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Efficacy of Edible Coatings in Alleviating Shrivel and Maintaining Quality of Japanese Plum (*Prunus salicina* Lindl.) during Export and Shelf Life Conditions

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Abstract: The effect of six edible coatings were investigated on the ability to alleviate shrivel and extend shelf life of plums. Fruit were subjected to a simulated shipping period (-0.5 ± 2 °C and $90 \pm 5\%$ relative humidity (RH)) for five weeks and a subsequent shelf life period (20 ± 2 °C and $80 \pm 5\%$ RH) for 20 d. Overall, the study showed that it is possible to alleviate shrivel and also extend shelf life of plum ('African Delight™') at export and shelf life conditions. Amongst the edible coatings investigated, the findings in fruit coated with gum arabic and the commercial products were comparable and promising for postharvest preservation of the investigated plum cultivar. The coatings showed a moderate delay of fruit ripening, significantly reduced weight loss and shrivel development, allowing for the export of fruit over a long distance (five weeks) and up to 20 d of shelf life.

Keywords: respiration; volatiles; South Africa; stone fruit; postharvest losses; radical scavenging activity

1. Introduction

The Japanese plum (*Prunus salicina* Lindl.) is one of the most popular stone fruits consumed worldwide [1]. Due to their high nutritional value and desirable taste, the global demand for plums is high. The major exporters of stone fruit are South Africa and Chile in the southern hemisphere, and Spain and Turkey in the northern hemisphere [2]. However, the economic value of the fruit is limited due to its climacteric and highly perishable nature [3,4]. Shrivel is the major physiological disorder in exported plums, rendering fruit unsaleable due to its undesirable appearance [5,6]. As plums lose moisture through transpiration, there is a loss of turgor in the epidermal cells, resulting in an overall reduction in fruit volume and shriveled appearance [5,6].

Additionally, when the fruit is stored at low temperature for extended periods, shrivel development has been reported to occur more rapidly and at a more moderate weight loss [7]. The most popular commercial postharvest technologies for alleviating shrivel and other quality losses in plums are low temperature storage and high density polyethylene (HDPE) bags. However, postharvest losses remain

high in exported plums, as the fruit are subjected to 4 to 6-week shipping period due to long distance to export markets [5]. Thus, additional preservation methods are needed.

Edible coatings (ECs) are alternative storage methods for fresh agricultural produce and are gaining attention because of environmental consideration and the trends towards the use of convenience foods [8]. ECs with semipermeable film can prolong postharvest fruit life through reducing moisture, respiration, gas exchange, and delay changes related to ripening such as fruit softening, color changes, loss of organic acids and the breakdown of starches into sugars [9].

Polysaccharides are most favorable ECs, as they are readily available, allergen-free and usually soluble in water. Furthermore, they have excellent gas barrier and mechanical properties as a result of their well-ordered and tightly packed hydrogen-bonded network structure [10,11]. The application of polysaccharide-based ECs has been proven to be effective in reducing moisture loss and preserving fruit quality during cold storage and shelf life [9]. The addition of lipids to polysaccharide-based ECs has been reported to increase coating hydrophobicity, enhancing the moisture barrier property of polysaccharide-based ECs [6]. However, the addition of lipids could also lead to the development of fermentative volatiles, resulting in undesirable off-flavor in fruit [12,13].

Although, the ability of edible coatings to reduce moisture loss, as well as textural and quality losses in stone fruit has been documented [14–18], only the study by Certel et al. [19] investigated the ability of edible coatings to reduce shrivel in stone fruit. According to the authors, sodium caseinate-milk protein alleviated shrivel in treated cherries stored at 4 °C and 80–85% RH for 20 days. It is therefore necessary to assess the efficacy of ECs in alleviating this economically important physiological disorder in plums. The purpose of this study was to evaluate the effectiveness of lab-formulated polysaccharide-based edible coatings and two commercial imported coatings (not in use in South Africa) on the lessening of shrivel and maintenance of plum quality during export and shelf life conditions.

2. Materials and Methods

2.1. Fruit Procurement and Handling

Plum fruit ('African Delight™') were hand-picked at commercial harvest (mid-February 2018 in Paarl, South Africa, 33.7342° S, 18.9621° E) and transported to the laboratory using an air-conditioned (20 °C) vehicle. Upon arrival, fruit were allowed to equilibrate at ambient temperature remove field heat. Fruit homogenous in size were sorted for blemishes, cracks and bruises, and stored at 2 °C and 90 ± 5% for 2 d before treatment, simulating the commercial packhouse operations.

2.2. Preparation of Edible Coatings

Polysaccharide-based edible coatings; alginate, chitosan, gellan gum and gum arabic (Sigma Aldrich, St. Louis, MO, USA) were used. The coatings were selected based on preliminary studies (data not shown), and formulations that controlled shrivel and delayed ripening of fruit in the preliminary study at ambient storage were chosen for the simulated export storage study. In order to increase the readiness level of this technology, two commercial coating products were imported and included in the trials. These included Sta-fresh (a xanthan gum-based coating made in Lakeland, FL, USA and provided by a local packhouse) and High shine (a carnauba wax-based coating, also containing vegetable oil fatty acid, ammonium hydroxide and potassium hydroxide and food grade silicone anti-foaming made in Wapato, WA, USA). The following formulations were prepared in the specific order and composition, using distilled water (60 °C);

1. Alginate (2% w/v) and canola oil (2% w/v) plus separate preparation of 2% calcium chloride solution as a supplementary dip to initiate cross-linkage
2. Chitosan (1.5% w/v), canola oil (1% w/v), tween-20 (0.05% w/v) and acetic acid (0.5% w/v)
3. Gellan gum (0.5% w/v), canola oil (1% w/v), glycerol (1% w/v) and tween-20 (0.1% w/v)
4. Gum arabic (2% w/v), canola oil (1% w/v) and glycerol (1% w/v)

5.   Sta-fresh was used at 8.75% concentration

6.   High shine was used in concentrated form

7.   Distilled water (control)

2.3. Coating Application

A completely randomized design was used. Seven boxes were used as replicates per treatment and each box contained approximately 50 randomly selected fruits. Coating application was carried out by immersion for 2 min in the prepared treatment solutions (1–7). Fruit were dried for 30 min at 23 ± 2 °C and 55 ± 5% relative humidity (RH) under a stream of air, hand-packaged into double-layer cartons ($3.9 \times 2.9 \times 1.2$ m) with high density polyethylene (HDPE) bags according to industry practice, and stored at -0.5 ± 2 °C and 90 ± 5% relative humidity (RH) for five weeks, simulating the shipping period. The cold storage period was followed by a 20 d shelf life period at 20 ± 2 °C and 75 ± 5% relative humidity (RH). The cartons were opened, and the HDPE bags were removed during this period. All measurements were carried out at weekly intervals during the cold storage period and at 5 d intervals for shelf life period.

2.4. Physiological Disorders and Responses

2.4.1. Weight Loss Percentage

Weight loss of plums during cold storage and shelf life was evaluated by monitoring weight change in fruit at different intervals using an electronic scale (Mettler, Toledo, Greifensee, Switzerland, 0.0001 g accuracy). The results were expressed as the percentage loss of the initial (0 day) weight. Ten fruits per treatment and control were evaluated, and results were expressed as mean ± S.E. of determinations obtained ($n = 20$) per treatment for each interval.

2.4.2. Shrivel Incidence

The quantity of shriveled fruit was visually inspected. Shrivel was counted when the shriveled skin extended over the shoulder of the fruit (Figure 1). Three cartons were used for each treatment, and shrivel incidence was per box ($n = 3$) and calculated as a percentage of shriveled fruit based on the initial fruit [20].

Figure 1. Shriveled versus non-shriveled 'African Delight™' plum.

2.4.3. Respiration Rate

Fruit respiration rate and ethylene production were measured using the closed system method as described by Fawole and Opara [21], with slight modification. Three randomly selected plums were placed in a 1 L hermetically sealed glass jar for 1 h with a lid containing a rubber septum. After incubation, CO_2 production inside each glass jar was measured from the headspace through the rubber

septum using an O_2/CO_2 gas analyzer (Checkmate 3, PBI Dansensor, Ringsted, Denmark). Results were expressed as mean ± S.E. of determinations obtained (n = 20) per treatment for each interval.

