Article

Edible Coatings Enhance Storability and Preserve Quality of Kiwiberry (*Actinidia arguta* L.) cv. Ken's Red

Adriana C. Guerreiro [1,2,*], Custódia Gago [3], Dário Passos [1,2], Jaime Martins [1,2], Sandra Cruz [1,4], Fernão Veloso [5], Rui Guerra [1,2] and Maria D. Antunes [3]

[1] CEOT—Centre for Electronics, Optoelectronics and Telecommunications, Faculdade de Ciências e Tecnologia, Edf. 2, Campus Gambelas, 8005-139 Faro, Portugal; dmpassos@ualg.pt (D.P.); jamartins@ualg.pt (J.M.); spcruz@ualg.pt (S.C.); rguerra@ualg.pt (R.G.)

[2] CISCA—Cyber-PhysIcal Systems research Center of Algarve, Faculdade de Ciências e Tecnologia, Edf. 2, Campus Gambelas, 8005-139 Faro, Portugal

[3] MED—Mediterranean Institute for Agriculture, Environment and Development & CHANGE—Global Change and Sustainability Institute, FCT, Universidade do Algarve, Edf. 8, Campus de Gambelas, 8005-139 Faro, Portugal; cgago@ualg.pt (C.G.); mantunes@ualg.pt (M.D.A.)

[4] ESCAD—Escola Superior de Ciências da Administração, 1950-396 Lisboa, Portugal

[5] Frutas Douro ao Minho, Lugar da Gandra, Briteiros St Estevão e Donim, 4805-446 Guimarães, Portugal; fernaoveloso@fdm.pt

* Correspondence: acguerreiro@ualg.pt

Abstract: Kiwiberries, an emerging fruit variety with increasing consumer demand, face significant commercialization challenges due to their short shelf life. This study evaluates the effectiveness of edible alginate-based coatings in extending the shelf life of kiwiberries. Two emulsion types—coarse (Coarse) and nanoemulsions (Nano)—and two application methods—spraying (Spray) and dipping (Dip)—were tested. Additionally, the use of visible/near-infrared (Vis-NIR) spectroscopy for non-destructive quality monitoring was explored. Coatings were prepared with 2% (*w*/*v*) alginate (SAlg) enriched with eugenol (Eg) and citral (Ct) at their minimum inhibitory concentrations (MICs) of 0.10% and 0.15%, respectively, as well as at double these concentrations. This resulted in a total of ten different treatments. The fruits were stored at approximately 5 °C, with evaluations conducted after 5 days, 2 weeks, and 4 weeks. Quality parameters, including color, firmness, soluble solid content (SSC), dry matter, weight loss, decay, total phenolic content (TPC), flavonoids, DPPH, FRAP, and malondialdehyde (MDA) levels, were analyzed. Over the storage period, color and SSC increased, while firmness decreased. Weight loss and MDA levels showed the most significant changes, particularly in treatments with higher essential oil concentrations. Notably, treatments such as SAlg Spray, SAlg Dip, SAlg Ct 0.15 + Eg 0.1 Nano Spray, SAlg Ct 0.15 + Eg 0.1 Nano Dip, and SAlg Ct 0.15 + Eg 0.1 Coarse Dip demonstrated superior preservation of kiwiberry quality. Moreover, Vis-NIR spectroscopy proved valuable for distinguishing between coating treatments, highlighting its potential for non-destructive quality assessment.

Keywords: hardy kiwi; spraying; dipping; nanoemulsions; coarse emulsions; Vis-NIR

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1. Introduction

In recent years, the sensory qualities, nutritional profile, and health benefits of *Actinidia arguta* have attracted considerable interest from both consumers and researchers [1]. Commonly referred to as "mini kiwi", "kiwiberry", "baby kiwi", or "hardy kiwifruit", this small grape-sized fruit features a thin, edible, hairless skin and a sweet, aromatic

flavor. Renowned as one of the most nutrient-dense fruits, *A. arguta* is an excellent source of antioxidants (notably polyphenols), vitamins (especially vitamin C), carotenoids, chlorophylls, sugars, dietary fiber, organic acids, and minerals [2–5]. However, its aroma, taste, and physicochemical properties are highly influenced by harvesting and storage conditions [3,6–8].

Despite its nutritional value, the commercialization of *A. arguta* faces two major challenges: labor-intensive harvesting and a short shelf life of 1–2 months at 0 °C. This limited shelf life is primarily caused by fruit softening, water loss leading to skin wrinkling, and degradation during storage [1,6–8]. To mitigate these issues, the fruits are typically harvested before full ripeness, at sugar levels corresponding to 6.5–8 °Brix [6,7,9,10].

Fruits are highly perishable products, requiring careful postharvest management to maintain quality and prevent spoilage. Postharvest diseases significantly affect the cost of produce storage and food production, posing a major barrier to the fresh horticultural trade [11,12]. Addressing these challenges, the food industry has prioritized reducing waste and extending the shelf life of fresh produce through innovative methods. Among these, edible coatings have emerged as a sustainable alternative to traditional packaging materials, enhancing both food safety and quality [13,14].

Recent studies have explored fabricated coarse emulsion and nanoemulsion coatings with various formulations to prolong the shelf life of fruits [15]. These coatings act as barriers against microbial contamination while modifying the storage atmosphere, reducing respiration and transpiration rates, and delaying senescence [16–19]. Edible coatings incorporating polysaccharides and essential oil components are widely used to mitigate water loss and maintain the quality of fresh fruits. The addition of essential oils or their compounds as antimicrobial agents enhances the efficacy of these coatings, extending shelf life and preserving product quality [20–22]. For consistency in coating properties, single-compound formulations are often preferred over essential oil mixtures due to their variability with seasonal and cultural practices [23,24].

Alginate, a naturally derived biopolymer from brown seaweed, is particularly suitable as an edible coating material due to its excellent film-forming properties. As a salt of alginic acid, alginate consists of D-mannuronic acid and L-guluronic acid monomers and forms stable gels through interaction with multivalent metal cations like calcium [21].

While the use of edible coatings for food preservation is not new, the topic has gained renewed attention in response to growing consumer demand for safe, high-quality, and minimally processed foods [16,25]. Coating application techniques, including dipping and spraying, play a crucial role in achieving uniform coverage. Dipping is advantageous for irregular surfaces requiring multiple applications, while spraying provides more uniform coatings [26].

This study addresses three key objectives: (1) to evaluate the effects of edible alginate-based coatings on the quality and shelf life of *A. arguta*, (2) to compare the performance of coatings formulated as coarse emulsions (Coarse) and nanoemulsions (Nano) using two application methods—spraying (Spray) and dipping (Dip)—and (3) to assess the utility of visible/near-infrared (Vis-NIR) spectroscopy for analyzing and interpreting coating-related data.

2. Materials and Methods

2.1. Fruit Material

For all trials, kiwiberry (*Actinidia arguta* cv. 'Ken's Red') was harvested from 5-year-old vines growing in several blocks on a commercially managed orchard located in north Portugal (Baião). In this area, the conventional harvest time occurs in September. Fruits were collected and transported to the postharvest laboratory at the University of Algarve

at ambient temperature, arriving within 24 h of harvest. Immediately upon arrival at the laboratory, 30 fruits were randomly selected for fruit maturity characterization (quality measurements). The remaining fruit was packed into single-layer trays, and the treatments below were performed.

2.2. Chemicals

Food-grade sodium alginate (SAlg) and nonionic surfactant Tween 80® (Polyoxyethylene sorbitan Monooleate) were purchased from Sigma–Aldrich Chemic (Steinhein, Germany). To obtain ultrapure water, a Milli-Q filtration system was used. Sigma-Aldrich Chemic (Steinhein, Germany) provided the calcium chloride, and Scharlau (Barcelona, Spain) provided the ascorbic acid. Citral (Ct) and eugenol (Eg), essential oil components, were bought from Sigma-Aldrich Chemic (Steinhein, Germany).

2.3. Preparation of Emulsions

Sodium alginate (2%, *w*/*w*) was dissolved in MilliQ water at 70 °C, with continuous stirring until complete dissolution; then, the solution was cooled down to 25 °C. This solution was the basis for the preparation of the coarse and nanoemulsions [15]. The essential oil (EO) compound concentrations, citral (Cit) and eugenol (Eug), used in the emulsions were based on previous studies where minimum inhibitory concentrations (MICs) and double MICs were utilized, 0.15 and 0.3% (*w*/*w*) for citral and 0.10 and 0.20% (*w*/*w*) for eugenol [27].

The coarse emulsions (Coarse), containing 2% (*w*/*w*) sodium alginate and EOs, were prepared as reported by Rojas-Graü et al. [28], by dissolving sodium alginate (AL) powders in distilled water while stirring until the solution became clear. Using an Ultra Turrax® T25 (IKA, Staufen, Germany), coating forming solutions were homogenized.

To prepare the nanoemulsions (Nano), the EOs were incorporated into the AL solution (2%, *w*/*w*) using a thermomix (Vorwerk & Co. KG, Wuppertal, Germany) in 6 series of 1 min at speed 9 (3028 g), avoiding exceeding 37 °C. Thereafter, the emulsion was mixed with a T-18 Ultra Turrax® (IKA, Staufen, Germany) for 1 min at 1762 g. Tween 80® concentrations were bound at an oil/surfactant ratio of 1:3 [15].

2.4. Coating Characterization

The particle size, polydispersity, and z-potential of coarse emulsions and nanoemulsions were assessed through dynamic light scattering (DLS) and phase analysis light scattering (PALS) [15]. To avoid the effects of repeated scattering, samples were diluted with Milli-Q water (1:10) before analysis. The emulsions were observed by negative-staining electron microscopy as a direct measurement of their droplet size and shape, as reported by Artiga-Artigas et al. [29]. A transmission electron microscope, the Morgagni 268D TEM (FEI Company, Eindhoven, The Netherlands), with a CCD Mega-View camera (Olympus, Tokyo, Japan), was used to observe the grids.

