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Research Article

Effect of Edible Xanthan Coating Enriched by *Crocus sativus* L. Extracts on Fresh Cut Zucchini Slices

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Biopolymeric coatings fortified with bioactive plant extracts applied on fruit and vegetable surfaces could further enhance product quality attributes. *Crocus sativus* L. extract is rich in bioactive compounds. It is the first time that this extract was added to xanthan coating to investigate its effects on fresh-cut zucchini slice quality during storage at 5°C for 7 days. Therefore, weight loss, pH, titratable acidity, total soluble solids, firmness, color characteristics, and microbiological changes were monitored. Xanthan gum coating decreased the weight loss of fresh-cut zucchini slices and maintained their firmness. Xanthan–*Crocus sativus* L. extract coatings showed similar effects compared to xanthan coating without extract. Titratable acidity and total solid values of zucchini fresh-cut slices were lower which might indicate a delay in the maturation process. Furthermore, fresh-cut zucchini slices coated with xanthan and *Crocus sativus* L. extract 0.05% w/w exhibited similar firmness values throughout the storage duration; the highest values were recorded on the seventh day. Coatings with increasing concentrations of *Crocus sativus* L. extract did not present any specific trend in color parameters. Additionally, no significant differences were recorded between treatments for the population of total viable counts, yeasts/molds, and Enterobacteriaceae, and only a slight increase in the lactic acid bacteria population was observed in xanthan–*Crocus sativus* L. extract coatings. So, this research enriches the knowledge of the effects on the quality properties of fresh-cut zucchini slices coated by biopolymers and enriched with plant extracts.

Keywords: coatings; *Crocus sativus* L.; quality; storage; xanthan; zucchini

1. Introduction

Packaging materials from biopolymers are very interesting for research in food science and the food industry. This novel packaging could help eliminate food loss and big environmental problems with social and economic consequences [1]. Also, the way of living requires convenience in food preparation and consumers prefer minimally processed fruits and vegetables such as fresh-cut ones to save time. Fresh-cut fruits and vegetables during storage are subjected to various biochemical changes that accelerate quality changes such as appearance and texture decay, development of enzymatic browning and undesirable aromas/flavors, and finally self-life reduction. All these changes turn fresh-cut fruits and vegetables into food waste. The application of edible coatings in fresh-cut fruits and vegetables is of great importance because they could enhance or replace their natural cuticle to improve quality properties and reduce degradation and microbiological spoilage [2].

The definition of coatings was given in 1995 as a thin layer of materials that covers the surface of food, which could be eaten as part of the whole product [3]. Since then, much research has been done on biodegradable coatings made from food biopolymers, which were used alone or in mixtures with materials suitable for food coatings because they can easily be applied on the surface of fruits and

vegetables. The best way of applying a coating on the epidermis of fruits and vegetables relies on the physicochemical characteristics of the material as the aim is to control the transmission of various gases, moisture loss, aroma, color changes, etc. [4, 5]. The role of food biopolymers varies and more specifically increases or maintains functional characteristics in products during storage. Xanthan gum is a widely used polysaccharide in food with many applications such as stabilizers, thickeners, or emulsifiers. Its ability to form viscous solutions at any temperature and small concentrations [6] made xanthan a promising edible biopolymer which as a coating played a protective role on the barrier and microbial characteristics for example on freshly cut lotus root during postharvest storage [7]. In recent studies, the coating of xanthan on jujube fruit delayed ripening and loss of firmness during storage at 20.0°C ± 1.0°C for 15 days [8]. Also, edible coating, based on xanthan gum fortified with cinnamic acid known for its antioxidant and antimicrobial activity, inhibited browning and increased the shelf life of fresh-cut pears [9].

The addition of natural compounds in edible films and coatings, which exhibit protective, antibrowning, antimicrobial, and antioxidant properties, improves the quality of coated food products by modifying the internal atmosphere [10] Also, adding bioactive compounds to edible films and coatings changes the structural properties of edible films and, consequently, their protective effects of food applied. Usually, herbs, spices, fruits, vegetables, plants, etc. could be sources of bioactive compounds and their extracts are often added to coatings [11, 12].

In this research, *Crocus sativus L.* was investigated to fortify xanthan gum coating. Dried saffron fragments *Crocus sativus* L. is known as "Red Gold" as it is the most expensive spice worldwide with anti-inflammatory, antioxidant, anticancer, and immunological properties [13]. Also, the three main secondary metabolites of *Crocus sativus* L. are crocin, picrocrocin, and safranal. These metabolites are responsible for the main food organoleptic characteristics such as color taste and aroma [14].

It is the first time that *Crocus sativus* L. extract is incorporated in edible coating and this study aims to investigate the influence of xanthan–*Crocus sativus* L. coatings on fresh-cut zucchini slices during cold storage for 7 days. Weight loss, pH, titratable acidity (TA), total soluble solids (TSSs), firmness, color characteristics, and microbial population changes were investigated to explore the effectiveness of the coatings on the storage of fresh-cut zucchini.

2. Materials and Methods

2.1. Preparation of Zucchini Slices. Zucchinis (*Cucurbita pepo* L. cv cylindrical) used in this research were at the commercial maturity stage. Zucchinis were purchased from a local supermarket in Larissa, Greece, and stored for 24 h at 5°C before being processed. All zucchini fruits had uniform size, shape, and color and were free from microbiological and physical damage. To prepare fresh-cut zucchini slices, zucchinis were washed with distilled water, peeled, and then carefully dried with absorbent paper [15]. Zucchini was cut into cylinders with specific dimensions: height 10 mm and diameter 30 mm.

2.2. Preparation of Crocus sativus L. Extract and Xanthan Gum Edible Coatings. The solution of edible coatings was prepared by using 0.3 g of xanthan gum from *Xanthomonas campestris* (Sigma-Aldrich, St. Louis, United States) and *Crocus sativus* L. KROKOS KOZANIS PDO–Greek red saffron in filaments, which was commercially purchased from a supermarket in Larissa, Greece. Extracts of *Crocus sativus* L. were prepared by stirring for 30 min red saffron in a specific amount of distilled water and then filtering it through Whatman filter paper. Xanthan gum solution was prepared by heating and stirring at 80°C for 1 h. Then, anhydrous glycerol and *Crocus sativus* L. were added during mixing at this temperature for another 15 min to prepare mixtures with the following concentrations: T1: 0.3% w/w xanthan; T2: 0.3% w/w xanthan and 0.005% w/w *Crocus sativus* L extract; T3: 0.3%w/w xanthan and 0.025% w/w *Crocus sativus* L. extract; and T4: 0.3% w/w xanthan and 0.05% w/w *Crocus sativus* L. extract. Control samples Ctr were zucchini slices without coatings. In all edible coatings, 1% w/w anhydrous glycerol was added. All zucchini samples were placed in plastic discs and stored for 7 days at 5°C. The quality properties of the samples during the storage period on Days 0, 1, 2, 3, and 7 were determined. The measurements were performed in triplicate.

