coatings

MDPI

Article

Extending the Shelf-Life of Nectarines through Fish Gelatin/Cellulose Nanocrystals/Cinnamon Essential Oil-Based Edible Coatings

Reza Akbari [1], Javad Tarighi [1,*], Mahsa Sadat Razavi [1], Mohammad Tahmasebi [1], Daniele Carullo [2] and Stefano Farris [2,*]

[1] Department of Biosystem Engineering, University of Mohaghegh Ardabili, Ardabil 56199-11367, Iran; r.akbari@uma.ac.ir (R.A.); mahsarazavi.68@gmail.com (M.S.R.); m.tahmasebi@uma.ac.ir (M.T.)
[2] Food Packaging Laboratory, Department of Food, Environmental and Nutritional Sciences (DeFENS), University of Milan, Via Celoria 2, 20133 Milan, Italy; daniele.carullo@unimi.it
* Correspondence: tarighi@uma.ac.ir (J.T.); stefano.farris@unimi.it (S.F.); Tel.: +98-04515517500 (J.T.); +39-0250316805 (S.F.); Fax: +98-04515520567 (J.T.); +39-0250316672 (S.F.)

Abstract: The effect of bacterial cellulose nanocrystal–fish gelatin/cinnamon essential oil (BCNCs–FGelA/CEO) nanocoatings containing different concentrations of essential oil (1.2, 1.8, and 2.4 mL/L) on reducing the ripening and aging processes of '*Red Gold*' nectarine fruit during cold storage (60 days, 4 °C) was studied. As a general trend, the application of the coating delayed the ripening process, and increasing the concentration of essential oil was effective in improving the coating efficacy. After 60 days, the lowest values of weight loss (6.93%), peroxidase and polyphenol oxidase activity (11.49 and 0.48 abs min^{-1} g^{-1}, respectively), soluble solid content (14.56%), and pH (4.17) were detected for samples covered with the BCNCs–FGelA coatings containing the highest tested CEO concentration, whereas the maximum values of the same parameters (20.68%, 18.74 and 0.76 abs min^{-1} g^{-1}, 17.93%, and 4.39, respectively) were found in the uncoated samples. In addition, increasing the concentration of the essential oil resulted in a better preservation of the firmness, ascorbic acid, and total acidity of the samples. Finally, the respiration rate and ethylene production of coated samples were lower than those detected in uncoated samples, though some differences arose depending on the amount of CEO loaded in the coatings. This study showed the capability of BCNCs–FGelA/CEO coatings to increase the cold storage period and preserve the quality of '*Red Gold*' nectarine fruit, thereby reducing losses and increasing economic efficiency in the fruit industry.

Keywords: chemical analysis; coating; ethylene; nectarine; respiration rate; shelf life

Citation: Akbari, R.; Tarighi, J.; Razavi, M.S.; Tahmasebi, M.; Carullo, D.; Farris, S. Extending the Shelf-Life of Nectarines through Fish Gelatin/Cellulose Nanocrystals/Cinnamon Essential Oil-Based Edible Coatings. *Coatings* **2024**, *14*, 736. https://doi.org/10.3390/coatings14060736

Academic Editors: Domingo Martínez-Romero, Huertas María Díaz-Mula and Juan Miguel Valverde

Received: 16 April 2024
Revised: 4 June 2024
Accepted: 6 June 2024
Published: 8 June 2024

1. Introduction

Nectarines (*Prunus persica* (L.) Batsch, var. *nucipersica* or *nectarina*) are a type of peach that differs from most of the commonly known varieties due to their smooth skin and sweeter taste, which represent the two distinctive attributes of their commercial success. As in most climacteric fruits, as well as in nectarines, ripening is associated with tissue softening, an increase in sugar–acid ratio, respiratory and enzymatic activities, and ethylene production. Nectarines, with their high metabolic activity and juicy flesh, are highly susceptible to spoilage. They typically last just 3–4 days at room temperature and 15–18 days under cold storage [1]. Quality loss in nectarines after harvest is primarily due to cell membrane breakdown [2] and fungal diseases like *Rhizopus* rot, *Penicillium* rot, or brown rot [3,4]. To address the issue related to such a limited shelf life, various methods exist, namely sub-zero temperature preservation, modified atmosphere packaging, and edible coatings, or a combination thereof. For instance, Zhao et al. [5] investigated the use of a near-freezing temperature (NFT) for storing nectarines and its impact on fruit quality. They identified a crucial aspect of NFT storage, that is, precise temperature control. Since NFT is

very close to the biological freezing point of the fruit, even minor temperature fluctuations can cause freezing injury. This necessitates a highly stable and controlled temperature environment for successful NFT storage of fresh produce. Additionally, optimal NFT storage temperatures may vary among different fruits and vegetables, thus potentially limiting the feasibility of storing a variety of items within the same refrigerator. Consequently, NFT storage often requires specialized equipment that might not be readily available or cost-effective everywhere.

Among all the above-mentioned techniques, edible coatings have recently gained popularity both at the academic and industrial levels. These coatings offer a wide range of benefits, such as improved appearance, extended shelf life, and maintained quality of fruit during storage [6,7]. As an eco-friendly technology, coatings achieve these desirable effects by regulating moisture loss, gas exchange, and oxidation processes [8]. Additionally, edible coatings create a modified atmosphere around the fruit by influencing its internal gas composition [8,9]. This has led researchers to explore various types of edible coatings for extending the shelf life of fruits. Over the years, covering the surface of fruits with bio-polymeric coatings (e.g., made of proteins, polysaccharides, lipids, or a combination thereof) has been proven as a viable strategy to reduce the rate of respiration and moisture loss, thereby slowing down the ripening and senescence processes of the product while maintaining its sensory properties. In addition, loading the coating formulations with bioactive compounds such as extracts and essential oils (EOs) from plants provides the final coatings with antimicrobial properties [10,11]. EOs have natural antimicrobial properties but are volatile and light-sensitive, which limits their use in food preservation [12,13]. Encapsulation offers a solution by improving EO stability [14,15]. Pickering emulsions use solid nanoparticles to stabilize oil–water interfaces, offering long-lasting protection against droplet merging [16,17]. Various particle shapes, including spheres, rods, and plates, have been successfully employed [18,19]. Gelatin, particularly from fish sources, is gaining attention in the food industry due to its excellent stabilizing and emulsifying properties, along with religious dietary considerations and safety concerns regarding mammalian sources [20,21]. Cellulose nanomaterials (CNFs and CNCs) are promising for emulsions due to their intrinsic properties such as excellent mechanical, thermal, and gas-barrier properties, high aspect ratio, and good wet stability [18]. Their amphiphilicity suggests the potential for both polar and hydrophobic interactions [22,23]. This property may facilitate the encapsulation of the hydrophobic oil phase with the hydrophilic gelatin phase while reinforcing the matrix of brittle gelatin. Conventional wood-based cellulose extraction harms the environment. Extracting cellulose nanofibers using Acetobacter xylinum bacteria offers a sustainable alternative. Excellent properties like high purity and biocompatibility make bacterial cellulose nanofibers promising for various applications [24]. Prior research showed that bacterial cellulose nanocrystals (BCNCs) can effectively emulsify various oils (olive, sunflower, peppermint, palm, canola, etc.) and other substances (essential oils) within Pickering emulsions [25–30]. Several studies have been conducted to investigate the effect of different coating formulations to preserve the quality of the nectarines during storage. For example, coatings made of zein and containing nisin [31], coatings made of carboxy-methyl cellulose and Arabic gum [32,33], eugenol-based nanocapsule coatings based on chitosan and carboxymethyl cellulose [34], multilayer coatings of chitosan and carboxymethyl cellulose, alone and in combination with marigold, moringa, and eucalyptus extracts [35,36], and coatings prepared using sodium chloride and salicylic acid [37] were successfully developed.