2.5. Spraying Application Method

To apply coarse emulsion and nanoemulsion preparations, the spraying method (Spray) was performed by spraying uniformly on the whole fruit surface with the use of a paint sprayer (Dexter nozzle 1.5 mm, ADEO services, Ronchin—France), at a pressure of 8 bar; the flow rate was 150 L. min^{-1}, and the spraying distance was 20 cm. After coating applications, fruit were dried at room temperature for 2–3 min, then a solution of calcium chloride 1% was applied, to form a uniform, transparent, water-insoluble and thermo-irreversible gel at room temperature, by cross-linking with di- or trivalent ions, promoted by the characteristics of alginates [30]. Then, the coatings formed on kiwiberries were allowed to dry for 1 h at room temperature (~20 °C), labeled, weighed, and then

randomly packed into polypropylene plastic trays (8 cm × 10 cm × 4 cm), perforated in the cover, and stored at 0.5 °C with a relative humidity (RH) of 95%. After 2 and 4 weeks, 30 fruits per treatment were sampled and stored for a 5-day shelf life at ~5 °C and 60% RH. Following this period, shelf life and quality parameters were assessed.

2.6. Dipping Application Method (D)

Each treatment, which included preparations for coarse emulsions and nanoemulsions, was carried out in two phases. First, the kiwiberries were immersed into the edible coating solution for two minutes. After that, the excess coating material was allowed to drip off for thirty seconds, and then the fruit were dipped again for one minute in the 1% calcium chloride solution to cause a cross-linking reaction. Subsequently, the fruit were weighed, tagged, and haphazardly arranged into polypropylene plastic trays (8 cm × 10 cm × 4 cm), perforated in the cover, and stored and sampled as those with the spraying treatment.

2.7. Quality Measurements

The quality analyses were performed on the control and ten treatment sets resulting from the combination of the multiple emulsion formulations and application methodologies (Table 1).

Table 1. List of combinations resulting from the emulsion formulation vs. application methodologies.

List of Combinations		
Num	**Description**	**Code**
1	Non-Treated fruit	Control
2	Sodium alginate 2%, applying by Spraying	SAlg Spray
3	Sodium alginate 2%, applying by Dipping	SAlg Dip
4	Nanoemulsion of Sodium alginate 2% +Citral 0.15% + Eugenol 0.1%, applying by Spraying	SAlg Ct 0.15 Eg 0.1 Nano Spray
5	Nanoemulsion of Sodium alginate 2% +Citral 0.15% + Eugenol 0.1%, applying by Dipping	SAlg Ct 0.15 Eg 0.1 Nano Dip
6	Coarse emulsion of Sodium alginate 2% +Citral 0.15% + Eugenol 0.1%, applying by Spraying	SAlg Ct 0.15 Eg 0.1 Coarse Spray
7	Coarse emulsion of Sodium alginate 2% +Citral 0.15% + Eugenol 0.1%, applying Dipping	SAlg Ct 0.15 Eg 0.1 Coarse Dip
8	Nanoemulsion of Sodium alginate 2% +Citral 0.3% + Eugenol 0.2%, applying by Spraying	SAlg Ct 0.3 Eg 0.2 Nano Spray
9	Nanoemulsion of Sodium alginate 2% + Citral 0.3% + Eugenol 0.2%, applying by Dipping	SAlg Ct 0.3 Eg 0.2 Nano Dip
10	Coarse emulsion of Sodium alginate 2% +Citral 0.3% + Eugenol 0.2%, applying by Spraying	SAlg Ct 0.3 Eg 0.2 Coarse Spray
11	Coarse emulsion of Sodium alginate 2% +Citral 0.15% + Eugenol 0.1%, applying by Dipping	SAlg Ct 0.3 Eg 0.2 Coarse Dip

Pulp color measurements were made using the CIE (Commission International de l'Eclairage). For that, a Minolta Chroma meter CR-300 (EC Minolta, Japan) was used using the CIELab scale (L*, a*, and b*). The L* represents color lightness (0 = black and 100 = white). Hue was calculated as h° = arctan (b*/a*) and color saturation (chroma) as C* = (a^{*2} + b^{*2})0.5 [31]. Kiwiberry firmness (Fm) was measured at the fruit's equator using a 45 mm diameter piston compressed at a speed of 1 mm s^{-1} using a Chatillon TCD200 and Digital Force Gauge DFIS 50 (Jonh Chatillon & Sons, Ametek Inc., Largo, FL, USA). The

result was represented in Newtons (N). Then, using an automated squeezer, each fruit was squeezed separately. The soluble solid content (SSC, in °Brix) of a portion of the juice was then determined using a digital refractometer (Atago Co. Ltd., Tokyo, Japan). A forced-air oven operating at 105 °C for 48 h was used to determine the dry matter (DMC), which was then expressed as a percentage of the starting weight. Weight loss (WL) was expressed as a percentage of the initial weight. The decay rate was determined as the percentage of fruits showing visible signs of decay, with three independent replicates per treatment, each consisting of 10 fruits. Inspections were conducted after 2 and 4 weeks of storage, followed by 5 days of shelf life. Fruits were classified as infected if they exhibited visible lesions, characterized by brown spots, softening in damaged areas, visible mold, or shriveling. Results were expressed as the percentage of infected fruits.

2.8. Malondialdehyde

Lipid peroxidation products were quantified by determining the malondialdehyde (MDA) content in frozen, ground tissue, following the methods described by Siguo Xiong et al. [32] and Antunes et al. [33], with modifications. Frozen kiwiberry tissues (1.0 g) were homogenized in 8 mL of 80% (*v*/*v*) ice-cold ethanol containing 5% (*w*/*v*) insoluble polyvinylpolypyrrolidone (PVPP) using an Ultra-Turrax homogenizer. The homogenate was centrifuged at 10,000× *g* for 20 min at 4 °C using a Microfuge® 18 Centrifuge (Beckman Coulter, Brea, CA, USA).

Two 0.6 mL aliquots of the supernatant were prepared. One was mixed with 0.6 mL of a solution without thiobarbituric acid (TBA), containing 20% trichloroacetic acid (TCA) and 0.01% butylated hydroxytoluene (BHT) (−TBA), and the other was mixed with 0.6 mL of a solution containing the same reagents plus 0.65% TBA (+TBA). Both mixtures were vigorously stirred and incubated at 95 °C for 25 min, then rapidly cooled on ice and centrifuged to separate the supernatant.

The absorbance of the supernatant was measured at 450, 532, and 600 nm using a spectrophotometer. The amount of MDA was calculated using the following formula: $6.45 \times (OD_{532} - OD_{600}) - 0.56 \times OD_{450}$. The MDA content in fresh weight was expressed in μmol kg^{-1}.

2.9. Total Phenolic Content and Flavonoids

The determination of total phenolic content was performed using the Folin–Ciocalteu colorimetric method [34], adapted for microplate analysis. Kiwiberry juice was prepared by homogenizing the fruit with an UltraTurrax® T 18 (IKA, Germany) for 2 min, followed by centrifugation at 5000 rpm for 5 min. For the assay, 80 μL of the juice was combined with 20 μL of sodium carbonate solution (75 g L^{-1}) and 100 μL of 10% (*w*/*v*) Folin–Ciocalteu reagent. The mixture was incubated for 30 min at room temperature, and absorbance was measured at 765 nm (Tecan Infinite M200, Swiss, Tecan, Männedorf, Switzerland). A calibration curve was constructed using gallic acid as the standard. The quantification of flavonoids was carried out on kiwiberry juice prepared as described above, following a modified version of the method by Miguel et al. [35], optimized for microplate analysis. Briefly, 100 μL of the sample or standard solution was mixed with 100 μL of a 2% (*w*/*v*) $AlCl_3$ ethanol solution. After 1 h incubation at room temperature, the absorbance was recorded at 420 nm (Tecan Infinite M200, Swiss). Quercetin served as the standard for the calibration curve.

2.10. Antioxidant Capacity Analysis

Antioxidant activity was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay, adapted from the method described by Brand-Williams et al. [36]. A stock solution of DPPH (0.1 mM) was prepared in methanol and stored in a dark

environment at room temperature. The working solution was obtained by diluting the stock solution with methanol until it reached an absorbance of approximately 0.9 ± 0.02 at 517 nm. For the assay, 195 µL of the DPPH working solution was added to 5 µL of kiwiberry juice extract or standard solution in a 96-well microplate. The mixture was incubated in the dark at room temperature for 30 min to allow the reaction to occur; the absorbance at 517 nm (Synergy HTX, Biotek, Santa Clara, CA, USA) was recorded to determine the concentration of the remaining DPPH. Results were expressed as the Trolox equivalent antioxidant capacity. Blanks were prepared using methanol instead of the sample, and a control containing only the DPPH solution was included to measure the maximum absorbance.

Antioxidant activity was assessed using the ferric reducing antioxidant power (FRAP) assay, as outlined by Benzie and Strain [37], with slight modifications for microplate analysis. The FRAP reagent was prepared daily by mixing 300 mM acetate buffer (pH 3.6), 10 mM 2,4,6-tripyridyl-s-triazine (TPTZ) solution in 40 mM HCl, and 20 mM ferric chloride ($FeCl_3 \cdot 6H_2O$) solution in a 10:1:1 ratio ($v/v/v$). The reagent was protected from light and warmed to 37 °C before use. For the assay, 180 µL of the FRAP reagent was added to 20 µL of the sample or standard in a 96-well microplate. The mixture was incubated at 37 °C for 30 min, and the absorbance was measured at 593 nm (Synergy HTX, Biotek, USA). A standard curve was prepared using Trolox, and the results were expressed as the Trolox equivalent antioxidant capacity in µmol Trolox per gram of sample. A blank was included for each sample by replacing the FRAP reagent with acetate buffer, and a reagent control (without sample) was used to account for background absorbance.