2.3. Weight Loss Measurements. Weight loss of zucchini fresh-cut slices was studied during a period of a total of 7 days. At Days 0, 1 2, 3, and 7, zucchini samples coated with edible biopolymers and control fresh cut slices were weighed using a laboratory scale high precision digital weighing balance according to the standard method of AOAC [16, 17] The weight loss was calculated by Equation (1).

$$\text{Weight loss}(\%) = \frac{(\text{Wi} - \text{Wf})}{\text{Wi}} \times 100 \quad (1)$$

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

2.4. pH, TA, and TSS Contents. pH, TA, and TSS were determined for all samples in triplicates for experimental Days 0, 1, 2, 3, and 7, at 5°C. The pH was measured by using a digital pH meter LAB-860. TA was calculated according to Khaliq, Ramzan, and Baloch [18]. For each treatment, 10 g of zucchini ground flesh was added in 40 mL distilled water, and the mixture was titrated with 0.1 M NaOH to a pH of 8.2. TA was calculated by Equation (2), and the results were expressed as a percentage of malic acid (Equation (2)).

$$\text{TA malic acid}\% = (\text{Volume of } 0.1\text{ M NaOH}) \times 10 \times 0.067 / \cdot (\text{Volume of sample}) \quad (2)$$

TSS of zucchini treatments was determined according to the method by Wantat, Rojsitthisak, and Seraypheap [19].

Five grams of zucchini sample of each treatment was added into a centrifuge tube, mixed with 10 mL distilled water, and then centrifuged for 5 min at 8000 × g at room temperature. TSS was determined by collecting the supernatant and the measurement took place by a digital handheld refractometer (Refractometer PAL-1, Atago) which was calibrated to zero with distilled water. TSS values were expressed as Brix.

2.5. Texture Analysis. Texture characteristics of fresh-cut zucchini samples were determined during the storage period, for all treatments. Texture analysis was performed on Day Samples 0, 1, 2, 3, and 7 at 5°C using a TMS-Pro Texture Analyzer (Food Technology Corporation, Virginia, United States), with a probe of 6 mm diameter. The samples have dimensions of 10 mm in height and 30 mm in diameter. A 70% compression of their initial height under identical conditions was performed on the samples with a jog rate of the prob (diameter) 1 mm/s [15]. The texture parameter studied in this research is firmness which is defined as the highest force (F_{max}) required to attain a given deformation. For each treatment, three replicates were analyzed.

2.6. Color Analysis. The color measurement was performed on the lateral surface of zucchini for each treatment according to the International de L'Eclairage (CIE) $L*a*b*$ system, and the color parameter values were determined by using a colorimeter (HunterLab MinScan XE Plus, United States). Specifically, $L*$ or brightness represents darkness in light on a scale of 0–100. The value $a*$ or redness corresponds to green to red on a scale of −60 to +60. The values $b*$ or yellowing represent blue to yellow on a scale of −60 to +60. In addition, values of $L*$, $a*$, and $b*$ were used to determine chroma ($C*$) (Equation (3)), Hue∗ or Hue∗ angle (Equation (4)), whiteness index (WI) (Equation (5)), and total color difference (ΔE) (Equation (6)) of all treatments.

$$\text{Chroma}* = \sqrt{(a2 + b2} \tag{3}$$

$$\text{Hue} * \text{angle} = \text{arctangent}\left(\frac{b*}{a*}\right) \tag{4}$$

$$\text{WI} = 100 - \sqrt{[(100 - L*)2 + (a*)2 + (b*)2]} \tag{5}$$

$$\Delta E = \sqrt{([(L*-\text{Lo}*)2 + (a*-\text{ao}*)2 + (b*-\text{bo}*)2])} \tag{6}$$

where Lo $*$, ao $*$, and bo $*$ indicate the initial color parameters of fresh-cut zucchini on 0 day. All measurements were repeated three times for each experimental treatment.

2.7. Microbiological Analysis. The samples were stored at 5°C and subjected to microbiological analysis to monitor the microbial population changes at selected time points. Ten grams in triplicates were homogenized in a Stomacher (Bug Mixer, Interscience, London, United Kingdom) with 90 mL MRD (maximum recovery diluent) (0.1% w/v peptone; 0.85% w/v NaCl). To count the total viable counts (TVCs) (tryptone soy agar (TSA), incubation at 25°C for 48–72 h), yeasts/molds (yeast extract agar, incubation at 25°C for 48–72 h), 0.1 mL of the 10-fold diluted sample was spread on the surfaces of the Petri dishes. Enterobacteriaceae (violet red bile glucose agar (VRBGA), incubation at 37°C for 24 h) and lactic acid bacteria (LAB) (De Man, Rogosa, Sharpe agar-MRS, incubation at 30°C for 72 h) populations were determined using the pour plate method with 1 mL of 10-fold diluted sample. The results were expressed as mean $\log \text{CFU g}^{-1} \pm$ standard deviation of three replicates.

2.8. Statistical Analysis. For each experimental day, all the measurements were repeated three times using three replicates. The results were calculated as means ± standard errors of the triplicate measurements. One-way analysis of variance (ANOVA) and least significant difference (LSD) test took place to assess the effect of the independent variables of treatment and storage period on the different quality parameters of fresh-cut zucchini slices treated and untreated for each sampling date, using IBM SPSS Statistics 26 software. The level of significance was $p < 0.05$.

