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Effects of post-harvest UV-B irradiation on phenolic content and antioxidant activity of *Rhodomyrtus tomentosa* fruit

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Abstract

In this study, *Rhodomyrtus tomentosa* (Ait.) Hassk. (sim) fruits were treated with UV-B radiation for 0, 1, 3 and 6 hours with an average fluency rate of 0.67 mW/cm^2 at a distance of 30 cm. Fruits were, then, stored at 8 °C to 10 °C for 21 days. During storage, the fruits were analysed for hardness, total soluble solids, and total dry matter every 7 days. The total phenolics, total anthocyanins and antioxidant capacity of the skin+pulp and the seed parts were determined. The results showed that the storage time and UV-B irradiation time significantly affected the antioxidant phenolic content of both skin+pulp and seed parts. The total polyphenols and antioxidant capacity increased immediately after UV-B treatment and decreased during storage. UV-B irradiation slowed down the decrease of antioxidant phenolic compounds in the fruit during storage. This indicated that UV-B irradiation could be a potential way to enhance phenolic antioxidants in fruits rich in phenolics.

Keywords: *Rhodomyrtus tomentosa*; UV-B treatment; Phenolic; Antioxidant; Anthocyanin; Fruit storage.

Highlights

- The total polyphenols and antioxidant capacity increased immediately after UV-B treatment of sim fruit.
- UV-B irradiation slowed down the decrease of antioxidant phenolic compounds in the fruit during storage.
- The increase in phenolic compounds right after UV-B irradiation indicated that the stimulation of phenolic biosynthesis in sim fruit took place mainly during irradiation.

1 Introduction

The sim (*Rhodomyrtus tomentosa* (Ait.) Hassk.) plant is a shrub of the Myrtaceae family, originating from South–East Asia and is identified as one of the 240 “Neglected and Underutilised Crop Species” of Vietnam, China, Thailand, and Cambodia by the scientific project “Agrofolio” in 2008. All parts of this plant, including leaves, roots, buds, and fruits, have been used in the traditional medicine of China, Vietnam, Indonesia,

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Malaysia, and Thailand for a long time. The sim fruits have been used to treat diarrhea, dysentery, and to boost the immune system. Research showed that sim fruit could be considered a new natural source of antioxidant phenolic compounds because of its high phenolic content (49.21 ± 0.35 mg gallic acid equivalent (GAE)/g Dry Weight (DW)) and antioxidant capacity (Oxygen Radical Absorbance Capacity (ORAC) value of 431.17 ± 14.56 µmol Trolox equivalent (TE)/g DW (Lai et al., 2015). Nineteen phenolic compounds were definitively or tentatively characterised in sim fruit and included stilbenes, ellagitannins anthocyanins, flavonols and gallic acid. Among these nineteen compounds, piceatannol, a potent health-promoting stilbene component with antioxidant, anti-cancer, anti-inflammatory, and anti-obesity properties, was the major phenolic compound in the fruit (19.28% of total identified phenolic compounds) with a concentration of 2.3 mg/g DW (Lai et al., 2013) and 94.20% of the piceatannol content of the whole fruit was recovered in the seeds (Lai et al., 2014).

Sim plants grow in mountain regions; hence, ripe sim fruits normally have to be transported to the city before being used as food material. Being berry fruits, they are easily attacked by microorganisms and damaged by mechanical action, leading to a decrease in quality and weight loss during transport and storage. If sim fruits are harvested at near ripen stage, transported to the city, and treated to be richer in anthocyanins, the post-harvest loss will be reduced and the quality of ripe fruit will be improved.

UV irradiation has been used to extend the shelf life of several fruits. It induces the accumulation of anthocyanins and increases the antioxidant capacity of fruits (Su et al., 2016., Huyskens-Keil et al., 2007; Yang et al., 2018). UV-B exposure increased total phenolic content and antioxidant activity in full-ripe blueberries (Nguyen et al., 2014). The increase in phenolic content was partly explained by the effect of UV-B treatment on the expression of some genes coding phenolic biosynthesis enzymes including phenylalanine ammonia-lyase (PAL), chalcone synthase (CHS), chalcone isomerase (CHI), flavonoid 3'-hydroxylase (F3'H), dihydroflavonol 4-reductase (DFR), anthocyanidin synthase (ANS) and UDP-Glc-flavonoid 3-O-glucosyl transferase (UFGT) (Su et al., 2016; Vogt, 2010; Yang et al., 2018).

