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Some physicochemical and bioactive features of organically grown blackberry fruits (Rubus fructicosus L.) as influenced by postharvest UV-C and chitosan treatments

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Abstract: Fresh blackberry fruits have easily perishable tissue and therefore have a very short postharvest storage life, although customers and marketers desire a longer shelf life. The ever-increasing demand of the world population for residue-free functional foods has motivated scientists to investigate environmentally friendly methodologies for the quality extension of perishable products like fresh blackberries. The present study was performed to determine the influences of UV-C treatment and chitosan coating on the extension of postharvest bioactive compounds and the marketable quality of fresh blackberry (*Rubus fructicosus* L.) fruits. Organically produced 'Jumbo' blackberry fruits were sorted into four equal groups for postharvest treatments: (a) untreated berries as a control, (b) UV-C irradiation for 5 min at 254 nm, (c) coating with 1% chitosan, and (d) UV-C + chitosan. After these treatments, blackberry fruits were stored in polypropylene cups of 12 × 15 cm at 1 ± 0.5 °C and 85% relative humidity for 14 days. Blackberries were sampled on the first day (day 0) and the 4th, 7th, 10th, and 14th days during cold storage. At the end of the 14-day storage period, the greatest weight loss was determined in control fruits (3.04%) while the lowest was found for UV-C irradiation + chitosan coating (1.59%). The activity of the polygalacturonase enzyme was significantly restricted by all treatments with the highest effect of UV-C + chitosan treatment, which also provided the best visual quality during storage. UV-C + chitosan was also the best treatment for delaying the changes in soluble solid content, titratable acidity, L^*, C^*, $h°$, antioxidants, ascorbic acid, and total anthocyanins. Overall, the findings revealed that postharvest chitosan coating at 1% concentration following UV-C irradiation at 254 nm for 5 min could be proposed as an effective, safe, healthy, ecofriendly, and sustainable strategy for extending the bioactive compounds and marketable quality of fresh blackberry fruits.

Key words: Blackberry, postharvest physiology, cold storage, bioactive compounds, edible coating, polygalacturonase

1. Introduction

Blackberries are widely cultivated and consumed as fresh or frozen fruit as well as dietary supplements worldwide as an essential source of biochemicals with great nutraceutical value (Milosevic et al., 2012). This fruit is rich in dietary fibers, carbohydrates, minerals and vitamins, and functionally bioactive compounds such as anthocyanins, catechins, flavanols, and flavones (Gündoğdu et al., 2016). These characteristics have induced the rapid development of blackberry cultivation for various purposes such as fresh consumption, nutraceutical markets, and other industrial uses. However, compared to other horticultural crops, they have a relatively limited shelf-life duration of approximate 3 to 5 days even under cold storage because of their highly perishable texture, which makes it difficult to conserve them without prestorage treatments (Guzmán et al., 2018). Using synthetic chemicals is still a common strategy worldwide to prevent postharvest diseases of fresh produce during cold storage. However, the random use of synthetic chemicals can be harmful to human and environmental health. Recent improvements in postharvest technologies have positively affected the food supply chain for the maintenance of marketable quality of products, supporting a better relationship between demand and supply in the food industry. Among them, UV-C light exposure, as a healthy postharvest treatment, is reported to trigger defense physiology in many agricultural products including fruits and vegetables. Sole or combined usage of UV-C irradiation with other nonchemical and environmentally friendly strategies has been widely proven to maintain the postharvest quality of perishable products such as strawberries (Nigro et al., 2000), tomatoes (Charles et al., 2005), and table grapes (Sabir et al., 2021). A previous study using stem-excised 'Michele Palieri' grape berries revealed that UV-C irradiation was effective in maintaining the freshness and organoleptic quality of the berries, even though it was not capable of delaying the weight loss of the berries (Sabir et al., 2020). Many studies have indicated that

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chitosan coating, as an N-acetylated derivative of the polysaccharide chitin, is an excellent alternative application as a naturally degradable organic material that possesses eliciting capacities and antimicrobial potential without modulating the sensorial quality characteristics of fruits and vegetables (Sharif et al., 2018). Chitosan is among the most widespread edible coatings used to extend the quality of fruit by delaying weight loss and suppressing fruit deterioration along with prolonged cold storage (Sabir et al., 2020). This substance is a linear cationic polysaccharide with a high molecular mass of β-(1–4)-2-acetamido-D glucose and β-(1–4)-2-amino-D-glucose derivative from chitin (Mansilla et al., 2013). In the food industry, chitosan is known as a nontoxic and biodegradable product for extending the quality of perishable fresh fruits such as strawberries, avocado, and papaya due to its excellent film-forming characteristics (El Ghaouth et al., 1991; Bautista-Baños et al., 2003; Elsabee and Abdou, 2013; Bill et al., 2014). However, the existing literature suggests that there is not enough experimental information about the effects of chitosan coating on the postharvest life of fresh blackberries, especially when used in combination with other healthy strategies like UV-C irradiation. Therefore, the aim of the present study was to evaluate the effectiveness of chitosan and UV-C treatments alone or in combination to extend the postharvest quality of blackberry fruits during cold storage.

