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Effect of grafting and harvest stage on the quality of black cherry tomatoes (*Solanum lycopersicum* cv. OG) cultivated in Vietnam

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Abstract

Black cherry tomato is an important source of nutraceutical compounds; however, the quality of fruits depends on the cultivation technique and maturity stage at harvest. In this study, the physical and chemical properties of non-grafted and grafted tomatoes (*Solanum lycopersicum* cv. OG) were evaluated at different stages of maturity to observe the effect of grafting on quality of fruits and select the appropriate harvest stage to achieve the highest content of bioactive compounds, especially anthocyanin. The obtained results found that harvesting non-grafted tomatoes on the 30th day after fruit formation would be suitable for storage with the highest anthocyanin level of 4.27 mg CE/100 g and the content of other bioactive compounds (lycopene 24.60 µg/g, vitamin C 42.79 mg/100 g and total phenolic 40.61 mg GAE/100 g). Meanwhile, the optimal harvest stage of grafted tomatoes was shortened, on the 28th day (anthocyanin 4.31 mg CE/100 g, lycopene 38.79 µg/g, vitamin C 55.69 mg/100 g, and total phenolic 38.69 mg GAE/100 g). The grafting technique should be applied for supporting the plant to grow faster as shown by the earlier stage of harvest and the harvested fruit possessed higher content of bioactive compounds.

1. Introduction

"Black" or "purple" cherry tomatoes are subspecies of *Solanum Lycopersicum* (Zhang *et al*., 2018) and exhibit a purplish-brown color on their skin (Mes *et al*., 2008). Lycopene is the most abundant (about 80-90% of total carotenoid content) and the highest antioxidant natural carotenoid found in tomatoes (Alda *et al.*, 2009). Epidemiological studies have shown that lycopene, a red pigment has the potential to reduce the risk of chronic diseases, most notably prostate cancer (Ford and Erdman, 2012). This red pigment also plays an important role in the prevention of cardiovascular disease (Mordente *et al*., 2011). Min and Min (2014) observed that consuming a large amount of lycopene-rich foods helped to lower the risk of mortality from Alzheimer's disease in adults. Kaur *et al*. (2011) also found that lycopene was beneficial in the treatment of Parkinson's disease and other neurological abnormalities by protecting against oxidative stress. In addition to carotenoids, tomatoes are good for other antioxidant compounds such as vitamin C and phenolics which also inhibit reactive oxygen species causing many dangerous diseases (Ilahy *et al*., 2009). It has been noticed that the content of phenolic compounds and carotenoid pigments, particularly lycopene in black cherry tomatoes are higher than in some red tomato varieties (Zhang *et al*., 2018). Especially, black cherry tomatoes also can produce a phytochemical of anthocyanin predominantly in the skin (Li *et al*., 2011). Anthocyanin has been proven to be associated with many health benefits, reduces cancer cell proliferation, protects against cardiovascular disease, prevents obesity and diabetes (Lila, 2004).

Despite containing many bioactive compounds, researches on black cherry tomatoes have been very limited, especially in Vietnam. Moreover, consumers are still sceptical about the anthocyanin component in black cherry tomatoes, because some studies in the world showed that some heirloom varieties result from mutations affecting chlorophyll breakdown and carotenoid content but are not related to anthocyanin production (Gonzali *et al*., 2009). Therefore, most of the black cherry tomatoes have primarily grown in Vietnamese gardens for visiting and retailing. This wastes a healthy source of black cherry tomatoes and does not create many choices for consumers and also affect the economic benefits for farmers.

Besides that, bacterial wilt, caused by *Ralstonia*

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solanacearum, can be very problematic for all tomato growers as a result of a lack of available resistance genes within cultivated tomato (Rivard and Louws, 2008). The cultivation of grafted vegetable plants has become more popular recently to manage soilborne pathogens (Besri, 2001; Bletsos, 2005). This technique is carried out when the rootstock and scion seedlings are very small, and the two are attached with a small silicon tube or clip (Rivard and Louws, 2006). Grafting with tolerant rootstock is also effective at overcoming abiotic stresses such as salinity (Cuartero *et al*., 2006), thermal stress (Rivard and Louws, 2008), and excessive soil moisture (Black *et al*., 2003). Although the use of grafted vegetables is associated with disease reduction and/or abiotic stressors, yield can be increased without the presence of these identified stressors (Yetisir and Sari, 2003). Grafted plants also produced higher fresh and dry matter than control (Yetisir and Sari, 2003).