Interestingly, in all the above studies, the quality preservation of nectarines was pursued through the incorporation of bioactive compounds in the main biopolymer network, which was finally used in the form of emulsions, nanoemulsions, or nanocapsules to obtain the following outcomes: (i) to achieve the controlled release of the active ingredient over time, (ii) maintain the stability of the active substance against external factors (e.g., light and oxygen), and (iii) reduce its sensory impact on the taste and aroma of the fruits [11]. However, it has been demonstrated that the stability of these emulsions is a key aspect

for these systems to work efficiently [38]. In our previous studies, we developed bacterial cellulose nanocrystals (BCNCs)–cinnamon essential oil Pickering emulsions stabilized with fish gelatin [38–40]. We demonstrated the key role of BCNCs in stabilizing the emulsion by preventing the coalescence phenomena, which was then reflected in the coating stability in terms of physical, mechanical, and chemical properties. Although the positive effect of CNCs as a coating to increase the shelf life of various food products has been widely demonstrated [41–47], their use on fruits is very new and only a few studies have been conducted in this field, especially for nectarines. It might be because of BCNCs' drawbacks in scaled-up production which is time-consuming and not preferred economically. But in a very recent article by Rahmadiawan et al. [24], this problem was partially resolved by producing BCNCs as a powder to be used in different areas and fields, specifically food packaging applications.

Therefore, in this research, the effect of the BCNCs–fish gelatin/cinnamon essential oil coating on the qualitative properties of nectarines from the "*Red Gold*" cultivar during storage was investigated. For this purpose, various quality parameters such as weight loss, tissue firmness, respiration rate, ethylene production, total acidity, ascorbic acid, pH, soluble solid content, peroxidase, and polyphenol oxidase enzyme activities, as well as sensory evaluation during 60 days of cold storage were considered.

2. Materials and Methods

2.1. Raw Materials and Chemicals

'*Red Gold*' nectarine fruits in the commercial ripening stage (70% skin color change) were harvested manually from a local garden in Pars Abad city (Ardabil province, northwest of Iran). Undamaged fruits of similar size were transferred to the laboratory and kept at a temperature of 4 ± 1 °C until being tested. All the chemicals used in this research for the preparation of the coating and for conducting quality chemical tests were similar to those reported in our previous research works [11,38–40,48]. The study utilized several commercially available materials. Type A fish gelatin (extracted by acid pretreatment, Kosher and Halal certified), with a gel strength of 200 Bloom, was obtained from Weishardt (Graulhet, France). The cinnamon bark essential oil (CEO, including E-cinnamaldehyde: 70.6%; E-cinnamyl acetate: 5.3%; β-caryophyllene: 5.1%; linalool: 4.2%; eugenol: 3.7%; 1,8-cineole + β-phellandrene: 1.2% by GC-MS) came from Plant Therapy Essential Oils Corporate (Twin Falls, ID, USA). Bacterial cellulose (BC) was produced through static fermentation using the bacteria *Komagataeibacter sucrofermentans* DSM 15973 (sourced from Leibniz Institute DSMZ—German Collection of Microorganisms and Cell Cultures, Braunschweig Germany), following a previously established procedure [49]. Finally, ethanol (96 *v*/*v* %), sulfuric acid (99 *v*/*v* %), and dialysis tubing (cellulose membrane, 12 kDa, average flat width 43 mm) were purchased from Sigma-Aldrich-Merck (Milan, Italy). Monosodium phosphate (NaH_2PO_4), disodium phosphate (Na_2HPO_4), polyvinylpolypyrrolidone (PVPP), Triton X-100, catechol, p-phenylenediamine, hydrogen peroxide (H_2O_2), and potassium iodate (KIO_3) were all obtained from Merck (Darmstadt, Germany). Separately, potassium iodide (KI), starch, hydrochloric acid (HCl), sodium hydroxide (NaOH), and phenolphthalein were purchased from Mojallali (Dr. Mojallali Industrial Chemical Complex Co., Tehran, Iran).

2.2. BCNCs Preparation

To obtain bacterial cellulose nanocrystals (BCNCs), an acid hydrolysis process was employed [49]. First, 0.914 g of dry BC was mixed with 6.226 g of distilled water and 100 g of a 50% (*w*/*w*) sulfuric acid solution. To ensure even distribution, the mixture was homogenized using a DI 25 basic homogenizer (Ika-Werke GmbH & Co., Stanfen, Germany) for 3 min at 9500 rpm. The actual hydrolysis involved stirring the mixture at 55 °C for 2 h at 800 rpm. Subsequently, the suspension was centrifuged at 8000 rpm for 50 min to remove excess sulfuric acid. The supernatant was discarded, and the remaining solid was re-dispersed in fresh distilled water. This washing step was repeated five times. Finally, the

suspension was transferred to dialysis tubes submerged in distilled water within a beaker. The dialysis water was changed every 4 h until the pH of the BCNC dispersions reached 5. To achieve complete dispersion of the nanocrystals, the final BCNC aqueous suspensions were ultrasonicated for 5 min using a UP 200 St ultrasonicator (200 W, 26 kHz–Hielscher, Teltow, Germany) equipped with a titanium sonotrode (S26d7D, surface area 42 mm^2) set at approximately 20 W power (25% pulse and 30% amplitude). The final BCNC suspension has been already characterized in terms of average size (length, nm), PDI, and ξ-potential (mV) in our previously published research [38], and the results are summarized as follows: length = 322.08 ± 30.0 nm, PDI = 0.340 ± 0.117, and ξ-potential = −27.72 ± 0.16 mV.

2.3. Coating Preparation

A schematic diagram of materials used, and the coating preparation procedure, is reported in Figure S1 of the Supplementary Material. First, three separate BCNC (0.4% *w*/*w*) suspensions were prepared in falcon tubes. Second, 0.6, 0.9, and 1.2 mL of cinnamon essential oil were added to each of them, followed by a dropwise addition of gelatin solution (a mixture of 8.5 g distilled water with 4.5 g of a 10% *w*/*w* fish gelatin stock solution), such that the three different emulsion coating formulations contained 3% *w*/*w* gelatin, 0.06% *w*/*w* BCNCs, and 1.2, 1.8, and 2.4 mL/L essential oil, respectively were obtained [38]. A TEM (transmission electron microscopy) image of the final coating emulsion is provided to demonstrate the morphology of the BCNC-stabilized CEO Pickering emulsion (e.g., size and droplet coverage) (Figure S2 of the Supplementary Material).

2.4. Coating Application on the Fruit Samples

Fruits with uniform size and without any sign of mechanical damage or fungal rot were washed and then disinfected with sodium hypochlorite solution (0.05% *w*/*w*) for 1 min and dried under ambient conditions. Coating application was carried out by dipping, that is, the nectarines were immersed in the coating solutions containing CEO at 1.2, 1.8, and 2.4 mL/L. The immersion of the fruits into the coating emulsions lasted 15 s at ambient temperature. Finally, the four samples coded as C0, C1.2, C1.8, and C2.4 were divided into four parcels of 24 specimens each. Coated nectarines were placed under a chemical hood and at ambient temperature for 12 h to allow the structuration of the coating by partial water evaporation. Also, uncoated nectarines were used as control samples. Nectarines were then put into a plastic basket with nectarine trays, packed in traditional packing papers, and kept under controlled conditions (4 ± 0.5 °C, 80%–85% RH) for up to 60 days. Physical and chemical measurements were carried out at the beginning of the investigation (time 0) and after 20, 40, and 60 days of storage.