2.5. Physicochemical Attributes

2.5.1. Flesh Firmness

Flesh firmness was determined according to the method described by Fawole and Opara [21], with modification. Fruit firmness was measured using a firmness analyzer (GÜSS-FTA, South Africa) fitted with an 11 mm diameter cylindrical probe and operation setting of 14.5 mm penetration at a speed of 10 mm/s. Tests were performed at each interval using 10 randomly selected fruit per treatment. Peak force (N) required to penetrate plum flesh was taken as flesh firmness. Results were expressed as mean ± S.E. of determinations obtained (n = 20) per treatment for each interval.

2.5.2. Peel Color Intensity

External fruit color intensity (C*) was measured on opposite sides of the equatorial region of individual fruit using a Minolta Chroma Meter CR-400 (Minolta Corp, Osaka, Japan). Results (C* values) were expressed as mean ± S.E. of determinations obtained (n = 20) per treatment for each interval [21].

2.5.3. Total Soluble Solids (TSS) and Titratable Acidity

TSS (°Brix) was determined using a digital refractometer (Palette, PR-32 ATAGO, Bellevue, WA, USA) calibrated with distilled water. Titratable acidity (TA, %) was determined using an automated titrator (Metrohm AG 760, Herisau, Switzerland) according to the method described by Fawole and Opara [22]. Pooled juice samples of two fruit per replicate, with five replicates per treatment, were measured. Results were expressed as mean ± S.E. of determinations obtained (n = 5) per treatment for each interval.

2.6. Volatile Analysis

Volatile analysis was performed using the method described by Mphahlele et al. [23], with modification. Samples were prepared by adding 10 mL of a pooled juice sample (two peeled fruit per replication) into a solid phase micro extraction (SPME) vial, followed by 3 mL 20% NaCl solution and 50 μL anisole-d8 (internal standard), before being vortexed and analysed on the GC-MS instrument by SPME-GC-MS with a gray (divinylbenzene, carboxen and polydimethyl siloxane (DVB/CAR/PDMS)) fiber. The volatile separation was performed on a gas chromatograph (6890N, Agilent technologies network) coupled to an Agilent technologies inert XL EI/CI Mass Selective Detector (MSD) (5975B, Agilent Technologies Inc., Palo Alto, CA, USA). The GC-MS system was coupled to a CTC Analytics PAL autosampler. Separation of the plum volatiles was performed on a polar STABILWAX (60 m, 0.25 mm ID, 0.25 μm film thickness) capillary column. Helium was used as the carrier gas at a flow rate of 1 mL/min. The injector temperature was maintained at 240 °C. The oven temperature was programmed as follows: 35 °C for 5 min; and ramped up to 70 °C at a rate of 3 °C/min for 3 min; followed by a ramping rate of 4 °C/min for 5 min until 120 °C and eventually to a maximum temperature of 240 °C at a rate of 10 °C/min and held for 5 min. The MSD was operated in a full scan mode, and the source and quad temperatures were maintained at 230 °C and 150 °C, respectively. The transfer line temperature was maintained at 250 °C. The mass spectrometer was operated under electron impact (EI) mode at ionization energy of 70 eV, scanning from 30 to 500 m/z. All samples were analysed in triplicate. Results were reported as mean peak area percentage at harvest, and at the end of cold storage, at 5 d shelf life and at 20 d shelf life per treatment.

2.7. Phytochemical Analysis

2.7.1. Total Phenolics, Total Flavonoids and Total Anthocyanins

Plums were peeled, segmented and frozen at −80 °C at each interval, and then freeze dried and finely ground in a coffee grinder using liquid nitrogen. Samples were extracted with 10 mL of 0.1% HCl (v/v) in 80% methanol, according to Wang et al. [1], with slight modification. The mixture was centrifuged at 4000 rpm for 15 min at 4 °C, the supernatant collected and used for further analyses. All results were expressed as mean ± S.E. ($n = 9$).

Total phenolics were determined, according to Tabart et al. [24]. Absorbance was measured at 750 nm using a microplate reader (Thermo Fisher Scientific multiskan FC 357, Shanghai, China). The results were expressed in grams of gallic acid equivalents (GAE) per gram of freeze-dried (FD) sample. Total flavonoids were determined using the method described by Mphahlele et al. [23], with modification to a microplate assay. Absorbance was measured at 517 nm using a microplate reader in triplicate. The results were expressed in milligrams catechin equivalents (CAE) per gram of freeze-dried (FD) sample. Total anthocyanins were determined using the pH differential method as described by Mphahlele et al. [23]. The results were expressed in micrograms of cyanidin-3-glucoside equivalent (C3gE) per gram of freeze dried (FD) sample.

2.7.2. Total Carotenoids and Ascorbic Acid

Extraction and determination of total carotenoids were carried out according to Joneset al. [25] and expressed in milligrams trans-β-carotene per gram of freeze dried (FD) sample. Ascorbic acid was determined according to the method described by Fawole and Opara [21], with modification to a microplate assay. Absorbance was measured at 517 nm in a microplate reader (Thermo Fisher Scientific multiskan FC 357, Shanghai, China) and results expressed in milligrams L-ascorbic acid (L-AA) per gram of freeze-dried (FD) sample. All measurements were performed in triplicate.

2.8. Radical Scavenging Antioxidant Activity

Radical scavenging activity (%RSA) of methanolic extracts was measured with a 2,2-Diphenyl-1-picryl-hidrazil (DPPH according to Nair et al. [26] with some modifications. In a 96-well microplate, 100 μL of blank (80% methanol), standard (0–0.08 mM Trolox) or sample extract was mixed with 200 μL DPPH working solution (98.5 mg DPPH with 250 mL of 100% methanol). Absorbance was measured at 520 nm using a microplate reader (Thermo Fisher Scientific multiskan FC 357, Shanghai, China) after a 5 min incubation period. Radical scavenging activity was expressed as the mean percentage inhibition of the DPPH radical. All results were expressed as mean ± S.E. ($n = 9$).

2.9. Statistical Analysis

Data was analyzed using a one-way analysis of variance (ANOVA), with coatings being the source of variation. ANOVA-generated *p*-values and significant differences between means were determined using Duncan's multiple range test with a 95% confidence interval. A factorial ANOVA was also performed to calculate the effects and interaction of the main factors, which were treatment and time interval. All analyses were performed with Statistica software package 13.3 (Tibco Software Inc., Palo Alto, CA, USA).

3. Results and Discussion

3.1. Weight Loss Percentage

The weight change during cold and shelf conditions shows the effectiveness against moisture loss of some of the coatings compared to control fruit (Table 1). At the end of cold storage, weight loss was significantly ($p < 0.05$) reduced in plums coated with High shine (0.63%) compared to the control (1.67%), although there was a significant interaction ($p < 0.0001$) between treatment and cold