This study aimed to determine the effect of UV-B treatment on the change of the phenolic content, total anthocyanins, antioxidant capacity of two fruit's parts, seed and skin+pulp of the sim fruit during cold storage. The study also investigated the effect of UV-B exposure on softness, and total soluble solid content. The results can suggest a way to have sim fruits with a higher biological activity which can be used in food technology.

2 Materials and methods

2.1 Sim fruit collection, UV-B treatment, storage condition, and sampling

The sim fruits (*R. tomentosa*) were harvested in September 2019 in the mountains of Son La province. The fruits at maturity stage M4 (M1-green with red streaks, M2-half red, M3-fully red, M4-purple, and M5-dark purple (Lai et al., 2013) (Figure 1) were hand-picked, placed in a plastic box, kept on ice, and transported to the laboratory on the same day.

In the laboratory, the fruits were treated with UV-B radiation by using UV-B G15T8E lamp tubes (Sankyo Denki, Japan). Fruit samples were exposed to UV-B radiation for 0, 1, 3, and 6 hours with an average fluency rate of 0.67 mW/cm^2 (measured by using UVA/B Light Meter 850009, Sper Scientific Direct, Arizona) at a distance of 30 cm above fruits (Figure 2). They were then separated into 250 g plastic boxes and stored at 8° C to 10 °C for 21 days. Sampling was carried out every seven days. For any time of sampling, three 250 g plastic boxes of each UV-B time treatment were taken. The weight loss, firmness of the fruit, and total soluble solids (TSS) were determined. The sim fruits were then freeze-dried at -58 °C for three days. After freeze-drying, they were manually separated into two parts, seed and skin+pulp, ground into powder ($d < 0.25$ mm) by using an Ultra Centrifugal Mill ZM 200 (Retsch, Germany) and stored at -18 °C until analysis of phenolic compounds and antioxidant capacity. UV-B treatment was done in triplicate.

Figure 1. Sim fruits at different maturity (Lai et al., 2013).

Figure 2. UV-B treatment chamber.

2.2 Chemicals and reagents

Gallic acid standards, Folin–Ciocalteu reagent, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical and Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) were purchased from Sigma–Aldrich (St. Louis, MO). Chlorohydric acid, potassium chloride, sodium carbonate, sodium acetate, vitamin C of analytical grade were from company Xilong (Guangdong, China).

2.3 Weight loss, TSS, firmness of the fruit measurement

At sampling time, the weight of the sim fruit box was measured. The weight loss was calculated and expressed as a percentage of weight reduction relative to the initial value of sim fruits in the box. TSS of the

sim fruit was analysed by using an Atago PAL-1 pocket refractometer (Japan). For each sample, 15 fruits were taken to analyse the firmness by using a Lutron FR-5120 fruit hardness tester (Lutron electronic, Taiwan) with a tip size of 3 mm. Firmness is determined by the force required for the tip to penetrate the flesh of the sim fruit at a distance of 2 mm. The measurement was made at one point in the center of the fruit.

2.4 Extraction and analysis of total phenolics, total anthocyanins, and antioxidant capacity

2.4.1 Phenolic extraction

Phenolic compounds of the seed and skin+pulp parts were extracted by using a protocol described by Lai et al. (2013) with minor modifications. Briefly, approximately 50 mg of freeze-dried powdered seed/skin+pulp was mixed with 1.5 ml of acetone: water: acetic acid (50:49:1; *v/v/v*) and shaken for 30 minutes at 37 °C. After centrifugation at 3642 *g* for 10 min at 4 °C, the supernatant was collected and the residue was extracted two more times with the same quantity of the same solvent. Supernatants from the three extraction steps were combined and the solvent was added to a total volume of 5 mL. This crude extract was used to analyse the total phenolics, total anthocyanins, and antioxidant capacity. Extraction was done in triplicate.

2.4.2 Folin-Ciocalteu reagent and total phenolic analysis

Total phenolics were determined by using the Folin–Ciocalteu reagent (Singleton & Rossi, 1965). Briefly, 1000 µL of diluted extract was mixed with 500 µL of Folin-Ciocalteu reagent 1 N. The mixture was incubated for 5 min at 25 °C in the dark before being added of 2500 µL Na_2CO_3 7.5%. After an incubation of 30 minutes in the dark, the absorbance at 755 nm was measured by using Shimadzu UV 1800 spectrophotometer (Japan). Gallic acid was used as standard in this test. The total phenolic content was calculated using a calibration curve describing the relation between gallic acid concentration and absorbance at 755 nm and was expressed in mg gallic acid equivalent per gram dry weight (mg GAE/g DW).