2. Materials and methods

2.1. Fruit material

Organically produced blackberry fruits (*Rubus fructicosus* L.) of the 'Jumbo' cultivar were harvested from a glasshouse at Selçuk University (Konya, Türkiye) in 2021 at the commercial ripening stage, when the fruit attained a cultivar-specific dark color and its soluble solid content (SSC) reached 11.2%, in the early morning. They were then immediately transported to the laboratory in a frigorific vehicle. Blackberry fruits were chosen according to fruit size, color, and defects of the fruits and unhealthy and damaged fruits were discarded. The selected fruits were disinfected with sodium hypochlorite (100 **µ**L/L) for 5 min and air-dried at 24 ± 1 °C under laboratory conditions for 1 h. The fruit pedicels were gently cut using sanitized sharp scissors, allowing 1–2 mm of the berry pedicel. The blackberries were then randomly divided into four equal treatment lots, including: (a) untreated berries as the control, (b) irradiation with UV-C, (c) coating with chitosan, and (d) UV-C + chitosan.

2.2. UV-C and chitosan treatments

For the UV-C applications, two groups of fruits (UV-C alone and UV-C + chitosan coating) were irradiated at 254 nm for 5 min in a steel chamber with two germicidal low-pressure mercury-vapor discharge lamps (15 W, Philips, Amsterdam, the Netherlands) with an emitting quasi-monochromatic UV-C radiation characteristic as explained by Xu et al. (2017). The blackberries were placed in metal wire-fence trays in a single layer about 12 cm away from the UV-C irradiation lamps. Fruits were exposed to the UV-C irradiation by ceiling and bottom lamps to ensure homogeneous irradiation (Sabir et al., 2021).

The chitosan solutions (Sigma-Aldrich, St. Louis, MO, USA), used at 1% as recommended by Sabir FK et al. (2019) for fresh berry fruits, were obtained by dissolving 10 g of chitosan using 10 mL (v/v) of acetic acid with 1 L of distilled water as described by Tezotto-Uliana et al. (2014). To completely cover the blackberry fruits with chitosan, they were dipped in the chitosan solution for 5 min. After coating, the fruits were kept at 24 ± 1 °C under laboratory conditions with slow air movement for 2 h, allowing any moisture on the fruits to evaporate.

2.3. Storage conditions

After treatments, about 300 g of fruits from each treatment was placed into a polypropylene cup of 12 × 15 cm, which was wrapped using a monolayer film polyester (thickness: 18 µm). The blackberry cups, with approximate surface area of 100 cm^2, were hermetically covered and stored at 1 ± 0.5 °C and 85% relative humidity for 14 days (Sabir and Sabir, 2013).

2.4. Weight loss and visual quality

Weight loss values were obtained with the following formula: weight loss = [(A – B)/A] × 100, where A is the blackberry fruit weight obtained with a precision balance prior to treatment and B is the fruit weight recorded at each sampling date during cold storage (Karabulut et al., 2004). The visual quality of the blackberry fruits was assessed by six panelists with a nine-point hedonic scale as previously defined by Sabir et al. (2020), where 9 = excellent appearance and freshness without any visible disorder, 7 = good, 5 = fair (limit of commercial marketability), 3 = fair (moderate condition), and 1 = unusable (>50% soft or brownish fruits).

2.5. Soluble solid content, titratable acidity, and pH

To determine the SSC, titratable acidity (TA), and pH of the fruits, blackberries were weighed to about 150 g and subjected to a juice extractor in the laboratory (24 ± 1 °C) to obtain fruit juice. Blackberry juice was centrifuged in three replicates. For these juice samples, SSC was measured with a hand refractometer (model 9313, ATAGO Co., Tokyo, Japan) and recorded as a percentage. TA was determined by titrating 10 mL of the blackberry juice (eluted using 90 mL of distilled water) with 0.1 N NaOH to an end point of pH 8.1 (Mattiuz et al., 2009). TA was expressed as percentage of citric acid equivalent. pH was directly determined using a pH meter (HI 2211, Hanna Instruments, Woonsocket, RI, USA).

2.6. Fruit color

Thirty blackberry fruits for each treatment group were used to determine the fruit color parameters of chroma (C^*), hue angle ($h°$), and lightness (L^*) at equatorial points on the berry surface using a colorimeter (CR-400, Konica Minolta, Osaka, Japan) (McGuire, 1992).

2.7. Total phenolic content and antioxidant activity

Extracts of blackberry fruits for total phenolic content (TPC) and antioxidant activity (AA) were obtained using the method proposed by Thaipong et al. (2006) with minor modifications. The blackberries were homogenized with pure methanol for 1 min using an Ultra-Turrax homogenizer (T18 digital, IKA, Staufen, Germany) and then mixed at 4000 × *g* at 5 °C for 30 min. The supernatant phase was recovered and conserved at –20 °C in dark-colored glass bottles until use during cold storage. For TPC, the methodology described by Singleton et al. (1999) was followed. An aliquot of 100 µL of each blackberry extract was mixed with 1.58 mL of water, 300 µL of sodium carbonate solution (200 g/L), and 100 µL of Folin–Ciocalteu reagent. The samples were then kept in the dark for 2 h at room temperature (24 ± 1 °C). The absorbance read at 760 nm was recorded using a spectrometer (U-5100, Hitachi, Tokyo, Japan). TPC was calculated as gallic acid equivalents (mg GAE 100 g^{-1}). The antioxidant capacity of the blackberry fruit sample was determined with the ferric reducing antioxidant potential (FRAP) method as described by Benzie and Strain (1996). The reagent for FRAP was a solution of 2.5 mL of 20 mM ferric chloride hexahydrate, 2.5 mL of 10 mM 2,4,6-tripyridyl-1,3,5-triazine (TPTZ), and 25 mL of acetate buffer (pH 3.0). The reaction of this mixture was commenced when 0.5 mL of the supernatant was supplemented into 5 mL of FRAP solution. The incubation of the reaction mixture was carried out at room temperature for 30 min and the absorbance was read at 630 nm. The antioxidant capacity was expressed as µmol TE/g FW.