3. Results and Discussion

3.1. Weight Loss. Many types of coatings based on polysaccharides have been used to maintain fruit quality after harvest and during storage at low temperatures [20, 21]. Weight loss in fresh-cut fruits and vegetables is associated with respiration and transpiration, and weight loss could be a factor in their freshness [22]. Also, many types of research show weight loss in fruits and vegetables as a factor related to the beginning of deterioration [23, 24]. In this research, the effects of xanthan–*Crocus sativus* L. coatings on water loss (%) on coated fresh-cut zucchini slices during a 7-day storage period in low-temperature conditions are presented in Figure 1. The highest weight loss (percent) values were observed for the untreated (Ctr) zucchini samples for all dates tested and for all samples on Day 7, where the total weight loss of the Ctr sample was up to 54.50% ± 1.20% of their initial weight and significantly higher ($p < 0.05$) than the other treatments. Also, the weight loss (percent) values of the T4 zucchini samples were different ($p < 0.05$) from the other treatments (44.44% ± 3.00%), and no differences were noticed among the T1, T2, and T3 samples. The highest weight loss values for T1, T2, and T3 treatments were 33.90% ± 3.50%, 32.10% ± 3.60%, and 33.30% ± 3.60%, respectively. In this research, the weight loss of all treated fresh-cut zucchini samples increased during storage at 5°C. However, it was found that the weight loss of the coated zucchini samples was lower than the noncoated samples. The same effect was observed when xanthan gum–based mixtures were used as coatings for fresh-cut lotus root samples [7]. The authors concluded that the decrease in the weight loss values in coated samples could be attributed to the fact that xanthan gum is a semipermeable barrier against O2, CO2, and moisture which follows that coatings based on gums have the above characteristics [25, 26]. In addition, coated guava fruits with 1% xanthan gum reduced weight loss [27], and in another research, the application of 1.4% xanthan gum as a coating on the acerola surface formed an active barrier by delaying the ripening process and preventing oxygen penetration [28]. Therefore, xanthan application on the surface of the crops reduces respiration and water loss [25]. In addition, the same results were obtained when a bilayer

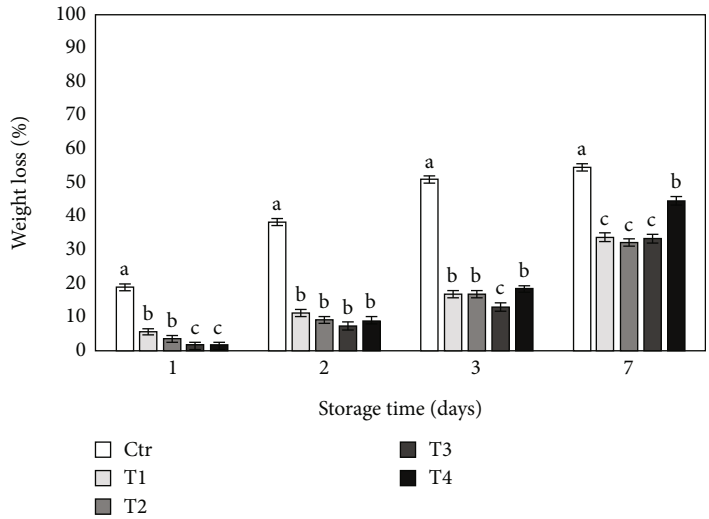


FIGURE 1: Weight loss (%) values of fresh-cut zucchini samples Ctr, T1, T2, T3, and T4 samples during a 7-day storage period at 5°C. Different letters indicate statistically significant differences ($p < 0.05$) among the treatments. All measurements were conducted in triplicates.

coating based on whey protein isolate, xanthan gum, and clove oil was used to prolong the shelf life of tomato samples during a 15-day storage period [29]. However, in this research, on the seventh day of storage, the xanthan coating fortified with the highest concentration of *Crocus sativus* L. extract had the highest weight loss compared to the rest of the coated samples. It is well known that *Crocus sativus* L. has great antioxidant potential because it contains polysaccharides around 59.53 ± 0.98 mg/g [30]. Therefore, according to recent research, some polysaccharide-based coatings provide poor moisture barriers, such as the gelatin–rice starch coating on freshly cut zucchini slices, where rice starch increases weight loss during storage [15, 20, 31]. In this study, the mixture of *Crocus sativus* L. with xanthan gum created a coating that decreased weight loss and did not alert the xanthan gum macromolecular network. *Crocus sativus* L. stigma contains mucilage, a group of complex polysaccharides that aid water absorption and retention [32]. These complex polysaccharides probably support the xanthan network and help to retain the ability of a coating to keep weight loss at lower levels compared to control. In addition, *Crocus sativus* L. stigma contains crocetin a precursor of crocin with lipophilic characteristics [33] that could be an active agent in imparting a better moisture barrier in xanthan–*Crocus sativus* L. coating.

3.2. TA, pH, and TSS. Except for the weight loss, we studied the freshness of cut zucchini slices by measuring TA, pH, and TSS which are three very important factors that could give an insight into fruits and vegetable quality. pH values of Ctr treatment samples were lower ($p < 0.05$) for all dates tested, although a decrease in p*H* values was observed during storage time. The highest pH values for all treatments were recorded on Day 0, while no differences ($p > 0.05$) were noticed among the T1, T2, T3, and T4 treatments during the storage period. The highest values recorded for Ctr, T1, T2, T3, and T4 treatments were 5.5 ± 0.01, 7.52 ± 0.06, 7.60 ± 0.03, 7.60 ± 0.04, and 7.60 ± 0.07, respectively. As shown in Figure 2, no significant differences ($p > 0.05$) were found among the treatments for all dates tested. Although no differences were noticed, the highest ($0.05\% \pm 0.00\%$) and lowest ($0.02\% \pm 0.00\%$) TA values were recorded on Day 0 and Day 1, referring to Ctr and T1 treatment, respectively. Figure 3 presents the TSSs (%) values of fresh-cut zucchini samples during a 7-day storage period. The coating of xanthan with *Crocus sativus* L. decreased TA values. TA is correlated with crop maturity. Consequently, fortified coatings decreased zucchini maturity during storage. Our results agree with another research on tomato fruit coated with whey protein isolate, xanthan gum, and clove oil, where TA values for coated samples decreased during storage time [29]. In our study, the pH measurements of fresh-cut zucchini slices coated by the fortified xanthan–*Crocus sativus* L. coatings were stable during storage and samples had higher pH values than the uncoated. The increase in pH values could be due to the breakdown of organic acids in fresh-cut products. In agreement with our results, it was shown that xanthan gum-based edible coating when applied on fresh-cut lotus root causes an increase in pH during the 16-day storage period at 20°C [7]. Another important parameter studied in our research is TSS which measures small soluble molecules of sugars during crop maturation from polysaccharide breakdown. The effect of xanthan–*Crocus sativus* L. coating on fresh-cut zucchini slices showed low values of TSS during cold storage and indicated a delay of maturity.