2.11. Experimental Setup of VIS/NIR Measurements

Non-destructive technology was employed as a complementary analytical method in this experiment. For the acquisition of the kiwiberry diffuse reflectance spectra, we used an optical setup consisting of a spectrometer (Hamamatsu C9405 CA, Hamamatsu, Japan) working in the range of 432–1147 nm, a tungsten light source (Ocean Optics HL 2000, Ocean Optics, Rochester, NY, USA), and a bifurcated optical fiber with a customized interactance probe described by Guerreiro et al. [38] (Figure 1). The protocol comprises the measurement of reference (Ref), dark (D), and sample spectra (S) as per normal. The reflectance, R, is then calculated as R = (S-D)/(Ref-D). The reference measurements were performed with the interactance probe kept 1 cm above a Spectralon™ disk. The kiwiberries were always measured in the equatorial zone. To achieve the best results, an average of 100 scans per 100 ms was taken for each fruit. The reflectance spectra were then grouped in a matrix of n samples by 1024 spectral features (wavelengths) and analyzed to investigate possible interactions between the coatings and fruit. The calculations were performed using MATLAB® 2018b (Natick, MA, USA) and Python 3.13.1. (Python Software Foundation, Beaverton, OR, USA).

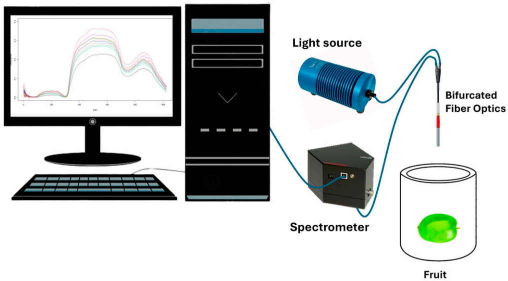


Figure 1. Spectrum acquisition scheme using an optical setup consisting of a spectrometer (Hamamatsu C9405 CA, Hamamatsu, Japan), a tungsten light source (Ocean Optics HL 2000, Ocean Optics, USA), and a bifurcated optical fiber with a customized interactance probe.

2.12. Statistical Methods

Statistical analysis was conducted using two software programs, and the experimental design followed a completely randomized block design.

Data analysis using SPSS 27.0 software (IBM, Inc., Armonk, NY, USA) on a PC workstation (Intel®(Core^{TM} i7, for a two-way analysis of variance (ANOVA)) was performed considering treatment and storage time as factors. A Duncan's multiple range test ($p < 0.05$) was used for pairwise comparisons of the means.

Additionally, RStudio (version 4.4.2, Integrated Development for R. RStudio, PBC, Boston, MA, USA) was employed for correlation analysis, multiple correspondence analysis (MCA), and principal component analysis (PCA). Pearson's correlation coefficient was used to assess relationships between variables, with statistical significance set at a 95% confidence level ($p < 0.05$); the corr() function was used. A multiple correspondence analysis (MCA) technique with standardized variables and two categorical independent variables was used to detect and represent underlying structures in a low-dimensional Euclidean space using a criterion of a convergence of 0.00001 and a maximum iteration of 100 and a squared Euclidean distance [39]. Since the representation alone is insufficient for creating a complete interpretation of the results, we applied an optimal scaling technique to analyze the relations among variables. PCA was applied to reduce data dimensionality and identify patterns of variability among the variables. Before performing PCA, the data were standardized using the scale() function to normalize variables and make them comparable. The analysis was conducted with the FactoMineR package [40], and the principal components were selected based on eigenvalues greater than 1 (Kaiser's criterion) and cumulative variance explained by the components (>55%). Correlation plots and PCA biplots were generated using the ggplot2 package [41] for better visualization and interpretation of the results.

3. Results and Discussion

3.1. Emulsion Characteristics

The preparation method plays a critical role in determining the structure and stability of emulsions. As shown in Table 2, the droplet size exhibited two distinct patterns. In coarse emulsions, SAlg Ct 0.15 Eg 0.1 Coarse presented a droplet size of 1706.67 ± 236.72 nm, while SAlg Ct 0.3 Eg 0.2 Coarse displayed a size of 1470.00 ± 101.36 nm. Conversely, nanoemulsions demonstrated significantly smaller droplet sizes, ranging from 236.73 ± 93.34 nm for SAlg Ct 0.15 Eg 0.1 Nano to 236.73 ± 93.34 nm for SAlg Ct 0.3 Eg 0.2 Nano. As expected, nanoemulsions produced droplets smaller than 500 nm, which corresponds to the nano-range. The reduced droplet size in nanoemulsions minimizes common stability issues such as creaming, sedimentation, and flocculation during storage [15].

Gago et al. [15,42] previously reported that nanoemulsions based on alginate combined with lemongrass or citral alone had lower droplet sizes. However, the inclusion of eugenol in the formulations led to increased droplet sizes, as observed in this study, while remaining within the nano-range. This increase in droplet size can be attributed to factors such as molecular structure, concentration of volatile compounds, interfacial tension, and surfactant affinity for specific essential oils (EOs) or their primary components [43].

Regarding the polydispersity index (PDI), two key variables influence its interpretation: higher PDI values indicate less uniform droplet sizes, whereas PDI values below 0.3 denote good particle size uniformity [15]. The highest PDI value in this study was observed for SAlg Ct 0.15 Eg 0.1 Coarse (0.82), while the lowest was recorded for SAlg Ct 0.3 Eg 0.2 Nano (0.62) (Table 2). Formulations with higher EO concentrations exhibited lower PDI values, suggesting improved droplet uniformity. These findings align with Gago et al. [42], although Yang et al. [44] and Salvia-Trujillo et al. [45] reported approximately half

of these values. Such discrepancies may stem from differences in the emulsion production process, which significantly influences droplet uniformity [15].

Table 2. Droplet size (nm), polydispersity index (PDI), and ζ-potential (mV) of coarse emulsions and nanoemulsions.

Emulsions	Droplet Size (nm)	Polydispersity Index (PDI)	ζ-Potential (mv)
SAlg Ct 0.15 Eg 0.1 Nano	236.73± 93.34	0.72 ± 0.08	−17.10 ± 2.40
SAlg-Ct 0.3 Eg 0.2 Nano	181.57 ± 58.42	0.62 ± 0.12	−41.13 ± 0.51
SAlg-Ct 0.15 Eg 0.1 Coarse	1706.67 ± 236.72	0.82 ± 0.12	−80.97 ± 4.30
SAlg-Ct 0.3 Eg 0.2 Coarse	1470.00 ± 101.36	0.72 ± 0.12	−75.53 ± 0.24

The ζ-potential, which measures the electrostatic interactions between particles, revealed unexpected results. Coarse emulsions displayed superior ζ-potential values (−80.97 ± 4.30 mV for SAlg Ct 0.15 Eg 0.1 Coarse and −75.53 ± 0.24 mV for SAlg Ct 0.3 Eg 0.2 Coarse) compared to nanoemulsions (−17.10 ± 2.40 mV to −41.13 ± 0.51 mV). According to Heurtault et al. [46], particles with ζ-potential values exceeding ±30 mV are generally considered stable due to the strong repulsive forces between droplets, typical of nanoemulsion systems. The observed variability may be linked to the type and concentration of the essential oils used, which affect the degree of dissociation and the presence of ionizable components in the emulsions [42].

These findings underscore the critical influence of the preparation method on emulsion characteristics, highlighting its role as a primary determinant of structural and stability properties.

3.2. General Quality Parameters of Fruits

3.2.1. Color

The results obtained from the CIE colorimetric analyses throughout the storage period were consistent with the visual observations (Figure 2). Regarding lightness (L*), a slight decrease in the value of fruit skin was observed across all treatments over time. This reduction can be attributed to the presence of specific compounds in the fruit, such as pigments, amino acids, and phenolic compounds, which are known to contribute to enzymatic browning and a decrease in luminosity (L* values) within the CIELab color scale [47]. Despite this decline, the reduction was marginal and did not significantly affect the external appearance of fruit. Statistically significant differences were observed at the end of the four-week storage period, with the treatments SALg Ct 0.15 Eg 0.1 Coarse Dip and SALg Ct 0.3 Eg 0.2 Nano Dip showing the highest L* values.

Greenness was assessed using the hue angle (h°), which ranged between 114 and 118. The color changes in green kiwifruit are predominantly characterized by quantitative parameters like h° rather than qualitative shifts [48]. In this study, the hue angle remained stable throughout the storage period, aligning with the expected values for kiwifruit harvested at the optimal maturity stage.

Chroma (C*), a metric of color intensity, reflects the degree of differentiation between a specific hue and a neutral gray with identical lightness. Higher chroma values indicate more intense colors as perceived by the human eye [47]. Overall, chroma values decreased with storage time. Although no significant differences were observed between treatments at the start of the experiment, a marked decline in chroma was recorded after four weeks. Treatments SALg Ct 0.15 Eg 0.1 Nano Spray and SALg Ct 0.3 Eg 0.2 Coarse Spray showed the highest chroma values and the least variation during storage. These

results indicate that kiwifruit progressively loses color intensity over time, regardless of the treatments applied.