The physical and chemical properties of tomatoes not only depend greatly on the grafting but also on the maturity stage at harvest. Maturation caused a slight softening in tomato when compared with less mature tomato fruits, which has a significant effect on the quality and influences consumer preferences, storability, shelf life, pathogen resistance, and transportability (Viskelis *et al*., 2008). Helyes *et al*. (2006) found that the Brix, carbohydrate, and lycopene content increased during maturation from the green mature to the deep red stage but polyphenol content changed little during tomato ripening. Moneruzzaman *et al*. (2008) reported that half-ripen tomato showed the highest value of vitamin C and titrable acidity.

Therefore, the objective of this study was to evaluate the effect of grafting and harvest stage on the physicochemical properties of a new variety of black cherry tomatoes grown in Vietnam (*Solanum lycopersicum* cv. OG). These results would help farmers to choose grafting/non-grafting techniques and suitable harvest maturity.

2. Materials and methods

2.1 Experimental design

Black cherry tomato (cv. OG) seeds were provided by the F1508 seed store (Ho Chi Minh City, Vietnam) and sown at Nam Long farm, Vinh Long province, Vietnam. After 23 days of sowing, 50 tomato plants were grafted with eggplant root (eggplant "EG 203" was obtained from the Asian Vegetable Development and Research Center). After 29 days of sowing, the remaining 50 tomato plants (without grafting) were transferred to pots for growing. After 13 days of grafting, 50 grafted tomato trees were also transferred to pots for growing. Sowing and growing process were all done at Nam Long farm (Vinh Long province). Marking the time when the flower started to form a fruit. At different stages (from 26-34 days and 24-32 days after fruit formation for non-grafted tomatoes and grafted tomatoes, respectively), fruits were harvested. Black tomatoes were put in perforated PVC and cardboard boxes and transported to the Food Technology laboratory of Can Tho University within 1 hr. Replications of three were made. The photos of fruit were taken and the physicochemical characteristics were determined.

2.2 Physical properties

2.2.1 Fruit weight and size parameters

The fruit weight was determined by an analytical balance with the accuracy of 0.0001 g (PR-series, Ohaus, USA). The fruit size was determined by two dimensions, namely height (H) and diameter (D), were measured by using digital calipers with an accuracy of 0.01 mm (MC 01120028, Gaogen, China). The geometric mean diameter (D_g) was calculated by equation 1 (Yıldız *et al*., 2015).

$$D_g(\text{mm}) = (HD^2)^{1/3} \quad (1)$$

The surface area (S_a) and aspect ratio (R_a) of the fruit were calculated by using equations 2 and 3, respectively (Yıldız *et al*., 2015).

$$S_a(\text{cm}^2) = \pi D_g^2 \quad (2)$$

$$R_a = D/H \quad (3)$$

The sphericity (S_p) defined as the ratio of the surface area of a sphere having the same volume as that of fruit to the surface area of the fruit was determined using equation 4 (Yıldız *et al*., 2015).

$$S_p(\%) = 100 \times (D_g/H) \quad (4)$$

2.2.2 Respiration rate

Tomatoes (200 g) were put into a 20x30 cm PE zip bag. The oxygen concentration was measured continuously. Respiration rate (R) was determined by equation 5. Where P is the permeability coefficient (mL.cm.cm^{-2}.h^{-1}), A is the surface area of the package (cm^2), L is the thickness of PE bag (cm), M is the weight of the sample (kg); y_{O2} is the oxygen concentration (% v/v) (o: outside, i: inside).

$$R(\text{mLO}_2/\text{kg.h}) = \frac{P_{O_2} \times A}{100 \times L \times M} \times \left(y^o_{O_2} - y^i_{O_2}\right) \quad (5)$$

2.2.3 Firmness

Fruit firmness was determined with a RheoTex (SD 700, Sun Science, Japan). Using a 1 cm - diameter cylindrical probe with a flat end in this case. The force required to press vertically into the middle of fruits for a 4 mm distance was measured and expressed in g/cm^2.

2.3 Chemical properties

2.3.1 Total soluble solids (TSS) content and pH value

The whole tomatoes were ground in a blender (MX-GM1011, Panasonic, Japan) for 1 min and the obtained puree was determined TSS content and pH value. The content of TSS was measured by a refractometer (0-32%, Atago, Japan) at 20°C. The pH value was measured with a pH meter (Edge HI2020-01, Hanna, Vietnam) at 20°C.