Refrigerated storage is considered an effective method for preserving the quality properties of vegetables. However, this storage method could delay biochemical reactions that end in ripening and degradation. Zucchini fruit with a subtropical origin when stored above 0°C provokes ROS production, inducing chilling damage at the cellular level and increasing the rate of ripening [34]. So, the addition of *Crocus sativus* L. in xanthan coatings enhances the protection of zucchini fresh-cut slices, as, according to other research, crocins and crocetin, which are known for their strong antioxidant activities in *Crocus sativus* L., could prevent the generation of free radicals and reduce lipid peroxidation and samples maturity.

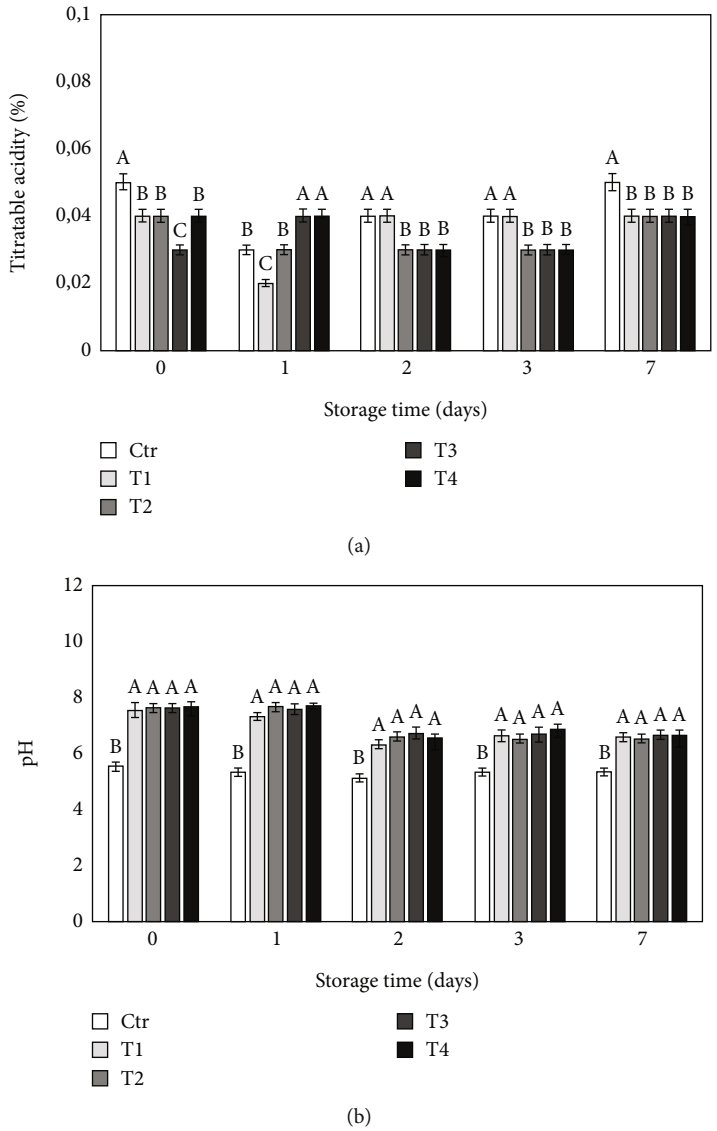


Figure 2: (a) Titratable acidity (%) and (b) pH values of fresh-cut zucchini samples Ctr, T1, T2, T3, and T4 during a 7-day storage period at 5°C. Different letters indicate statistically significant differences ($p < 0.05$) among the treatments. All measurements were conducted in triplicates.

3.3. Texture Analysis. One of the main quality characteristics of fruits and vegetables is texture and especially firmness. Some vegetables and fruits are eaten by the skin, and firmness is an indicator of their maturity. In general, the application of coatings on the surface of a crop could affect the perception of texture and the overall firmness of the final product. Firmness values (N) of fresh-cut zucchini samples during a 7-day storage period are presented in Figure 4. Although statistically significant differences ($p < 0.05$) were observed among the different treatments, no specific trend was observed for the firmness values of the fresh-cut zucchini samples during the storage period. The greatest values for Days 0, 1, 2, and 3 were observed for the Ctr (11.10 ± 0.83) and T1 (13.70 ± 0.39) fresh-cut zucchini samples, respectively. Moreover, T4 zucchini samples had the lowest firmness values on the first days of the storage period, while the opposite was observed on Day 7, where the T4 zucchini samples showed the highest firmness values (8.60 ± 0.15) compared to the other treatments. Also, as shown in Figure 4, the T4 treatment seemed to retain and increase zucchini firmness during the storage period, while a decrease in firmness was observed for the zucchini samples Ctr, T1, T2, and T3. For all samples, the lowest values were observed on Day 7. Softening of zucchini flesh is an indicator of ripening which is closely related to fruit cell wall degradation induced by various types of enzymes [4, 35]. During the ripening process, polysaccharide molecules break down into smaller soluble molecules-compounds and the flesh becomes softer. In this research, the highest concentration of *Crocus sativus* L. extract on xanthan coating on the seventh day of storage influenced fresh-cut zucchini samples, which showed the greatest firmness compared to the rest samples. The presence of the highest concentration of *Crocus sativus* L. extract reduces the oxidation reaction rates

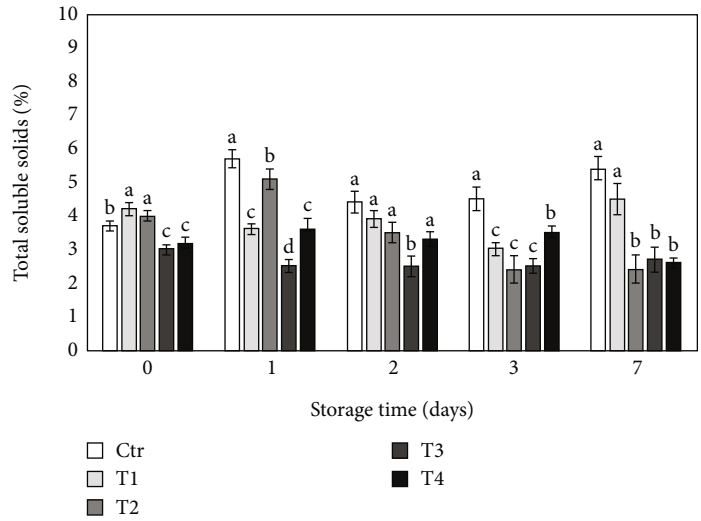


Figure 3: Total soluble solids (%) values of fresh-cut zucchini Ctr, T1, T2, T3, and T4 samples during a 7-day storage period at 5°C. Different letters indicate statistically significant differences ($p < 0.05$) among the treatments.

