Relationships between Surface Blushing and Qualitative Components of Japanese Apricot (*Prunus mume* Sieb. et Zucc.) ‘Nanko’ Fruit

Takaaki Oe*, Naoki Sakurai, Keiichi Negoro, Aki Kuwabara, Mieko Okamuro, Takahiko Mitani and Masato Hosohira

1 Fruit Tree Experiment Station, Wakayama Research Center of Agriculture, Forestry and Fisheries, Minabe, Hidaka, Wakayama 645-0021, Japan
2 Graduate School of Biosphere Sciences, Hiroshima University, Kagamiyama, Higashi-Hiroshima 739-8521, Japan
3 Faculty of Biology-Oriented Science and Technology, Kinki University, Nishimitani, Kinokawa, Wakayama 649-6493, Japan

The relationships between surface blushing and the content of qualitative components of the Japanese apricot ‘Nanko’ fruit were investigated. Brightly blushed fruit covering over 25% of its surface had higher levels of citric acid, phenolics, and antioxidant activity in its flesh than non-blushed fruit. Shading apricot fruit from ultraviolet (UV) light for about 3 weeks before harvest produced a clear decrease in surface blushing, phenolic content, and antioxidant activity. UV-B irradiation for 12 h to the inner canopy fruit 10 days before harvest resulted in blushing and increased the antioxidant activity. These results showed that brightly blushed fruit was rich in phenolics and antioxidant activity and that UV light played an important role in blushing, phenolic content, and antioxidant activity in the Japanese apricot ‘Nanko’ fruit. When fruit shaded from sunlight was exposed to sunlight for about 3 weeks before harvest by cutting off the shoot with leaves around the fruit to increase UV irradiation, surface blushing was caused, and the phenolic content and antioxidant activity in flesh were increased. On the other hand, placing reflecting films under the outer canopy for 40 days had no effect on the development of the bright red color.

Key Words: antioxidant activity, blushing, organic acid, phenolics, ultraviolet.

Introduction

Fruit quality is generally evaluated by items related to taste, such as the sugar content, acid content, and hardness, in addition to appearance, such as size and coloration. Nondestructive determination of these items has also been carried out for quality evaluation (Kawano et al., 1993; Taniwaki and Sakurai, 2010); however, the Japanese apricot is not evaluated by taste because raw apricot is inedible. Since consumers have recently become more interested in health, fruit is being reevaluated for its health utility. Studies of the content of functional components in fruit (Kim et al., 2003; Sun et al., 2002) and attempts to increase these contents using cultivation techniques and breeding (Hagimori et al., 2005) have been carried out. The Japanese apricot has been recognized as a healthy food and it is used medicinally in Japan. The effects of cultivation on the components related to health have not been studied. The Japanese apricot fruit is known to be rich in citric acid (Ito, 1991; Ozaki, 2004), β-carotene (Tanaka et al., 2001), and phenolics (Ishikawa-Takano et al., 1999). Citric acid has proven to be beneficial to humans recovering from fatigue and it contributes to improvements in blood circulation (Ozaki, 2004). The Japanese apricot belongs to the Rosaceae family, which is rich in sorbitol, a type of sugar alcohol, responsible for intestinal regulation (Ito, 1991; Toda and Takano, 2006). These components are all listed as functional ingredients that have health improving or disease risk-reduction properties (Ozaki, 2004; Yano, 1999). Moreover, the Japanese apricot fruit is highly ranked among fruit and vegetables regarding its antioxidant activity, which is the ability to remove active oxygen. Increase of antioxidant activity in blood was found in rats fed a
polyphenol fraction of Japanese apricot fruit (Mitani and Yano, 2006). Since active oxygen is the cause of many diseases, antioxidant activity is expected to have a protective effect against lifestyle-related diseases (Aoyagi, 2008). In a previous study, we clarified that the content of these components and the antioxidant activity are influenced by a number of factors, such as the timing of harvest, fruit size, and the ripening period of Japanese apricot fruit (Oe et al., 2006, 2007, 2008). The content of phenolics in fruit, which are responsible for antioxidant activity, is influenced by soil conditions (Kubota and Kudo, 1992), temperature (Tomana et al., 1979; Yamada et al., 1988), and cultivation management (Kubota et al., 1993a, b).