2.4.3 pH differential method and total anthocyanin analysis

Total anthocyanins were determined by using AOAC Official Method 2005.02. Briefly, the extract was diluted five times with pH 1 and pH 4.5 buffers. After an incubation of 30 minutes, absorbance measurements at 520 nm and 700 nm were measured (Shimadzu UV 1800, Japan). Anthocyanin concentration, expressed as cyanidin-3-glucoside equivalents, was calculated according to the following equation: Anthocyanin concentration (mg/L) = A*MW*DF*10^3/ε/1 where A = $(A_{520nm} - A_{700nm})_{pH1.0} - (A_{520nm} - A_{700nm})_{pH4.5}$; MW (molecular weight) = 449.2 g/mol for cyanidin-3-glucoside which was the major anthocyanin of the sim fruit (Lai et al., 2013); DF = dilution factor; l = pathlength in cm; e = 26900 molar extinction coefficient for cyanidin-3-glucoside, in L/mol/cm; and 10^3 = factor for conversion from g to mg.

2.4.4 DPPH assay and determination of antioxidant capacity

The antioxidant capacity of the extracts of the different fruit parts was measured by the DPPH radical scavenging test described by Duan et al. (2007) with minor modifications. Briefly, 100 µL of diluted extract was mixed with 2900 µL of 0.1 mM DPPH radical in methanol solution. The mixture was incubated for 30 min at 25 °C in the dark and the decrease in absorbance at 517 nm was measured. The control contained methanol instead of the diluted extract/standard solution. The inhibition of DPPH radicals by the sample was calculated according to the following equation: DPPH-scavenging activity (%) = 100*(absorbance of control - absorbance of sample)/absorbance of control. Trolox was used as standard. The antioxidant capacity was calculated using a calibration curve describing the relation between Trolox concentration and DPPH-scavenging activity. The antioxidant capacity was expressed in µmol Trolox equivalent per gram dry weight (µmol TE/g DW).

2.5 Statistical analysis

Data were analysed using the statistical software SAS 9.4 (SAS Institute, Cary, NC). Analysis of Variance (ANOVA) was carried out using a Generalised Linear Model (GLM) procedure to determine the effect of the UV-B treatment time, storage time and their interactions on TSS, firmness, phenolic content, anthocyanin content and antioxidant capacity. The model configuration was $Y_i = a + b_1*X_1 + b_2*X_2 + b_{12}*X_1*X_2$ (Y_i: the investigated index; X_1: UV-B treatment time and X_2: storage time). Besides, a one-way analysis of variance and the Turkey's test were used to determine the differences amongst the means. p-values < 0.05 were significantly different.

3 Results and discussion

3.1 Change of the weight loss, firmness, TSS and dry matter of sim fruits during storage

3.1.1 Weight loss

The weight loss expressed in percentage of initial quantity is presented in Figure 3. UV-B treatment time and storage time significantly affect the weight loss of sim fruit ($p = 0.0149$ and $p < 0.0001$) (Table 1). The interaction between these two factors (Storage time* Treatment time) had no significant effect. In general, the weight loss of sim fruits increased and reached a maximum level on the 21st day of storage. A similar trend had been observed in peaches treated with UV-B in the work of Abdipour et al. (2019). This was mainly due to water loss caused by transpiration from the tissue surface and respiration processes of sim fruits and contaminating microorganisms during long storage (Xanthopoulos et al., 2017).