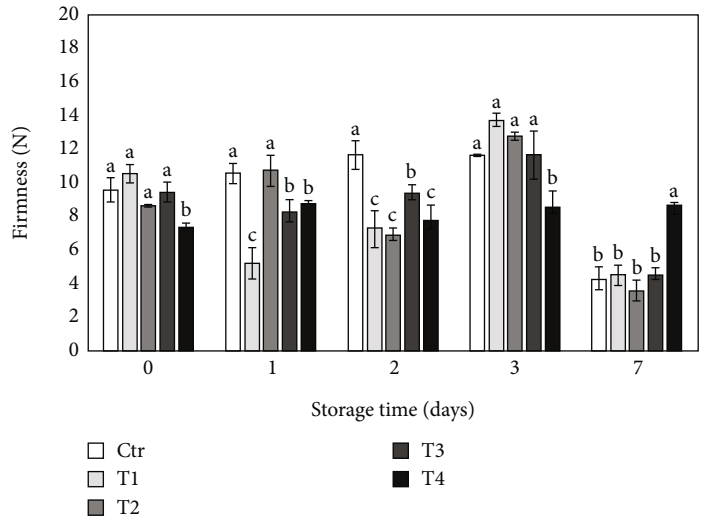


Figure 4: Firmness (N) values of fresh-cut zucchini Ctr, T1, T2, T3, and T4 during a 7-day storage period at 5°C. Different letters indicate statistically significant differences ($p < 0.05$) among the treatments.

[36] and protects the zucchini texture. In addition, complex polysaccharides that contain the *Crocus sativus* L. stigma could aid water absorption and retention and be responsible for the highest firmness in coated zucchini slices with the higher *Crocus sativus* L. concentration. [32]. So, the firmness of zucchini fresh cut slices is related to water content [37], and xanthan–*Crocusus sativus* L. coating provides low moisture loss and results in firmer samples. The same results were observed when an edible coating containing xanthan gum was applied on tomato samples [29]. These findings also agree with our previous research where gelatin coating maintained the firmness of fresh-cut zucchini samples during storage at 5°C [15].

3.4. Color Measurements. The development of different colors during the storage of fresh-cut fruit and vegetables is the result of pigment formation. Color development in fresh-cut crops is mainly affected by the concentration, temperature, and pH values of specific chemical compounds; degradation; and also by the physical structure of crops and the light reflection on fruits and vegetable surfaces [38]. In the case of fresh-cut fruits and vegetables, color parameters could also be one of the indicators of freshness. In this research color measurements $L*$, $a*$, $b*$, chroma$*$, and hue$*$ angle of fresh-cut zucchini samples during a 7-day storage period at 5°C are presented in Table 1. Zucchini samples were affected by the different treatments. More specifically, our data showed that $L*$ values of uncoated samples were always higher ($p < 0.05$) than the coated ones during all the days of cold storage. The highest $L*$ values were recorded on Day 0, for the T3 zucchini samples (79.14 ± 1.72), and the lowest on Day 7, for the T4 zucchini samples (57.28 ± 1.90). The opposite was found for chroma$*$,

Table 1: Color parameters $L*$, $a*$, $b*$, chroma$*$, and hue$*$ angle of fresh-cut zucchini samples during a 7-day storage period.