2.3.2 Moisture content

The moisture content (*W*) was determined by drying the sample at 105°C to a constant weight and calculated using equation 6. Where m_o is the weight of the original sample, *m* is the weight of the sample after drying.

$$W(\%) = \frac{m_o - m}{m_o} \times 100 \quad (6)$$

2.3.3 Total sugar content

The total sugar content was determined by the colorimetric method with DNS reagent (Luong, 2003). Tomato puree (3 g) was weighed into a 100 mL flask with 50 mL of distilled water and 5 mL of 36.5% HCl solution. The hydrolysis process was carried out at 60°C for 15 mins. The mixture was neutralized by the 30% NaOH solution to pH 7 then filled up to a volume of 100 mL with distilled water and filtered through a filter paper. The filtrate (2 mL) was added 1 mL DNS reagent and placed in boiling water for 5 mins. The absorbance of the mixture was read at 540 nm using Spectrophotometer UV-VIS (722N, Inesa, China). The total sugar content (*S*) was determined using equation 7. Where *A* is the reducing sugar content derived from the standard curve (mg/mL), *n* is the dilution factor, *V* is the volumetric flask volume (100 mL), *m* is the weight of the sample (g).

$$S(\%) = \frac{A \times n \times V \times 100}{m \times 1000} \quad (7)$$

2.3.4 Total acid content

The total acid content was determined by the titration method (Yıldız *et al*., 2015). Tomato puree (10 g) was shaken with neutral water for 1 hr. The mixture was filled to a volume of 50 mL with neutral water and allowed to settle. The supernatant (25 mL) was added 5 drops of phenolphthalein and titrated with the 0.1 N NaOH solution until the mixture had a stable light pink. The total acid content was calculated by equation 8. Where *n* is the volume of the 0.1 N NaOH solution used to titrate (mL), *K* is the coefficient of citric acid (0.0064), *P* is the weight of the sample (g).

$$A(\%) = n \times K \times \frac{50}{25} \times \frac{100}{P} \quad (8)$$

2.3.5 Anthocyanin content

The anthocyanin content was determined by the pH differential method (Lee *et al*., 2005) with some modifications. Tomato puree (5 g) was filled to a volume of 50 mL with ethanol/water (1/1) solvent containing 1% HCl and extracted for 60 mins. The mixture was then separated by a centrifuge at 7000 × *g* for 10 mins. The supernatant was diluted with two buffers of pH 1.0 and 4.5 and read the absorbance at both 520 and 700 nm versus a blank of distilled water. The anthocyanin content was calculated as cyanidin-3-glucoside equivalent (equation 9). Where *A* is (A_{520nm}-A_{700nm})pH 1.0 - (A_{520nm}-A_{700nm})pH 4.5, *M* is 449.2 g/mol for cyanidin-3-glucoside, *k* is the dilution factor, *l* is the pathlength (cm), *ε* is 26900 - molar extinction coefficient for cyanidin-3-glucoside (L × mol^{-1} × cm^{-1}), *V* is the volume of extract (mL), *m* is the weight of the sample (g).

$$Anthocyanin\ (\text{mg CE}/100\ \text{g}) = \frac{A \times M \times k \times V}{m \times \varepsilon \times l} \times 100 \times 1000 \quad (9)$$

2.3.6 Lycopene content

The lycopene content was determined by the low volume hexane extraction method (Fish *et al*., 2002; Davis *et al*., 2003). Tomato puree (0.6 g) was mixed with 5 mL of acetone containing 0.05% butylated hydroxytoluene, 5 mL of 95% ethanol, 10 mL of hexane in a vial and extracted for 15 mins on a shaker at a speed of 180 rpm. The mixture was then added 3 mL of deionized water and shaken for 5 mins. The vial was left for 5 mins. The absorbance of the supernatant was read at 503 nm against a blank of hexane. The lycopene content was determined using equation 10. Where A_{503} is the absorbance of the extract at 503 nm, *m* is the weight of the sample (g).