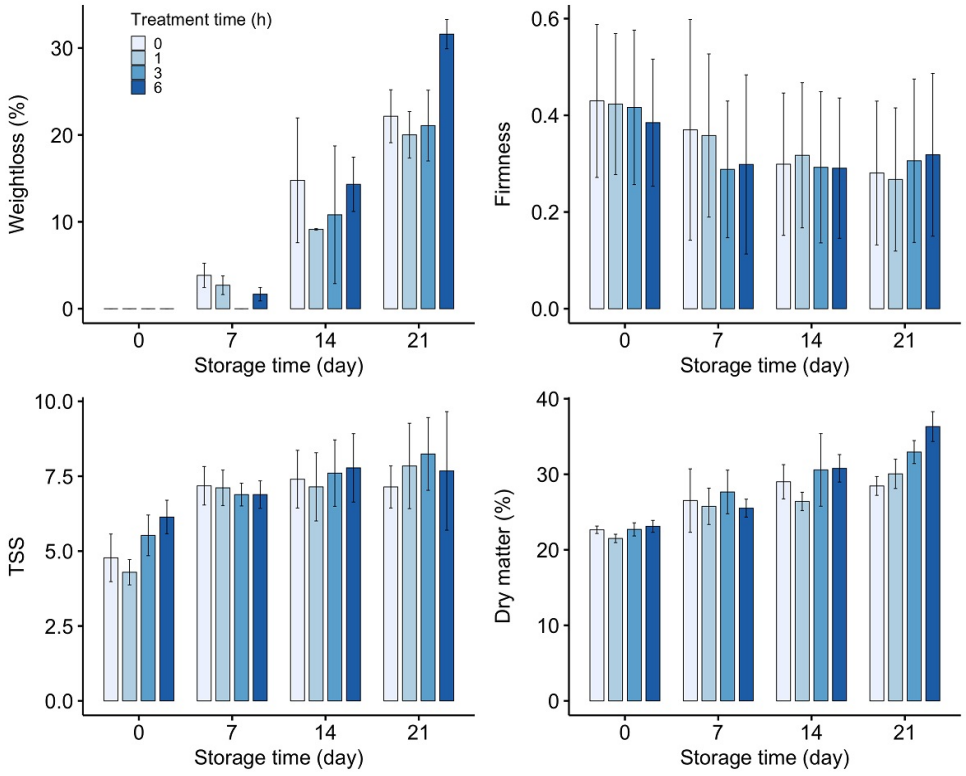

Figure 3. Effect of UV-B treatment and storage time on the weight loss, firmness, TSS and dry matter content of sim fruits.

Table 1. Results of significant differences for weight loss, firmness, total soluble solids, dry matter and antioxidant phenolic compounds of sim fruits according to storage and treatment time.

Variables	Factors	DF	F-value	*p*-value
Weight loss	Treatment time	3	4.28	0.0149
	Storage time	2	103.38	<.0001
	Storage time* Treatment time	6	2.11	0.0899
Firmness	Treatment time	3	0.83	0.4751
	Storage time	3	21.31	<.0001
	Storage time* Treatment time	9	1.34	0.2118
TSS	Treatment time	3	2.80	0.0426
	Storage time	3	47.03	<.0001
	Storage time* Treatment time	9	1.98	0.0471
Dry matter	Treatment time	3	14.38	<.0001
	Storage time	3	109.47	<.0001
	Storage time* Treatment time	9	5.51	<.0001
TP in skin+pulp	Treatment time	3	391.95	<.0001
	Storage time	3	6.28	0.0005
	Storage time* Treatment time	9	1.14	0.3396
TA in skin+pulp	Treatment time	3	77.70	<.0001
	Storage time	3	93.06	<.0001
	Storage time* Treatment time	9	17.29	<.0001
AC in skin+pulp	Treatment time	3	99.78	<.0001
	Storage time	3	267.32	<.0001
	Storage time* Treatment time	9	4.39	<.0001
TP in seed	Treatment time	3	28.92	<.0001
	Storage time	3	4.08	0.0084
	Storage time* Treatment time	9	0.30	0.9750
AC in seed	Treatment time	3	158.20	<.0001
	Storage time	3	51.44	<.0001
	Storage time* Treatment time	9	4.47	<.0001

TP: Total phenolics; TA: Total anthocyanins; AC: Antioxidant capacity.

In short-term storage (7 days) and short exposure UV-B (3h), these samples had lower weight loss than the control and 1-hour UV-B treatment samples. The use of UV-B treatment that lower weight loss was also shown in peach, peaches irradiated with UV-B during 10 to 20 minutes at 0.36 to 0.72 kJ/m^2 had a reduction of water loss in comparison with the control (Abdipour et al., 2019). A proposed explication for the mechanism of reducing the water loss by short irradiation was the formation of a thin dried layer on the surface of the fruits that reduces water evaporation (Manzocco & Nicoli, 2015). However, the sim fruits treated with UV-B for 6 hours had the highest weight loss (31.60%) after 21 days of storage. In fact, long exposure to UV-B radiation could cause oxidative stress, resulting from Reactive Oxygen Species (ROS) generation (Hideg et al., 2013). Under the UV-B treatment, *Withania somnifera* (L.) Dunal leaves had increased malondialdehyde (MDA) (a characteristic product of lipid peroxidation) and H_2O_2 contents (Takshak and Agrawal, 2014). Sim fruits treated with UV-B during 6 hours could accumulate ROS which affected the cell wall, and subsequently, increase water loss.