storage time. A significant interaction was also observed between treatment and time at shelf life ($p = 0.0328$). Nonetheless, after 5 d shelf life, weight loss was significantly ($p < 0.05$) reduced in plums coated with gellan gum (2.62%), gum arabic (1.99%), High shine (1.61%) and Sta-fresh (1.96%), compared to control plums (3.70%). At 20 d shelf life, plums coated with gellan gum, gum arabic, High shine and Sta-fresh had weight loss of 5.46%, 4.91%, 4.61% and 7.02% weight loss, respectively, compared to 9.56% weight loss observed in control fruit (Table 1). Postharvest moisture loss occurs as a result of transpiration and is driven by the vapor pressure deficit that exists between the fruit and the surrounding environment [5]. Based on the significantly ($p < 0.05$) reduced weight loss in fruit coated with gellan gum, gum arabic, High shine and Sta-fresh, it is logical to assumed that the coatings created a physical barrier to moisture loss throughout storage. However, weight loss in plums coated with alginate and chitosan was significantly ($p < 0.05$) higher than in control plums throughout the storage duration (Table 1). This contradicts the findings of similar studies, whereby alginate and chitosan were reported to reduce weight loss in other plum cultivars [16,27,28]. These discrepancies could be due to differences in coating formulation and cultivar. For instance, in our study, vegetable oil was incorporated into both coatings in an attempt to increase coating hydrophobicity. However, lipid migration could have occurred during the extended storage period, increasing coating porosity [29], consequently reducing the moisture barrier properties of the coatings.
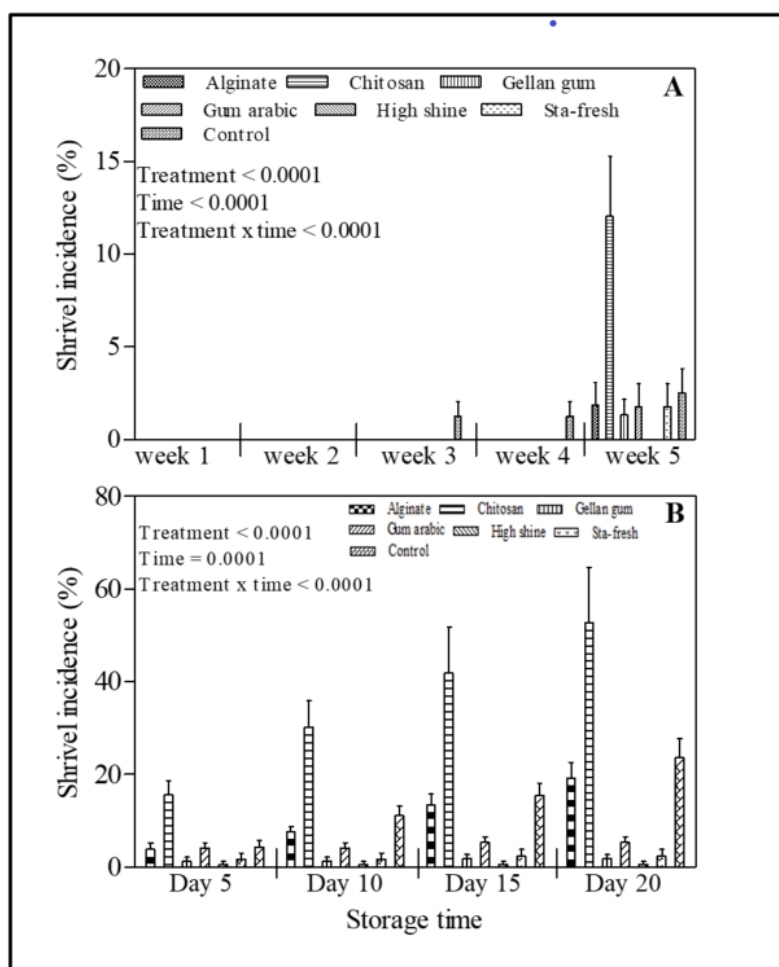
3.2. Shrivel Incidence

A significant interaction ($p < 0.0001$) was observed between treatment and storage time for both cold storage and shelf life conditions. At the end of cold storage, shrivel incidence in control plums was 2.52% (Figure 2A). In coated plums, shrivel incidence was lower ($\leq$1.86%) than control plums at the end of cold storage, except for plums coated with chitosan (12.05%) that developed shrivel symptoms at 5 weeks cold storage (Figure 2A). At 5 d shelf life, shrivel incidence was lower in all coated plums (ranging from 0.60% to 4.17%) compared to the control (4.31%), except for plums coated with chitosan, which had 15.55% shrivel incidence (Figure 2B). Control fruit had 11% and 16% shrivel incidence at 10 and 15 d shelf life, respectively. At the end of the 20 d shelf life, control fruit had higher shrivel incidence (23.62%) in comparison to plums coated with gellan gum (1.93%), gum arabic (5.36%), Sta-fresh (2.38%) and High shine (0.60%) (Figure 2B). Shriveling in fruit has been linked to moisture loss, resulting from a loss of turgor in the underlying epidermal cells [5,30]. In our study, a strong positive relationship ($R^2 = 0.653$) was observed between weight loss and shrivel occurrence in 'African Delight™' plums. Therefore, the effect of gellan gum, gum arabic, High shine and Sta-fresh on shrivel development can be linked to the moisture barrier properties of the coatings. On the contrary, chitosan promoted shrivel in the investigated plum cultivar. At 20 d shelf life, shrivel incidence of 52.19% was recorded. The observed adverse effect of chitosan on shrivel incidence may be attributed to the inability of chitosan to control moisture loss [31]. Similar results were observed in 'Alberta' peaches coated with chitosan and stored for 60 d at 4 °C and 80 ± 2% RH [32]. Although not clear, chitosan may have also modified the biomechanics of the fruit cuticle thereby magnifying the appearance of shrivel.

Table 1. Weight loss (%) in plums ('African Delight™') during a simulated shipping period (cold storage; −0.5 ± 2 °C and 90 ± 5% RH for 5 weeks) and shelf life (20 ± 2 °C and 75 ± 5%) RH for 20 d).

Treatment	Cold Storage					Shelf Life			
	Week 1	Week 2	Week 3	Week 4	Week 5	Day 5	Day 10	Day 15	Day 20
Alginate	0.87 ± 0.10 [b]	1.58 ± 0.18 [a]	1.96 ± 0.24 [a]	2.23 ± 0.28 [a]	2.60 ± 0.34 [a]	4.68 ± 0.52 [b]	5.87 ± 0.61 [b]	6.96 ± 0.69 [b]	8.33 ± 0.83 [ab]
Chitosan	1.19 ± 0.13 [a]	1.95 ± 0.21 [b]	2.33 ± 0.26 [a]	2.58 ± 0.31 [a]	3.21 ± 0.40 [a]	6.16 ± 0.71 [a]	7.72 ± 0.82 [a]	9.02 ± 0.95 [a]	10.62 ± 1.09 [a]
Gellan gum	0.34 ± 0.04 [de]	0.75 ± 0.06 [de]	0.97 ± 0.09 [c]	1.09 ± 0.10 [b]	1.43 ± 0.10 [b]	2.62 ± 0.17 [c]	3.73 ± 0.22 [c]	4.30 ± 0.25 [c]	5.46 ± 0.31 [cd]
Gum arabic	0.25 ± 0.03 [cde]	0.56 ± 0.04 [cde]	0.73 ± 0.06 [bc]	0.87 ± 0.09 [bc]	1.10 ± 0.10 [bc]	1.99 ± 0.17 [c]	3.09 ± 0.22 [c]	3.91 ± 0.29 [c]	4.91 ± 0.35 [cd]
High shine	0.10 ± 0.02 [c]	0.32 ± 0.04 [c]	0.36 ± 0.04 [b]	0.41 ± 0.04 [c]	0.63 ± 0.07 [c]	1.61 ± 0.16 [c]	2.61 ± 0.23 [c]	3.37 ± 0.30 [c]	4.61 ± 0.40 [d]
Sta-fresh	0.20 ± 0.02 [cd]	0.51 ± 0.03 [cd]	0.66 ± 0.05 [bc]	0.78 ± 0.07 [bc]	1.09 ± 0.09 [bc]	1.96 ± 0.16 [c]	3.36 ± 0.30 [c]	4.67 ± 0.83 [c]	7.02 ± 1.18 [bc]
Control	0.44 ± 0.05 [e]	0.87 ± 0.08 [e]	0.95 ± 0.09 [c]	1.10 ± 0.12 [b]	1.67 ± 0.20 [b]	3.70 ± 0.36 [b]	5.54 ± 0.51 [b]	6.81 ± 0.60 [b]	9.56 ± 0.77 [a]
Prob. > F									
Treatment	<0.0001					<0.0001			
Time	<0.0001					<0.0001			
Treatment x time	<0.0001					0.0328			

Means ± standard errors with different letters within columns are significantly different (*p* < 0.05) according to Duncan's multiple range test. In other to determine the interaction effects, factorial ANOVA was performed for main factors; treatment and storage time separately for cold storage and shelf life periods.

Figure 2. Cumulative shrivel occurrence (%) in 'African Delight™' plums during (**A**) a simulated shipping period (cold storage; −0.5 ± 2 °C and 90 ± 5% RH for 5 weeks) and (**B**) a subsequent shelf life period (20 ± 2 °C and 75 ± 5% RH for 20 d). Each bar represents mean ± standard error. In other to determine the interaction effects, factorial ANOVA was performed for main factors; treatment and storage time separately for cold storage and shelf life periods.

3.3. Respiration and Ethylene Production

There was a significant interaction ($p < 0.0001$) between treatment and storage time for both cold storage and shelf life conditions for both respiration and ethylene production (Table 2). Generally in all treatments, the respiration rate increased until 3 weeks of cold storage, then decreased, with no significant difference ($p > 0.05$) observed between coated plums and control plums (Table 2). However, plums coated with chitosan had a significantly ($p < 0.05$) higher respiration rate (11.13 mL/kg·h) compared to the other treatments, ranging from 4.16 mL/kg·h to 6.57 mL/kg·h. Respiration rate increased significantly ($p < 0.05$) in all treatment at shelf life condition (Table 2). However, coated plums generally had a lower respiration rate than control plums, although the interaction between treatment and storage time was significant ($p = 0.0392$). Edible coatings are widely reported to reduce gaseous exchange by sealing lenticels and covering the epicarp, consequently reducing fruit respiration rate [16,33–35]. In our study, the suppressed respiration rate in coated plums could be linked to coating gas barrier properties.