2.5. Physical and Chemical Tests

2.5.1. Weight Loss (WL%)

To determine the weight loss, the samples were weighed at the beginning of the experiment and during the storage period using a digital scale (GF-600, A&D Weighing, Tokyo, Japan) with an accuracy of 0.0001 g. Weight loss (Equation (1)) was calculated based on the percentage of initial weight using five replicates [50]:

$$WL\ (\%) = (W_i - W_t)/W_i \times 100 \quad (1)$$

where W_i and W_t are the initial weight of the fruit and the weight at each specific sampling time over the 60 days storage time, respectively.

2.5.2. Firmness

This test was performed using a fruit firmness device (STEP SYSTEM, Nürnberg, Germany) mounting a steel rod with a standard diameter of 8 mm. The force corresponding to the maximum penetration value (penetration force) of up to a depth of 5 mm was considered as a firmness index. Experiments were performed on 6 replicates for each treatment [51].

2.5.3. Soluble Solids Content (SSC), pH, Total Acidity (TA), and Ascorbic Acid (AA)

For each treatment and for each storage time, the chemical parameters of the nectarines were measured using the juice obtained from several fruits. SSC (%) was measured by a scaled optical refractometer (RHB-32/ATC, Brix 0%–32%, 0.2% accuracy; Hong Kong, China), whereas the pH of fruit juice was assessed using a digital pH meter (Metrohm-827, Zofingen, Switzerland) at ambient temperature. TA was determined by a titrimetric method as a malic acid equivalent, starting from the amount of NaOH consumed in the titration. For this purpose, 5 mL of fruit juice and 1 mL of phenolphthalein (10 g L^{-1}) were first mixed. Distilled water was then added up to a total volume of 200 mL. At this point, NaOH 0.1 N was added dropwise to the solution until a pH = 8.2 was reached and the color of the solution turned pink. The amount of titratable acidity was calculated according to the malic acid (fruit main acid) and according to Equation (2):

$$TA = (mL_{NAOH} \times N_{NAOH} \times acidmeq.factor)/mL_{juice} \times 100 \quad (2)$$

where TA is the titratable acidity (%), mL_{NaOH} is the consumed volume of sodium hydroxide (mL), N_{NaOH} is the molarity of the consumed sodium hydroxide (N) and equivalent to 0.1 N, acidmeq.factor is the fruit main acid factor (malic acid) of 0.067 g/moleq, and mL_{juice} is the volume of the used fruit juice [52].

Ascorbic acid content was quantified through a titration method using potassium iodate (KIO_3). For this purpose, 20 mL of fruit juice, starch 0.5% (*w*/*w*), 5 mL of HCl 1 M, and 5 mL potassium iodide (KI) 0.006 M were added to distilled water to a total volume of 200 mL. The titration was performed using KIO_3 (0.002 M) and continued until the blue color was revealed, and then the amount of ascorbic acid (AA) was calculated based on Equation (3):

$$AA = 5/(2836 \times V \times 1000) \quad (3)$$

where AA is the amount of ascorbic acid obtained per 100 g of fruit juice (mg) and V is the volume of consumed potassium iodates (µL) [53].

2.5.4. Respiration Rate and Ethylene Production

Respiration rate (as CO_2 is produced) and ethylene evolution were monitored using a gas analysis device (Oxybaby 6, Witt, Witten, Germany) and a GC-MS (Agilent 7890A, Santa Clara, CA, USA), respectively [11]. At least 3 replicates were considered for each test.

2.5.5. Peroxidase (POD) and Polyphenol Oxidase (PPO) Enzyme Activity

For the POD enzyme, the enzyme extract was obtained from the fruit tissue using a sodium phosphate buffer (0.4 M). The enzyme extraction solution was then prepared by the addition of polyvinylpyrrolidone (PVP) 4% (*w*/*v*) and Triton-X 1% (*v*/*v*) to the sodium phosphate buffer 0.2 M. Finally, 10 g of fruit tissue, after homogenization, was mixed with 20 g of enzyme extraction solution, which was then centrifuged at 7500 rcf and 4 °C for 10 min (Lisa, Château-Gontier, France). The supernatant was separated and used to measure enzymatic activity. Experiments were performed in triplicate.

For the PPO enzyme, 75 µL of supernatant was mixed with 3 mL sodium phosphate buffer 0.05 M, containing catechol 0.07 M. A similar method was used for the control, except for the enzyme extraction solution that was replaced by distilled water. The absorbance kinetic was measured at 420 nm wavelength for 10 min by spectrophotometry (Nanodrop One C, Thermo Scientific, Waltham, MA, USA) at ambient temperature. Finally, the enzymatic activity was determined based on adsorption changes per minute per gram of the sample [54,55].

2.5.6. Sensory Test

At the end of the storage period, the taste, odor, firmness, color, and overall quality of the samples were evaluated by twelve experienced fruit tasters with a nine-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely) [56,57]. Each

sample was washed with purified water before being presented to the panelists. The experiment was replicated four times, with the order of samples randomized to avoid bias.

2.6. Statistical Analysis

All analyses were conducted at least three times unless otherwise specified. The mean values and standard deviations of the experimental data were calculated. Statistically significant differences among the averages were evaluated using a one-way analysis of variance and Tukey's test ($p \leq 0.01$). Statistical analysis was conducted using Minitab 18 (Coventry, UK) software.

3. Results and Discussion

3.1. Weight Loss (WL%)

Weight loss changes over time are shown in Figure 1a. Both time and CEO concentration significantly influenced WL ($p < 0.01$). In particular, WL increased with storage time because of two effects that include the more intense metabolism of the fruit (e.g., respiration and perspiration) and the higher activity of microorganisms. Conversely, the presence of the coating mitigated WL in a proportional way to the CEO concentration.

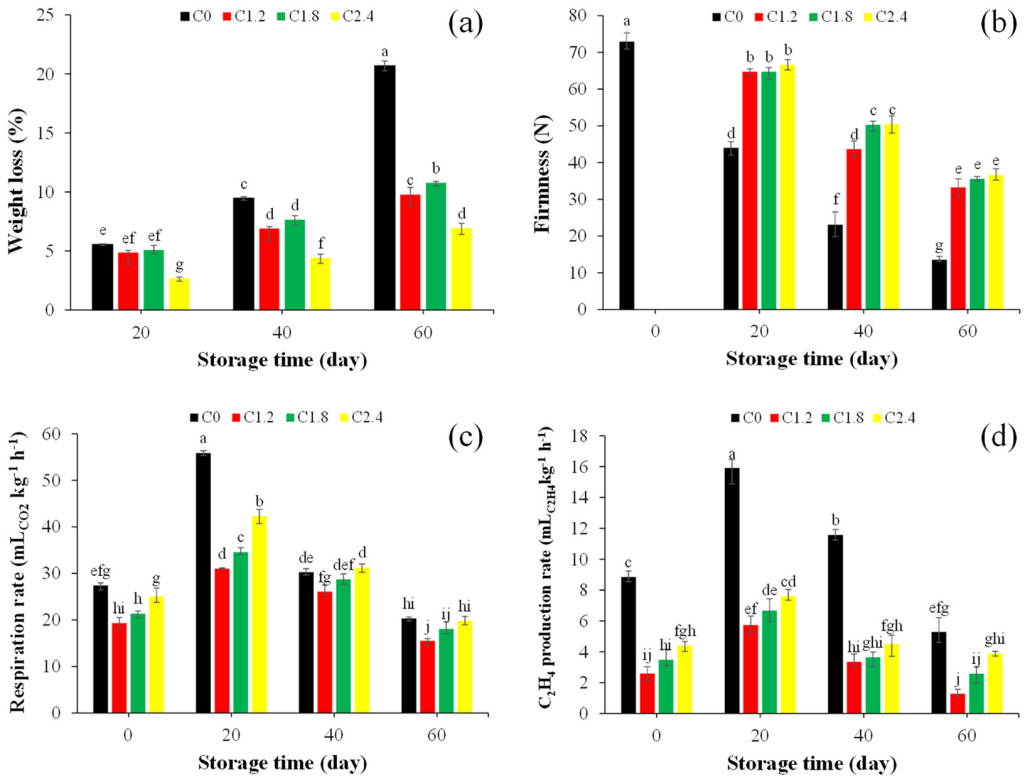

Figure 1. Values of (**a**) weight loss, (**b**) tissue firmness, (**c**) respiration rate, and (**d**) ethylene production rate of untreated (control) and coated (CEO concentration = 1.2–2.4 mL/L) '*Red Gold*' nectarine fruits during 60 days of cold storage (4 °C). Different letters above the bars denote significant ($p < 0.01$) differences among mean values.