2.8. Ascorbic acid analysis

Blackberry samples of 5 g were ground with 45 mL of 0.4% oxalic acid in a Waring blender (Waring Commercial, McConnellsburg, PA, USA) and then the mixture was filtered with Whatman 42 filter paper (Sigma-Aldrich). Filtrate (1 mL) and 2,6-dichlorophenolindophenol sodium ($C_{12}H_6C_{l-2}NO_2$-Na) solution (9 mL) were mixed and then the absorbance read at 520 nm was recorded using a spectrophotometer (Sabir F et al., 2019).

2.9. Total anthocyanin content

Total anthocyanin content (TPC) was determined by pH differential methodology as described by Cheng and Breen (1991). Dilution was carried out by adding 1.9 mL of potassium chloride (pH 1.0) and sodium acetate (pH 4.5) solutions to 0.1 mL of blackberry fruit extract. Sample absorbances were read at 520 nm and 700 nm against pure water with a spectrometer. TPC was expressed as cyanidin-3-glucoside (mg/100 g).

2.10. Polygalacturonase analysis

The activity of polygalacturonase (PG) was determined by performing slight modifications to the dinitrosalicylic acid (DNS) method (Pathak and Sanwal, 1998). For PG analysis, 100 µL of pectin solution was added to 20 µL of fruit sample and the solution was incubated in an oven at 30 °C for 10 min. The solution was then mixed with 120 µL of DNS and incubated in a hot water bath (96 °C) for 4 min. The solution was allowed to cool for 3 min on ice and samples were read at 530 nm using a spectrometer.

2.11. Statistical analysis

A total of 48 polypropylene cups were used for this study, 11 of which represented each postharvest treatment excluding the first analysis on day 0. Three cups (replicates) per treatment were used for each analysis during storage. Statistical analyses were carried out in triplicate for the four different treatments. Means and standard deviations were first calculated. The numerical data were analyzed using ANOVA and Student's t-test at $p < 0.05$ with SPSS 13.0 for Windows (Efe et al., 2000). Treatment × storage time interactions were evaluated according to least significant differences (LSDs) in tables or figures.

3. Results and discussion

3.1. Physical characteristics of the fruits

The weight loss of fresh blackberry fruits significantly increased during the prolonged storage duration at 1 °C in all treatments (Figure 1). After 7 days of storage, fruits treated by UV-C, chitosan, and their combination had significantly lower losses in weight than the control fruits. At the end of 14 days of storage, the highest weight loss was determined in control fruits (3.04%) followed by the UV-C treatment (2.08%). Weight loss of 6% is accepted commercially, since fresh blackberries can easily lose their water by dehydration as they lack epicuticular wax (Paniagua et al., 2013). The fruits treated by UV-C + chitosan coating had the lowest weight loss (1.59%) compared to the control. Such a high reduction in weight loss could be due to induced physiological defense responses of the fresh fruits to UV-C (Stevens et al., 2004) and the selective barrier formation of chitosan on the surface of the fruits (Elsabee and Abdou, 2013), which decreases respiration (Jiang and Li, 2001) and slows the moisture loss of fresh produce (Tezotto-Uliana et al., 2014).

The visual quality of the blackberries remained unchanged for up to 7 days of storage, as shown in Figure 2. After this period, there was a significant decrease in visual quality with the highest decrease observed in control fruits. In contrast, the lowest loss in visual quality was found in the fruits treated with a combination of UV-C