Day	Treatment	$L*$	$a*$	$b*$	Chroma$*$	Hue$*$
0	Ctr	78.89 ± 1.20^{a}	1.00 ± 0.06^{a}	26.72 ± 1.96^{b}	26.73 ± 1.23^{b}	87.85 ± 0.52^{b}
	*T*1	76.44 ± 1.00^{a}	0.85 ± 0.13^{b}	28.71 ± 1.34^{b}	28.72 ± 1.11^{b}	88.30 ± 0.66^{a}
	*T*2	74.94 ± 1.84^{ab}	0.88 ± 0.22^{b}	33.90 ± 1.78^{a}	33.92 ± 1.43^{a}	88.51 ± 0.50^{a}
	*T*3	79.14 ± 1.72^{a}	0.56 ± 0.05^{c}	34.84 ± 1.58^{a}	34.84 ± 1.26^{a}	89.07 ± 0.59^{a}
	*T*4	71.56 ± 1.11^{b}	0.70 ± 0.20^{b}	32.89 ± 1.03^{a}	32.89 ± 1.40^{a}	88.78 ± 0.65^{a}
1	Ctr	77.27 ± 1.70^{a}	1.49 ± 0.13^{a}	24.59 ± 1.72^{d}	24.60 ± 1.10^{d}	86.53 ± 0.50^{a}
	*T*1	79.04 ± 1.09^{a}	1.59 ± 0.12^{a}	$28.13 \pm 0.1.05^{c}$	28.17 ± 1.50^{c}	86.37 ± 0.58^{a}
	*T*2	72.11 ± 1.09^{b}	1.37 ± 0.26^{b}	29.44 ± 1.70^{c}	33.92 ± 1.25^{a}	87.33 ± 0.60^{a}
	*T*3	70.67 ± 1.66^{b}	1.40 ± 0.19^{b}	38.69 ± 1.75^{a}	34.84 ± 1.20^{a}	87.92 ± 0.40^{a}
	*T*4	78.05 ± 1.98^{a}	0.68 ± 0.16^{c}	33.06 ± 1.50^{b}	32.89 ± 1.83^{a}	87.82 ± 0.60^{a}
2	Ctr	72.48 ± 1.31^{a}	0.45 ± 0.08^{d}	27.61 ± 1.44^{a}	27.61 ± 1.10^{a}	89.06 ± 0.96^{a}
	*T*1	64.77 ± 1.90^{b}	0.47 ± 0.08^{d}	25.65 ± 1.83^{b}	25.65 ± 1.25^{b}	88.90 ± 0.90^{a}
	*T*2	59.16 ± 1.02^{c}	1.40 ± 0.39^{b}	27.92 ± 1.20^{a}	27.95 ± 1.43^{a}	87.12 ± 0.93^{ab}
	*T*3	57.24 ± 1.35^{c}	2.50 ± 0.30^{a}	28.86 ± 0.83^{a}	28.96 ± 1.19^{a}	85.04 ± 0.95^{b}
	*T*4	60.49 ± 1.42^{c}	0.82 ± 0.12^{c}	26.84 ± 1.69^{a}	26.85 ± 1.08^{a}	88.30 ± 0.95^{a}
3	Ctr	74.57 ± 0.61^{a}	0.95 ± 0.21^{e}	25.10 ± 1.55^{b}	25.11 ± 1.18^{b}	87.83 ± 0.91^{a}
	*T*1	67.33 ± 1.64^{b}	1.09 ± 0.09^{d}	25.61 ± 1.12^{b}	25.63 ± 1.26^{b}	87.56 ± 0.91^{a}
	*T*2	67.70 ± 1.26^{b}	1.74 ± 0.18^{c}	26.79 ± 1.40^{b}	26.84 ± 1.18^{b}	86.28 ± 0.83^{a}
	*T*3	68.87 ± 1.26^{b}	2.61 ± 0.21^{b}	28.37 ± 0.86^{ab}	28.49 ± 0.95^{ab}	84.73 ± 0.78^{b}
	*T*4	68.32 ± 1.69^{b}	3.40 ± 0.27^{a}	30.29 ± 0.85^{a}	30.48 ± 0.89^{a}	83.58 ± 0.85^{b}
7	Ctr	63.26 ± 1.88^{ab}	4.03 ± 0.35^{a}	26.42 ± 1.99^{ab}	26.72 ± 1.25^{ab}	81.31 ± 0.83^{b}
	*T*1	67.54 ± 1.27^{a}	2.55 ± 0.19^{d}	24.24 ± 1.14^{b}	24.37 ± 1.17^{b}	83.99 ± 0.95^{a}
	*T*2	68.80 ± 1.44^{a}	3.98 ± 0.09^{b}	31.41 ± 1.46^{a}	31.72 ± 0.82^{a}	82.77 ± 0.70^{ab}
	*T*3	64.85 ± 1.41^{ab}	4.55 ± 0.35^{a}	34.20 ± 1.03^{a}	34.50 ± 1.25^{a}	82.41 ± 0.95^{ab}
	*T*4	57.28 ± 1.90^{b}	2.76 ± 0.18^{c}	27.19 ± 1.92^{ab}	27.32 ± 0.96^{ab}	84.17 ± 0.76^{a}

Note: Different letters within the columns indicate significant differences ($p < 0.05$) among the different treatments. All measurements were conducted in triplicates.

and the highest chroma$*$ values were recorded for the T3 treatment samples (34.84 ± 1.26), on Day 0. No clear trends were found for the rest of the color parameters $a*$, $b*$, hue$*$. The highest $a*$ values were recorded on Day 7 (57.28 ± 1.90) and the lowest on Day 2 (0.45 ± 0.08), referring to T4 and Ctr samples, respectively. The highest and the lowest parameter $b*$ values were recorded for T3 (38.69 ± 1.75) and Ctr (25.10 ± 1.15) treatments on Day 1 and Day 3, respectively. The highest and the lowest hue$*$ angle values were recorded on Day 0 for sample T3 (89.07 ± 0.59) and Day 3 for control (81.31 ± 0.83). In the literature, it is described that the application of xanthan gum builds a macromolecular network that creates a modified atmosphere between the surface of the zucchini fresh cut slices and the applied coating which delays the absence of O_2 and the appearance of undesirable colors [39]. In addition, recent research has shown that xanthan coating with citric acid decreased color parameters with increasing xanthan gum concentration due to increased oxidation barrier functionality [7].

The WI (%) values of fresh-cut zucchini samples are presented in Figure 5. WI values of zucchini samples showed a decrease during storage time. Ctr and T1 samples had the highest WI values for all days of storage and differed significantly from the other treatments ($p < 0.05$). The highest WI values were recorded on Day 2 and were $66.48\% \pm 2.38\%$ (Ctr) and $64.88\% \pm 2.38\%$ (T1). The lowest WI value recorded was $51.42\% \pm 0.78\%$ (T3), which is significantly different from the other treatments ($p < 0.05$). Also, the highest total color difference (ΔE) values were observed for the T3 treatment samples for all dates tested (Figure 6). The lowest ΔE values were recorded on Day 1, 2.72 ± 0.04 (Ctr) and 3.06 ± 0.07 (T1), respectively. Generally, in our research, the effect of *Crocus sativus* L. extract on the color of fresh-cut zucchini samples varied probably because extracts had the glycoside of crocetin and an uncommon water-soluble carotenoid dicarboxylic acid polyene monosaccharide ester which influence their color [40, 41]. *Crocus sativus* L. extract also has antioxidant activities mainly attributed to its phenolic and flavonoid compounds, and they protect fresh-cut zucchini slices from enzymatic browning caused by polyphenol oxidase (PPO). In addition, the color parameters and color intensity in this research are aslo subjects of the crocin family of *Crocus sativus* L. There are few investigations on the application of *Crocus sativus* L. as a color agent in foods, and it has been used for many decades as an ingredient in dairy products. The color changes in

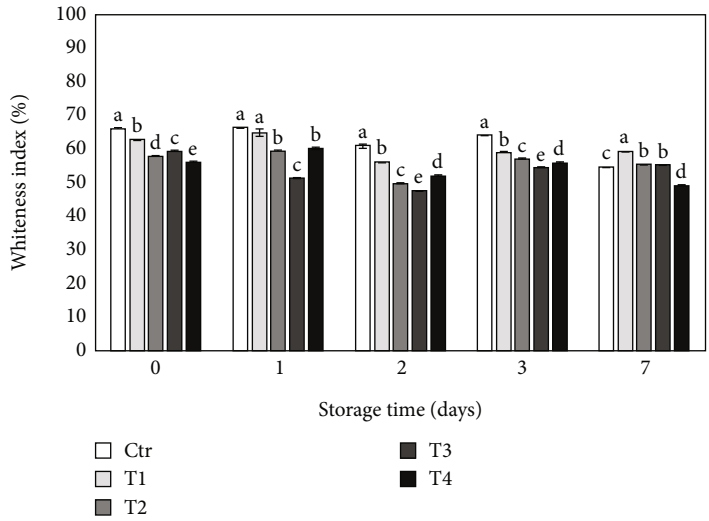


Figure 5: Whiteness index (%) values of fresh-cut zucchini Ctr, T1, T2, T3, and T4 samples during a 7-day storage period at 5°C. Different letters indicate statistically significant differences ($p < 0.05$) among the treatments. All measurements were conducted in triplicates.