The Japanese apricot ‘Nanko’ fruit, which is the main cultivar in Wakayama prefecture, has a characteristic of red blushes partially in sunlight. Many studies of red pigmentation have been undertaken in other fruit. The red color of mango skins is exposed by exposing the fruit to a high light intensity (Sasaki and Utsunomiya, 2002). Antioxidant activity is enhanced by sunlight in the skin of lemons and apples (Kondo et al., 2003). UV light plays an important role in the anthocyanin synthesis of sweet cherry (Arakawa, 1993; Kataoka et al., 1996) and peach (Kataoka and Beppu, 2004); anthocyanin is a type of red pigment and a phenolic component. Blushed Japanese apricot fruit under sunlight is also expected to have more phenolics and antioxidant activity. In addition, the market price of bright blushed fruit, in which over 30% of the surface is red, is about 2–3 times higher than that of regular fruit because of its beautiful appearance; therefore, an effective cultivation technique that would promote red coloration would be quite promising for improving producers’ profits. However, to our knowledge, few studies have been carried out on the coloring mechanism and quality of blushed fruit in the Japanese apricot.

In this paper, we investigate the relationships among blushing, organic components and antioxidant activity for the purpose of developing technology to increase the quality of the Japanese apricot.

Materials and Methods

Relationships between blushing and content of the qualitative components

Three trees in 2002 and five trees in 2007 of Japanese apricot ‘Nanko’ grown in Hidaka area of Wakayama Prefecture were used. At the commercial harvest time (June 7, 2002 and June 4, 2007), average-sized fruit brightly blushed over 25% area of its surface (blushed fruit) and non-blushed fruit nearby were harvested from the outer canopy. Ten fruit in 2002 and 5 fruit in 2007 from each tree were used for each treatment. The fresh weight (gram), diameter index (longitudinal diameter/transverse diameter), firmness measured by rheometer (COMPACK-100; Sankagaku Co., Japan), and the b* value of skin color determined with a color-difference meter (NR-3000, Nippon Denshoku Co., Japan) of each fruit were considered as the index of ripeness, because these items vary with the maturation process. Firmness measured by rheometer was the maximum load by moving a probe (5 mm in diameter) downward at a speed of 1 mm·s⁻¹ into the fruit to a depth of 1 mm. The b* value of skin color was measured at the equator of the non-blushed side of the fruit (one point per fruit). The percentage of blush on the fruit surface was also assessed visually in units of 5 percentage points, and scores were given in percentages from 0% to 100% by referring to a previous report (Whale and Singh, 2007). The a* value of skin color was also measured at the center of the blushed part in blushed fruit and at the equator in non-blushed fruit in 2002. The measured fruit were sampled for the analysis of organic components. Ten grams of flesh (with skin) were collected evenly from fruit of each category and stored at −28°C until analysis. The contents of organic acid, sorbitol, β-carotene, and phenolics and the antioxidant activity were then analyzed using the method previously reported (Oe et al., 2006). Ten grams of frozen sample were homogenized with 80% aqueous ethanol and adjusted to 100 mL. The extract was filtered through a 0.45 μm filter and then analyzed for organic acid and sorbitol using a high-performance liquid chromatography (HPLC) system (LC-10Avp, Shimadzu Co., Japan) and for phenolics and antioxidant activity using a spectrophotometer (V-550, Jasco Co., Japan). Organic acid analysis was carried out using two tandem Shim-pack SCR-102H columns (300 × 7.9 mm, Shimadzu Co.) maintained at 40°C. Elution was performed with 5 mM p-toluensulfonic acid at a flow rate of 0.8 mL·min⁻¹. Post-column derivatization was carried out with 5 mM p-toluensulfonic acid containing 100 μM EDTA and 20 mM Bis-Tris at a flow rate of 0.8 mL·min⁻¹. The organic acid concentrations of the elution were monitored using a conductivity detector (CDD-6A, Shimadzu Co.). Sorbitol was analyzed using a Shim-pack SCR-101P column (300 × 7.9 mm, Shimadzu Co.) maintained at 80°C. Elution was performed with water at a flow rate of 1 mL·min⁻¹ and monitored using a refractive index detector (RID-10A, Shimadzu Co.). The phenolic content was analyzed by the Folin & Ciocalteu method and expressed as a chlorogenic acid equivalent. The extracting solution of 0.2 mL was added to 5 mL of Folin & Ciocalteu’s phenol reagent diluted 25-fold and shaken. After 3 min, 1 mL of 10% Na₂CO₃ was added and mixed. After incubation for 60 min at room temperature, absorbance at 760 nm was determined using a spectrophotometer. Antioxidant activity was analyzed using 1,1-diphenyl-2-picrylhydrazyl (DPPH) and expressed as an alpha-tocopherol equivalent. The extracting solution of 0.2 mL was added to a mixture of 0.8 mL of a 0.1 M Tris buffer (pH 7.4) and 1 mL of a 500 μM DPPH ethanol solution and shaken. After incubation for 20 min at room temperature, absorbance at 517 nm was determined. The β-carotene content was analyzed by a method described in previous reports (Mizda et al., 2002; Hamauzu and...
Chachin, 1995) using an HPLC system. Ten grams of a frozen sample were homogenized with acetone and filtered through a glass filter (11G-3, Sansyo Co., Japan) rinsing its residue with acetone. The extract was adjusted to 100 mL with acetone and filtered through a 0.45 μm filter. β-Carotene analysis was carried out using a Shim-pack VP-ODS column (150 × 4.6 mm, Shimadzu Co.) maintained at 40°C. Elution was performed using the gradient by increasing solvent B (ethyl acetate) to solvent A (90% aqueous acetonitrile) at a flow rate of 1.5 mL·min⁻¹ and monitored at 450 nm using a UV-VIS detector (SPD-10Avp, Shimadzu Co.). The t-test was used for statistical analysis.