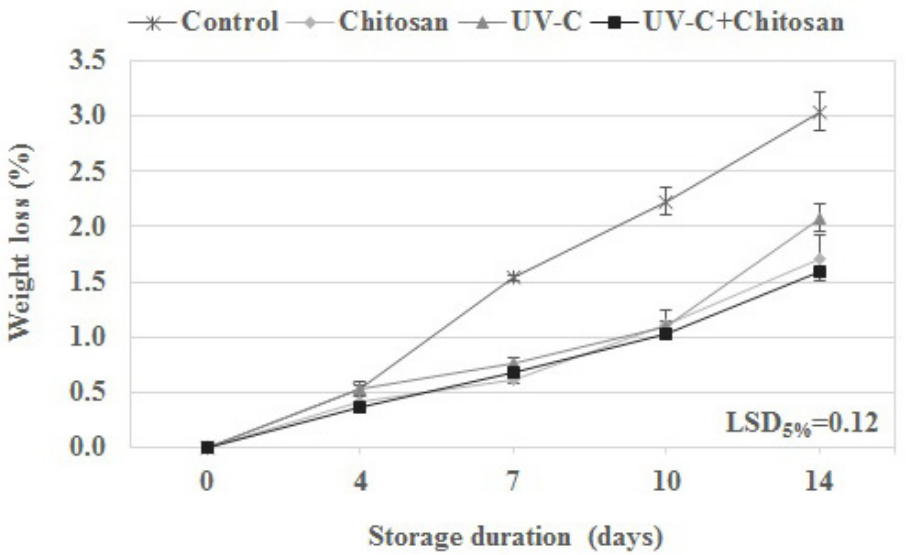

Figure 1. Changes in weight loss (%) of 'Jumbo' blackberry in response to postharvest UV-C and chitosan treatments. Mean values of three replications ± standard deviation. Values represent the means of weight loss measurements in three replicate cups. Vertical bars represent standard deviations.

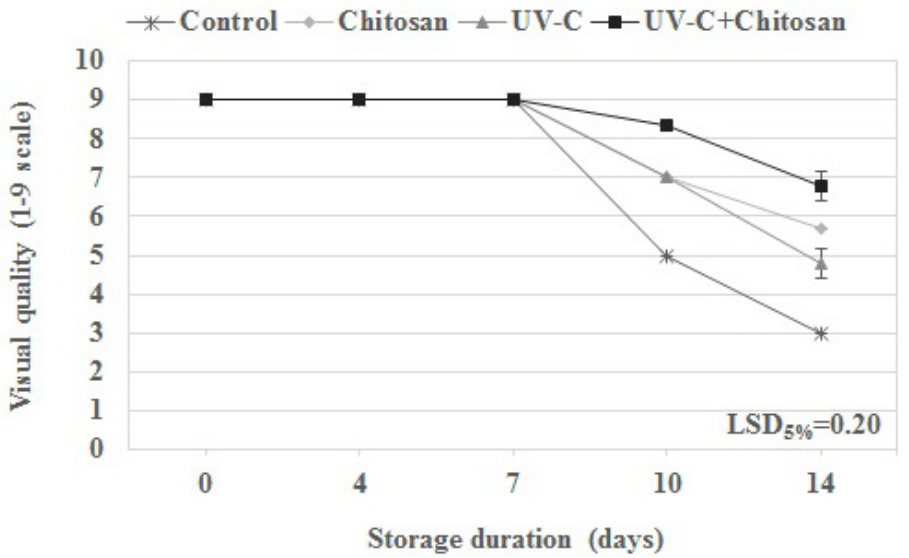

Figure 2. Changes in visual quality (1-9 scale) of 'Jumbo' blackberry in response to postharvest UV-C and chitosan treatments. Mean values of three replications ± standard deviation. Values represent the means of measurements in three replicate cups. Vertical bars represent standard deviations.

and chitosan (6.8), followed by those coated with chitosan. At the end of 14 days of storage, control fruits had very low visual quality scores (3.0), approaching unmarketable levels, while the UV-C-treated fruits were also almost unmarketable (4.8). These changes in visual quality correlated with a gradual increase in fruit weight loss as previously demonstrated by Sabir F et al. (2019), who studied the postharvest physiology of blackberries as influenced by salicylic acid and $CaCl_2$ immersion. Enzyme activities, respiration, and water loss accelerate postharvest senescence in fresh fruits (Meneghel et al., 2008). An increase in these reactions leads to the rapid development of physi-

ological disorders, ultimately resulting in reduced visual quality and a shorter storage life.

3.2. Biochemical characteristics

Table 1 shows that the SSC and TA values of fresh blackberries significantly decreased during cold storage, whereas pH values gradually but insignificantly increased as TA values declined over the extended storage period. The decline in SSC during the postharvest period has been reported for different berry fruits including strawberry (Ayala-Zavala et al., 2004) and blackberry (Joo et al., 2011). The highest changes in both SSC and TA were determined in control fruits while the lowest changes for these parameters occurred in fruits treated with UV-C + chitosan.

An increase in the respiration rate after harvest is a well-known physiological phenomenon in vegetables and fruits (Jiang and Li, 2001; Ayala-Zavala et al., 2004), resulting in a reduction in SSC as organic sugars and acids are primarily substances for the respiration process (Meighani et al., 2015). The combined application of UV-C and chitosan effectively delayed changes in the biochemical characteristics of the blackberries. Regardless of the treatments, the pH value of the blackberries insignificantly increased as TA progressively decreased, since they are inversely related during storage. Similarly, in peaches, general acidity declined and pH increased slightly after the harvest (Kakiuchi et al., 1981).

3.3. Fruit color

The ANOVA results revealed significant differences in the color attributes of the blackberry fruits due to treatments and extended storage time (Table 2). All blackberries showed gradual treatment-dependent decreases in C^*, L^* and $h°$ values during storage. The decrease in color coordinates may be primarily attributed to the oxidation of phenolic compounds and other physicochemical processes in fruits (Pathare et al., 2012), such as the formation of adducts or complex substances between anthocyanins and quinones (produced through polyphenol oxidation) and the weight loss that occurs during storage (Cortés Rodríguez et al., 2020). The desirable red/purple-bluish color in blackberries is due to anthocyanins, and during the postharvest life of the fruit, certain variations occur in pigments determining the fruit color (Mannozzi et al., 2018). At the end of the storage time, the highest changes in color parameters were observed in control fruits while the lowest decreases occurred in the fruits treated with UV-C + chitosan, followed by chitosan coating alone. These results suggest that the chitosan barrier has a protective effect on berry skin, as previously demonstrated for minimally processed fresh grapes cold-stored for 21 days after UV-C irradiation and/or chitosan coating (Sabir et al., 2020).