Table 2. Physiological responses in plums ('African Delight™') during a simulated shipping period (cold storage; -0.5 ± 2 °C and $90 \pm 5\%$ RH for 5 weeks) and shelf life (20 ± 2 °C and $75 \pm 5\%$ RH for 20 d).

Treatment	Respiration Rate (mL CO_2/kg·h)					Ethylene Production (µL C_2H_4/kg·h)				
Cold Storage	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**
Alginate	3.64 ± 0.73 [ab]	2.21 ± 0.00 *	2.22 ± 0.00 *	2.97 ± 0.74 [c]	4.48 ± 0.00 [b]	0.50 ± 0.26 [b]	0.53 ± 0.21 [b]	0.62 ± 0.15 [bc]	0.55 ± 0.13 [b]	0.73 ± 0.09 [b]
Chitosan	2.88 ± 0.72 [b]	2.19 ± 0.00	2.20 ± 0.00	5.88 ± 0.74 [b]	11.13 ± 1.28 [a]	0.39 ± 0.14 [b]	0.44 ± 0.10 [bc]	0.70 ± 0.13 [b]	0.82 ± 0.25 [b]	0.82 ± 0.37 [b]
Gellan gum	2.47 ± 0.00 [b]	2.48 ± 0.00	4.14 ± 0.83	4.97 ± 0.00 [b]	4.16 ± 0.83 [b]	0.26 ± 0.09 [b]	0.43 ± 0.08 [bc]	0.22 ± 0.03 [cd]	0.33 ± 0.02 [b]	0.26 ± 0.02 [b]
Gum arabic	3.96 ± 0.79 [ab]	2.39 ± 0.00	2.39 ± 0.00	4.79 ± 0.00 [b]	5.61 ± 0.80 [b]	0.96 ± 0.13 [a]	1.06 ± 0.19 [a]	1.27 ± 0.27 [a]	2.12 ± 0.62 [a]	2.57 ± 0.75 [a]
High shine	2.44 ± 0.00 [b]	2.45 ± 0.00	3.27 ± 0.82	4.91 ± 0.00 [b]	6.57 ± 0.82 [b]	0.26 ± 0.04 [b]	0.26 ± 0.05 [bc]	0.30 ± 0.02 [bcd]	0.42 ± 0.06 [b]	0.37 ± 0.07 [b]
Sta-fresh	2.45 ± 0.00 [b]	3.28 ± 0.82	4.11 ± 0.82	5.76 ± 0.82 [b]	4.96 ± 0.00 [b]	0.29 ± 0.10 [b]	0.22 ± 0.09 [bc]	0.17 ± 0.01 [d]	0.26 ± 0.05 [b]	0.57 ± 0.17 [b]
Control	4.83 ± 0.00 [a]	3.24 ± 0.82	4.05 ± 0.81	8.12 ± 0.81 [a]	4.91 ± 0.00 [b]	0.06 ± 0.03 [b]	0.11 ± 0.02 [c]	0.10 ± 0.01 [d]	0.12 ± 0.02 [b]	0.31 ± 0.05 [b]
Prob. > F										
Treatment	0.0001					<0.0001				
Time	<0.0001					<0.0001				
Treatment x time	<0.0001					0.0005				
Shelf Life	**Day 5**	**Day 10**	**Day 15**	**Day 20**		**Day 5**	**Day 10**	**Day 15**	**Day 20**	
Alginate	20.76 ± 1.33 [cd]	26.60 ± 5.64 [a]	17.49 ± 2.10 [cd]	21.09 ± 4.29 [b]		11.23 ± 1.54 [a]	30.67 ± 4.85 [a]	30.74 ± 3.42 [ab]	34.14 ± 1.85 [c]	
Chitosan	19.36 ± 0.77 [d]	22.98 ± 2.10 [a]	16.16 ± 1.62 [d]	21.52 ± 2.98 [b]		10.80 ± 0.65 [a]	19.70 ± 3.47 [abc]	25.01 ± 3.88 [bc]	33.29 ± 1.12 [cd]	
Gellan gum	24.56 ± 0.85 [bcd]	27.52 ± 1.72 [a]	22.54 ± 0.87 [abc]	37.01 ± 8.50 [a]		4.12 ± 0.29 [bc]	13.90 ± 2.50 [bcd]	16.89 ± 1.89 [cd]	30.97 ± 0.16 [d]	
Gum arabic	27.60 ± 2.15 [ab]	27.20 ± 1.43 [a]	21.68 ± 0.83 [bcd]	22.84 ± 2.93 [ab]		5.82 ± 1.18 [b]	16.76 ± 4.39 [bcd]	19.30 ± 3.21 [cd]	25.94 ± 0.05 [e]	
High shine	25.80 ± 0.83 [abc]	32.91 ± 4.38 [a]	24.73 ± 3.41 [ab]	26.90 ± 2.30 [ab]		2.40 ± 0.05 [c]	5.43 ± 0.60 [d]	8.69 ± 0.86 [d]	14.27 ± 0.70 [f]	
Sta-fresh	30.95 ± 3.02 [a]	26.45 ± 3.08 [a]	25.23 ± 0.87 [ab]	27.01 ± 3.12 [ab]		3.45 ± 0.27 [bc]	24.78 ± 6.51 [ab]	36.19 ± 5.68 [a]	48.31 ± 0.27 [a]	
Control	25.26 ± 1.46 [bc]	28.52 ± 2.59 [a]	28.16 ± 1.76 [a]	29.31 ± 3.30 [ab]		10.08 ± 1.53 [a]	10.58 ± 3.06 [cd]	14.06 ± 3.09 [cd]	39.65 ± 0.21 [b]	
Prob. > F										
Treatment	0.0023					<0.0001				
Time	<0.0001					<0.0001				
Treatment x time	0.0392					<0.0001				

Means ± standard errors with different letters within columns are significantly different ($p < 0.05$) according to Duncan's multiple range test. In other to determine the interaction effects, factorial ANOVA was performed for main factors; treatment and storage time separately for cold storage and shelf life periods for each attribute. At harvest, respiration rate was 2.88 ± 0.72 mL CO_2/kg·h and ethylene production was 0.09 ± 0.00 µL C_2H_4/kg·h; * not significant.