$$Lycopene\ (\mu\text{g/g}) = \frac{A_{503} \times 31.2}{m} \quad (10)$$

2.3.7 Vitamin C content

The vitamin C content was determined by the titration method (Lam *et al*., 2004). Tomato puree (10 g) was filled to a volume of 100 mL with 5% HCl solution and filtered through a filter paper. The filtrate (10 mL) was added 5 drops of the 1% starch solution and titrated with the 0.001 N KIO_3/KI solution until the blue-black color appears. For the control, the sample extract was replaced by the 1% HCl solution. The vitamin C content was calculated using equation 11. Where *a* and *b* is the volume of 0.001 N KIO_3/KI solution used for titration the extract and the control, respectively (mL), 100 is the volume of extract (mL), 0.088 is the weight of ascorbic acid corresponds to 1 mL of 0.001 N KIO_3/KI solution (mg), *m* is the weight of the sample (g).

$$Vitamin\ C\ (\text{mg}/100\ \text{g}) = \frac{(a-b) \times 0.088 \times 100}{10} \times \frac{100}{m} \quad (11)$$

2.3.8 Total phenolic content

The total phenolic content was determined using Folin-Ciocalteu reagent (Teixeira *et al*., 2013) with some modifications. Tomato puree (5 g) was filled to a volume of 50 mL with 95% ethanol and extracted for 60 mins. The mixture was then separated by a centrifuge at 7000 × *g* for 10 mins. The supernatant (0.2 mL) was added 1.0 mL of 10% Folin-Ciocalteu reagent, left for 5 mins and then added 1.2 mL of 5% Na_2CO_3 solution. After 2 hrs, the absorbance was recorded at 750 nm. The total phenolic content was calculated as gallic acid equivalent (equation 12). Where *C* is the content of gallic acid derived from the standard curve (mg/mL), *V* is the volume of extract (mL), *m* is the weight of the sample (g), *k* is the dilution factor.

$$\text{Phenolic (mg GAE/100 g)} = \frac{\text{C} \times \text{V}}{\text{m}} \times \text{k} \times 100 \quad (12)$$

2.3.9 Antioxidant activity

Antioxidant activity was determined using the DPPH assay (Teixeira *et al*., 2013) with some modifications. Tomato puree (5 g) was filled to a volume of 50 mL with 95% ethanol and extracted for 60 mins. The mixture was then separated by a centrifuge at 7000 × *g* for 10 mins. The supernatant (0.1 mL) was added 2 mL of DPPH solution (0.21 mM in 95% ethanol). For the control, the sample extract was replaced with 95% ethanol. The mixture was kept for 1 hr before absorbance reading at 517 nm. The percentage of DPPH free radical scavenging was calculated by equation 13. Where $A_{control}$ is the absorbance of the control, A_{sample} is the absorbance of the sample.

$$DPPH(\%) = \frac{A_{control} - A_{sample}}{A_{control}} \times 100 \quad (13)$$

2.4 Data analysis

Data analyses were carried out using the Statgraphics Centurion XV (U.S.A.). The significance/non-significance of results was determined using the One-Way ANOVA and Duncan test at the 95% confidence level (P = 0.05).

3. Results and discussion

3.1 The physical properties of black cherry tomatoes

The color chart of the black cherry tomato "OG" variety at different maturity stages presented in Figure 1. Along with the color change was the change in physical properties and content of nutrients of the fruit. The tomato color gradually converted from green to green-orange to orange-red to deep red during maturation as a consequence of the synthesis of lycopene and depletion of chlorophyll (Arias *et al*., 2000). However, this change in the fruit skin was not obvious as in the fruit flesh due to the presence of anthocyanin.

The respiration rate of non-grafted tomatoes was still low on the 28th day after fruit formation (1.54 mLO_2/kg.h). This value increased gradually and reached its highest on the 32nd day (1.84 mLO_2/kg.h) and then decreased slightly on the 34th day (Figure 2a). Similarly, the respiration rate of grafted fruits decreased from the 24th day (1.73 mLO_2/kg.h) to the 26th day (1.54 mLO_2/kg.h), then increased to the 30th day (1.92 mLO_2/kg.h) and decreased again on the 32nd day (1.72 mLO_2/kg.h) (Figure 2b). It was shown that the non-grafted tomatoes reached the maturity after 28 days of fruit formation and the 32nd day was the full ripening time. For grafted tomatoes, the maturity and full ripening age were on the 26th and 30th day, indicating that the maturity of grafted fruits was faster. Tomato is classified as a climacteric ripening pattern, which means that they have a significant rise in respiration and ethylene production rates at the onset of the ripening process (Toivonen, 2007).