3.4. Bioactive compounds

The total anthocyanin content of blackberry fruits significantly decreased during storage, although a slight increase was observed in the fruits treated with UV-C + chitosan during the first 7 days (Figure 3). At the end of 14 days of storage, the greatest degradation of anthocyanins (from 366.5 mg/kg to 240.8 mg/kg) occurred in control fruits, at a rate of 33.2%, in comparison to those treated with UV-C +chitosan (18.7%). Ngo et al. (2006) found that total anthocyanins in strawberry fruits decreased by 69% over 60

Table 1. Changes in SSC, TA, and pH of 'Jumbo' blackberry in response to postharvest UV-C and chitosan treatments.

	Treatments	Storage time (days)				
		0	4	7	10	14
SSC	Control	11.20 a	10.80 c	9.93 ef	9.40 h	9.33 h
	Chitosan		11.00 b	10.07 e	9.47 h	9.73 g
	UV-C		10.80 c	10.27 d	9.80 fg	9.47 h
	Chitosan + UV-C		11.07 ab	10.33 d	9.93 ef	9.80 fg
TA	Control	1.167 a	1.094 b	0.974 c	0.758 d	0.572 f
	Chitosan		1.123 ab	1.083 b	0.805 d	0.627 ef
	UV-C		1.149 ab	1.188 a	0.815 d	0.610 ef
	Chitosan + UV-C		1.171 a	1.092 b	0.811 d	0.670 e
pH	Control	3.37	3.48	3.48	3.56	3.73
	Chitosan		3.49	3.45	3.51	3.63
	UV-C		3.43	3.44	3.52	3.66
	Chitosan + UV-C		3.41	3.42	3.46	3.61

Different letters following values indicate significant differences. LSD for SSC: 0.20; TA: 0.067; pH: N.S.

Table 2. Changes in L^*, C and $h°$ values of 'Jumbo' blackberry in response to postharvest UV-C and chitosan treatments.

	Treatments	Storage time (days)				
		0	4	7	10	14
L*	Control	19.82 a	18.26 cd	17.77 cd	17.57 cde	15.75 g
	Chitosan		19.09 ab	17.50 de	16.79 ef	16.82 ef
	UV-C		19.18 a	17.71 cd	17.46 de	16.55 f
	Chitosan + UV-C		19.08 ab	18.36 bc	18.19 cd	17.73 cd
C*	Control	2.87 cd	2.32 fgh	2.03 hi	1.71 i	1.69 i
	Chitosan		3.02 bc	3.00 bc	2.76 cde	2.17 gh
	UV-C		2.71 cde	2.61 def	2.45 efg	1.80 i
	Chitosan + UV-C		3.69 a	3.24 b	2.97 bc	2.59 def
Hue	Control	0.60 a	0.57 b	0.43 fg	0.39 h	0.34 i
	Chitosan		0.57 b	0.47 de	0.43 g	0.35 i
	UV-C		0.57 b	0.46 ef	0.44 fg	0.36 i
	Chitosan + UV-C		0.59 ab	0.50 c	0.48 cd	0.40 h

Different letters following values indicate significant differences. LSD for L^*: 0.80; C^*: 0.34; $h°$: 0.03.

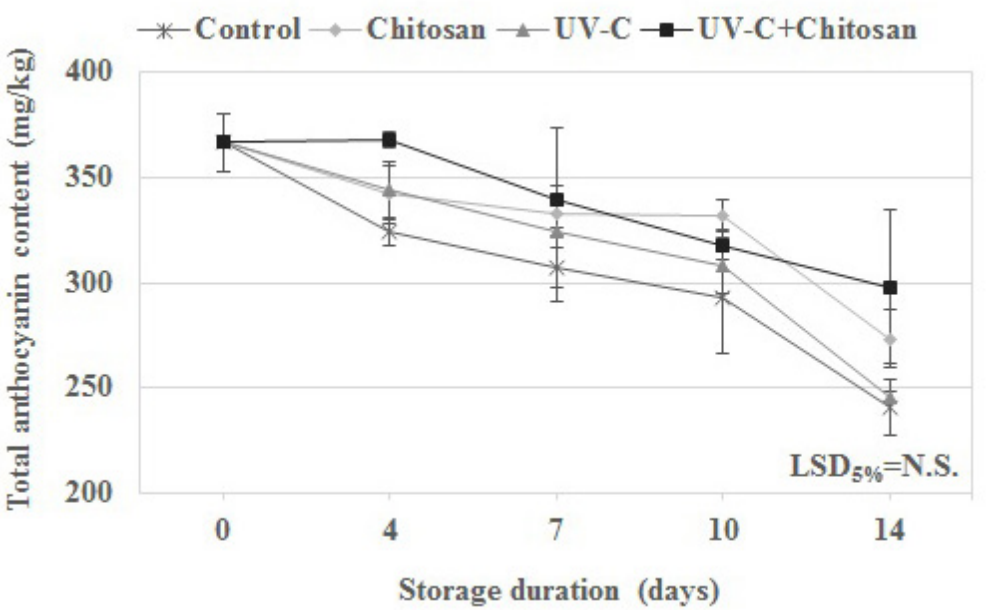

Figure 3. Changes in total anthocyanin content (mg/kg) of 'Jumbo' blackberry in response to postharvest UV-C and chitosan treatments. Mean values of three replications ± standard deviation. Values represent the means of total anthocyanin analyses in three replicate cups. Vertical bars represent standard deviations.