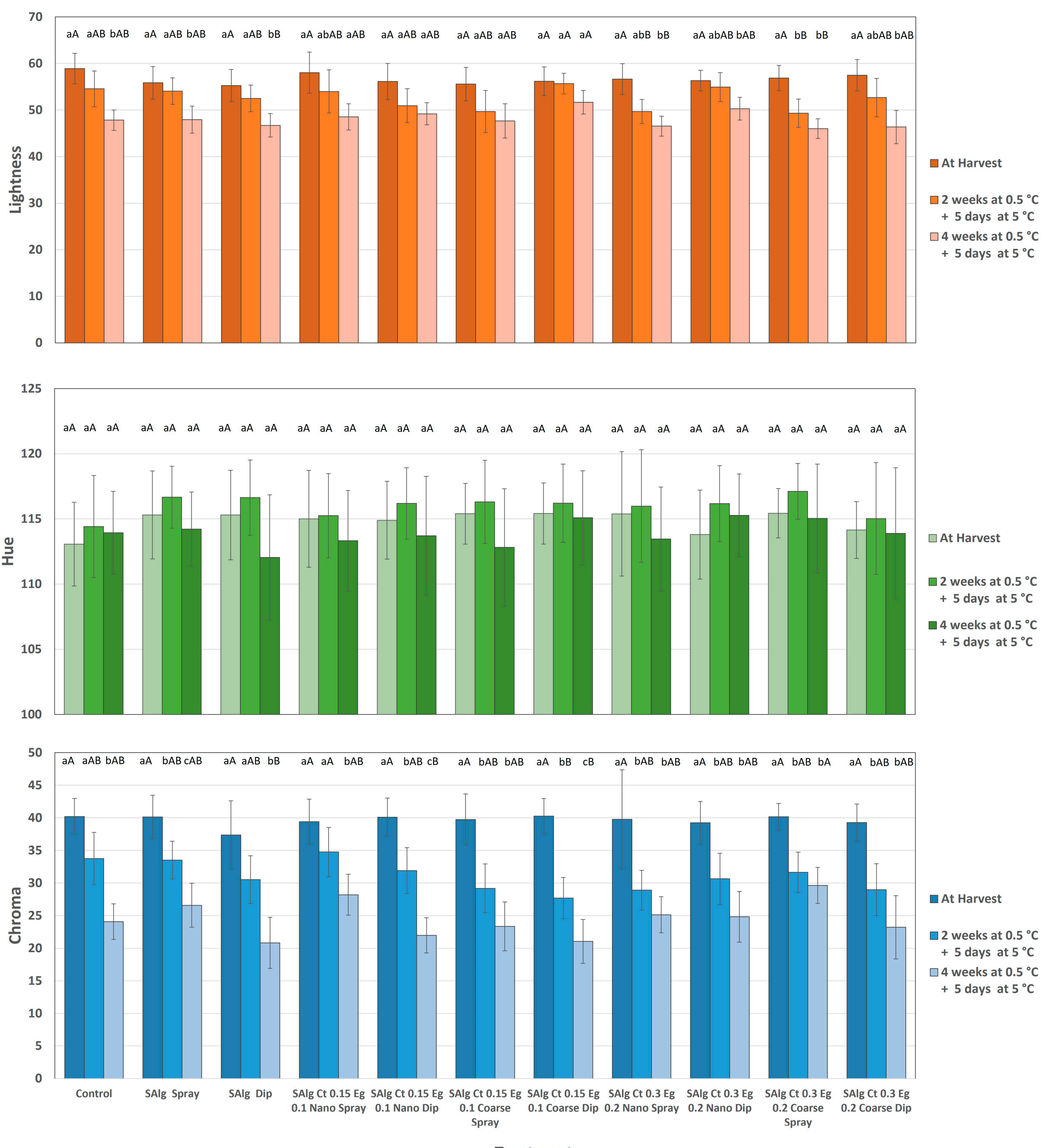


Figure 2. Color parameters L*, hue, and chroma of kiwiberries covered with different alginate-based emulsions during storage. Parameters were evaluated at harvest (before treatments) and after 2 and 4 weeks followed by 5 days at 5 °C. Values represent the mean ± standard deviation of three replicates. For each storage period, bars with different lowercase letters show significant differences among storage periods for the same treatment, while capital letters indicate significant differences among treatments according to a Duncan's multiple range test ($p < 0.05$).

Based on the lightness, hue, and chroma graphs, the treatments that remained closest to the initial state (at harvest) were those with the smallest variations in these parameters

throughout the storage period. In general, the fruits darkened during storage, transitioning from an intense green to a darker green by the end of the period. The results also indicate that the SAIg Spray and SAIg Dip treatments were the most effective in preserving the fruits' initial visual characteristics during storage. Specifically, for lightness, these treatments exhibited the smallest reductions compared to the values observed at harvest. Regarding hue, the differences between the treatments and the initial state were minimal, suggesting a consistent preservation of color tone. For chroma, SAIg Spray and SAIg Ct 0.15 Eg 0.1 Nano Spray treatments stood out by maintaining color saturation closest to the initial levels. These findings are consistent with those reported by Fisk et al. [17], Stefaniak et al. [49], and Mendes da Silva et al. [48], who observed similar color changes in their studies.

3.2.2. Firmness and SSC

The recommended optimal harvesting period for green kiwiberries is when the SSC (soluble solid content) of the fruit reaches 6.5% [9,50]. The soluble solid content (SSC) gradually increased over time (Figure 3), as would be expected for a climacteric fruit harvested at optimum maturity. At harvest, the fruit had a brix of 6.5%. After two weeks of storage, there was a rapid increase in all treatments, peaking at around 15%. By the end of the fourth week of storage, the differences among treatments were minimal, with values around 16%. There were no differences in the treatments applied or the method of emulsion application at the end of the storage period. The observed changes are similar to those obtained in the studies by Krupa et al. [3], Stefaniak et al. [49], and Han et al. [50].

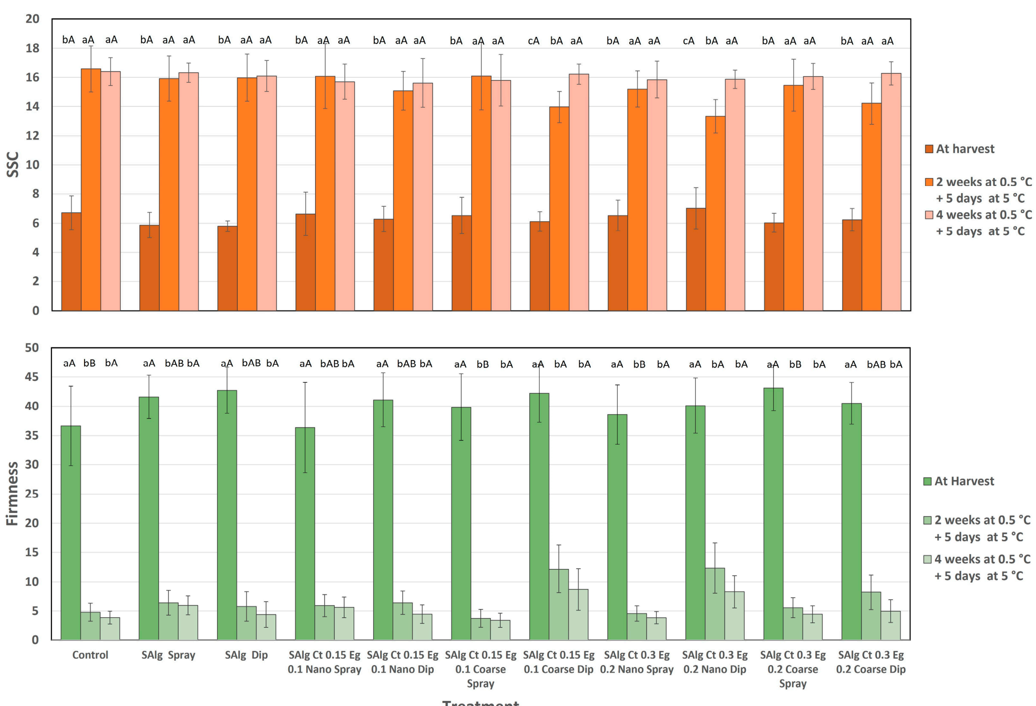


Figure 3. Firmness (N) and soluble solid content (SSC in °Brix) of kiwiberries covered with different alginate-based emulsions. Parameters were evaluated at harvest (before treatments) and after 2 and 4 weeks followed by 5 days at 5 °C. Values represent the mean ± standard deviation of three replicates. For each storage period, bars with different lowercase letters show significant differences among storage periods for the same treatment, while capital letters indicate significant differences among treatments according to a Duncan's multiple range test ($p < 0.05$).

Firmness, along with SSC, are probably the best predictors of kiwifruit ripening and shelf life [51,52]. According to the results obtained for firmness (Figure 3), it was observed that the values decreased over time in all analyzed samples. There was a marked decrease

at two weeks of storage and a slight decrease at the end of the fourth week of storage. The treatments SALg Ct 0.15 Eg 0.1 Coarse Dip and SALg Ct 0.3 Eg 0.2 Nano Dip present slightly higher values at the end of the storage period, but these are not statistically significant. The loss of firmness is a physiological process that occurs during ripening and directly affects postharvest. Short-term storage is a major problem for kiwiberries, as firmness decreases significantly during storage [3]. Fisk et al. [9], Stefaniak et al. [49], Burdon et al. [53], Krupa et al. [54], and Oh et al. [7] obtained similar results over the same storage times, even though different cultivars were used.

It is interesting to note that, in kiwiberry, similar to "Hayward" kiwifruit, the most significant increase in SSC (soluble solid content) and decrease in firmness occurred during the first half of the storage period, with only slight changes observed afterward [55].

3.2.3. Weight Loss and Dry Matter Content

The Organisation for Economic Co-operation and Development (OECD) [56] recommends an average dry matter content (DMC) of approximately 15% at harvest for high-quality fruits. In this study, the DMC ranged between 15% and 20% (Figure 4). The values remained stable throughout the storage period, and no significant effect was observed regarding the type of emulsion or the application methodology on this quality parameter.