The weight and size of fruit are also important quality parameters that necessary for designing the post-harvest system including sorting, handling, packaging, storage, and processing. These parameters of black cherry tomatoes were determined at the time of full maturity when fruits reached the maximum size (on the 28th day for non-grafted tomatoes and on the 26th day for grafted tomatoes). It was observed that the non-grafted and grafted tomatoes had the same weight and size (Table 1). Furthermore, the shape indexes of them, such as the sphericity (from 96.73% to 97.28%) and the aspect ratio (from 0.95 to 0.96) indicated that the black cherry

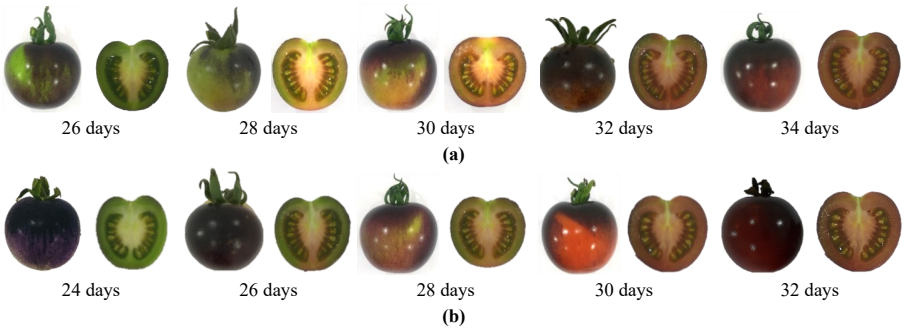

Figure 1. The color chart of (a) non-grated tomatoes and (b) grafted tomatoes at different harvest stages

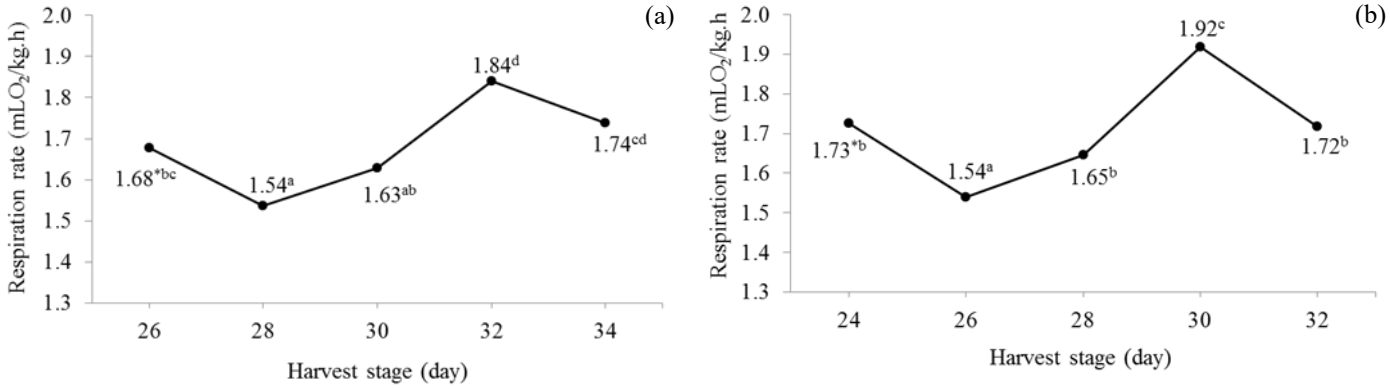

Figure 2. The respiration rate of (a) non-grated tomatoes and (b) grafted tomatoes at different harvest stages. Values are expressed as the mean of three replicates. Values with different superscript are significantly different at 5% significance level (P<0.05).