3.1.2 Firmness

The change of firmness of sim fruit during cold storage is presented in Figure 3. Storage time significantly affected the firmness of the sim fruit ($p < 0.0001$) During storage, the firmness of sim fruit decreased both treated and untreated with UV-B, and UV-B treatment time had no significant effect ($p = 0.4751$). The reduction in texture firmness had been also observed in peaches (Abdipour et al., 2019), apples (Assumpção et al., 2018), and ripe tomato (Vunnam et al., 2014) treated or untreated with UV-B.

In fact, fruit softening is usually related to some enzymes participating in fruit maturation such as pectinases, cellulases, hemicellulases (Payasi et al., 2009). Scattino et al. (2016) analysed the activity of Exo-polygalacturonase (Exo-PG), endo-1,4-β-D-glucanase/β-D-glucosidase (EGase), β-galactosidase (β-Gal) and pectin methylesterase (PME) in peaches and nectarine treated and no-treated (control). The results showed that activity of Exo-PG of 'Suncrest' variety as well as Exo-PG and EGase of 'Big Top' increased in treated samples but the activities of other enzymes were substantially unaffected by the treatment. Further investigation on texture softening enzymes would provide an in-depth understanding about the effect of UV-B irradiation on the firmness of fruits.

3.1.3 Total soluble solid

The change of TSS of sim fruit during cold storage is presented in Figure 3. Total soluble solid content of sim fruit increased during the first week of storage ($p = 0.0186$) and then did not change during the two following weeks ($p < 0.0001$).

Variation of TSS during storage was different in several fruits. In peaches, an increase of TSS was associated with an increase in water loss (Abdipour et al., 2019) while in ripe tomatoes and apples, slight TSS reduction was related to sugar metabolism (respiration for example) (Vunnam et al., 2014). UV-B treatment showed significantly affected TSS content of sim fruit. Indeed, TSS increased in sim fruits treated for 3 and 6 hours at the beginning of storage (day 0). From the second week, the TSS of all sim fruit samples (with and without UV-B treatment) were equal. This suggested that UV-B irradiation promoted the maturation of the sim fruit during the treatment time and the sim fruits could reach the highest maturity stage (S5) after one week of storage.

3.1.4 Dry matter

The change of dry matter content of sim fruit during cold storage is presented in Figure 3. Storage time and UV-B treatment time significantly affected the dry matter content of the sim fruit ($p < 0.0001$ for all). During storage, the dry matter content increased in all sim fruit samples. The longer the UV-B treatment, the higher increase in dry matter content of sim fruit. After 21 days of storage, the dry matter of control, 1-hour, 3-hour, and 6-hour UV-B treatment samples increased by 5.79%, 8.6%, 10.24%, and 13.20% respectively, compared with the one at the beginning of storage. The augmentation in dry matter was the result of transpiration and relative to the fruit weight loss.

3.2 Total phenolic, anthocyanin content and antioxidant capacity of skin+pulp and seed parts of sim fruit

3.2.1 Total phenolics of skin+pulp part

UV-B treatment time and storage time significantly affected the total phenolic content of the skin+pulp part of the sim fruit ($p < 0.0001$ and $p = 0.0005$) while the interaction between these two factors presented any effect ($p = 0.3396$) (Figure 4). Just after UV-B irradiation, phenolic content of skin+pulp part increased significantly. The rate of increase depended on the irradiation time, the longer the irradiation time, the greater the total polyphenols. After UV-B treatment, phenolic content of 1-hour, 3-hour and 6-hour UV-B treated sim fruits had 10.18%, 19.75%, and 25.89% higher than the one of the controls, respectively. During storage, the phenolic content of control fruits decreased slightly while one of the UV-B irradiated samples did not change. It is possible that UV-B irradiation had the effect of stimulating the biosynthesis of phenolic compounds mainly during the irradiation period.