3.4. Physicochemical Attributes

3.4.1. Flesh Firmness

Table 3 illustrates the effect of edible coatings during cold storage and shelf life on the firmness of plums. Initially, the firmness value of plums was 49.25 ± 0.19 N and decreased gradually over time, with significant interaction ($p = 0.0467$) between treatment and storage time. Among the treatments, gum arabic coated fruit significantly ($p < 0.05$) retained firmness (49.69 N) till the end of the cold storage period, with gellan gum coated plums being the least firm fruit (35.99 N) (Table 3). Flesh firmness declined rapidly during shelf life except for alginate and chitosan, which remained firm in an undesirable way throughout shelf life (Table 3). For instance, flesh firmness in plums coated with alginate and chitosan at 20 d shelf life was similar to that of control fruit at 5 d shelf life (26.46 N), indicating a significant delay in fruit ripening. This could delay sale and consumption of fruit until 20 d shelf. Although a significant interaction ($p < 0.0001$) was observed between treatment and storage time, at 10 d commercial sell-by practice, uncoated fruit had lost 85.27% of firmness and could be deemed unacceptable, whereas fruit coated with gellan gum, gum arabic and the commercial coatings remained moderately firm with shelf life potential between 15 and 20 d (Table 3). Fruit firmness is an important quality parameter of fresh fruits for consumer preference. As plums ripen, cell wall hydrolyzing enzymes such as β-galactosidase, polygalacturonase, 1,4-β-D-glucanase/glucosidase and pectin methylesterase reduce cell-to-cell adhesion and cell wall mechanical strength, causing a loss of flesh firmness [14,28]. Enzyme activity has been reported to increase in shelf life conditions, resulting in a more rapid loss of texture [36]. According to Maftoonazad et al. [14], coatings delay ripening by reducing cell wall hydrolyzing enzymes and respiration in fruit.
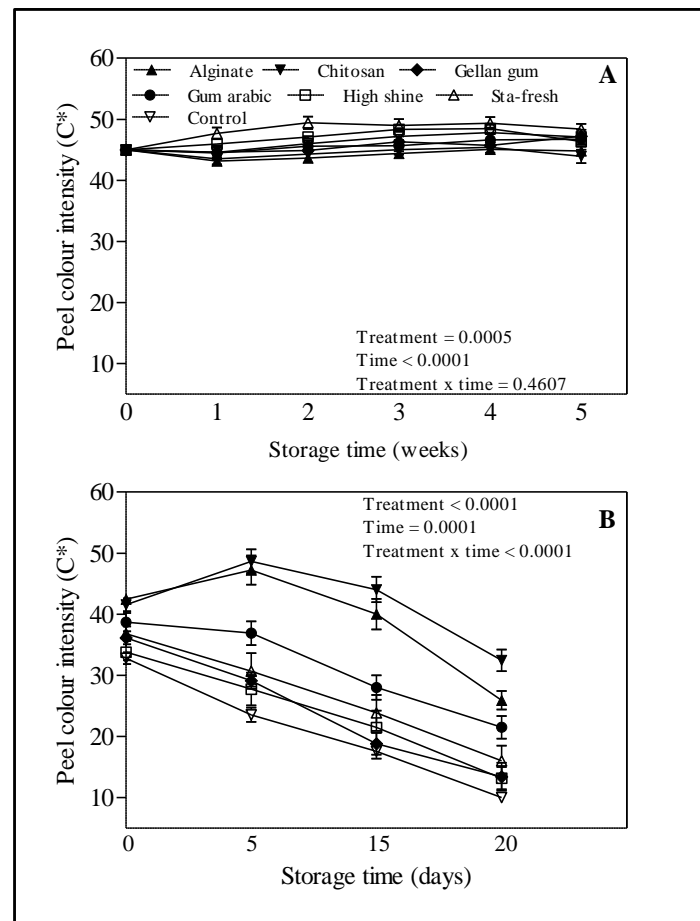
3.4.2. Fruit Peel Color Intensity (C*)

Color is another important factor in the perception of fruit quality. Figure 3 illustrates that the change in plum peel color was significantly ($p < 0.05$) influenced by the treatment and storage time for the cold storage period. The peel color intensity (C*) changed from 44.99 at harvest to between 43.93 (chitosan; $p > 0.05$) and 48.39 (alginate; $p < 0.05$) by the end of the cold storage period, although visually, the fruit remained bright red regardless of treatment (not shown). Although the interaction between treatment and storage time was significant ($p < 0.0001$) at shelf life period, peel color C* value decreased gradually as plums turned from bright red to dull red with time at shelf life period. Fruit coated with alginate and chitosan were an exception (Figure 3B), as the color change (from bright red to dull red) was less pronounced throughout the storage period, suggesting delayed ripening and suppressed anthocyanin synthesis [28].

Table 3. Flesh firmness (N) in plums ('African Delight™') during a simulated shipping period (cold storage; −0.5 ± 2 °C and 90 ± 5% RH for 5 weeks) and shelf life (20 ± 2 °C and 75 ± 5% RH for 20 d).

Treatment	Cold Storage					Shelf Life			
	Week 1	Week 2	Week 3	Week 4	Week 5	Day 5	Day 10	Day 15	Day 20
Alginate	40.52 ± 1.28 [b]	43.29 ± 1.40 [ab]	44.16 ± 1.62 *	44.25 ± 2.41 [a]	42.25 ± 2.38 [abc]	42.38 ± 1.83 [a]	44.34 ± 4.24 [a]	30.65 ± 2.98 [a]	25.42 ± 3.57 [ab]
Chitosan	42.28 ± 1.86 [ab]	45.90 ± 2.87 [a]	43.30 ± 2.68	38.94 ± 1.87 [abc]	42.15 ± 1.99 [abc]	39.29 ± 2.98 [a]	40.82 ± 4.67 [a]	31.05 ± 5.41 [a]	29.94 ± 4.26 [a]
Gellan gum	42.41 ± 2.54 [ab]	39.14 ± 1.84 [b]	37.91 ± 1.72	31.67 ± 1.75 [c]	35.99 ± 3.21 [c]	24.52 ± 3.57 [b]	27.96 ± 4.86 [b]	16.60 ± 3.31 [b]	6.82 ± 1.04 [d]
Gum arabic	47.09 ± 2.97 [ab]	39.89 ± 2.91 [ab]	43.88 ± 2.54	45.06 ± 3.45 [a]	49.69 ± 2.97 [a]	26.03 ± 2.33 [b]	27.27 ± 2.78 [b]	16.03 ± 1.96 [b]	20.06 ± 3.26 [bc]
High shine	48.49 ± 3.63 [a]	40.82 ± 1.92 [ab]	42.36 ± 2.35	45.10 ± 3.09 [a]	44.79 ± 3.00 [ab]	15.46 ± 2.16 [c]	14.13 ± 3.46 [cd]	12.19 ± 3.78 [bc]	12.53 ± 3.94 [cd]
Sta-fresh	42.58 ± 1.69 [ab]	43.47 ± 1.53 [ab]	37.74 ± 2.36	35.25 ± 3.18 [bc]	40.90 ± 3.27 [bc]	20.05 ± 3.02 [bc]	17.71 ± 2.56 [bc]	15.32 ± 1.80 [b]	11.15 ± 2.45 [cd]
Control	47.46 ± 2.54 [ab]	43.87 ± 1.42 [ab]	39.51 ± 1.66	42.06 ± 1.62 [ab]	40.29 ± 2.09 [bc]	26.46 ± 2.83 [b]	7.25 ± 0.45 [d]	5.60 ± 0.84 [c]	9.12 ± 1.83 [d]
Prob. > F									
Treatment	<0.0001					<0.0001			
Time	<0.0001					<0.0001			
Treatment x time	0.0467					<0.0001			

Means ± standard errors with different letters within columns are significantly different ($p < 0.05$) according to Duncan's multiple range test. In other to determine the interaction effects, factorial ANOVA was performed for main factors; treatment and storage time separately for cold storage and shelf life periods. Flesh firmness at harvest was 49.25 ± 0.19 N; * not significant.

Figure 3. Peel color intensity (chroma; C*) in plums ('African Delight™') during (**A**) a simulated shipping period (cold storage; −0.5 ± 2 °C and 90 ± 5% RH for 5 weeks) and (**B**) shelf life (20 ± 2 °C and 75 ± 5% relative humidity (RH) for 20 d). Means ± standard errors presented. In other to determine the interaction effects, factorial ANOVA was performed for main factors; treatment and storage time separately for cold storage and shelf life periods.

3.4.3. Total Soluble Solids (TSS) and Titratable Acidity

Total soluble solids (TSS) was generally maintained in all treatments during storage (Table 4). At the end of the cold storage (Week 5) and during shelf life period, there was no significant difference amongst treatments. According to the factorial analysis, it was clear that both the treatments and storage time did not have a significant effect on TSS. In contrast, titratable acidity decreased over time and there was a significant interaction between treatment and storage duration in cold storage and shelf life conditions. Overall, there was a significant interaction ($p < 0.05$) between treatment and storage time for both cold storage and shelf life conditions for titratable acidity (Table 4). The highest titratable acidity (TA) was obtained from alginate-treated fruit at the end of cold storage, albeit not significantly ($p > 0.05$) different from other treatments. Similarly, TA contained in fruit at shelf life condition was not significantly ($p > 0.05$) different between treated and control fruit (Table 4). During ripening, organic acids are used as primary substrates in metabolic processes such as respiration [28,37]. The observed insignificant differences in TSS and TA amongst treatments, especially during shelf life could be explained by non-differential increased in fruit respiration in all treatment, resulting in depletion of TA in all treatments.

Table 4. Total soluble solids (TSS, °Brix) and titratable acidity (TA, % malic acid) in plums ('African Delight™') during a simulated shipping period (cold storage; −0.5 ± 2 °C and 90 ± 5% RH for 5 weeks) and shelf life (20 ± 2 °C and 75 ± 5% RH for 20 d).