The positive effect of the coating can be explained by considering its capability of preventing water evaporation from the product's tissue to the surrounding environment. This effect was clearly emphasized by increasing CEO concentration, which could be due to the hydrophobicity of CEO and its repellency against water molecules. These results are in line with those earlier reported for nectarine using salicylic acid and calcium chloride coatings [37], carboxymethylcellulose and Arabic gum [32,33], carboxymethylcellulose and chitosan, alone and in combination with the marigold, moringa, and eucalyptus extracts [35]. Studies by Sowmyashree et al. [35] and Abdi et al. [58] demonstrated the

effectiveness of layer-by-layer coatings and beeswax coatings, respectively, in preserving nectarines during cold storage. These coatings significantly minimized moisture loss and water diffusion between the fruit and the surrounding environment. Additionally, the studies revealed a slower ripening process in coated fruits compared to uncoated controls. Interestingly, Abdi et al. [58] observed that waxing nectarines for storage at ambient temperature might not be as effective in preventing moisture loss as cold storage with waxing. This suggests that ambient temperature may influence the moisture content of the wax, thus hindering its ability to create a robust moisture barrier on the fruit's surface.

3.2. Tissue Firmness

When purchasing fruits, physical attributes such as firmness and appeal are important deciding factors. Firmness is one of those parameters that consumers look forward to when buying any kind of fruit, as in the case of nectarines. Tissue firmness decreased during the storage time for all the samples (Figure 1b). The radicals formed by aerobic respiration (such as superoxide and nitric oxide) weaken the cell wall and make the pectin accessible to pectinase, which eventually causes firmness reduction [59]. The presence of the coating on the fruit surface prevented the fruit from microbial spoilage due to a reduction in the respiration rate, which was more evident when the highest amount of CEO loaded in the formulation was employed. In turn, this translated into a higher firmness of the fruit tissue, in agreement with those obtained by other researchers using marigold, moringa, and eucalyptus extracts in coatings made of carboxymethylcellulose and chitosan [35,36], carboxymethylcellulose and Arabic gum at a specific concentration [32,33] on nectarine fruits.

3.3. Respiration Rate and Ethylene Production

The respiration rate for all samples increased after 20 days of storage (Figure 1c), thereby indicating the product ripening caused by the intense physiological activities during this time window. Afterward, and up to the 60th day of monitoring, the rate of respiration decreased. The same trend was also observed for ethylene production (Figure 1d). For climacteric fruits, such as nectarine, before the peak of climacteric (pre-climacteric), there is a sharp increase in ethylene production due to physiological and biochemical changes that are responsible for the transition from the ripening to the senescence of the fruit. According to these results, the ripening process of the fruit occurred until the 20th day of storage, after which the senescence phase and subsequent fruit deterioration took place. As far as the coated samples are concerned, it was observed that the application of the coating led to a reduction in both respiration rate and ethylene production as compared to the non-coated samples. This is plausibly explained in terms of the effectiveness of the applied coating in relenting some physiological phenomena such as respiration, as the coating is able to control O_2 permeation [39]. The fact that both respiration rate and ethylene production increased with CEO concentration can be explained considering that the CEO acts as a plasticizer and the gas permeability generally increases proportionally to the concentration of plasticizers. This phenomenon can be attributed to the increase in the intermolecular volume within the main phase of the coating caused by the increase in CEO concentration [11].

3.4. Soluble Solids Content (SSC), pH, Total Acidity (TA), and Ascorbic acid (AA)

Changes in soluble solids, pH, titratable acidity, and ascorbic acid of nectarines are displayed in Figure 2, whereas the ratio of SSC/TA is provided in Table 1. The overall comparison revealed that with increasing storage time, SSC (Figure 2a) and pH (Figure 2b) increased, whereas TA (Figure 2c) and ascorbic acid (Figure 2d) decreased. Concerning SSC, this value naturally increases during storage and physiological maturity of the fruit due to the activity of the sucrose phosphate synthase (SPS) enzymes, which convert starch to simple sugars such as glucose phosphate [60]. Decreasing TA and increasing pH are due to the consumption of organic acids during the respiration process [61]. Some reports suggest that TA decreases as SSC levels increase in fruits. Also, substrate consumption

through respiration or microorganism activity leads to changes in TA [62]. Finally, the decrease in the ascorbic acid concentration during storage was also expected, considering that it is strongly affected by phenolase enzymes, temperature, light, oxygen, and pH [63]. Interestingly, the presence of the coating seemed to slow down the changes in SSC, pH, TA, and AA as described before. Again, the positive effect of the BCNCs–FGelA/CEO coating can be ascribed to the coating's capability to act as a barrier against gases and vapors. In particular, the BCNCs–FGelA/CEO coating reduced the oxygen gas transmission, which first explains the less intense ascorbic acid oxidation during storage. At the same time, a lower permeation of oxygen led to a less intense degradation of organic acids as a consequence of a slowed down respiration rate and, in turn, delayed ripening of nectarines [35,64,65].