days of storage at ambient temperature. Anthocyanins, as bioactive phytochemicals, contribute to the nutritional value and organoleptic quality characteristics (Espín and Tomas-Barberan, 2001). The chemical stability of anthocyanins is the prime consideration of most recent studies because of their many potential uses as well as essential impacts and potential as alternatives to synthetic colorants in foods. Studies have shown that the postharvest anthocyanins of fresh berry fruits can decrease, remain stable, or even increase during storage (Mikkelsen and Poll, 2002; Kalt, 2005). The success of a storage process depends on maintaining the biochemical and physical characteristics

of the produce. Anthocyanins in fruits and vegetables undergo enzymatic degradation during storage or processing, since anthocyanins and other phenolic compounds are inevitably oxidized during prolonged storage. In the present study, UV-C + chitosan effectively protected anthocyanin compounds in fresh blackberries, likely by inhibiting enzymatic activity and oxidative degradation during cold storage.

Figure 4 shows the variation in TPC in response to treatments during storage. Initially, blackberries had TPC of 71.5 mg GAE/100 g. However, as the cold storage prolonged, TPC significantly increased across all fruit treatments up to the 10th day of cold storage. The highest increase was observed in control fruits (98.0 mg GAE/100 g), while the lowest change occurred in those treated with UV-C + chitosan (89 mg GAE/100 g). After this point, TPC began to decline, likely due to cell structure breakdown resulting from physiological senescence (Macheix et al., 1990). This pattern is consistent with findings from Gol et al. (2015), who studied the effects of chitosan on Indian blackberry quality during cold storage. Phenolic compounds are extensively distributed as organically synthesized substances in fruits and vegetables with high potential to scavenge free radicals (Pila et al., 2010). They are key components of total antioxidant capacity and their increased synthesis contributes to reduced microbial growth and enhanced antimicrobial activity (Dixon and Paiva, 1995). Figure 5 illustrates the significant changes in the AA of the stored fruits. AA slightly decreased for all fruits up to the 10th day of storage, except for control fruits, which showed a sharp decline. Thereafter, the decline was more noticeable, with the lowest change determined in the fruits treated with UV-C + chitosan. These findings indicate that treated blackberries had significantly higher AA compared to control fruits for up to 10 days of storage. At the end of 14 days of storage, the greatest protective effect was observed in the fruits treated with UV-C + chitosan. Stewart et al. (1999) reported that extended storage durations lead to decreased AA due to O_2-induced phenolic oxidation and ascorbic acid (vitamin C). The higher AA of blackberry fruits at the end of 14 days of cold storage could be attributed to the reduced losses of bioactive substances, including phenolic compounds and anthocyanins (Barman et al., 2014).

Figure 6 shows the changes in ascorbic acid retention in blackberry fruits during storage. The amount of ascorbic acid was significantly affected by the postharvest treatments. Loss in ascorbic acid was easily noticeable in control fruits throughout the 14-day storage period, while all postharvest treatments significantly restricted the decrease in ascorbic acid during the 14 days of storage. At the end of the 14-day cold storage, the highest ascorbic acid was determined in fruits treated with UV-C + chitosan, closely followed by those treated with chitosan coating. These findings can be explained by the influence of chitosan treatment in slowing the ripening and effectively restrict-