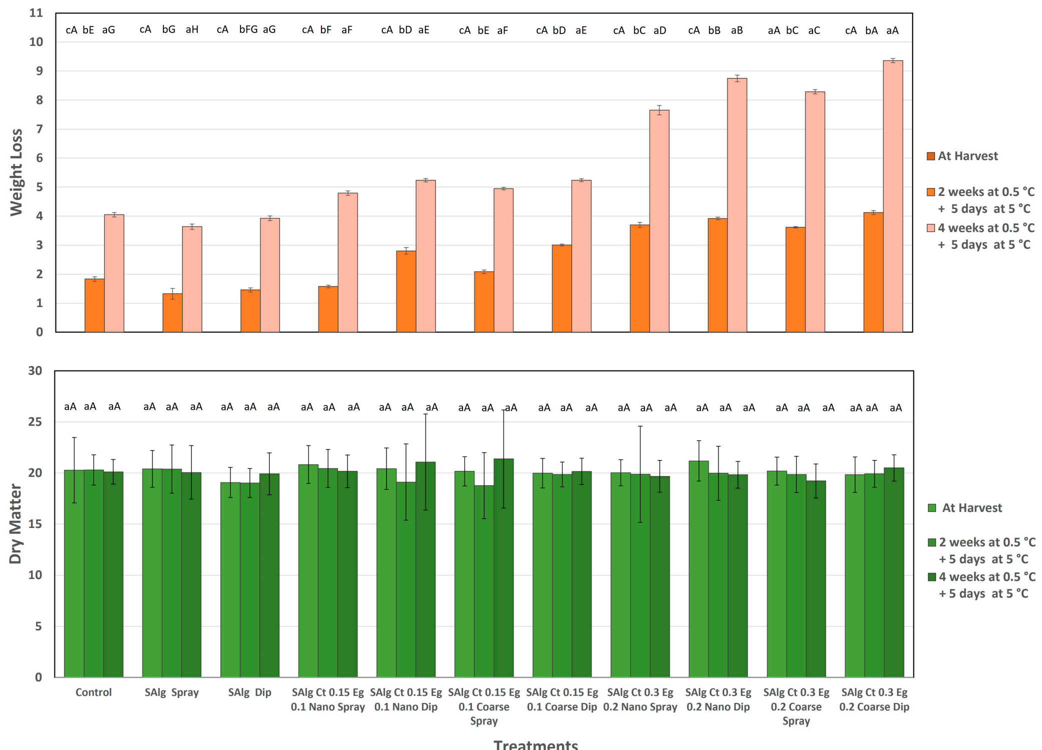


Figure 4. Weight loss (%) and dry matter content (%) of kiwiberries covered with different alginate-based emulsions. Parameters were evaluated at harvest (before treatments) and after 2 and 4 weeks followed by 5 days at 5 °C. Values represent the mean ± standard deviation of three replicates. For each storage period, bars with different lowercase letters show significant differences among storage periods for the same treatment, while capital letters indicate significant differences among treatments according to a Duncan's multiple range test ($p < 0.05$).

Weight loss is indicative of water loss and is closely related to fruit shriveling. Consumer acceptance and fruit freshness are negatively affected when weight loss exceeds 4–5% [57]. In this study, during the first two weeks of storage, although some significant differences were observed among treatments, the fruits displayed low weight loss. How-

ever, by the end of the four-week storage period, a distinct pattern emerged. Fruits treated with formulations containing higher concentrations of essential oils (EOs) showed greater weight loss, while those treated with alginate alone, without EOs, exhibited significantly lower weight loss. The application methodology did not significantly influence the results.

The migration of water from the fruit to the surrounding environment is a key factor driving weight loss during storage [58]. Edible coatings provide an additional barrier layer that coats the stomata, thereby reducing transpiration and minimizing weight loss. This effect has been demonstrated across various fruits, including fresh-cut kiwifruit, apples, apricots, peppers, peaches, sweet cherries, and lychees [27,59–61].

Furthermore, the water vapor permeability of polysaccharides used in the formulation of edible coatings plays a significant role in their ability to reduce weight loss. Similar results have been observed in strawberries and raspberries [62,63]. For kiwiberries, previous studies have reported a slight increase in weight loss in untreated fruits [7,20,64].

These findings highlight the importance of polysaccharide-based coatings, particularly those without added EOs, in mitigating weight loss during storage and maintaining postharvest fruit quality.

3.3. Decay and Malondialdehyde (MDA)

Decay is a key indicator of postharvest fruit quality, and its management is critical for extending shelf life and minimizing economic losses [65]. Our results show that decay increased significantly over time across all treatments, with the highest values observed after four weeks of storage at 0.5 °C, followed by five days at 5 °C.

Interestingly, as seen with weight loss, treatments with higher concentrations of essential oils (EOs) exhibited greater decay rates. Although we cannot confirm the mechanism at this stage, we hypothesize that elevated EO concentrations may compromise the integrity of the fruit epidermis, facilitating microbial ingress. Among the treatments analyzed, formulations without EOs demonstrated the best performance in preserving fruit quality (Figure 5).

These findings align with previous studies reporting that prolonged storage under suboptimal conditions accelerates microbial activity and physiological degradation [65,66]. However, alginate-based emulsions, especially those containing lower EO concentrations, effectively mitigated decay compared to the control group. This suggests that the antimicrobial and barrier properties of EOs are essential in delaying fruit spoilage. The effectiveness of EOs likely stems from their ability to disrupt microbial cell membranes, as documented by Yammine et al. [67].

Malondialdehyde (MDA), a marker of lipid peroxidation and oxidative stress, progressively increased during storage in all treatments, with the highest levels observed in the control group. This trend reflects the natural oxidative processes associated with fruit senescence and storage, which are exacerbated under adverse environmental conditions [68].

Treatments with alginate-based emulsions, particularly those incorporating essential oils (EOs), significantly reduced MDA levels compared to the control (Figure 5). This reduction suggests that these treatments effectively mitigated oxidative stress, likely by forming a physical barrier that decreased oxygen permeability and protected cell membranes from oxidative damage [69].

Among the tested treatments, nanoemulsions with lower EO concentrations demonstrated the greatest efficacy in maintaining low MDA levels. This observation may be attributed to the smaller droplet size of nanoemulsions, which enhances the uniformity and effectiveness of the coating. These findings are consistent with reports by Panwar et al. [70], who showed that nanoemulsions improve the distribution of active compounds and enhance their bioactivity. However, further investigations are necessary to

elucidate the specific mechanisms involved and to optimize formulation parameters for maximum efficacy.

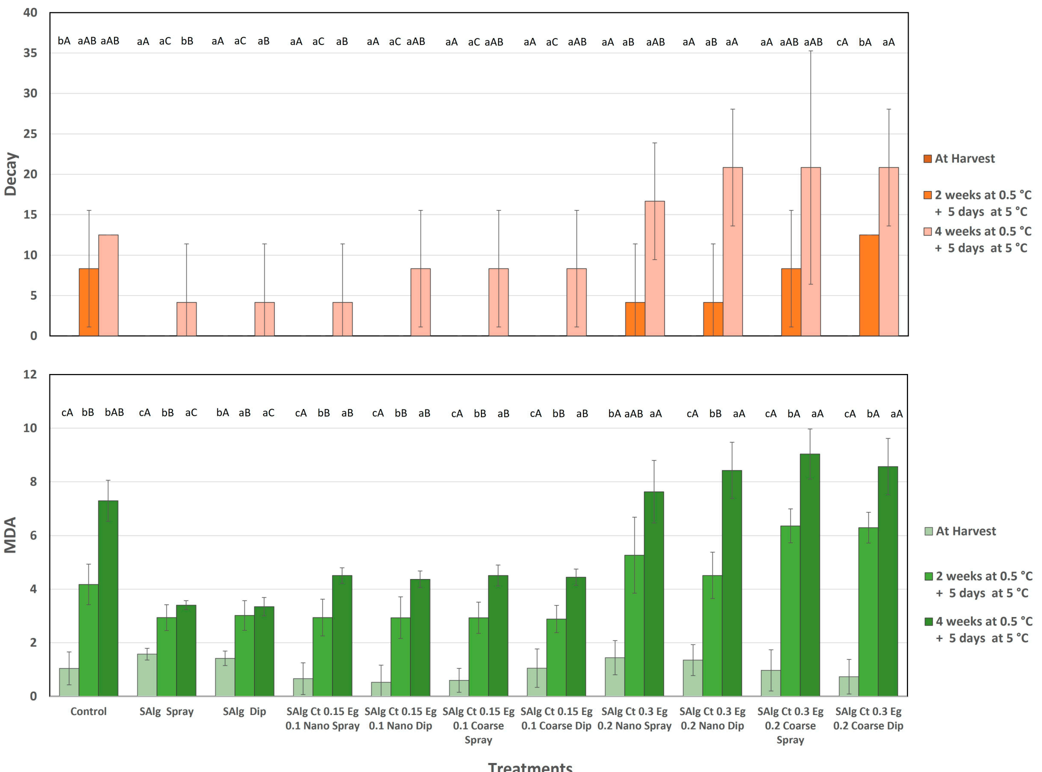


Figure 5. Decay (%) and MDA (mol g^{-1}) of kiwiberries covered with different alginate-based emulsions. Parameters were evaluated at harvest (before treatments) and after 2 and 4 weeks followed by 5 days at 5 °C. Values represent the mean ± standard deviation of three replicates. For each storage period, bars with different lowercase letters show significant differences among storage periods for the same treatment, while capital letters indicate significant differences among treatments according to a Duncan's multiple range test ($p < 0.05$).

The results presented in this study align with the values and trends reported by Wang et al. [71] and Xiong et al. [32]. Interestingly, the contrasting patterns observed between decay and MDA levels highlight that while both parameters are influenced by storage duration and treatment, they respond differently to external factors.

3.4. Total Phenolic Content and Flavonoids

The preservation of bioactive compounds, such as total phenolic content (TPC) and flavonoids, is crucial for maintaining the nutritional and antioxidant quality of fruits during storage. The results, presented in two graphics (Figure 6), compare the concentration of TPC and flavonoids across different treatments throughout the storage period.

Regarding TPC, its levels remained stable during storage across all treatments, with minimal fluctuations. Treatments containing emulsions with higher concentrations of essential oils (SAIg Ct 0.3 Eg 0.2, both in the Nano and Coarse formulations) exhibited slightly higher TPC values at the end of the storage period, indicating a potential protective effect of these formulations. In contrast, the control treatment showed lower TPC values, suggesting that the absence of emulsions may accelerate the degradation of phenolic compounds. Among the treatments, SAIg Ct 0.3 Eg 0.2 Nano Dip and Nano Spray were the most effective in preserving or even increasing TPC levels during storage. These findings highlight the potential of nanoemulsions to minimize the loss of phenolic compounds,

likely due to their ability to form more uniform protective barriers and control the release of active compounds.