**Effect of ultraviolet light cutting on blushing and the content of organic components**

Fruit under sunlight collected from one tree in 2005 and four trees in 2007 grown in Japanese Apricot Laboratory were used. One group (UV-cut fruit) of 8 fruit in 2005 and 10 fruit in 2007 per tree were covered individually using transparent UV cut-off film, which cut light with wavelengths under 400 nm (King Seisakusyo Co., Japan) for about 3 weeks (25 days in 2005 and 19 in 2007). The other group (non-treated fruit) of 8 or 10 fruit nearby was exposed to natural light. At commercial harvest time (June 14, 2005 and June 4, 2007), the fruit were collected and the blushed area was identified. The a* value of skin color was measured on the sunlit side in 2005 and the content of organic components and antioxidant activity were determined using the method mentioned above. Analysis was carried out for each fruit in 2005, since only one tree was used. The t-test was used for statistical analysis.

**Effects of irradiation of ultraviolet light on blushing and the content of organic components**

Inner canopy fruit shaded from sunlight on one ‘Nanko’ tree in the Japanese Apricot Laboratory were used in 2010. The fruit were irradiated with a reflected UV-B light, which reflected a UV-B lamp (Model GL20SE: 20W, peak wavelength 306 nm; Sankyo Denki Co., Japan) using reflecting film (white film without holes, DuPont Co., USA) laid on the ground for 12 h at night before 10 days of harvest. The reflectivity (degree of 40 cm above ground/degree of direct light × 100) of UV light of reflecting film measured with an ultraviolet meter (Lutron UV-340, range of 290–390 nm, EKT Electronics Co., Canada) was 68%. The reflecting film was laid under one side (irradiated side) of the outer canopy (1~2.5 meters from the trunk), and the UV-B lamp was set 2.5 meters from the trunk. At commercial harvest time (June 20, 2010), ten blushed fruit (UV-B-irradiated fruit) on the irradiated side of the inner canopy and ten non-blushed fruit (non-treated fruit) on the side opposite the irradiated side were collected. The blushed area was identified and UV-B irradiated fruit were divided into the blushed side and non-blushed side. The content of organic components and antioxidant activity were determined for each fruit using the method mentioned above. The t-test or Tukey’s test was used for statistical analysis.