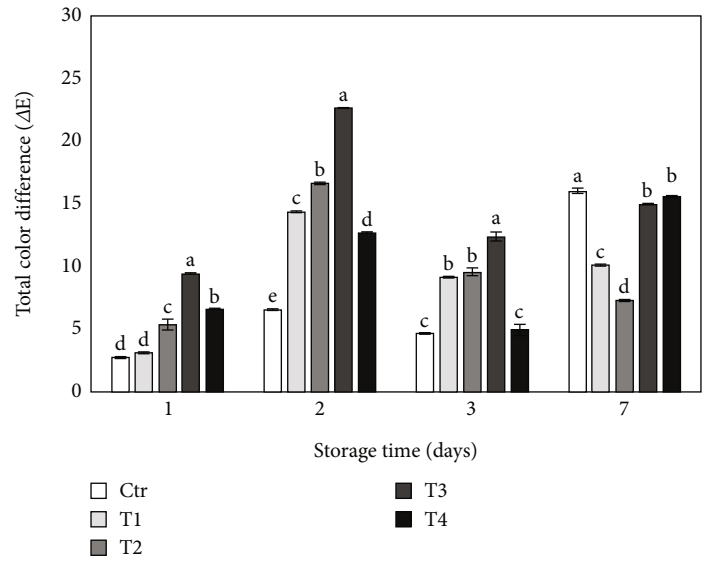
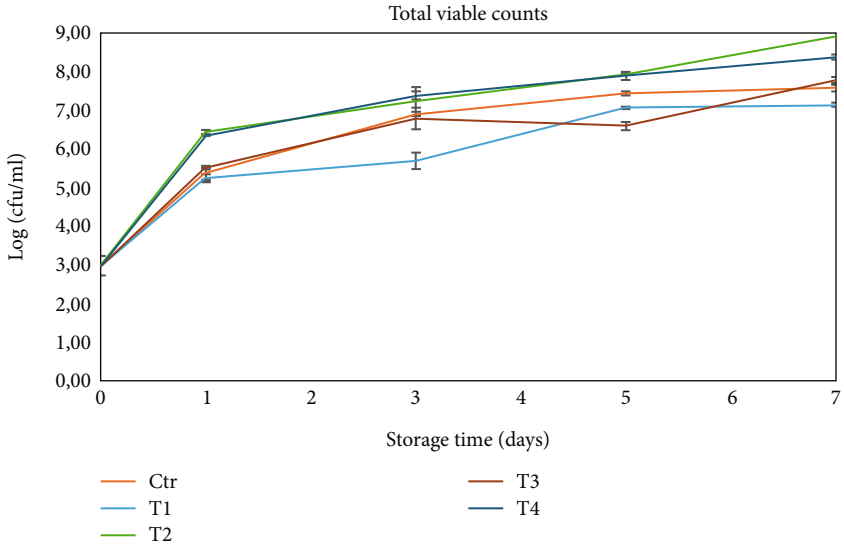


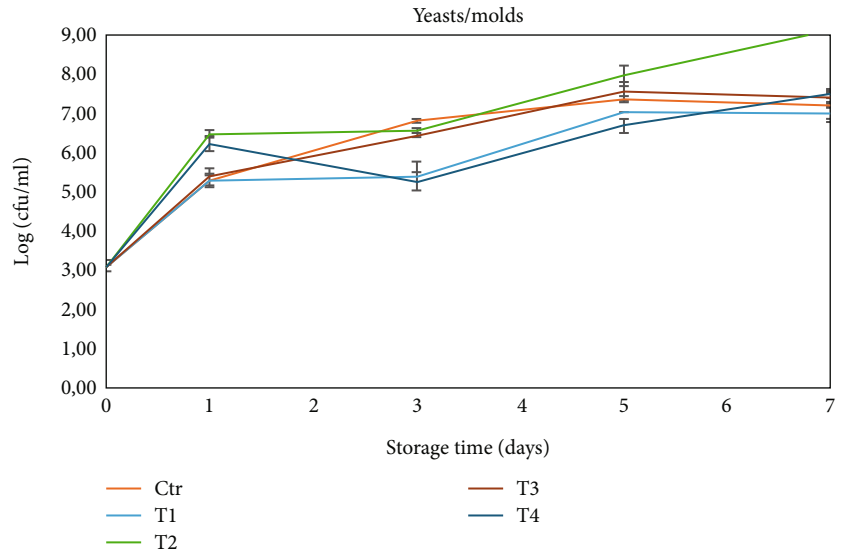
Figure 6: Total color difference (%) values of fresh-cut zucchini samples Ctr, T1, T2, T3, and T4 during a 7-day storage period at 5°C. Different letters indicate statistically significant differences ($p < 0.05$) among the treatments. All measurements were conducted in triplicates.

milk, for example, were found when increasing *Crocus sativus* L. concentrations and milk fat, due to interactions between milk phospholipids with crocetin esters [42]. In our research, we do not have fat as a constituent in our coatings, and the color characteristics of coated fresh-cut zucchini slices during storage at 5°C did not follow any specific trend. Except for the delay of enzymatic browning and oxidation due to the antioxidants, the color of *Crocus sativus* L. in xanthan-based coatings could be changed according to *Crocus sativus* L. concentration. More investigation into the color effect of *Crocus sativus* L. applied on coatings or foods should be conducted in the future. Our results are not similar to other research on coatings that were fortified by common antioxidants.

3.5. Microbiological Analysis. The findings of the microbiological analysis are presented in Figure 7. Results indicated that throughout the storage time, TVC, yeasts and molds, Enterobacteriaceae, and LAB experienced an increased population level with the passage of storage time. A similar growth rate was recorded between the treatments in all studied microbial groups, except for LAB, the population levels of which were significantly higher in xanthan–*Crocus sativus* L. extract coatings (with 0.05 and 0.025% w/w concentration of Crocus Sativus *L.* extract). Indeed, according to previous work, *Crocus sativus* L. enhances the growth of LAB 49 [43] which agrees with the present study. More specifically, the initial levels of TVC were about 2.97 log CFU/g. Samples with xanthan coating seem to preserve TVC stability from



(a)



(b)

Figure 7: Continued.