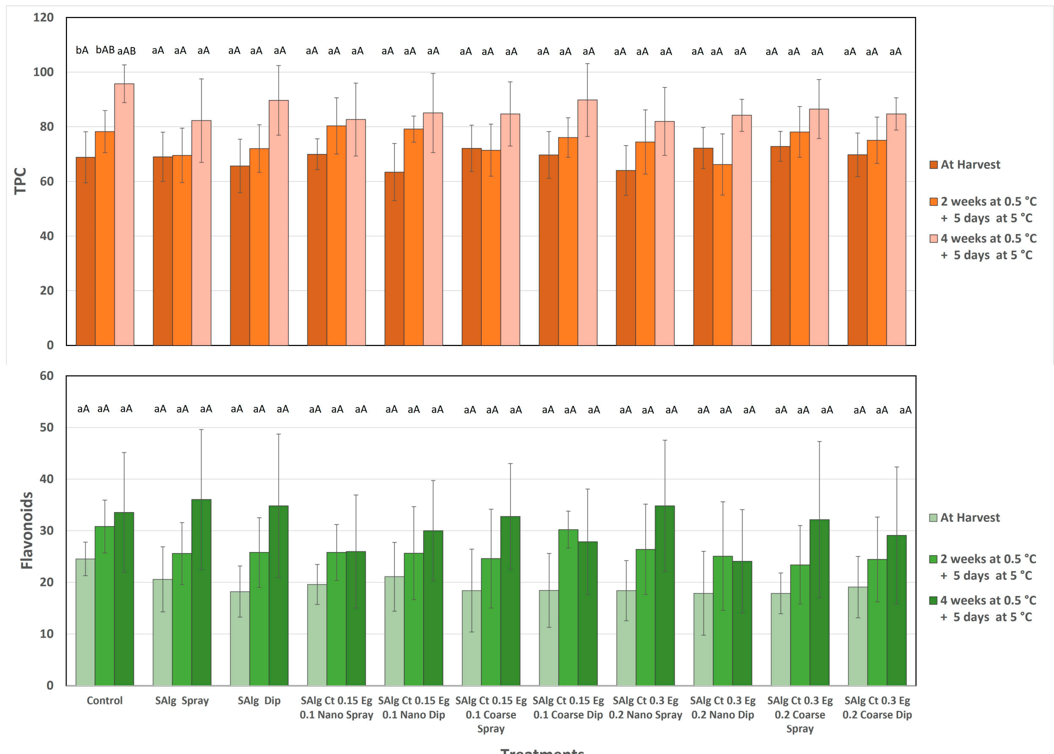


Figure 6. Total phenol content (mg 100 g^{-1} FW) and flavonoids content (mg 100 g^{-1} FW) of kiwiberries covered with different alginate-based emulsions. Parameters were evaluated at harvest (before treatments) and after 2 and 4 weeks followed by 5 days at 5 °C. Values represent the mean ± standard deviation of three replicates. For each storage period, bars with different lowercase letters show significant differences among storage periods for the same treatment, while capital letters indicate significant differences among treatments according to a Duncan's multiple range test ($p < 0.05$).

Flavonoid levels, on the other hand, showed an increasing trend during storage, particularly in treatments containing emulsions with essential oils. This trend was most pronounced in treatments SAlg Ct 0.3 Eg 0.2 Nano and Coarse, which displayed the highest flavonoid concentrations at the end of the storage period. In contrast, the control treatment and emulsions without essential oils recorded the lowest flavonoid levels, suggesting that the absence of active compounds in the formulations limits their effectiveness in preserving these bioactives. Similar to TPC, the treatments SAlg Ct 0.3 Eg 0.2 Nano Dip and Nano Spray were the most effective in retaining and enhancing flavonoid concentrations during storage.

Similar trends have been observed in studies on *Actinidia arguta*, where phenolic compounds were shown to play a significant role in the fruit's antioxidant properties and response to postharvest treatments [1,71,72].

3.5. Antioxidant Activity

Figure 7 shows the evolution of antioxidant capacity through storage and treatments as determined by the FRAP (ferric reducing antioxidant power) and DPPH (2,2-diphenyl-1-picrylhydrazyl) techniques.

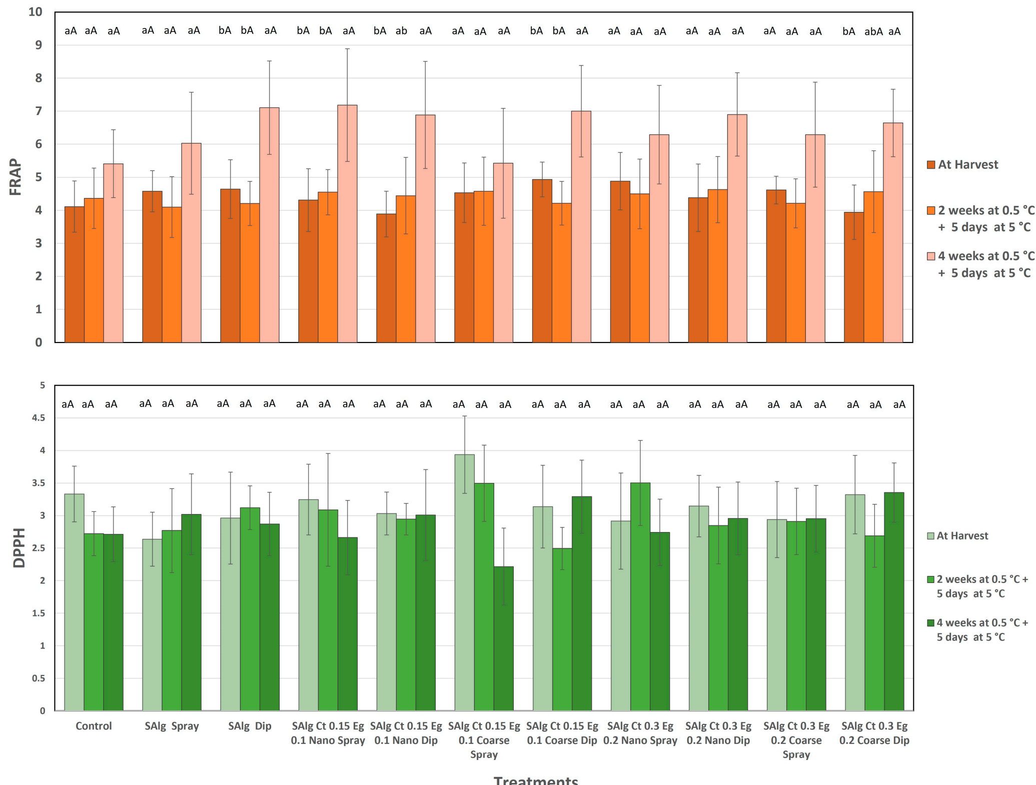


Figure 7. FRAP (µm of Fe^{2+} mL^{-1}) and DPPH (µM TE g^{-1}) of kiwiberries covered with different alginate-based emulsions. Parameters were evaluated at harvest (before treatments) and after 2 and 4 weeks followed by 5 days at 5 °C. Values represent the mean ± standard deviation of three replicates. For each storage period, bars with different lowercase letters show significant differences among storage periods for the same treatment, while capital letters indicate significant differences among treatments according to a Duncan's multiple range test ($p < 0.05$).

For FRAP, the results show consistent variations among treatments and storage times. The initial antioxidant capacity (at harvest) was relatively high for most treatments, with those involving bioactive compounds, such as sodium alginate alone (SAlg) and combinations with nanoparticles, demonstrating prominent performance. During storage (2 and 4 weeks at 0.5 °C followed by 5 days at 5 °C), the antioxidant capacity exhibited variable trends. While some treatments, such as those with nanoparticles applied via spray, maintained relatively stable levels, others, such as treatments involving dipping, showed a slight reduction after 4 weeks. The combined treatment SAlg + Ct 0.3 Eg 0.2 Spray preserved the highest antioxidant levels over time, suggesting a potential synergy between the compounds used and the application method. These findings indicate that the stabilization of antioxidant capacity is influenced by both the type of compound and the treatment method.

For DPPH, a similar trend was observed, with a slight decrease in antioxidant capacity during prolonged storage depending on the treatment. Treatments involving SAlg and nanoparticle combinations also showed better performance in maintaining antioxidant activity. In particular, the SAlg + Ct 0.15 Eg 0.1 Nano Spray treatment maintained high antioxidant activity even after 4 weeks of storage. Interestingly, the difference between application methods (dipping vs. spraying) was more pronounced for DPPH, with spraying proving more effective in preserving antioxidant capacity. This may be attributed to better uniformity and penetration of the antioxidant compounds during spray application.

Comparing the FRAP and DPPH methods, both highlighted the importance of treatment type in preserving antioxidant properties during storage. While there were some

differences in absolute values, the overall trends were consistent, underscoring the reliability of the applied treatments in extending antioxidant quality. In both methodologies, there were no statistically significant differences between the treatments. According to Pinto et al. [1], we obtained values slightly lower than those described by them but similar to those of Figiel-Kroczyńska et al. [73], Leontowicz et al. [74], and Wojdyło et al. [75].

3.6. Spectral Analysis

To investigate if the different types of coatings were distinguishable from a spectral point of view, the spectra obtained in fruit at the beginning of the experiment (week 0) were analyzed. Restraining this analysis to the 330 fruit (30 fruit per class) sampled in week 0 allows the separation of ripening effects and effectively focuses the onus of the analysis on the coating treatments.