**Effects of cultivation methods exposing fruit to sunlight on blushing and the content of organic components**

Fruit shaded from sunlight on one ‘Nanko’ tree in 2003 and three trees in 2004 in the Hidaka area of Wakayama Prefecture were used. Ten fruit per tree were exposed to sunlight for 3~4 weeks (28 days in 2003 and 22 days in 2004) by cutting off the shoot with leaves around the fruit (sunlit fruit). Ten other nearby fruit were used as a control (non-treated fruit). At commercial harvest time (June 6, 2003 and June 8, 2004), the remaining fruit on trees (7~10 fruit for each tree) were collected, the blushed area was identified, and the content of organic components and antioxidant activity were determined using the method mentioned above. In addition, the anthocyanin content was analyzed using the method previously published (Ueda, 2000) and reported (Akagi et al., 2011). Ten grams of frozen sample were homogenized with 5% aqueous formic acid and adjusted to 100 mL. Anthocyanin was extracted for 24 hours at 4°C in the dark, and the extract was filtered through a 0.45 μm filter. The anthocyanin content was analyzed using an HPLC system. Anthocyanin analysis was carried out using a Shim-pack VP-ODS column (150 × 4.6 mm, Shimadzu Co.) maintained at 40°C. Elution was performed using the gradient by increasing solvent B (10% aqueous formic acid containing 40% acetonitrile) to solvent A (10% aqueous formic acid) at a flow rate of 1 mL·min⁻¹ and monitored at 530 nm using a UV-VIS detector. Analysis was carried out for each fruit in 2003.

The effect of laying two types of reflecting film, used for the purpose of causing coloration in fruit such as sweet cherry and apple, on blushing under the outer canopy for 40 days was determined in 2007 and 2008 in the Hidaka area of Wakayama Prefecture. The two types of reflecting film were white film without holes (DuPont Co.) and silver film with holes (8 mm in diameter, 30 × 20 cm in interval scale, Hitachi AIC Co., Japan). In addition, the reflectivities (degree of 40 cm above ground/degree of direct sunlight × 100) of the photon flux density and UV light were measured for each reflecting film with a light quantum meter (LI-250A, Li-cor Co., USA) and an ultraviolet meter, respectively, in 2008. Tukey’s test was used for statistical analysis.

**Results**

**Relationships between the degree of blushing and the content of organic components**

The average blushed area of blushed fruit was 36% in both years, and blushed fruit had a significantly higher a* value of skin color than non-blushed fruit in 2002 (Table 1). Although there were no significant differences in blushed and non-blushed fruit in weight, diameter
index (longitudinal diameter/transverse diameter), and firmness, there were significant differences in the content of some organic components and antioxidant activity of flesh (with skin) (Table 2). Blushed fruit had significantly higher contents of citric acid (1.06–1.12 times) and total organic acid (sum of citric acid and malic acid, 1.05–1.07 times) than non-blushed fruit in 2002 and 2007. There were no significant differences in blushed and non-blushed fruit in the contents of malic acid and β-carotene. Blushed fruit had a significantly higher level of sorbitol content in 2007 (1.53 times) than non-blushed fruit. Blushed fruit had significantly higher levels of phenolic content (1.27–1.28 times) and antioxidant activity (1.20–1.28 times) than non-blushed fruit in both years.

Effects of ultraviolet cutting on blushing and the content of organic components

No expression of red color was observed in UV-cut fruit, while non-treated fruit developed a red color in 2005 (44%) and 2007 (36%) (Table 3). UV-cut fruit had a significantly lower a* value of skin color in the sunlit part than non-treated fruit in 2005. UV-cut fruit had significantly higher citric acid content (1.06 times) in 2005 than non-treated fruit, but the difference was not observed in 2007. There were no significant differences in UV-cut fruit and non-treated fruit in the contents of malic acid, total organic acid, and sorbitol. The effect of UV cutting on the β-carotene content was inconsistent. Its content of treated fruit was significantly higher in 2005 (1.06 times) and lower in 2007 (0.74 times) than in non-treated fruit. Non-treated fruit had significantly higher levels of phenolic content (1.24 times) and antioxidant activity (1.24–1.25 times) than UV-cut fruit in both years.