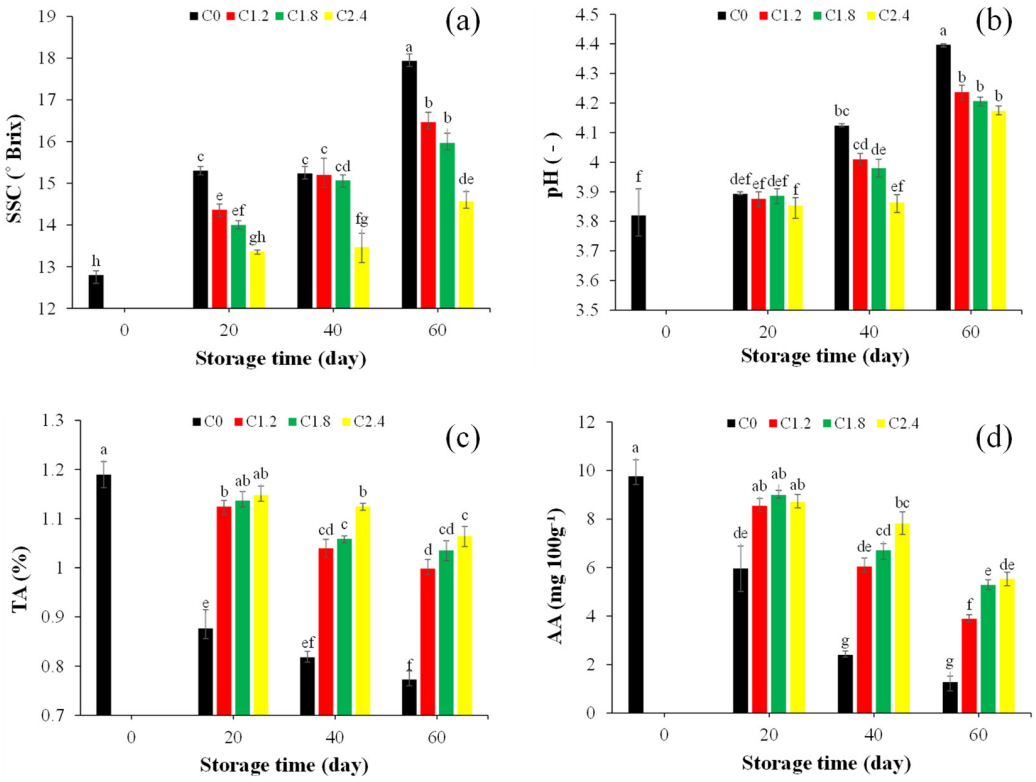

Figure 2. Values of (**a**) soluble solids content (SSC), (**b**) pH, (**c**) total acidity (TA), and (**d**) ascorbic acid of untreated (control) and coated (CEO concentration = 1.2–2.4 mL/L) '*Red Gold*' nectarine fruits during 60 days of cold storage (4 °C). Different letters above the bars denote significant ($p < 0.01$) differences among mean values.

Table 1. The SSC/TA ratio of untreated (control) and coated (CEO concentration = 1.2–2.4 mL/L) '*Red Gold*' nectarine fruits during 60 days of cold storage (4 °C). Different lowercase letters above mean values denote significant ($p < 0.01$) differences among samples.

Sample	SSC/TA Ratio			
	Day 0	Day 20	Day 40	Day 60
C0	10.76 ± 0.13^{i}	17.45 ± 0.74^{c}	18.62 ± 0.38^{b}	23.21 ± 0.27^{a}
C1.2		12.77 ± 0.03^{fg}	14.62 ± 0.60^{de}	16.49 ± 0.46^{c}
C1.8		12.32 ± 0.12^{gh}	14.23 ± 0.21^{e}	15.42 ± 0.14^{d}
C2.4		11.64 ± 0.02^{hi}	11.97 ± 0.43^{gh}	13.68 ± 0.34^{ef}

3.5. POD and PPO Enzyme Activity

The activity of the POD enzyme increased over the 60 days in cold storage for all treatments (Figure 3a). However, this increasing trend was mitigated and less intense for coated samples, in a proportional way to the CEO concentration. In the case of the PPO enzyme, a first increase was followed by a decrease within the coated nectarines (Figure 3b).

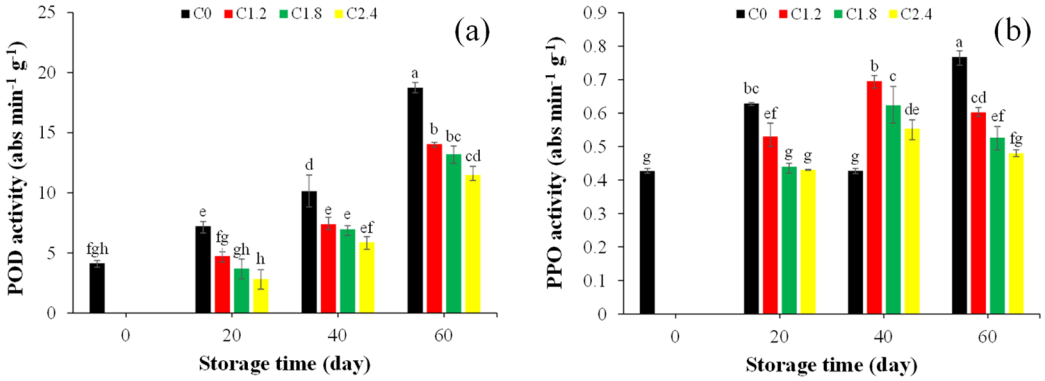

Figure 3. Values of (**a**) POD activity, and (**b**) PPO activity of untreated (control) and coated (CEO concentration = 1.2–2.4 mL/L) '*Red Gold*' nectarine fruits during 60 days of cold storage (4 °C). Different letters above the bars denote significant ($p < 0.01$) differences among mean values.

Figure 1c shows that the respiration rate initially increases and then decreases. This trend can influence the POD-driven process, which relies on oxygen. Since respiration also consumes oxygen, it can indirectly affect the POD enzyme's ability to counteract browning caused by phenolic compounds in the fruit. This competition for oxygen ultimately leads to the formation of brown pigments within the fruit tissue. Also, considering the findings of the previous section and knowing that the amount of ascorbic acid is effective in controlling the tissue browning caused by PPO enzyme activity, it was expected that PPO amount increases in proportion to ascorbic acid reduction over time. However, an increasing and then decreasing trend was observed for PPO, which can be the result of the combination of an increase in the respiration rate and the concentration of ascorbic acid, which may be less effective at certain concentrations. It should also be considered that besides ascorbic acid, CEO is an antioxidant compound. This means that an increase in CEO concentration is expected to lead to a decrease in enzyme activity, which is affected by the amount of antioxidant compounds [66–68].

3.6. Sensory Evaluation

The result of the panel test is shown in Figure 4. According to the results, the application of the BCNCs–FGelA/CEO coating significantly affected the sensory properties of nectarines including color, firmness, odor, taste, and overall acceptance. Interestingly, the score increased by increasing the CEO concentration, thus indicating the best fruit quality perception for the C2.4 treatment. It is interesting to note that, according to the consumer panel, the concentration of 2.4 mL/L had no negative impact on the odor and taste of nectarines. Our previous research [38] showed a positive correlation between CEO concentration and encapsulation efficiency (EE) within the emulsion matrix. This suggests that higher CEO concentrations might impact its volatility and odor dispersion, potentially explaining the lower consumer panel scores at lower CEO levels. Furthermore, findings from earlier sections indicate that higher CEO concentrations are associated with desirable sensory attributes, including lower weight loss (WL) and soluble solids content (SSC), higher firmness, and increased titratable acidity (TA). These factors directly contribute to taste and odor perception by influencing sweetness/sourness and tissue texture [69–71]. Abdi et al. [58] reported that coated nectarines obtained higher scores (nearly three times more than control samples) for all the sensory attributes of flavor, sourness, appearance, taste, texture, and overall acceptance as compared to the untreated counterpart.

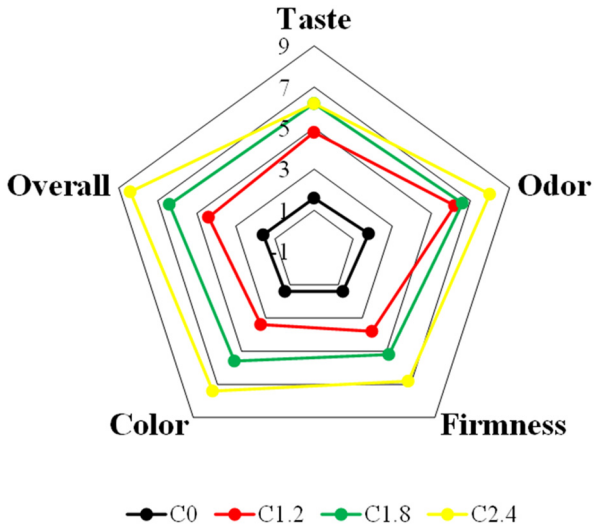

Figure 4. Radar plots showing the effect of BCNCs–FGelA/CEO coatings loaded with different CEO concentrations (1.2–2.4 mL/L) on the sensory characteristics of '*Red Gold*' Nectarine after 60 days of cold storage at 4 °C. Numbers indicate the average score attributed by panelists to each parameter upon the hedonic test.