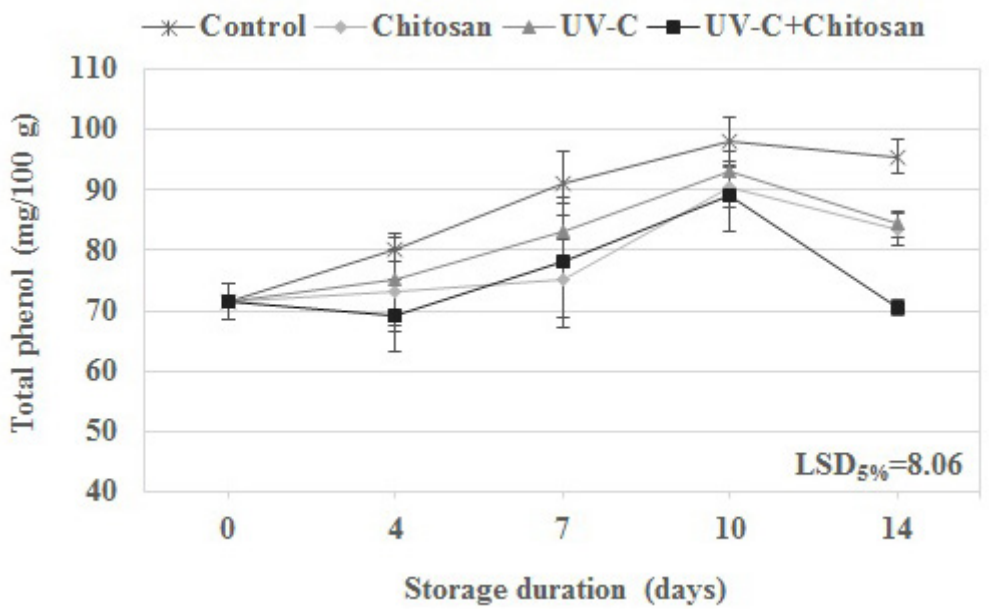

Figure 4. Changes in total phenol (mg/100 g) of 'Jumbo' blackberry in response to postharvest UV-C and chitosan treatments. Mean values of three replications ± standard deviation. Values represent the means of total phenol analyses in three replicate cups. Vertical bars represent standard deviations.

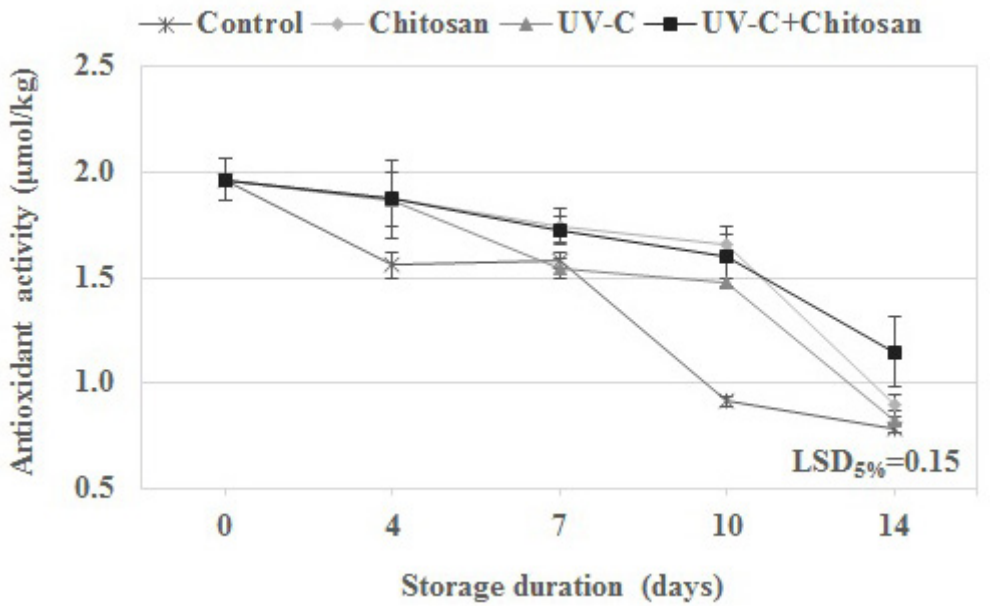

Figure 5. Changes in antioxidant activity (µmol/kg) of 'Jumbo' blackberry in response to postharvest UV-C and chitosan treatments. Mean values of three replications ± standard deviation. Values represent the means of antioxidant activity analyses in three replicate cups. Vertical bars represent standard deviations.

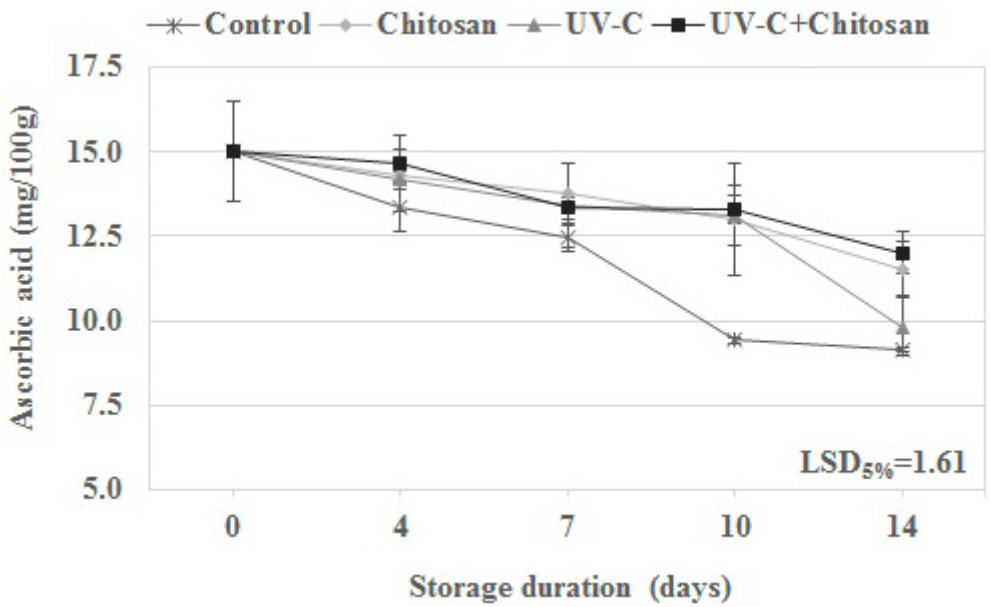

Figure 6. Changes in ascorbic acid (mg/100 g) of 'Jumbo' blackberry in response to postharvest UV-C and chitosan treatments. Mean values of three replications ± standard deviation. Values represent the means of ascorbic acid analyses in three replicate cups. Vertical bars represent standard deviations.

ing the metabolic activity, which can result in ascorbic acid oxidation. Fruits and vegetables are generally known for their rich vitamin C (ascorbic acid) contents, contributing to the human diet. It is also well established that ascorbic acid levels decrease as fruit ripening progresses (Lee and Kader, 2000).