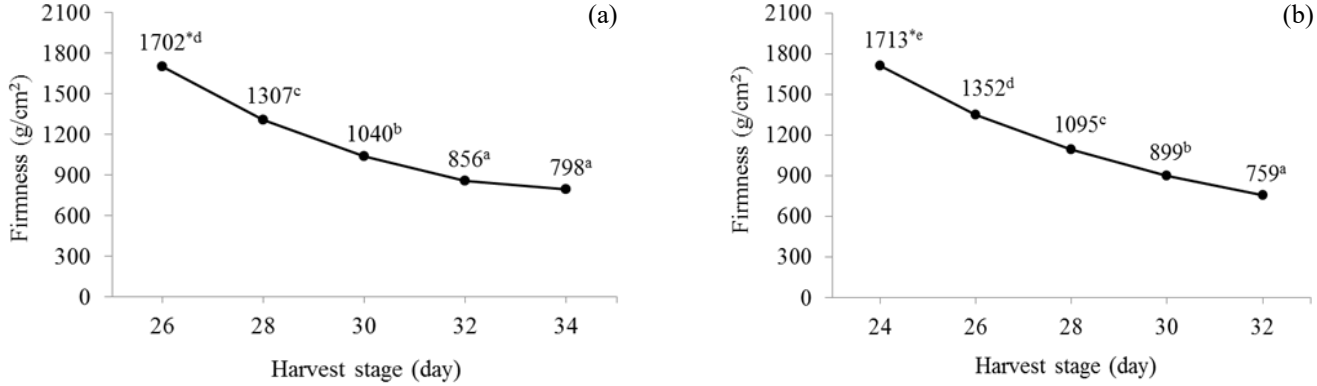

Figure 3. The firmness of (a) non-grated tomatoes and (b) grafted tomatoes at different harvest stages. Values are expressed as the mean of three replicates. Values with different superscript are significantly different at 5% significance level (P<0.05).

tomato fruit could be considered as an equivalent sphere.

The firmness decreased rapidly at the early harvest stage and then more slowly at the later harvest stage in both non-grafted and grafted tomatoes but there was no significant difference in firmness between two types of fruits (Figure 3). The texture and firmness of fruits and vegetables are based on the presence and interactions of different chemical components, like pectins in the middle lamellae and the cellulose/hemicellulose matrix in the primary cell wall, and on physical aspects like arch structure and turgor. The turgor and part of pectin are susceptible to enzymatic degradation during ripening, thereby contributing to the variable part of the firmness (Van Dijk *et al*., 2006).

Table 1. Fruit weight and size of non-grafted tomatoes on the 28th day and grafted tomatoes on the 26th day

Fruit weight and size	Non-grafted tomatoes	Grafted tomatoes
Weight (g)	21.99±1.61	22.25±1.28
Height (mm)	25.98±1.75	26.40±1.36
Diameter (mm)	24.87±2.14	25.11±1.83
Geometric mean diameter (mm)	25.21±1.84	25.52±1.64
Sphericity (%)	97.28±2.70	96.73±1.37
Surface area (cm^2)	20.03±2.90	20.51±2.64
Aspect ratio	0.96±0.11	0.95±0.08

Values are expressed as mean±standard deviation.

3.2 The chemical properties of black cherry tomatoes

The moisture content varied from 92.73 to 94.86% and 92.45 to 94.23% for non-grafted and grafted fruits, respectively with higher values in the first harvest stage, followed by reductions in the content throughout the ripening cycle (Figure 4). During the ripening of the fruit, chemical compounds are synthesized reaching maximum content at the end of ripening, therefore the content of moisture decreases gradually (Schulz *et al*., 2015).

As could be seen in Table 2, the content of total sugar and TSS of non-grafted tomatoes increased by harvest stage and peaked on the 32nd day, after that, it tended to decrease on the day of 34th. When the harvest stage was extended from 26 to 32 days, the increase in total sugar content was due to the conversion of starch during fruit ripening (Prasad *et al*., 2018), however, after the fruit was fully ripening, the hydrolysis process no longer took place and the sugar participated in the respiration leading to a decrease in total sugar (Bashir and Abu-Goukh, 2003). Similarly, the total sugar and TSS content of grafted fruits increased from the 24th harvest day and reached the highest value on the 30th day, then decreased on the 32nd day (Table 3). These results were also consistent with the obtained results of Mini (2017) for the "PKM-1" tomato variety.