4. Conclusions

In this study, we have shown that coatings produced with bacterial cellulose nanocrystals and fish gelatin containing different concentrations of cinnamon essential oil had a positive effect on the overall quality of '*Red Gold*' nectarine fruits over a cold storage period of 60 days. In particular, it was observed that the presence of the coating curbed phenomena like weight/firmness loss, respiration rate, and ethylene production, thus delaying the natural senescence of the fruit over time. In most cases, the protective effect of the coating linearly increased as a function of the employed concentration of essential oil, thus reaching maximum effect when the highest amount of essential oil was used (2.4 mL/L). Somehow, surprisingly, this amount did not impair the sensory attributes of the nectarines, which can be considered an important target for any envisaged commercialization of the product. For this reason, BCNCs–FGelA/CEO coatings at the highest tested concentration of CEO can be profitably used as an edible coating to reduce the post-harvest life of nectarine fruits.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/coatings14060736/s1, Figure S1: Schematic diagrams of materials and coating preparation. (a) Preparation of BCNCs solution, (b) Preparation of coating system, and (c) application of coating solution to nectarine fruits; Figure S2: Transmission electron microscopy image of BCNCs–FGelA/CEO Pickering emulsions at the highest CEO concentration (2.4 mL/L or 0.24% *w*/*v*).

Author Contributions: Conceptualization, M.S.R., M.T., R.A. and J.T.; methodology, M.S.R., M.T. and R.A.; software, M.S.R. and M.T.; validation, J.T., S.F. and D.C.; formal analysis, M.T.; investigation, J.T., S.F. and D.C.; resources, J.T., R.A. and S.F.; data curation, M.S.R. and M.T.; writing—original draft preparation, M.S.R.; writing—review and editing, J.T., S.F., D.C., M.T. and R.A.; visualization, M.S.R. and M.T.; supervision, J.T. and S.F.; project administration, J.T.; funding acquisition, J.T. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported financially by the University of Mohaghegh Ardabili.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Sharma, R.; Krishna, H. *A Textbook of Temperate Fruits*; CBS Publishers: New Delhi, India, 2018.
2. Jayarajan, S.; Sharma, R. Impact of nitric oxide on shelf life and quality of nectarine (*Prunus persica* var. *nucipersica*). *Acta Physiol. Plant.* **2018**, *40*, 207.
3. Zhang, H.; Zheng, X.; Yu, T. Biological control of postharvest diseases of peach with Cryptococcus laurentii. *Food Control* **2007**, *18*, 287–291. [CrossRef]
4. Tahmasebi, M.; Golmohammadi, A.; Nematollahzadeh, A.; Davari, M.; Chamani, E. Control of nectarine fruits postharvest fungal rots caused by Botrytis Cinerea and Rhizopus Stolonifer via some essential oils. *J. Food Sci. Technol.* **2020**, *57*, 1647–1655. [CrossRef]
5. Zhao, H.; Shu, C.; Fan, X.; Cao, J.; Jiang, W. Near-freezing temperature storage prolongs storage period and improves quality and antioxidant capacity of nectarines. *Sci. Hortic.* **2018**, *228*, 196–203. [CrossRef]
6. Nottagh, S.; Hesari, J.; Peighambardoust, S.H.; Rezaei-Mokarram, R.; Jafarizadeh-Malmiri, H. Effectiveness of edible coating based on chitosan and Natamycin on biological, physico-chemical and organoleptic attributes of Iranian ultra-filtrated cheese. *Biologia* **2020**, *75*, 605–611. [CrossRef]
7. Parven, A.; Sarker, M.R.; Megharaj, M.; Meftaul, I.M. Prolonging the shelf life of Papaya (*Carica papaya* L.) using Aloe vera gel at ambient temperature. *Sci. Hortic.* **2020**, *265*, 109228. [CrossRef]
8. Mahajan, B.V.C.; Tandon, R.; Kapoor, S.; Sidhu, M.K. Natural coatings for shelf-life enhancement and quality maintenance of fresh fruits and vegetables—A review. *J. Postharvest Technol.* **2018**, *6*, 12–26.
9. Cha, D.S.; Chinnan, M.S. Biopolymer-based antimicrobial packaging: A review. *Crit. Rev. Food Sci. Nutr.* **2004**, *44*, 223–237. [CrossRef]
10. Farahi, M.H. The impact of Aloe vera gel as postharvest treatment on the quality and shelf life of table grape cv. 'Askari'. *Agric. Commun.* **2015**, *3*, 30–36.
11. Razavi, M.S.; Golmohammadi, A.; Nematollahzadeh, A.; Ghanbari, A.; Davari, M.; Rovera, C.; Carullo, D.; Farris, S. Impact of bacterial cellulose nanocrystals-gelatin/cinnamon essential oil emulsion coatings on the quality attributes of 'red delicious' apples. *Coatings* **2022**, *12*, 741. [CrossRef]
12. Ribeiro-Santos, R.; Andrade, M.; de Melo, N.R.; Sanches-Silva, A. Use of essential oils in active food packaging: Recent advances and future trends. *Trends Food Sci. Technol.* **2017**, *61*, 132–140. [CrossRef]
13. Ju, J.; Chen, X.; Xie, Y.; Yu, H.; Guo, Y.; Cheng, Y.; Qian, H.; Yao, W. Application of essential oil as a sustained release preparation in food packaging. *Trends Food Sci. Technol.* **2019**, *92*, 22–32. [CrossRef]
14. Reineccius, G. Use of proteins for the delivery of flavours and other bioactive compounds. *Food Hydrocoll.* **2019**, *86*, 62–69. [CrossRef]
15. Anal, A.K.; Shrestha, S.; Sadiq, M.B. Biopolymeric-based emulsions and their effects during processing, digestibility and bioaccessibility of bioactive compounds in food systems. *Food Hydrocoll.* **2019**, *87*, 691–702. [CrossRef]
16. Hu, Z.; Ballinger, S.; Pelton, R.; Cranston, E.D. Surfactant-enhanced cellulose nanocrystal Pickering emulsions. *J. Colloid. Interface Sci.* **2015**, *439*, 139–148. [CrossRef]
17. Dickinson, E. Strategies to control and inhibit the flocculation of protein-stabilized oil-in-water emulsions. *Food Hydrocoll.* **2019**, *96*, 209–223. [CrossRef]
18. Zhang, X.; Zhou, J.; Chen, J.; Li, B.; Li, Y.; Liu, S. Edible foam based on pickering effect of bacterial cellulose nanofibrils and soy protein isolates featuring interfacial network stabilization. *Food Hydrocoll.* **2020**, *100*, 105440. [CrossRef]
19. He, K.; Zhang, X.; Li, Y.; Li, B.; Liu, S. Water-insoluble dietary-fibers from Flammulina velutiper used as edible stabilizers for oil-in-water Pickering emulsions. *Food Hydrocoll.* **2020**, *101*, 105519. [CrossRef]
20. Karim, A.; Bhat, R. Fish gelatin: Properties, challenges, and prospects as an alternative to mammalian gelatins. *Food Hydrocoll.* **2009**, *23*, 563–576. [CrossRef]
21. Rostami, M.; Yousefi, M.; Khezerlou, A.; Mohammadi, M.A.; Jafari, S.M. Application of different biopolymers for nanoencapsulation of antioxidants via electrohydrodynamic processes. *Food Hydrocoll.* **2019**, *97*, 105170. [CrossRef]
22. Dankovich, T.A.; Gray, D.G. Contact angle measurements on smooth nanocrystalline cellulose (I) thin films. *J. Adhes. Sci. Technol.* **2011**, *25*, 699–708. [CrossRef]
23. Lindman, B.; Karlström, G.; Stigsson, L. On the mechanism of dissolution of cellulose. *J. Mol. Liq.* **2010**, *156*, 76–81. [CrossRef]
24. Rahmadiawan, D.; Shi, S.-C.; Abral, H.; Ilham, M.K.; Sugiarti, E.; Muslimin, A.N.; Ilyas, R.; Lapisa, R.; Putra, N.S.D. Comparative Analysis of the Influence of Different Preparation Methods on the Properties of TEMPO-Oxidized Bacterial Cellulose Powder Films. *J. Nat. Fibers* **2024**, *21*, 2301386. [CrossRef]
25. Yan, H.; Chen, X.; Song, H.; Li, J.; Feng, Y.; Shi, Z.; Wang, X.; Lin, Q. Synthesis of bacterial cellulose and bacterial cellulose nanocrystals for their applications in the stabilization of olive oil pickering emulsion. *Food Hydrocoll.* **2017**, *72*, 127–135. [CrossRef]
26. Zhou, Y.; Sun, S.; Bei, W.; Zahi, M.R.; Yuan, Q.; Liang, H. Preparation and antimicrobial activity of oregano essential oil Pickering emulsion stabilized by cellulose nanocrystals. *Int. J. Biol. Macromol.* **2018**, *112*, 7–13. [CrossRef]
27. Kasiri, N.; Fathi, M. Entrapment of peppermint oil using cellulose nanocrystals. *Cellulose* **2018**, *25*, 319–329. [CrossRef]
28. Varanasi, S.; Henzel, L.; Mendoza, L.; Prathapan, R.; Batchelor, W.; Tabor, R.; Garnier, G. Pickering emulsions electrostatically stabilized by cellulose nanocrystals. *Front. Chem.* **2018**, *6*, 409. [CrossRef]