3.5. Polygalacturonase (PG) activity

Figure 7 illustrates the effect of treatments on PG activity. The initial PG activity was 0.79 mmol/kg/h, and it gradually and significantly increased as previously reported in a similar blackberry storage study (Gol et al., 2015). PG activity peaked at the end of the storage period (on day 14),

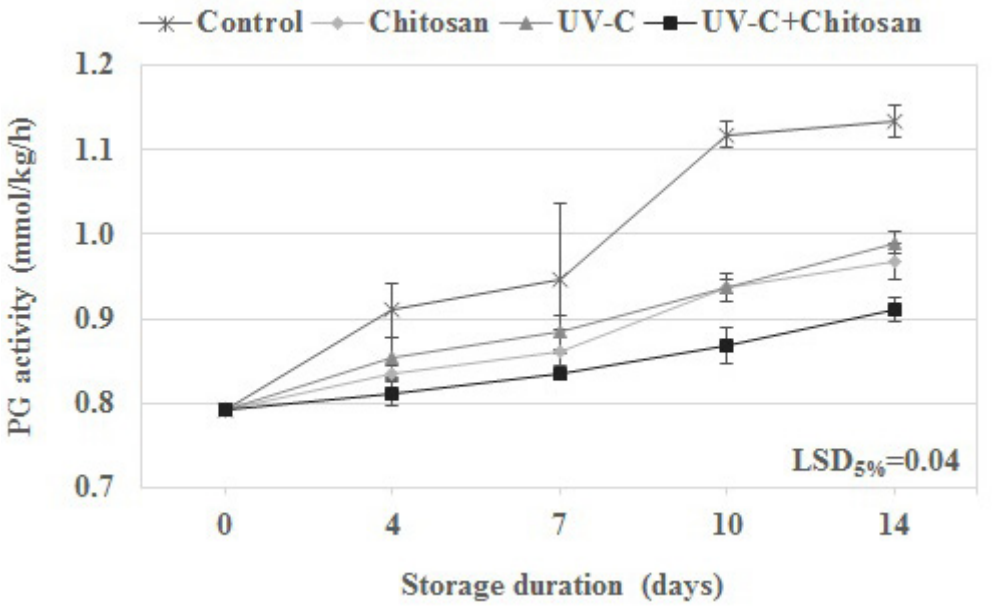

Figure 7. Changes in PG activity (mmol/kg/h) of 'Jumbo' blackberry in response to postharvest UV-C and chitosan treatments. Mean values of three replications ± standard deviation. Values represent the means of PG activity analyses in three replicate cups. Vertical bars represent standard deviations.

indicating that PG could show weak physiological action in the early stage of fruit storage (up to day 7). However, the blackberries treated with UV-C irradiation + chitosan coating had significantly lower PG activity. The control fruits showed a dramatic increase in PG activity after the 7th day of storage, reaching 1.12 mmol/kg/h, while blackberries treated with chitosan and UV-C had similar values of 0.97 and 0.99 mmol/kg/h, respectively. On the 10th day of storage, fruits treated with UV-C + chitosan had roughly 22.3% PG activity in comparison to the control fruits. A study on the storage of perishable fruits like peaches showed that an increase in PG activity is directly correlated with fruit senescence and physiological deterioration (Ruoyi et al., 2005). Thus, inhibiting PG activity is a crucial physiological consideration for extending the postharvest life of perishable fruits.

4. Conclusion

The present study demonstrated significant effects of postharvest UV-C irradiation (5 min, 254 nm) and 1% chitosan coating on protecting the bioactive compounds and biochemical and marketable characteristics of organically produced 'Jumbo' blackberry fruits during 14 days of storage at 1 °C and 85% relative humidity. Fresh fruits tend to lose weight, visual quality, and biochemical and bioactive compounds such as total anthocyanins and ascorbic acids, resulting in a decrease in antioxidants over time. These changes were significantly delayed by the treatments applied in this study, with the most effective protection provided by the combined UV-C and chitosan treatment. At the end of the 14-day storage period, control fruits had experienced considerable weight loss, while the lowest weight loss was observed in fruits treated with UV-C + chitosan coating. PG activity was effectively suppressed by the treatments, with the greatest effect seen for UV-C + chitosan, resulting in the best marketable quality during storage. UV-C + chitosan was also superior in delaying changes in SSC, TA, L^*, C^*, $h°$, antioxidant activity, ascorbic acid content, and total anthocyanin values in fresh blackberries. Therefore, using a 1% chitosan coating and UV-C irradiation at 254 nm for 5 min can be recommended as an environmentally safe, sustainable, and healthy postharvest strategy for protecting bioactive compounds and marketable quality in fresh blackberries.

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