Treatment	Total Soluble Solids (TSS, °Brix)					Titratable Acidity (TA, % Malic Acid)				
Cold Storage	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**
Alginate	15.46 ± 1.00 *	15.28 ± 0.52 *	16.16 ± 0.48 [a]	16.08 ± 0.47 [ab]	15.12 ± 0.85 *	1.40 ± 0.12 *	1.40 ± 0.08 [bc]	0.77 ± 0.05 [ab]	0.99 ± 0.03 [c]	0.92 ± 0.04 *
Chitosan	15.20 ± 0.40	15.78 ± 0.34	15.78 ± 0.21 [ab]	16.82 ± 0.25 [a]	15.12 ± 0.36	1.37 ± 0.08	1.37 ± 0.07 [bc]	0.78 ± 0.05 [ab]	0.97 ± 0.03 [cd]	0.81 ± 0.01
Gellan gum	16.04 ± 0.38	16.48 ± 0.12	15.90 ± 0.38 [ab]	15.38 ± 0.48 [ab]	15.26 ± 0.47	1.35 ± 0.06	1.18 ± 0.04 [a]	0.81 ± 0.02 [ab]	0.70 ± 0.04 [a]	0.87 ± 0.04
Gum arabic	15.50 ± 0.94	16.26 ± 0.34	14.68 ± 0.70 [b]	15.74 ± 0.37 [ab]	15.46 ± 0.40	1.34 ± 0.10	1.22 ± 0.06 [ac]	0.77 ± 0.02 [ab]	0.81 ± 0.04 [ab]	0.83 ± 0.03
High shine	16.42 ± 0.32	16.14 ± 0.42	16.34 ± 0.39 [a]	16.56 ± 0.49 [a]	15.22 ± 0.83	1.25 ± 0.06	1.15 ± 0.06 [a]	0.86 ± 0.04 [b]	0.86 ± 0.06 [bd]	0.83 ± 0.05
Sta-fresh	16.22 ± 0.55	16.30 ± 0.36	16.14 ± 0.28 [a]	15.42 ± 0.79 [ab]	16.10 ± 0.52	1.32 ± 0.07	1.24 ± 0.03 [ac]	0.72 ± 0.03 [a]	0.79 ± 0.03 [ab]	0.87 ± 0.04
Control	15.12 ± 0.79	16.34 ± 0.45	15.34 ± 0.47 [ab]	14.38 ± 0.84 [b]	15.78 ± 0.36	1.32 ± 0.02	1.45 ± 0.04 [b]	0.81 ± 0.06 [ab]	0.77 ± 0.03 [ab]	0.82 ± 0.06
Prob. > F										
Treatment	0.4942					0.0046				
Time	0.4681					<0.0001				
Treatment x time	0.7871					0.0107				
Shelf Life	**Day 5**	**Day 10**	**Day 15**	**Day 20**		**Day 5**	**Day 10**	**Day 15**	**Day 20**	
Alginate	15.08 ± 0.48 [a]	14.64 ± 0.77 *	14.58 ± 0.53 [ab]	15.78 ± 0.15 [a]		0.80 ± 0.04 [c]	0.69 ± 0.05 [ab]	0.59 ± 0.03 [b]	0.56 ± 0.03 [b]	
Chitosan	15.30 ± 0.45 [a]	15.74 ± 0.15	14.12 ± 0.58 [b]	15.46 ± 0.56 [ab]		0.75 ± 0.06 [c]	0.83 ± 0.03 [b]	0.61 ± 0.04 [b]	0.54 ± 0.02 [b]	
Gellan gum	13.44 ± 0.74 [b]	15.02 ± 0.50	15.18 ± 0.30 [ab]	15.50 ± 0.90 [ab]		0.53 ± 0.02 [ab]	0.71 ± 0.04 [ab]	0.61 ± 0.03 [b]	0.50 ± 0.02 [ab]	
Gum arabic	14.42 ± 0.35 [ab]	14.64 ± 0.74	14.28 ± 0.72 [b]	15.24 ± 0.16 [ab]		0.57 ± 0.05 [ab]	0.68 ± 0.03 [ab]	0.61 ± 0.02 [b]	0.56 ± 0.02 [b]	
High shine	15.94 ± 0.23 [a]	15.68 ± 0.28	15.94 ± 0.25 [a]	15.86 ± 0.29 [a]		0.49 ± 0.02 [b]	0.73 ± 0.09 [ab]	0.50 ± 0.01 [a]	0.43 ± 0.03 [a]	
Sta-fresh	14.58 ± 0.15 [ab]	15.60 ± 0.59	15.20 ± 0.51 [ab]	14.08 ± 0.51 [b]		0.60 ± 0.01 [a]	0.61 ± 0.04 [a]	0.64 ± 0.02 [b]	0.53 ± 0.02 [b]	
Control	15.96 ± 0.69 [a]	15.16 ± 0.34	16.12 ± 0.53 [a]	15.62 ± 0.45 [ab]		0.51 ± 0.02 [ab]	0.61 ± 0.04 [a]	0.58 ± 0.02 [b]	0.49 ± 0.03 [ab]	
Prob. > F										
Treatment	0.3390					<0.0001				
Time	0.8124					<0.0001				
Treatment x time	0.2401					<0.0001				

Means ± standard errors with different letters within columns are significantly different ($p < 0.05$) according to Duncan's multiple range test. In other to determine the interaction effects, factorial ANOVA was performed for main factors; treatment and storage time separately for cold storage and shelf life periods for each attribute. At harvest, total soluble solids were 15.84 ± 0.73 °Brix, and titratable acidity was 0.99 ± 0.03 % malic acid; * not significant.

3.5. Off-Flavour Volatile Development

In a study on 'Bartlett' pears stored in low oxygen or high CO_2 conditions, an accumulation of acetaldehyde, ethanol, and ethyl acetate was implicated in fruit fermentation [38]. Satora et al. [39] also reported acetaldehyde and ethyl acetate, as well as methanol and 2-phenyl ethyl acetate as fermentative products in the plum spirits of four varieties ('Wegierka Dabrowicka', 'Wegierka Zwykła', 'Čacanska Lepotica' and 'Stanley'). Edible coatings have the potential to reduce respiration rates to critical levels in fruit, and this can result in anaerobic respiration. Amongst the esters targeted in this study, only ethyl acetate was detected. Although the volatile occurs naturally in fresh plums, it can also be formed during fermentation [39]. There was no significant difference ($p > 0.05$) in ethyl acetate abundance between treatments throughout storage (data not shown). Overall, only ethyl acetate was detected amongst the fermentation esters screened, and its abundance in coated fruit did not differ significantly ($p > 0.05$) from control fruit (data not shown).

3.6. Phytochemical Analysis

3.6.1. Total Phenolics, Total Flavonoids and Total Anthocyanins

There were the increases in contents of total phenolics (TPC), total flavonoids (TFC) and total anthocyanins (TAC) during cold storage and shelf life in all treatments, with significant interaction between treatment and storage time (Figure 4). In the last measurement of cold storage, fruit coated with gellan gum had significantly higher TPC. The shelf life duration was characterized with higher TPC, TFC and TAC compared to the cold storage regardless of treatments. This could be linked to fruit ripening at higher temperature [40]. It was observed that there were lower TPC in plums coated with alginate and chitosan than in control plums during shelf life (Figure 4). This could be attributed to the suppression of the biosynthesis of phenolics in the fruit [41]. Similar to our findings, sweet cherries coated with 5% alginate were reported to contain lower TPC than the control [34]. The increase in TFC fluctuated amongst treatments during shelf life, with no significant distinction between coated and control fruit (Figure 4). Flavonoids are one of the major polyphenols in plums, and hence, the increase in TFC could be associated with the observed increase in TPC [42]. A moderate, positive correlation coefficient between TPC and TFC confirmed this ($r = 0.642$). Similarly, TAC fluctuated throughout cold and shelf life storage (Figure 4). At the end of cold storage, however, in comparison with control, gum arabic-coated fruit had a significantly ($p < 0.05$) higher TAC, while alginate, chitosan and gellan gum coated fruit had significantly ($p < 0.05$) lower TAC. As observed for TFC, the increase in TAC also fluctuated amongst treatments during shelf life, with no specific trends in coated and control fruit. Anthocyanins form part of the larger group of flavonoids [43]; however, the positive relationship between TFC and TAC was weak ($r = 0.296$).