29. Rollini, M.; Musatti, A.; Cavicchioli, D.; Bussini, D.; Farris, S.; Rovera, C.; Romano, D.; De Benedetti, S.; Barbiroli, A. From cheese whey permeate to Sakacin-A/bacterial cellulose nanocrystal conjugates for antimicrobial food packaging applications: A circular economy case study. *Sci. Rep.* **2020**, *10*, 21358. [CrossRef] [PubMed]
30. Efthymiou, M.-N.; Tsouko, E.; Papagiannopoulos, A.; Athanasoulia, I.-G.; Georgiadou, M.; Pispas, S.; Briassoulis, D.; Tsironi, T.; Koutinas, A. Development of biodegradable films using sunflower protein isolates and bacterial nanocellulose as innovative food packaging materials for fresh fruit preservation. *Sci. Rep.* **2022**, *12*, 6935. [CrossRef]
31. Mendes-Oliveira, G.; Gu, G.; Luo, Y.; Zografos, A.; Minas, I.; Nou, X. Edible and water-soluble corn zein coating impregnated with nisin for Listeria monocytogenes reduction on nectarines and apples. *Postharvest Biol. Technol.* **2022**, *185*, 111811. [CrossRef]
32. Jayarajan, S.; Sharma, R.; Sethi, S.; Asrey, R.; Awasthi, O.; Paul, V.; Bhatia, H.; Sharma, V. Influence of hydrocolloid-based edible coatings on fruit firmness and quality of nectarine (*Prunus persica* var. *nucipersica*) cv. Snow Queen at low temperature storage. *Indian J. Agric. Sci.* **2020**, *90*, 1582–1586.
33. Jayarajan, S.; Sharma, R. Postharvest life and quality of 'Snow Queen' nectarine (*Prunus persica* var. *nucipersica*) as influenced by edible coatings during cold storage. *Acta Physiol. Plant.* **2020**, *42*, 123.
34. Jacumazo, J.; Parchen, G.P.; Garcia, M.J.; Santos, N.C.; Mio, L.L.D.; Marques, F.A.; Freitas, R.A.d. Nectarine Coated with Biopolymeric Nanocapsules Containing Eugenol to Control Brown Rot. *J. Braz. Chem. Soc.* **2023**, *34*, 1030–1039. [CrossRef]
35. Sowmyashree, A.; Sharma, R.; Rudra, S.G.; Grover, M. Layer-by-layer coating of hydrocolloids and mixed plant extract reduces fruit decay and improves postharvest life of nectarine fruits during cold storage. *Acta Physiol. Plant.* **2021**, *43*, 112. [CrossRef]
36. Sowmyashree, A.; Sharma, R.; Rudra, S.G.; Verma, M.; Grover, M. Influence of plant extract and edible coatings on quality of nectarine (*Prunus persica*) fruits. *Indian. J. Agric. Sci.* **2021**, *91*, 113–116.
37. Hajiesmaeili, E.; Danaee, E. Evaluation of the Effect of Postharvest Salicylic Acid and Calcium Chloride Treatment on the Quality and Storage Life of Nectarine Fruit (*Prunus persica* L. Batsch). *Erwerbs-Obstbau* **2024**, *66*, 495–503. [CrossRef]
38. Razavi, M.S.; Golmohammadi, A.; Nematollahzadeh, A.; Fiori, F.; Rovera, C.; Farris, S. Preparation of cinnamon essential oil emulsion by bacterial cellulose nanocrystals and fish gelatin. *Food Hydrocoll.* **2020**, *109*, 106111. [CrossRef]
39. Razavi, M.S.; Golmohammadi, A.; Nematollahzadeh, A.; Rovera, C.; Farris, S. Cinnamon essential oil encapsulated into a fish gelatin-bacterial cellulose nanocrystals complex and active films thereof. *Food Biophys.* **2021**, *17*, 38–46. [CrossRef]
40. Golmohammadi, A.; Razavi, M.S.; Tahmasebi, M.; Carullo, D.; Farris, S. Cinnamon Essential-Oil-Loaded Fish Gelatin–Cellulose Nanocrystal Films Prepared under Acidic Conditions. *Coatings* **2023**, *13*, 1360. [CrossRef]
41. Jung, J.; Deng, Z.; Zhao, Y. Mechanisms and performance of cellulose nanocrystals Pickering emulsion chitosan coatings for reducing ethylene production and physiological disorders in postharvest 'Bartlett' pears (*Pyrus communis* L.) during cold storage. *Food Chem.* **2020**, *309*, 125693. [CrossRef]
42. Da Silva, I.S.V.; Prado, N.S.; De Melo, P.G.; Arantes, D.C.; Andrade, M.Z.; Otaguro, H.; Pasquini, D. Edible coatings based on apple pectin, cellulose nanocrystals, and essential oil of lemongrass: Improving the quality and shelf life of strawberries (*Fragaria ananassa*). *J. Renew. Mater.* **2019**, *7*, 73–87. [CrossRef]
43. Deng, Z.; Jung, J.; Simonsen, J.; Zhao, Y. Cellulose nanocrystals Pickering emulsion incorporated chitosan coatings for improving storability of postharvest Bartlett pears (*Pyrus communis*) during long-term cold storage. *Food Hydrocoll.* **2018**, *84*, 229–237. [CrossRef]
44. Deng, Z.; Jung, J.; Simonsen, J.; Wang, Y.; Zhao, Y. Cellulose nanocrystal reinforced chitosan coatings for improving the storability of postharvest pears under both ambient and cold storages. *J. Food Sci.* **2017**, *82*, 453–462. [CrossRef]
45. Fakhouri, F.; Casari, A.; Mariano, M.; Yamashita, F.; Mei, L.I.; Soldi, V.; Martelli, S. Effect of a gelatin-based edible coating containing cellulose nanocrystals (CNC) on the quality and nutrient retention of fresh strawberries during storage. *IOP Conf.Ser. Mater. Sci.Eng.* **2014**, *64*, 012024. [CrossRef]
46. Dong, F.; Li, S.; Liu, Z.; Zhu, K.; Wang, X.; Jin, C. Improvement of quality and shelf life of strawberry with nanocellulose/chitosan composite coatings. *Bangladesh J. Bot.* **2015**, *44*, 709–717.
47. Azeredo, H.M.; Miranda, K.W.; Ribeiro, H.L.; Rosa, M.F.; Nascimento, D.M. Nanoreinforced alginate–acerola puree coatings on acerola fruits. *J. Food Eng.* **2012**, *113*, 505–510. [CrossRef]
48. Razavi, M.S.; Golmohammadi, A.; Nematollahzadeh, A.; Ghanbari, A.; Davari, M.; Carullo, D.; Farris, S. Production of Innovative essential oil-based emulsion coatings for fungal growth control on postharvest fruits. *Foods* **2022**, *11*, 1602. [CrossRef] [PubMed]
49. Rovera, C.; Ghaani, M.; Santo, N.; Trabattoni, S.; Olsson, R.T.; Romano, D.; Farris, S. Enzymatic hydrolysis in the green production of bacterial cellulose nanocrystals. *ACS Sustain. Chem. Eng.* **2018**, *6*, 7725–7734. [CrossRef]
50. Denavi, G.; Tapia-Blacido, D.R.; Añon, M.C.; Sobral, P.J.D.A.; Mauri, A.N.; Menegalli, F. Effects of drying conditions on some physical properties of soy protein films. *J. Food Eng.* **2009**, *90*, 341–349. [CrossRef]
51. Vargas, M.; Albors, A.; Chiralt, A.; González-Martínez, C. Quality of cold-stored strawberries as affected by chitosan–oleic acid edible coatings. *Postharvest Biol. Technol.* **2006**, *41*, 164–171. [CrossRef]
52. Ghasemlou, M.; Aliheidari, N.; Fahmi, R.; Shojaee-Aliabadi, S.; Keshavarz, B.; Cran, M.J.; Khaksar, R. Physical, mechanical and barrier properties of corn starch films incorporated with plant essential oils. *Carbohydr. Polym.* **2013**, *98*, 1117–1126. [CrossRef] [PubMed]
53. Jouki, M.; Yazdi, F.T.; Mortazavi, S.A.; Koocheki, A. Quince seed mucilage films incorporated with oregano essential oil: Physical, thermal, barrier, antioxidant and antibacterial properties. *Food Hydrocoll.* **2014**, *36*, 9–19. [CrossRef]