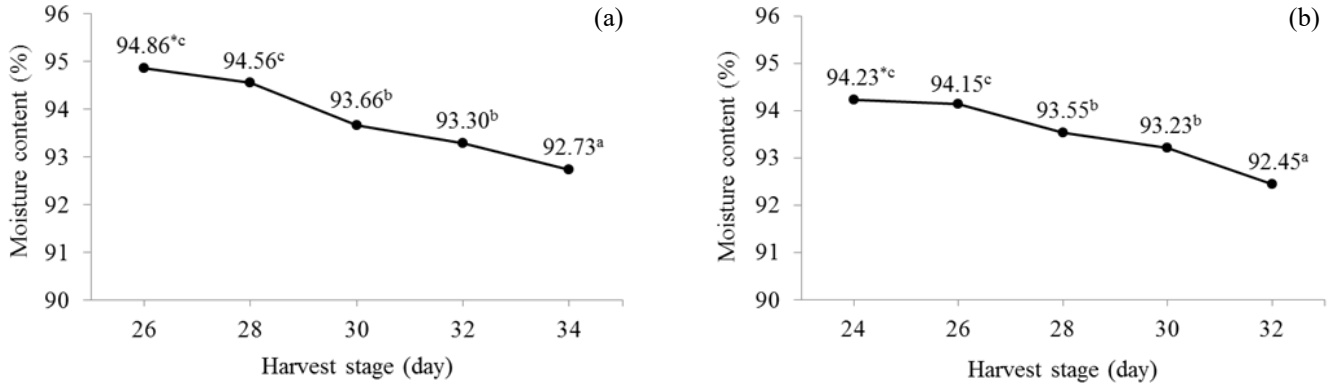

Figure 4. The moisture content of (a) non-grated tomatoes and (b) grafted tomatoes at different harvest stages. Values are expressed as the mean of three replicates. Values with different superscript are significantly different at 5% significance level (P<0.05).

Table 2. The total sugar and TSS content of non-grafted tomatoes at different harvest stages

Harvest stage (day)	Total sugar content (%)	TSS content (%)
26	2.92[a]	3.83[a]
28	3.39[b]	4.50[b]
30	4.41[c]	5.53[c]
32	4.89[d]	6.17[e]
34	4.57[cd]	5.83[d]

Values are expressed as the mean of three replicates. Values with different superscript within the column are significantly different at 5% significance level (P<0.05).

Table 3. The total sugar and TSS content of grafted tomatoes at different harvest stages

Harvest stage (day)	Total sugar content (%)	TSS content (%)
24	3.46[a]	4.57[a]
26	4.53[b]	5.77[b]
28	4.94[c]	6.20[c]
30	4.27[d]	6.47[d]
32	5.11[cd]	6.17[c]

Values are expressed as the mean of three replicates. Values with different superscript within the column are significantly different at 5% significance level (P<0.05).

The total acid content and pH changed in two opposite directions (Tables 4 and 5). The total acid content increased with the harvest stage until the fruit was fully ripening and reached its highest values, 0.578% and 0.506%, for non-grafted and grafted tomatoes on the 32nd and the 30th day, respectively. This component tended to decrease later. The predominant acid in tomatoes is malic acid and is utilized as a substrate for respiration and esterification, creating a special aroma for fruits, which is the reason for the decreasing trend in acidity in the later stage (Mini, 2017). Conversely, the pH value reached the lowest on the 32nd day (4.21) and the 30th day (4.35) for non-grafted and grafted tomatoes corresponding to the time of the highest total acid content.

The bioactive compounds such as anthocyanin, lycopene, vitamin C, and other phenolics were all valuable components in black cherry tomatoes, which determine the antioxidant activity of fruits. During ripening, these components changed in different directions (Tables 6 and 7).

It was worth noting that the non-grafted black tomatoes reached the highest anthocyanin content on the 34th day of harvest stage (4.32 mg CE/100 g) but there was no statistically significant difference between the two days of 30th and 32nd. The anthocyanin accumulation process takes place in three stages: the first phase with a rapid increase in the concentration, a transitional phase characterized by a decreasing accumulation rate until a maximum concentration, and a final phase of decreasing concentration (Schulz *et al*., 2015). At the first stage of harvest, the content of lycopene was very low (8.74 µg/g) which increased almost 5 times during ripening and reached 42.28 µg/g on the 34th day. Increased level of lycopene in tomatoes with the harvest stage is due to the ripening advancement of fruits and conversion of

Table 4. The total acid content and pH value of non-grafted tomatoes at different harvest stages

Harvest stage (day)	Total acid content (%)	pH
26	0.288[a]	4.94[d]
28	0.447[b]	4.66[c]
30	0.501[c]	4.43[b]
32	0.578[d]	4.21[a]
34	0.514[c]	4.40[b]

Values are expressed as the mean of three replicates. Values with different superscript within the column are significantly different at 5% significance level (P<0.05).

Table 5. The total acid content and pH value of grafted tomatoes at different harvest stages

Harvest stage (day)	Total acid content (%)	pH
24	0.354[a]	4.80[d]
26	0.437[b]	4.68[c]
28	0.484[c]	4.47[b]
30	0.506[c]	4.35[a]
32	0.487[c]	4.43[ab]

Values are expressed as the mean of three replicates. Values with different superscript within the column are significantly different at 5% significance level (P<0.05).