The effect of UV-B on phenolic synthesis was reported by several studies. Huyskens-Keil et al. (2007) showed that UV-B treatments (8.2 Ws/m^2 at a distance of 30 cm to fruits) resulted in a continuous increase

of phenolic compounds until the exposure time increased from 0 to 90 minutes. Cantos et al. (2000) demonstrated that postharvest treatments of grapes with UV-B induced a large increase in resveratrol derivatives leading to an increase in total phenolic content. Similarly, ultraviolet-B light treatment increased total phenolics in carrots and carrot products (Avena-Bustillos et al., 2012) in peaches (Abdipour et al., 2019) and in peanut sprouts (Nguyen et al., 2020). The induction was dose-dependent and partly explained by the increase in PAL activity (Huyskens-Keil et al., 2007; Avena-Bustillos et al., 2012), a key enzyme in the phenylpropanoid pathway that produces antioxidant phenolic compounds (Dewick., 2002; Strack., 1997).

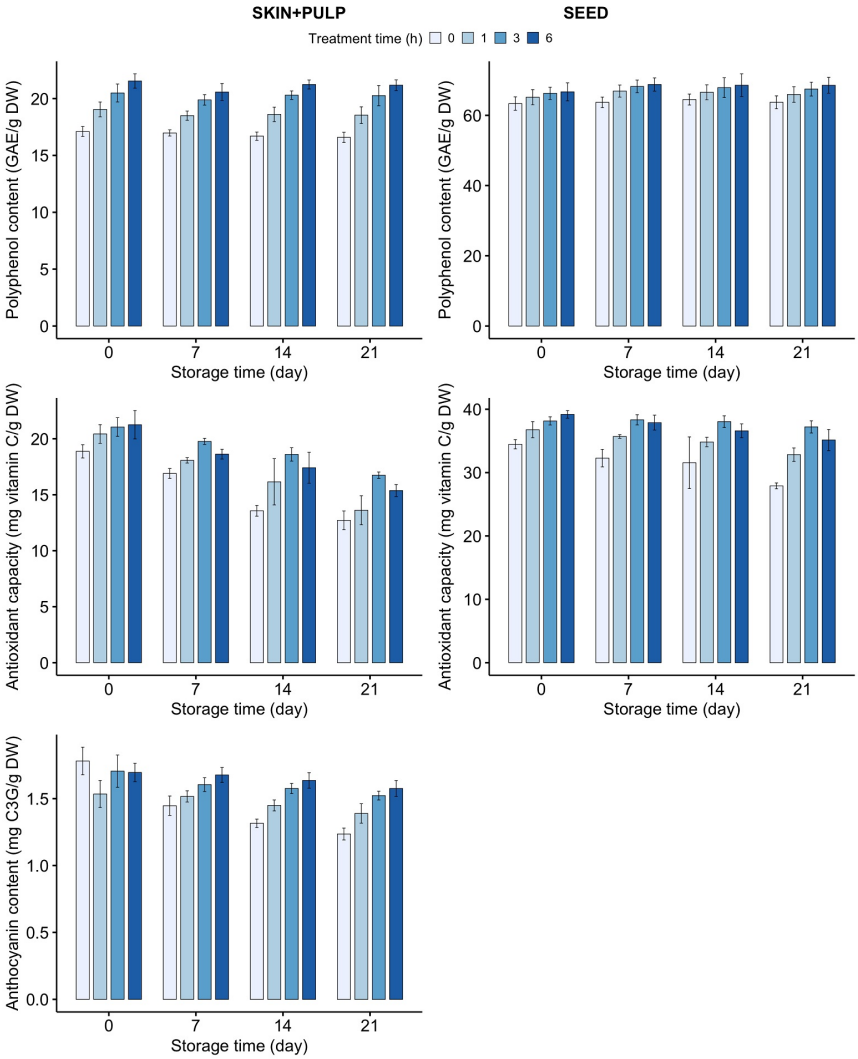

Figure 4. Effect of UV-B treatment and storage time on total phenolics, total anthocyanins and antioxidant capacity of sim fruit skin+pulp and seed parts.