Univariate and multivariate approaches were used. In the univariate approach, a t-test in the absorbance spectra (A = log(1/R), where R is the reflectance) was conducted between the control group and all the other groups. The test was performed for each wavelength. The results are depicted in Figure 8. The area plot shows the average variation in absorbance between the coating and control groups (the coating group absorbs more than the control in the wavelengths where the area plot is positive). The gray bands mark the regions where the average spectra are different with a 95% confidence level, and the dashed bands mark the regions where the normality assumption does not hold, as evaluated by the Jarques–Bera test [76]. In these regions, the results of the t-test may not hold.

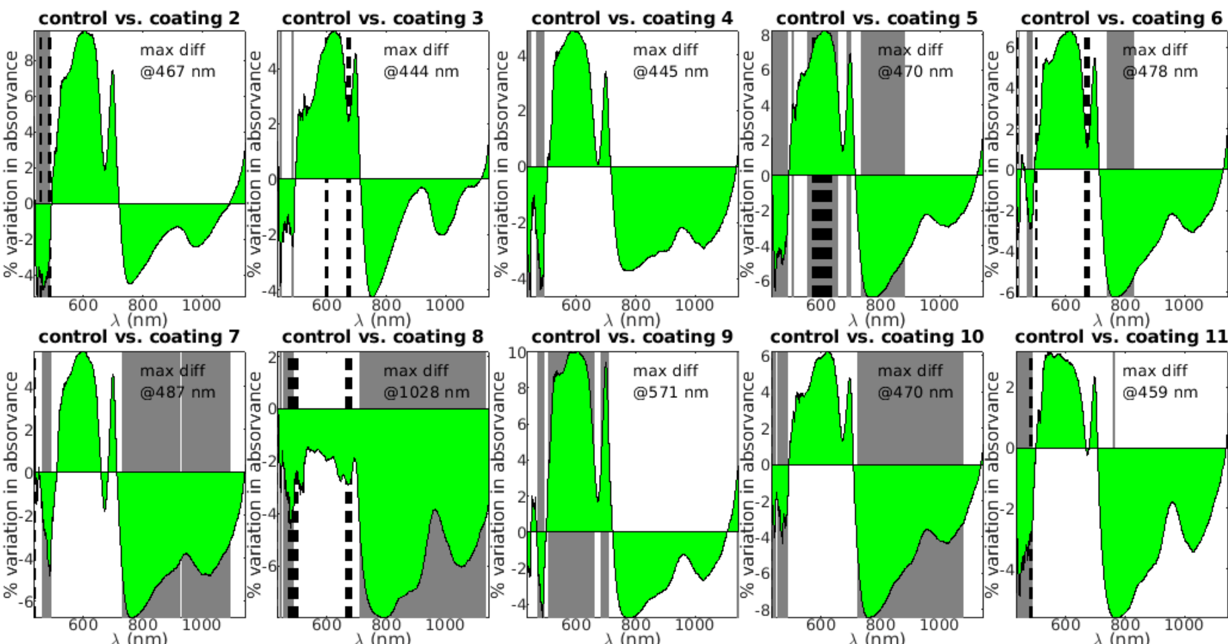
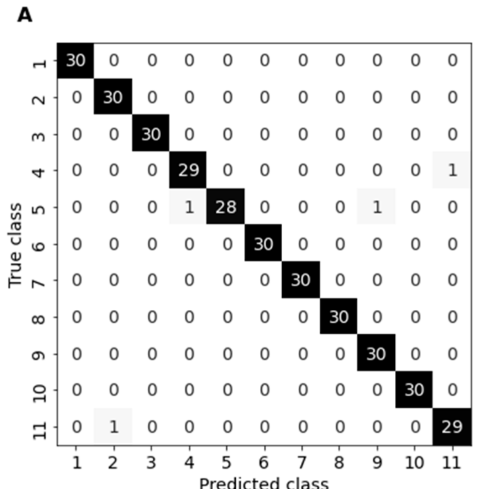


Figure 8. T-tests in the absorbance spectra between the control group and all the other groups. The test was performed for each wavelength. The area plot shows the average variation in absorbance between the coating and control (coating–control). The gray bands mark the regions where the average spectra are different with a 95% confidence level, and the dashed bands mark the regions where the normality assumption does not hold. The wavelength with maximal difference between the groups is indicated by "max diff".

Except for coating 9, the general pattern is the same for all the other coatings: (i) a decrease in absorption below approximately 500 nm; (ii) an increase in absorption between approximately 500 nm and 720 nm; and (iii) a decrease in absorption from 720 nm onwards. Since carotenoids absorb mainly up to 500 nm, observation (i) suggests that carotenoid

content is higher in the control, meaning that the coating promotes its degradation, while observation (ii) suggests, on the contrary, that the coating extends the lifetime of chlorophyll. Finally, observation (iii) shows that in all, the NIR plateau is affected, pointing to a global change in tissue structure, possibly increasing scattering and reflection. This would translate into a decrease in absorption since absorption and reflectance are inversely related. It is interesting to note that the baseline of the NIR plateau is indented at the water peak around 960 nm. Because of the dominant NIR plateau shift, it is not clear if water loss is reduced by the coating. The NIR plateau shift is so important in coating 8 that it brings all the spectral amplitudes down. This points to drastic tissue structural changes. Finally, it is also interesting to note that for almost all the coatings (except 8 and 9), the largest difference between the groups is below 500 nm. This suggests that the more important changes occur in the pigments, especially in the carotenoids.

For the multivariate analysis, the different treatments were used as labels for a classification problem, where the independent variables are the 1024 spectral features/wavelengths in the range of 432 nm to 1146 nm. A linear discriminant analysis (LDA) with 10 components was used as a classifier. The LDA algorithm focuses on maximizing the separability between the classes by fitting class conditional densities to the data and using Bayes' rule to establish decision boundaries [77]. Using the reflectance spectra (with no preprocessing applied) as input and a fivefold cross-validation approach, the LDA classifier attains 99 ± 0.01% accuracy. Figure 9A shows the confusion matrix for the several treatments/classes, while Figure 9B portrays the first two LDA components where most classes are evenly separated (even though this is a low-dimensional representation of the clusters).



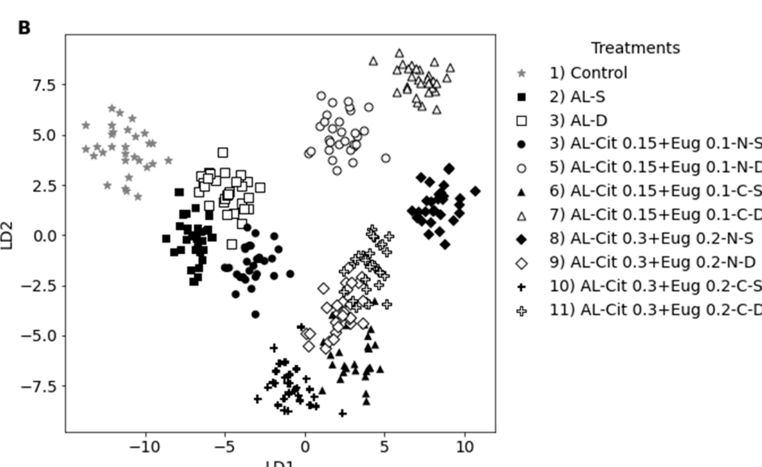


Figure 9. (**A**) Confusion matrix of the LDA classifier for fruit in week 0 (off-diagonal numbers represent wrong predictions). (**B**) LDA dimensional reduction using the first two components. Gray stars correspond to the control group, while black and white symbols help distinguish between the sprayed and dipped treatment variants.

This analysis suggests that the reflectance spectra acquired provide sufficient information for accurate classification of the different treatments. Similar analyses conducted at weeks 2 and 4 revealed a slight decrease in accuracy, to 97 ± 0.04%, along with a markedly different low-dimensional representation in the LDA.

3.7. Statistical Analysis

Considering the results obtained, the statistical analysis was performed in two phases. First, we examined the different correlations between the analyzed variables, and then

we proceeded to assess the effect of the treatments over the storage time to identify their differences through principal component analysis (PCA).

Figure 10 presents the correlation matrix of the physicochemical and biochemical variables analyzed, represented as a heatmap. The correlations were calculated using Pearson's correlation coefficient, allowing for the identification of linear associations between the evaluated variables.

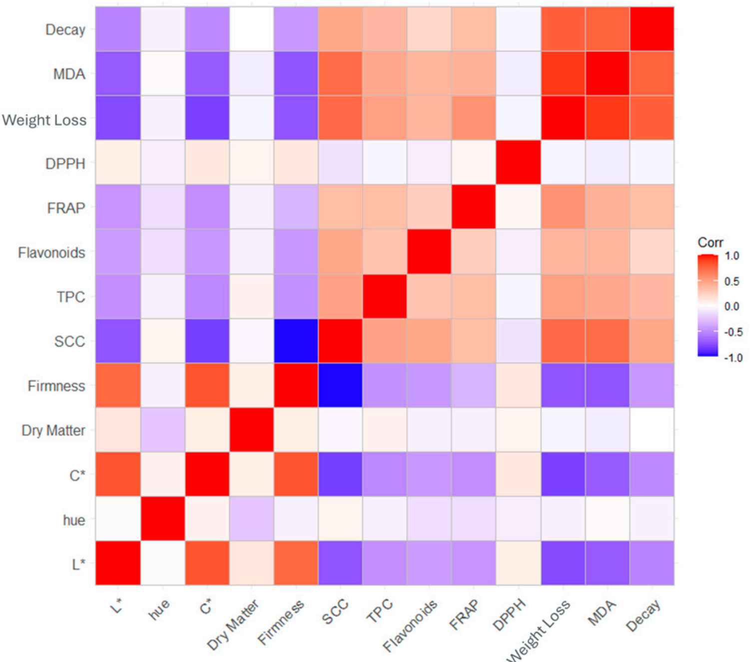


Figure 10. Heatmap of Pearson's correlation coefficients between the physicochemical and biochemical variables. Positive correlations are represented by red tones, while negative correlations are represented by blue tones. The intensity of the color indicates the strength of the correlation, ranging from −1 (strong negative correlation) to +1 (strong positive correlation).

