coatings maintain the firmness and breaking force of untreated fresh cut zucchini samples during storage at a low temperature [43]. The softening of the texture of fruits and vegetables results from the combination of several factors. The effect of water loss on softening is unclear, making it difficult to predict the structural consequences of using post-harvest technologies that relate firmness to water loss [44]. In general, fruit softening is a feature of ripening, which is closely related to the change in cell wall structure, components and fruit cell wall degradation induced by various types of enzymes [45]. In our study, the coatings of gelatin and gelatin–rice starch maintain physiological parameters, chemical and biochemical constituents and consequently textural characteristics of fresh cut zucchini slices which were found to be the same as the control during all days of storage. These data provide new knowledge for the application of edible coatings on fresh cut fruits slices when the maintenance of textural characteristics is desirable.

The development of different colors in food texture during storage of fresh and fresh cut fruits and vegetables results from the accumulation of different compounds. Color in food is affected not only by the concentration, temperature or pH of specific pigments, but also by the physical structure and light reflection of the food surface [46]. In our study, during the storage of fresh cut zucchini slices coated with a gelatin–rice starch mixture, the zucchini slices became significantly darker as revealed by the L* value drop compared to untreated fresh cut slices and to slices treated with gelatin. At the same time, the gelatin–rice starch coating caused an increase in a* and b* values during storage. This could be explained as starch-based coating formulations are more permeable to O_2 due to the presence of a plasticizer, which decreases the intermolecular interactions among adjacent polymeric chains and facilitates gas mobility and permeability, functions that could cause changes in color due to oxidation damages [47]. In addition, the main function of the effective of coatings and edible films is to preserve changes in physicochemical parameters and biochemical processes such as enzymatic oxidation caused by polyphenol oxidase (PPO), that is responsible for the browning. This is in contrast with previously published works indicating the effectiveness of coatings based on gelatin–starch [22,48,49]. Studies of edible coatings of cassava starch showed that it was beneficial in preventing enzymatic browning in fresh cut apples for 12 days [50] and cassava starch had similar benefits on the color characteristics of fresh cut mangos [51]. Interestingly the application of a gelatin coating in a study demonstrated a superior ability to preserve weight loss of sliced zucchini fruit during storage at a low temperature, causing a drop in L*. Although it should be mentioned that in our treatments there was no added antioxidant or antimicrobial factor, such as fruit juice or chitosan, respectively, which needs to be further investigated.

Another color parameter which studied was whiteness index. Fresh cut zucchini slices coated with the gelatin–rice starch mixture presented higher WI values compared to other untreated and gelatin-treated samples during all days of storage. Whiteness Index changes are connected to moisture sorption characteristics in association to humidity and temperature storage [52]. This could be due to the functional properties of rice starch such as high values of whiteness and also higher hydrophilicity compared to gelatin coating [53]. In addition, rice starch influences the relative humidity of coated zucchini samples and dehydrates them. This dehydration could also be responsible for the high values found in the total color difference ΔE of samples coated with the gelatin–rice starch mixture during all days of storage. When zucchini slices are coated, humidity could migrate in the tissue of the zucchini and could compete with rice starch for free water. These processes are responsible for decreased freshness zucchini slice characteristics, possibly due to the absence of protective tissues of the cuticle peel and exposure of the internal tissues to the biodegradable coatings [40]. This behavior of the coating with rice starch is also in agreement with the effect on weight loss during the 7 days of storage.

Taking into account that gelatin protects the texture and prevents water loss, a gelatin coating could be interesting to use for the development of biodegradable packaging in fresh cut zucchini slices. The coating of gelatin–rice starch only protected untreated samples' texture properties, but on the other hand accelerated water loss and caused decreased L* and higher a* and b* values. After 7 days of storage, zucchini slices coated by the gelatin–rice starch mixture showed obvious color differences compared to the rest of the samples. Rice starch is an inexpensive polysaccharide which, due to growing environmental awareness, could be, in combination with gelatin, an ideal coating to be used on fresh cut zucchini slices when preservation is necessary at the same time as dehydration.

5. Conclusions

This study provides novel information on gelatin-based edible coatings and their effects on quality characteristics of fresh cut zucchini slices stored at 5 °C for 7 days. A gelatin edible biodegradable coating applied on the surface of sliced zucchini promotes the adhesion of macromolecule dispersions, increases resistance to weight loss of samples and contributes to the preservation of zucchini slices' mechanical behavior. On the other hand, the addition of rice starch to gelatin increases the hydrophilic nature of the edible coating and maintains zucchini slices' firmness and breaking force. Additionally, the application of the gelatin–rice starch mixture on zucchini slices accelerates the increase in weight loss, total color differences ΔE and presents a large drop of L^* at 5 °C during long term storage. In conclusion, coatings with gelatin and rice starch could be useful when both preservation and dehydrating processes at low temperature are desirable for zucchini slices by preserving texture characteristics. These results could be interesting for research and development in industry, helping to save thermal energy and enrich knowledge about gelatin-based coatings.

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