3.6.2. Total Carotenoid Content (TCC) and Ascorbic Acid (AAC)

Generally, during storage and shelf life, total carotenoid content (TCC) was maintained in all treatments. Although there were slight increases in TCC at shelf life, there was no significant difference ($p > 0.05$) or pattern in TCC between coated plums and control, except for alginate-coated fruit, where TCC was significantly ($p < 0.05$) lower than control plums throughout shelf life, albeit there was a significant interaction between the main factors (Table 5). Our results are in agreement with those reported by Valero et al. [28], who reported a delay in carotenoid synthesis in alginate-coated plums ('Blackamber', 'Golden Globe', 'Larry Ann' and 'Songold') at the end of storage (2 °C and 90% RH for 35 d, followed by 20 °C and 65% RH for 3 d). It could be hypothesized that the mode of action of alginate is similar in plums regardless of cultivar.

Despite some fluctuations, ascorbic acid content (AAC) was generally maintained throughout storage, control plums containing 109.34 mg L-AA/g at harvest, 99.72 mg L-AA/g at the end of cold storage, 100.45 mg L-AA/g at 5 d shelf life and 108.53 mg L-AA/g at 20 d shelf life (Table 5). No coating was observed to have a consistent, significant effect on AAC compared to control plums throughout

storage, and there was a significant interaction between the main factors (Table 5). On the contrary, coated fruit have been reported to contain higher AAC than control fruit in sweet cherry [17] and guava [26].
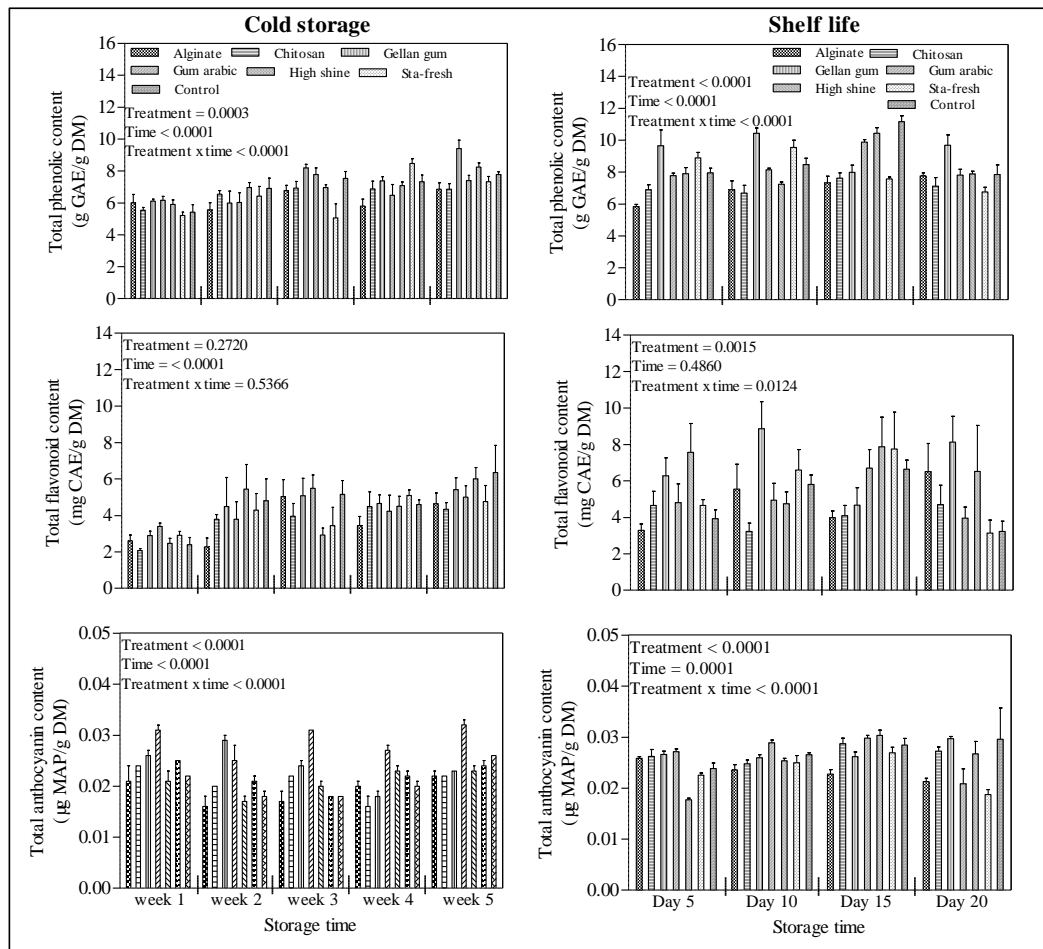
Figure 4. Total phenolic content (g GAE/g), total flavonoid content (mg CAE/g) and total anthocyanin content (µg MAP/g) in plums ('African Delight™') during a simulated shipping period (cold storage; −0.5 ± 2 °C and 90 ± 5% RH for 5 weeks) and shelf life (20 ± 2 °C and 75 ± 5% RH for 20 d). Means ± standard errors presented. In other to determine the interaction effects, factorial ANOVA was performed for main factors; treatment and storage time separately for cold storage and shelf life periods for each attribute.

3.7. Radical Scavenging Antioxidant Activity

The antioxidant capacity (AOC) of plums is determined mainly by the content of polyphenols, ascorbic acid and carotenoids within the fruit. It may fluctuate during postharvest storage, depending on both biotic and abiotic factors [44]. In this study, the radical scavenging activity (RSA) increased significantly ($p < 0.05$) in all treatments from harvest (74.70%) throughout cold storage, and a significant ($p < 0.0001$) interaction was established between treatment and storage time (Figure 5A). High radical scavenging activities were maintained regardless of treatment and time during the shelf life period (Figure 5B). The high RSA ranged between 82% and 91%, with no significant ($p = 0.1660$) differences amongst the coatings. According to Matthes and Schmitz-Eiberger [45], polyphenols are the primary source of antioxidants in fruit. This is in support of the strong and positive relationship ($r = 0.759$) established between total phenolic content and DPPH.

Table 5. Carotenoid content (mg trans-β-carotene/g) and Ascorbic acid content (mg L-AA/g) in plums ('African Delight™') during a simulated shipping period (cold storage; −0.5 ± 2 °C and 90 ± 5% RH for 5 weeks) and shelf life (20 ± 2 °C and 75 ± 5% RH for 20 d).