The colors in the heatmap range from blue (negative correlations) to red (positive correlations), with the intensity of the color indicating the strength of the correlation. Correlations close to 1 or −1 denote strong positive or negative associations, respectively, while values near 0 indicate a weak or no association.

Among the most notable results, a strong positive correlation was observed between dry matter and firmness ($r > 0.8$), suggesting that fruits with higher solid content tend to be firmer. This relationship aligns with previous studies indicating that dry matter contributes to cell structure, directly influencing fruit firmness.

Conversely, a significant negative correlation was found between decay and firmness ($r < -0.7$), indicating that firmer fruits are less susceptible to deterioration. This finding supports the hypothesis that fruits with greater structural integrity exhibit higher resistance to degradation processes, such as enzymatic activity or microbial colonization.

Furthermore, total phenolic content (TPC) showed moderate positive correlations with the variables related to antioxidant capacity, such as FRAP and DPPH ($0.5 < r < 0.7$), confirming the role of these compounds in the antioxidant activity of the fruit. On the other hand, a negative correlation was observed between TPC and weight loss, which may suggest that fruits with higher phenolic content retain more water or undergo less degradation during storage.

Relationships between the color parameters (L*, C*, and hue) and biochemical variables were also evident. For instance, hue exhibited moderate negative correlations with

malondialdehyde (MDA), a marker of oxidative stress, suggesting that color changes may be associated with oxidative degradation processes.

These results highlight important interrelationships between the physicochemical and biochemical variables analyzed, providing insights into the factors affecting fruit quality during storage. The correlation analysis enables the identification of potential quality indicators that can be utilized in monitoring and improving postharvest management programs.

Principal component analysis (PCA) was conducted to explore the variability and interrelationships among the physicochemical and biochemical variables analyzed, as well as to identify differences between the samples. Figure 11A presents the distribution of the samples in the two-dimensional space defined by the first two principal components, while Figure 11B displays the biplot, showing the contributions of the variables to these components. The first principal component (Dim1) explained 31.1% of the total variability, while the second component (Dim2) explained 24.3%. Together, these two components captured 55.4% of the total variability, providing a comprehensive overview of the patterns within the data.

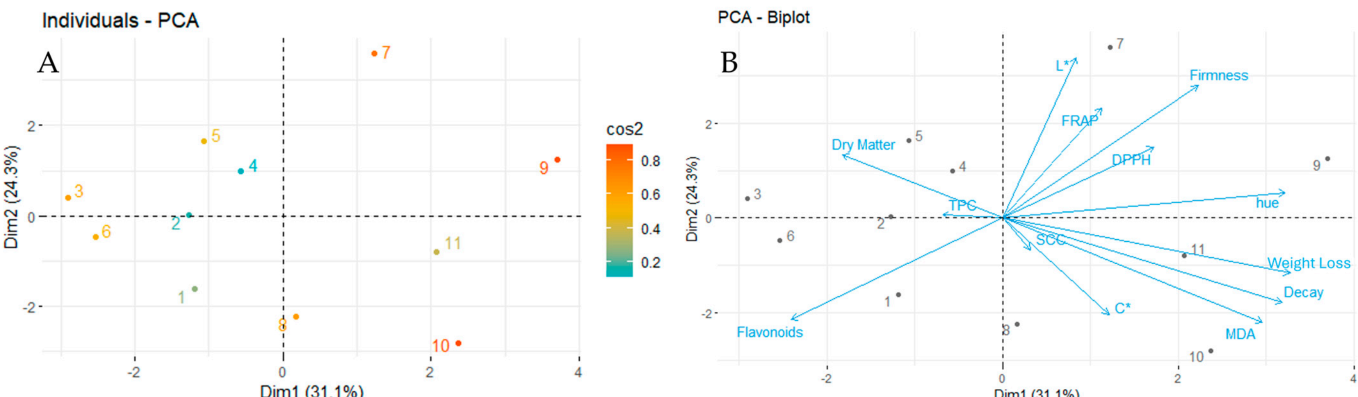


Figure 11. (**A**). Scatter plot representing the distribution of samples in the two-dimensional space defined by the first two principal components (Dim1 and Dim2). Each point corresponds to a sample, with the size and color intensity indicating the cos2 values (quality of representation). (**B**) Biplot combining the distribution of samples and the contribution of variables to the first two principal components. Arrows indicate the direction and strength of each variable's contribution, with longer arrows representing stronger associations.

In Figure 11A, the samples are distributed based on their physicochemical and biochemical characteristics, with the intensity and size of the points representing the cos2 values (quality of representation in the PCA space). It was observed that samples such as 9 (SAlg Ct 0.3 Eg 0.2 Nano Dip), and 10 (SAlg Ct 0.3 Eg 0.2 Coarse Spray) contributed strongly to Dim1, while sample 7 (SAlg Ct 0.15 Eg 0.1 Coarse Dip) exhibited a higher variability along Dim2. Proximal samples, such as 8 (SAlg Ct 0.3 Eg 0.2 Nano Spray) and 11(SAlg Ct 0.3 Eg 0.2 Coarse Dip), indicate similar profiles, whereas more dispersed samples, such as 7 (SAlg Ct 0.15 Eg 0.1 Coarse Dip, 9(SAlg Ct 0.3 Eg 0.2 Nano Dip), and 10 (SAlg Ct 0.3 Eg 0.2 Coarse Spray), possess unique characteristics that differentiate them from the others.

Figure 11B, which combines the sample distribution with the variables, allows for a more detailed interpretation of the relationships among the factors analyzed. Variables such as hue, firmness, and decay contributed positively to Dim1, whereas flavonoids and dry matter were more negatively aligned with this component. This pattern suggests that Dim1 reflects a combination of properties related to structural integrity and degradation processes. In contrast, Dim2 was strongly influenced by antioxidant variables, such as FRAP and

DPPH, along with L*, indicating that this component is associated with antioxidant capacity and visual quality parameters. The proximity of vectors such as TPC (total phenolic content) and SCC (soluble solid content) reinforces the role of these compounds in the functional quality of the fruits.

Differences among the samples were also evident in the graphs. Samples 9 (SAlg Ct 0.3 Eg 0.2 Nano Dip) and 10 (SAlg Ct 0.3 Eg 0.2 Coarse Spray), located at the positive end of Dim1, showed high values for variables such as hue, decay, and firmness, indicating that they may be associated with an advanced stage of ripening or degradation. On the other hand, samples 1 (control) and 6 (SAlg Ct 0.15 Eg 0.1 Coarse Spray), located at the negative end of Dim1, stood out for their high levels of flavonoids and dry matter, suggesting that these fruit are more mature.

Separation along Dim2 was also significant. Sample 7 (SAlg Ct 0.15 Eg 0.1 Coarse Dip), at the positive extreme, was strongly associated with FRAP, DPPH, and L*, suggesting high antioxidant capacity and prominent changes in visual attributes, particularly color. In contrast, samples 2 (SAlg Spray), 3 (SAlg Dip), 4 (SAlg Ct 0.15 Eg 0.1 Nano Spray), and 5 (SAlg Ct 0.15 Eg 0.1 Nano Dip), located in the negative region of Dim2, exhibited lower antioxidant activity and reduced luminosity, potentially reflecting less mature fruit.

Overall, the dispersion and clustering of samples in the PCA space revealed heterogeneous physicochemical and biochemical profiles, likely influenced by ripening stage, applied treatments, or genetic variations among the fruit. Samples such as 9 and 10, associated with high levels of decay and weight loss, represented fruits at advanced degradation stages. The biplot further emphasized the key relationships among variables, such as the positive correlation between TPC, FRAP, and DPPH, reinforcing the central role of phenolic compounds in the antioxidant capacity of the fruits.

4. Conclusions

In this study, we demonstrated that fresh kiwiberry (*Actinidia arguta* cv. Ken's Red) can be preserved for up to four weeks at 0.5 °C, followed by an additional five days of shelf life at ~5 °C, while maintaining acceptable quality. This conclusion is supported by the qualitative and quantitative analyses of fruit parameters throughout the storage period. Our findings indicate that the use of coarse emulsions or nanoemulsions, as well as the method of application, did not significantly affect the evaluated parameters. However, the concentration of essential oils (EOs) in the emulsions emerged as a key determinant of fruit quality, with higher EO concentrations (double the MIC) negatively impacting shelf life and visual appearance, primarily due to increased weight loss.

Emulsions with optimized EO concentrations proved to be effective natural postharvest treatments, delaying senescence and preserving kiwiberry quality for up to four weeks at 0.5 °C. Among the tested formulations, SALg Spray, SALg Dip, SALg Ct 0.15 Eg 0.1 Nano Spray, SALg Ct 0.15 Eg 0.1 Nano Dip, and SALg Ct 0.15 Eg 0.1 Coarse Dip consistently outperformed the control, showing superior performance in reducing weight loss, decay, and MDA and maintaining overall fruit quality.

Spectral analysis using Vis-NIR spectroscopy further highlighted that (i) significant differences in the spectra are found for all coatings, pointing to some chemical and structural changes either in the skin or pulp; (ii) the coatings with better performance (treatments SALg Spray, SALg Dip, and SALg Ct 0.15 Eg 0.1 Nano Spray) are also those with better *t*-test comparations, with limited spectral changes, and only below 500 nm; (iii) the other coatings tend to also show differences in the NIR plateau, indicating important tissue changes; and (iv) the Vis-NIR spectral analysis could be used in situations where coating discrimination needs to be performed, e.g., commercial control of coated/non-coated fruit.

In conclusion, these findings highlight the potential of properly formulated emulsions as natural and effective postharvest treatments for extending the storage life of kiwiberries while preserving their quality. Future studies should further explore the interactions between coatings and fruit tissues and evaluate their scalability for commercial applications.

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Data Availability Statement: The original contributions presented in this study are included in the article; further inquiries can be directed to the corresponding author.

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

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