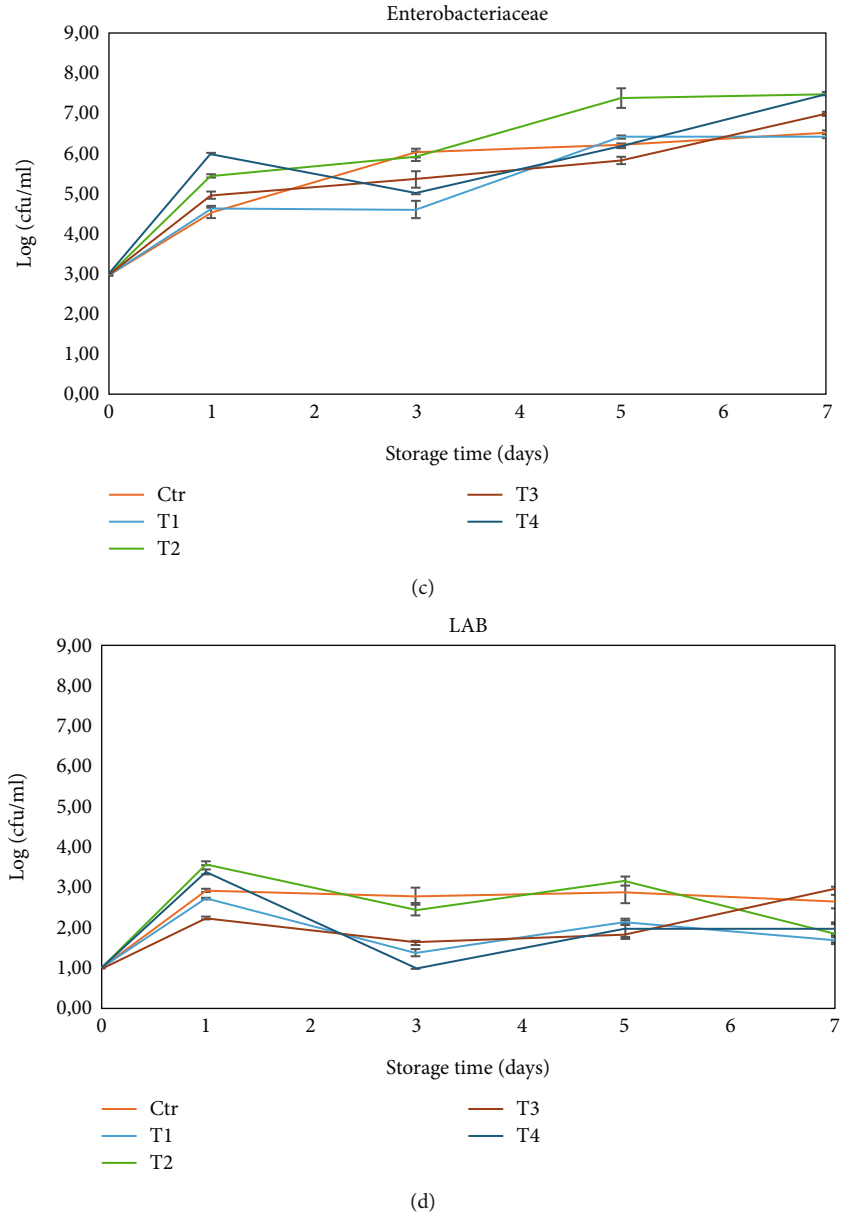


Figure 7: Changes of microbial populations. (a) Total viable counts, (b) yeasts/molds, (c) Enterobacteriaceae, and (d) LAB on fresh-cut zucchini samples Ctr, T1, T2, T3, and T4 during a 7-day storage period at 5°C. Each point is the mean of three replicates ± standard deviation.

Day 1 to Day 3 at 5.2–5.6 log CFU/g, while from Day 5 to Day 7 increased to 7 log CFU/g. Regarding yeasts and molds, zucchini slices with xanthan coating remained stable from Day 1 to Day 3 at 5.3 log CFU/g, but from Day 5 to Day 7 raised at 7 log CFU/mL. Zucchini slices with xanthan coating incorporated with 0.005 *Crocus sativus* L. showed a slight decrease from Day 1 to Day 3, from 6.2 to 5.2 log CFU/g on yeasts and molds and the same with Enterobacteriaceae from 5.9 to 5 log CFU/g. LAB seems to have a variable population during storage with decreased and increased values every 2 days as depicted in the graph (Figure 7). As results indicated, there is no specific differentiation in microbial population during storage among the different treatments. This is because xanthan and *Crocus sativus* L. do not show any antimicrobial properties against the indigenous bacteria of sliced zucchinis; nevertheless, *Crocus sativus* L. exhibits antimicrobial activity against *Listeria* spp., *Pseudomonas* spp., and *E. coli* [44, 45].

4. Conclusions

The application of edible-biodegradable coatings on fresh-cut fruits and vegetables is of great importance to store them maintain their quality properties and extend their shelf life. This novel research was designed to investigate the possible protection of the fresh-cut zucchini slices stored at 5°C for 7 days by xanthan coating fortified with *Crocus sativus* L. extracts which are known for their bioactive compounds.

Coating of xanthan with the highest concentration of the *Crocus sativus* L. extract maintains firmness in similar levels with the fresh-cut zucchini at Day 0 during storage. Although *Crocus sativus* L. exhibits antimicrobial activity against *Listeria* spp., *Pseudomonas* spp., and *E. coli* in our research, xanthan and *Crocus sativus* L. do not show any antimicrobial properties against the indigenous bacteria of sliced zucchinis. All the coatings decrease zucchini weight loss during 7 days of cold storage compared to fresh-cut uncoating samples. Also, the effect of xanthan–*Crocus sativus* L. coatings on fresh-cut zucchini slices showed low values of TSS during cold storage and indicated a delay in the maturation process. This research enriches the knowledge of the fortification of biopolymer coatings with plant extracts and the development of fresh-cut coated zucchini slices with increased quality characteristics during cold storage.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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