3.2.2 Total anthocyanins of skin+pulp part

UV-B exposure time, storage time, and interaction between the two factors significantly affected the total anthocyanin content of sim fruits ($p < 0.0001$ for all) (Figure 4). The UV-B treatment did not induce anthocyanin accumulation in the skin+pulp part of sim fruit just after the irradiation because the total anthocyanins did not change when the UV-B exposure time increased on day 0. A similar observation was obtained in the skin of "cv. Napoleon table" grapes when the fruits were irradiated with UV-B (Cantos et al., 2000). However, some authors found the induction of anthocyanin synthesis by UV-B lights. Huyskens-Keil et al. (2007) reported an increase of 60% anthocyanins in black currant fruit after 120 minutes of UV-B

irradiation. Yang et al. (2018) indicated an increase in anthocyanin content of 61% when blueberries (*Vaccinium corymbosum* L.) at the turning stage (S6) were treated with UV-B lights at 30 cm distance (above the fruits) for 10 min (dose 2.76 kJ/m^2). The accumulation of anthocyanins was also detected in red Chinese sand pears (*Pyrus pyrifolia* Nakai) fruit treated with UV-B continuously for 10 days (Zhang et al., 2012). The difference in the effect of UV-B on anthocyanin content between the sim fruit (in the present study) and other fruits could be partly due to the fruit treatment after UV-B irradiation. In this study, the treated sim fruits were immediately frozen while fruits in others had an adaptation time after treatment before being stocked (2 to 22 hours for black currant (Huyskens-Keil et al., 2007) and 24 hours for blueberries (Yang et al., 2018) or were treated continuously (pears, Zhang et al., 2012). The induction of anthocyanin synthesis in pears was temperature-dependent and due to the expression of five anthocyanin structural genes including *Pp*PAL, *Pp*CHI, *Pp*CHS, *Pp*F3H, and *Pp*ANS (Zhang et al., 2012). Postharvest UV-B irradiation of blueberries at the turning stage activated the expression of *Vc*DFR, *Vc*UFGT gens and then promoted activities of the downstream synthetases (DFR and UFGT) leading to the accumulation of anthocyanin (Yang et al., 2018). In the present study, biochemical changes in the anthocyanin biosynthetic pathway may not occur when sim fruit samples were frozen immediately after UV-B irradiation. Another possible reason was the balance between anthocyanin biosynthesis and anthocyanin degradation occurred in sim fruits because of the enhancement activity of oxidizing enzymes during irradiation. Csepregi et al. (2019) demonstrated an increase in peroxidase activity immediately after the UV treatment of the table grape Emperor cultivar. A similar mechanism, a temporary increase in fruit skin peroxidase activities may be the explanation for the observed decrease in flavonoid contents of two other table grape cultivars, 'Queen of Vineyard' and 'White Sultana' (Csepregi et al., 2021). As the anthocyanin content of sim fruit did not change right after the irradiation, the increase in polyphenol content after treatment may be explained by the accumulation of other phenolic compounds than anthocyanins in sim skin and pulp.

The effect of UV-B treatment time on anthocyanins synthesis was clearer during sim storage. During storage, anthocyanin content decreased. The rate of decrease depended on the time of UV-B treatment. The longer the irradiation time is, the lower the anthocyanin reduction rate will be. After 21 days of storage, anthocyanin content decreased by 30.34%, 9.15%, 11.63% and 7.06% in the control and 1-hour, 3-hour and 6-hour UV-B treated samples. In fact, during storage, anthocyanin biodegradation and biosynthesis can occur simultaneously. Anthocyanins were degraded as a result of oxidation, either in a direct reaction with ROS, or during electron donation to polyphenol oxidase (Csepregi et al., 2021) because these compounds are strong antioxidants (Martín et al., 2017). Indeed, the chemical structure of anthocyanins is appropriate for acting as antioxidants, as they can donate hydrogen or electrons to the free radicals or trap them and then delocalize them in their aromatic structure (Martín et al., 2017). In the UV-B irradiated samples, the synthesis could be stronger than in the control samples (without irradiation) leading to a lesser decrease in total anthocyanin content.