Effects of irradiation of ultraviolet light on blushing and the content of organic components

The expression of red color (23%) was found in UV-B-irradiated fruit (Table 4). There were no significant differences in UV-B-irradiated fruit and non-treated fruit in the contents of organic acid, sorbitol, and phenolics. The blushed side of UV-B-irradiated fruit had a significantly higher level of antioxidant activity (1.40 times) than non-treated fruit.

Effects of cultivation methods exposing fruit to sunlight on blushing and the content of organic components

A higher expression of red color (23–33%) was found in sunlit fruit than in non-treated fruit (0–5%) in 2003 and 2004 (Table 5). There was no significant difference

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**Table 1. Qualities of blushed and non-blushed Japanese apricot fruit.**

<table>
<thead>
<tr>
<th></th>
<th>Average of blushed area (%)</th>
<th>Skin color</th>
<th>Average weight (g)</th>
<th>Diameter index</th>
<th>Firmness (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Blushed side</td>
<td>Non-blushed side</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>a* value</td>
<td>b* value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blushed fruit</td>
<td>36 36</td>
<td>28.2 35.3</td>
<td>31.8 31.8</td>
<td>28.9 40.4</td>
<td>1.06 1.06</td>
</tr>
<tr>
<td>Non-blushed</td>
<td>0 0</td>
<td>−8.9 33.2</td>
<td>30.6 1.06</td>
<td>1.06 1.07</td>
<td>1.47 2.11</td>
</tr>
<tr>
<td>Significance</td>
<td>* NS</td>
<td>** NS</td>
<td>* NS</td>
<td>NS NS</td>
<td>NS NS</td>
</tr>
</tbody>
</table>

* Skin color a* value is measured at the center of the blushed part in blushed fruit and at the equator in non-blushed fruit. Skin color b* value is measured at the equator of the non-blushed side of the fruit.

† The diameter index is the longitudinal diameter/transverse diameter.

‡ Firmness using a rheometer is measured to the maximum load by pushing a 5 mm probe in diameter at a speed of 1 mm·s⁻¹ to a depth of 1 mm.

§ The blushed area is over 25% of the fruit surface.

# NS and * indicate a non-significant and a significant difference with $P < 0.05$ by the t-test, respectively (n = 3 in 2002, n = 5 in 2007).

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**Table 2. Content of organic components and antioxidant activity of Japanese apricot flesh with skin in blushed and non-blushed fruit.**

<table>
<thead>
<tr>
<th></th>
<th>Organic acid (g/100gFW)</th>
<th>Sorbitol (mg/100gFW)</th>
<th>β-Carotene (mg/100gFW)</th>
<th>Phenolics (mgCE/100gFW)</th>
<th>Antioxidant activity (µmolTE/100gFW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Citric acid Malic acid</td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blushed fruit</td>
<td>4.23 4.14 4.15 2.02 5.74 6.16</td>
<td>4.50 23 0.41 0.26</td>
<td>103 128</td>
<td>416 583</td>
<td></td>
</tr>
<tr>
<td>Non-blushed</td>
<td>3.78 3.89 3.89 1.99 5.37 5.88</td>
<td>252 152 0.22 0.24</td>
<td>81 100</td>
<td>348 454</td>
<td></td>
</tr>
<tr>
<td>Significance</td>
<td>* NS ** NS NS ** NS NS</td>
<td>NS ** NS NS NS NS NS</td>
<td>NS ** NS NS NS NS NS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Total is sum of citric acid and malic acid.

† CE indicates a chlorogenic acid equivalent.

‡ TE indicates an alpha-tocopherol equivalent.

§ The blushed area is over 25% of the surface area.