54. Eshghi, S.; Hashemi, M.; Mohammadi, A.; Badii, F.; Mohammadhoseini, Z.; Ahmadi, K. Effect of nanochitosan-based coating with and without copper loaded on physicochemical and bioactive components of fresh strawberry fruit (*Fragaria* x *ananassa* Duchesne) during storage. *Food Bioprocess. Technol.* **2014**, *7*, 2397–2409. [CrossRef]
55. Terefe, N.S.; Matthies, K.; Simons, L.; Versteeg, C. Combined high pressure-mild temperature processing for optimal retention of physical and nutritional quality of strawberries (*Fragaria*× *ananassa*). *Innov. Food Sci. Emerg. Technol.* **2009**, *10*, 297–307. [CrossRef]
56. Meilgaard, M.C.; Carr, B.T.; Civille, G.V. Does a sensory difference exist between samples. In *Sensory Evaluation Techniques*, 1st ed.; Meilgaard, M.C., Carr, B.T., Civille, G.V., Eds.; CRC Press: Boca Raton, FL, USA, 2007; p. 42.
57. Lawless, H.T.; Heymann, H. *Sensory Evaluation of Food: Principles and Practices*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2010.
58. Abdi, K.; Getenesh, T.; Bilatu, A.; Firew, K.; Habtamu, S. Improving shelf life of nectarine fruit (*Prunus persica*) by beeswax coating and cold storage application. *Afr. J. Food Sci.* **2021**, *15*, 262–271. [CrossRef]
59. Chitravathi, K.; Chauhan, O.; Raju, P. Influence of modified atmosphere packaging on shelf-life of green chillies (*Capsicum annuum* L.). *Food Packag. Shelf Life* **2015**, *4*, 1–9. [CrossRef]
60. Tavarini, S.; Degl'Innocenti, E.; Remorini, D.; Massai, R.; Guidi, L. Polygalacturonase and β-galactosidase activities in Hayward kiwifruit as affected by light exposure, maturity stage and storage time. *Sci. Hortic.* **2009**, *120*, 342–347. [CrossRef]
61. Lo Piero, A.R.; Puglisi, I.; Rapisarda, P.; Petrone, G. Anthocyanins accumulation and related gene expression in red orange fruit induced by low temperature storage. *J. Agric. Food Chem.* **2005**, *53*, 9083–9088. [CrossRef]
62. Jiang, Y.R.; Fu, Y.B.; Li, D.L.; Xu, W.C. Effects of 1-MCP and controllable-release SO_2 packaging on cold preservation of grapes (CV Muscat Hamburg). *Adv. Mat. Res.* **2013**, *750*, 2335–2339.
63. Dhinesh Kumar, V.; Ramasamy, D.; Jerish, J. Effect of active modified atmosphere packaging material on biochemical and microbial characteristics of pomegranate arils during storage. *Int. J. Chem. Stud.* **2018**, *6*, 95–99.
64. Ding, J.; Zhang, R.; Ahmed, S.; Liu, Y.; Qin, W. Effect of sonication duration in the performance of polyvinyl alcohol/chitosan bilayer films and their effect on strawberry preservation. *Molecules* **2019**, *24*, 1408. [CrossRef] [PubMed]
65. Mahmood, T.; Anwar, F.; Abbas, M.; Boyce, M.C.; Saari, N. Compositional variation in sugars and organic acids at different maturity stages in selected small fruits from Pakistan. *Int. J. Mol. Sci.* **2012**, *13*, 1380–1392. [CrossRef] [PubMed]
66. Buendía, L.; Sánchez, M.J.; Antolinos, V.; Ros, M.; Navarro, L.; Soto, S.; Martínez, G.B.; López, A. Active cardboard box with a coating including essential oils entrapped within cyclodextrins and/or halloysite nanotubes. A case study for fresh tomato storage. *Food Control* **2020**, *107*, 106763.
67. López-Gómez, A.; Navarro-Martínez, A.; Martínez-Hernández, G.B. Active paper sheets including nanoencapsulated essential oils: A green packaging technique to control ethylene production and maintain quality in fresh horticultural products—A case study on flat peaches. *Foods* **2020**, *9*, 1904. [CrossRef] [PubMed]
68. Othman, O.C. Polyphenoloxidase and perioxidase activity during open air ripening storage of pineapple (*Ananas comosus* L.), mango (*Mangifera indica*) and papaya (*Carica papaya*) fruits grown in Dar es Salaam, Tanzania. *Tanz. J. Sci.* **2012**, *38*, 84–94.
69. Lavin, J.G.; Lawless, H.T. Effects of color and odor on judgments of sweetness among children and adults. *Food Qual. Prefer.* **1998**, *9*, 283–289. [CrossRef]
70. Kühn, B.F.; Thybo, A.K. The influence of sensory and physiochemical quality on Danish children's preferences for apples. *Food Qual. Prefer.* **2001**, *12*, 543–550. [CrossRef]
71. Gatti, E.; Di Virgilio, N.; Magli, M.; Predieri, S. Integrating sensory analysis and hedonic evaluation for apple quality assessment. *J. Food Qual.* **2011**, *34*, 126–132. [CrossRef]