3.2.3 Antioxidant capacity of skin+pulp part

UV-B treatment time and storage time significantly affected the antioxidant capacity of sim skin and pulp ($p < 0.0001$ for both) (Figure 4). During storage, antioxidant capacity decreased 33.63%, 34.24%, 20.97%, and 28.37% in control, 1-hour, 3-hour, and 6-hour UV-B treatment fruit samples, respectively. Immediately after UV-B irradiation, the antioxidant capacity of treated samples increased by 8.46-12.98% in comparing to the control samples. The increase in antioxidant activity was observed in harvested black currant fruits (21%) after 120 min UV exposure with an adaptation time of 22 h (Huyskens-Keil et al., 2007). After being treated with UV-B lights, all carrot products showed a significant increase in antioxidant capacity (1.4-3.2-fold) compared with untreated samples when exposed to a low UV-B dose (1.3 kJ/m^2) in the research of Avena-Bustillos et al. (2012). The increase of antioxidant capacity in sim fruit skin+pulp part may be partly explained by the increase of phenolic compounds when exposed to UV-B lights. However, although the phenolic content in the fruit samples seems to be constant or slightly decreased following storage the antioxidant capacity declined. This indicated the presence of other antioxidants in skin+pulp part of sim fruit such as vitamin C, vitamin E or others

(Lai et al., 2015). The possible reduced content of these compounds during storage led to a decrease in the antioxidant capacity of skin+pulp part in all samples, with and without UV-B irradiation.

3.2.4 Total phenolic of seed part

UV-B treatment time and storage time significantly affected the phenolic content of sim seeds ($p < 0.0001$ and $p = 0.0084$, respectively) whereas interaction between these two factors had any influence ($p = 0.9750$) (Figure 4). During storage, the phenolic content of control and UV-B treated samples keep constant. After irradiation, the polyphenol content of UV-B treated samples was 2.86%, 4.63%, and 5.26% higher than the control one. This indicated that UV-B irradiation may stimulate phenolic compound biosynthesis in sim seeds, the inner part of the fruit. In fact, the penetration of UV-B lights into the sim seeds was possible because of the small distance between the skin and seeds. In a sim fruit that measures only 1 to 1.5 cm in diameter, there are many deltoid seeds of 1.5 mm in diameter, located in 6 (-8) pseudo-locules divided by thin false septa. This stimulation was smaller in the seed part than in the skin+pulp part (10.18%, 19.75% and 25.89%) which was directly exposed to UV-B light. Another difference between the two parts of sim fruit is that the polyphenol content in the skin+pulp part decreased during storage while the one of seeds seemed to remain constant. Seed is the inner part of sim fruit and has rigid structure that makes sim seed being less exposed to oxygen and its polyphenols could be less oxidized. In addition, anthocyanins (10.40% of total polyphenols of skin+pulp part) responsible of the purple-black color of the fruit were easily oxidized during storage contributing to the reduction of polyphenols in the skin+pulp part during storage.

3.2.5 Antioxidant capacity of seed part

The antioxidant capacity of the seed part was significantly influenced by UV-B irradiation time and storage time ($p < 0.0001$ for both) (Figure 4). After irradiation, the antioxidant capacity of the seed increased when the UV-B exposure time increased from 0 to 3 hours and then did not change. During storage, antioxidant capacity decreased while phenolic content seemed to remain stable. This indicated the possible presence of other antioxidant compounds than polyphenols in the sim seed. Another explication could be the change of phenolic profile of sim seed during storage. In fact, the antioxidant activity of a polyphenol depends upon the number of hydroxyl substitutions in its backbone structure. The more hydroxyl substitutions, the stronger the antioxidant activity (Cao et al., 1997).

The degree of reduction in antioxidant capacity was dependent on UV-B irradiation time. The longer time of UV-B irradiation, the smaller decrease in the antioxidant capacity. At day 21 of storage, the antioxidant capacity of the control samples, 1-, 3-, and 6-hour UV-B irradiated decreased by 19.64%, 11.03%, 2.54%, and 10.65%, respectively.

After 21 days of storage, the polyphenol content of 3- and 6-hour UV-B irradiated samples were the highest. The antioxidant capacity of the sample exposed to UV-B for 3 hours was the greatest.

4 Conclusion

During storage, the hardness, and the total soluble solids content of the sim fruit decreased while total dry matter content increased. UV-B irradiation did not significantly affect the firmness and TSS of the fruit but enhanced the rate of increase in total dry matter content. Concerning the antioxidants, storage time and UV-B exposure time significantly affected the antioxidant phenolic content in the skin+pulp and seed parts. Total polyphenols, total anthocyanins, and antioxidant capacity of skin+pulp decreased during storage. In the seed part, the antioxidant capacity decreased while the phenolic content did not change. UV-B irradiation slowed down the decrease of antioxidant phenolic compounds in the fruit during storage. The increase in phenolic compounds right after UV-B irradiation indicated that the stimulation of phenolic biosynthesis in sim fruit took place mainly during irradiation.

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