Table 6. The content of bioactive compounds and DPPH free radical scavenging activity of non-grafted tomatoes at different harvest stages

Harvest stage (day)	Anthocyanin (mg CE/100 g)	Lycopene (µg/g)	Vitamin C (mg/100 g)	Phenolic (mg GAE/100 g)	DPPH (%)
26	3.42[a]	8.74[a]	30.18[a]	48.74[d]	57.21[a]
28	3.82[b]	17.70[b]	34.98[a]	42.73[c]	60.50[b]
30	4.27[c]	24.60[c]	42.74[b]	40.61[b]	68.56[c]
32	4.31[c]	38.79[d]	55.69[d]	38.69[a]	76.58[d]
34	4.32[c]	42.28[e]	49.47[c]	37.99[a]	76.33[d]

Values are expressed as the mean of three replicates. Values with different superscript within the column are significantly different at 5% significance level (P<0.05).

Table 7. The content of bioactive compounds and DPPH free radical scavenging activity of grafted tomatoes at different harvest stages

Harvest stage (day)	Anthocyanin (mg CE/100 g)	Lycopene (µg/g)	Vitamin C (mg/100 g)	Phenolic (mg GAE/100 g)	DPPH (%)
24	3.88[a]	17.14[a]	32.12[a]	47.29[c]	65.61[a]
26	4.21[b]	22.54[b]	36.78[a]	41.73[b]	66.82[b]
28	4.39[c]	32.62[c]	47.35[b]	39.37[a]	73.50[c]
30	4.45[c]	41.12[d]	63.53[c]	39.15[a]	81.63[e]
32	4.42[c]	44.49[e]	51.61[b]	38.67[a]	79.84[d]

Values are expressed as the mean of three replicates. Values with different superscript within the column are significantly different at 5% significance level (P<0.05).

chloroplasts to chromoplasts (Mini, 2017). The vitamin C content also increased from 30.18 mg/100 g on the 26th day to 55.69 mg/100 g on the 32nd day, and then decreased to 49.47 mg/100 g on the 34th day. In tomato fruits, ascorbic acid content increases with maturity and stage of ripening, however, once fruit reaches the fully ripe stage, ascorbic acid content starts to decline (Mini, 2017). A decrease in total phenolic content with ripening was observed. This content decreased sharply from the 26th day (48.74 mg GAE/100 g) to the 32nd day (38.69 mg GAE/100 g). The phenolic content on two harvest days of 32th and 34th was not different significantly. Phenolic acts as an antibody of a plant, in the early stages of development, many antibodies are needed to resist nature. After adapting to the environment, plants do not synthesize phenolic compounds. Meanwhile, during ripening, phenolic can be oxidized by polyphenol oxidase (Ayaz *et al*., 2008). The antioxidant activity of non-grafted tomatoes expressed by the DPPH free radical scavenging activity reached the highest level on the 32nd harvesting day (76.59%), after which there was a decreasing trend on the harvest day of 34th but they were not different significantly. The phenolic compounds were a major contributor to the antioxidant activity of plants (Song *et al*., 2010), so a decrease in phenolic content would affect the antioxidant activity of black cherry tomatoes. However, the antioxidant activity of tomatoes is derived from a mixture of antioxidant compounds, including carotenoids, ascorbic acid, and total phenolic (Bhandari *et al*., 2016). It was observed that the changing trend of bioactive compounds in grafted tomatoes was also similar. However, the anthocyanin content was found highest on the 30thday (4.45 mg CE/100 g) but not significantly different compared to the 28th and 32nd days.

4. Conclusion

The appropriate harvest stage of black cherry tomatoes (cv. OG) was on the 30th day for non-grafted fruits and on the 28th day for grafted fruits, at this time, the anthocyanin content was maximum while the other bioactive compounds remained low. If collected at the fully ripening stage, the fruits would be vulnerable in transport and storage. Tomato is a climacteric fruit, so that, it will ripen and the remaining compounds may continue changing under storage conditions. Anthocyanin is synthesized on plants during growing under the sunlight, this component does not increase after harvesting. The grafting helped the plant to grow faster as shown by an earlier harvesting stage and the harvested fruits had a higher level of bioactive compounds such as anthocyanin, lycopene, and vitamin C than the non-grafted fruits. It is necessary to further investigate the impact of grafting on the resistance to bacterial wilt of the black cherry tomato plants to better understand the importance of this technique.

Conflict of interest

The authors declare no conflict of interest.

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