Treatment	Carotenoid Content (mg Trans-β-Carotene/g)					Ascorbic Acid Content (mg L-AA/g)				
Cold Storage	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**
Alginate	0.32 ± 0.01 [c]	0.27 ± 0.03 [b]	0.26 ± 0.01 [bc]	0.33 ± 0.03 [bc]	0.26 ± 0.02 [b]	118.45 ± 1.05 [a]	113.31 ± 0.73 [b]	113.62 ± 1.37 [a]	100.12 ± 4.02 [b]	116.25 ± 2.24 [a]
Chitosan	0.26 ± 0.01 [b]	0.23 ± 0.01 [b]	0.28 ± 0.01 [bc]	0.30 ± 0.04 [ac]	0.31 ± 0.02 [ab]	117.47 ± 0.68 [ab]	113.69 ± 0.43 [b]	114.04 ± 1.37 [a]	112.38 ± 2.50 [a]	96.32 ± 3.53 [c]
Gellan gum	0.30 ± 0.01 [bc]	0.46 ± 0.06 [a]	0.24 ± 0.02 [c]	0.27 ± 0.02 [ac]	0.26 ± 0.03 [ab]	115.86 ± 0.54 [b]	112.11 ± 0.79 [bc]	109.56 ± 1.47 [a]	109.81 ± 4.62 [ab]	103.06 ± 1.23 [bc]
Gum arabic	0.39 ± 0.02 [a]	0.54 ± 0.07 [a]	0.36 ± 0.02 [a]	0.34 ± 0.02 [bc]	0.34 ± 0.03 [a]	117.42 ± 1.08 [ab]	109.31 ± 0.92 [c]	112.00 ± 0.67 [a]	112.58 ± 0.88 [a]	103.95 ± 1.34 [bc]
High shine	0.32 ± 0.01 [c]	0.25 ± 0.01 [b]	0.29 ± 0.03 [bc]	0.24 ± 0.01 [a]	0.29 ± 0.02 [ab]	117.72 ± 0.90 [ab]	104.17 ± 1.61 [d]	112.71 ± 1.02 [a]	106.99 ± 4.67 [ab]	97.98 ± 6.45 [bc]
Sta-fresh	0.33 ± 0.02 [c]	0.23 ± 0.01 [b]	0.26 ± 0.01 [bc]	0.39 ± 0.03 [b]	0.29 ± 0.01 [ab]	116.44 ± 0.36 [ab]	116.84 ± 1.03 [a]	110.90 ± 3.16 [a]	107.12 ± 1.23 [ab]	107.09 ± 0.96 [b]
Control	0.26 ± 0.03 [b]	0.29 ± 0.01 [b]	0.30 ± 0.02 [b]	0.33 ± 0.03 [bc]	0.31 ± 0.02 [ab]	117.97 ± 0.36 [ab]	112.79 ± 0.98 [b]	97.68 ± 7.42 [b]	109.69 ± 1.98 [ab]	99.72 ± 1.29 [bc]
Prob. > F										
Treatment	<0.0001					0.0046				
Time	0.0193					<0.0001				
Treatment x time	<0.0001					0.0107				
Shelf Life	**Day 5**	**Day 10**	**Day 15**	**Day 20**		**Day 5**	**Day 10**	**Day 15**	**Day 20**	
Alginate	0.26 ± 0.02 [c]	0.33 ± 0.03 [c]	0.31 ± 0.02 [b]	0.41 ± 0.03 [c]		106.36 ± 4.99 [ab]	102.01 ± 2.81 [b]	109.59 ± 2.27 [a]	108.30 ± 3.03 *	
Chitosan	0.34 ± 0.02 [bc]	0.58 ± 0.08 [b]	0.48 ± 0.03 [cd]	0.50 ± 0.07 [cd]		110.52 ± 1.11 [a]	107.07 ± 3.73 [ab]	109.79 ± 1.44 [a]	112.48 ± 1.71	
Gellan gum	0.46 ± 0.06 [a]	0.53 ± 0.02 [b]	0.45 ± 0.02 [c]	0.57 ± 0.05 [ad]		103.80 ± 1.15 [ab]	110.19 ± 1.81 [a]	104.88 ± 2.38 [ab]	105.99 ± 2.80	
Gum arabic	0.29 ± 0.02 [c]	0.40 ± 0.02 [ac]	0.58 ± 0.05 [ad]	0.77 ± 0.03 [b]		103.06 ± 2.51 [ab]	107.12 ± 1.52 [ab]	98.71 ± 4.15 [b]	107.12 ± 1.44	
High shine	0.46 ± 0.02 [a]	0.39 ± 0.01 [ac]	0.55 ± 0.01 [acd]	0.50 ± 0.04 [cd]		105.08 ± 1.30 [ab]	111.48 ± 1.20 [a]	109.79 ± 2.07 [a]	110.70 ± 3.67	
Sta-fresh	0.34 ± 0.02 [bc]	0.48 ± 0.04 [ab]	0.50 ± 0.05 [cd]	0.58 ± 0.05 [ad]		108.13 ± 0.83 [ab]	102.26 ± 1.42 [b]	98.83 ± 3.60 [b]	108.50 ± 1.59	
Control	0.39 ± 0.01 [ab]	0.48 ± 0.02 [ab]	0.64 ± 0.02 [a]	0.68 ± 0.05 [ab]		100.45 ± 2.76 [b]	113.39 ± 2.25 [a]	108.30 ± 4.15 [a]	108.53 ± 1.87	
Prob. > F										
Treatment	0.0374					0.1617				
Time	<0.0001					0.0030				
Treatment x time	<0.0001					<0.0001				

Means ± standard errors with different letters within columns are significantly different ($p < 0.05$) according to Duncan's multiple range test. In other to determine the interaction effects, factorial ANOVA was performed for main factors; treatment and storage time separately for cold storage and shelf life periods for each attribute. At harvest, carotenoid content at harvest was 0.30 ± 0.02 mg trans-β-carotene/g and ascorbic acid content at harvest was 109.34 ± 1.42 mg L-AA/g; * not significant.
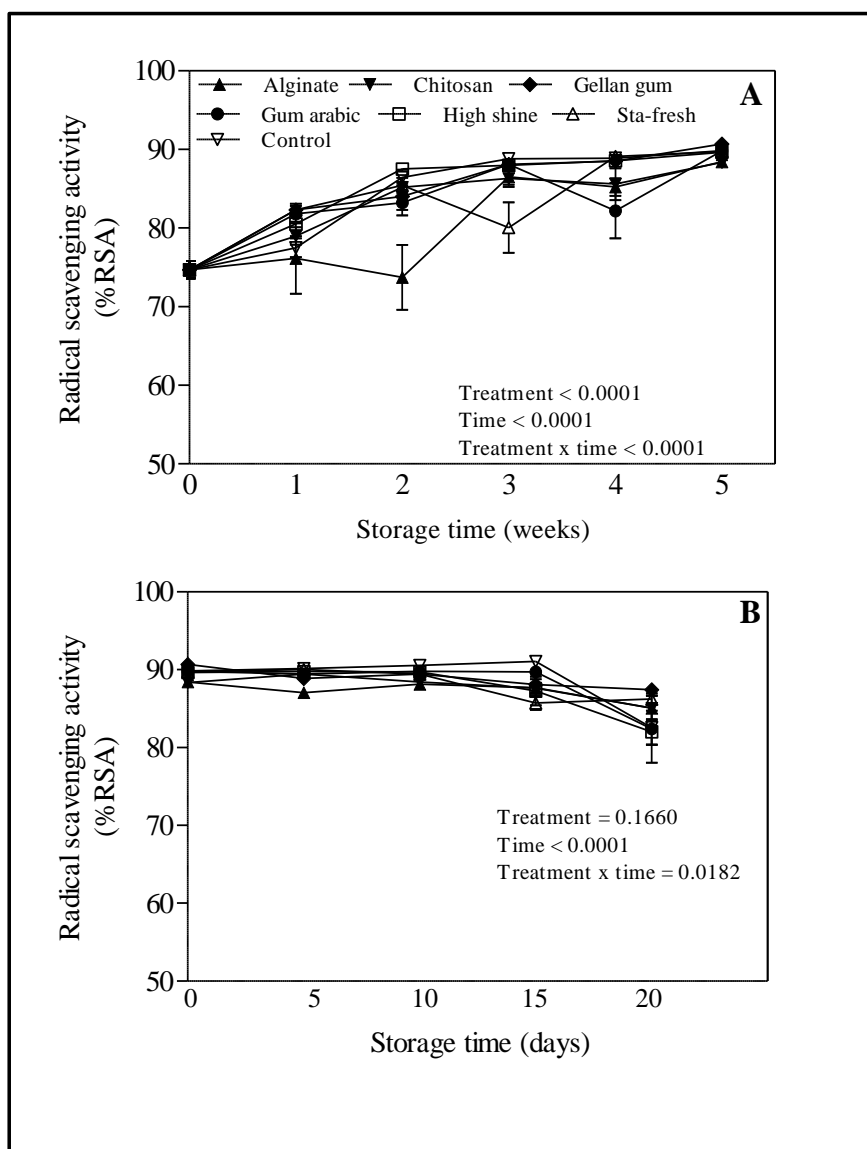
Figure 5. Radical scavenging activity (%RSA), based on 2,2-Diphenyl-1-picryl-hidrazil (DPPH) radical scavenging method, in plums ('African Delight™') during (**A**) a simulated shipping period (cold storage; −0.5 ± 2 °C and 90 ± 5% RH for 5 weeks) and (**B**) shelf life (20 ± 2 °C and 75 ± 5% for 20 d). Means ± standard errors presented. In other to determine the interaction effects, factorial ANOVA was performed for main factors; treatment and storage time separately for cold storage and shelf life periods.

4. Conclusions

In summary, edible coatings could be beneficial in alleviating shrivel and maintaining quality and extending shelf life of the investigated plum cultivar during a simulated export condition. However, fruit coated with alginate and chitosan had undesirable practical effects. The coatings promoted shrivel incidence, delayed the ripening process and slowed the physico-chemical changes in fruit throughout storage. Although the interaction between treatment and time was significant in some of the investigated attributes, amongst the edible coatings investigated, the findings in fruit coated with gum arabic and the commercial products were comparable. These coatings are considered promising for postharvest preservation of exported plums. In particular, the coatings showed a moderate delay in fruit ripening, significantly reduced weight loss and shrivel development, allowing for the export of fruit over a long distance (5 weeks) and up to 20 d of shelf life. Further research is needed to investigate

the effect of these coatings on a semi-commercial scale and also establish the effect on the sensory attributes of the investigated plum cultivar.

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