# NS, * and ** indicate a non-significant and a significant difference with $P < 0.05$ and a significant difference with $P < 0.01$ by the t-test, respectively (n = 3 in 2002, n = 5 in 2007).
Table 3. Effects of cutting off ultraviolet light of sunlight to fruit on blushing, the content of organic components, and the antioxidant activity of Japanese apricot flesh with skin.

<table>
<thead>
<tr>
<th>Average of blushed area (%)</th>
<th>Skin color a* value of sunlit side</th>
<th>Organic acid (g/100gFW)</th>
<th>Sorbitol (mg/100gFW)</th>
<th>β-Carotene (mg/100gFW)</th>
<th>Phenolics (mgCE/100gFW)</th>
<th>Antioxidant activity (µmolTE/100gFW)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Citric acid</td>
<td>Malic acid</td>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UV-cut fruit</td>
<td>0</td>
<td>0</td>
<td>−1.4</td>
<td>4.76 4.03</td>
<td>1.58 1.55</td>
<td>6.33 5.58</td>
</tr>
<tr>
<td>Non-treated fruit</td>
<td>44</td>
<td>36</td>
<td>35.1</td>
<td>4.50 3.80</td>
<td>1.72 1.88</td>
<td>6.22 5.67</td>
</tr>
<tr>
<td>Significance**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>NS NS NS NS NS NS NS NS NS NS NS NS NS ** ** ** **</td>
<td>0.85 0.23 0.71 0.31 0.23 0.33 104 509 463 129 630 578</td>
<td></td>
</tr>
</tbody>
</table>

a Skin color a* value is measured at the center of the blushed part in blushed fruit and at the equator in non-blushed fruit.

b Total is sum of citric acid and malic acid.

c CE indicates a chlorogenic acid equivalent.
d TE indicates an alpha-tocopherol equivalent.
e UV cut fruit is covered with transparent ultraviolet light cut-off film, and non-treated fruit was exposed to sunlight on the tree.
f NS, * and ** indicate a non-significant and a significant difference with $P < 0.05$ and a significant difference with $P < 0.01$ by the $t$-test, respectively (n = 8 in 2005, n = 4 in 2007).

Table 4. Effects of UV-B irradiation on blushing, the content of organic components and the antioxidant activity of Japanese apricot flesh with skin.

<table>
<thead>
<tr>
<th>Average of blushed area (%)</th>
<th>Organic acid (g/100gFW)</th>
<th>Sorbitol (mg/100gFW)</th>
<th>Phenolics (mgCE/100gFW)</th>
<th>Antioxidant activity (µmolTE/100gFW)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Citric acid</td>
<td>Malic acid</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>UV-B-irradiated fruit</td>
<td>23 a</td>
<td>4.62 a</td>
<td>0.94 a</td>
<td>5.56 a</td>
</tr>
<tr>
<td>Blushed side</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-blushed side</td>
<td></td>
<td>4.58 a</td>
<td>0.94 a</td>
<td>5.51 a</td>
</tr>
<tr>
<td>Non-treated fruit</td>
<td>0 b</td>
<td>4.73 a</td>
<td>1.11 a</td>
<td>5.84 a</td>
</tr>
</tbody>
</table>

g Total is sum of citric acid and malic acid.
h CE indicates a chlorogenic acid equivalent.
i TE indicates an alpha-tocopherol equivalent.
j Different letters indicate a significant difference with $P < 0.05$ by the $t$-test or Tukey’s test (n = 10).

Table 5. Effects of cutting off the shoot with leaves around the fruit on blushing, the content of organic components and the antioxidant activity of Japanese apricot flesh with skin.

<table>
<thead>
<tr>
<th>Average of blushed area (%)</th>
<th>Organic acid (g/100gFW)</th>
<th>Sorbitol (mg/100gFW)</th>
<th>β-Carotene (mg/100gFW)</th>
<th>Phenolics (mgCE/100gFW)</th>
<th>Anthocyanin (µg/100gFW)*</th>
<th>Antioxidant activity (µmolTE/100gFW)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Citric acid</td>
<td>Malic acid</td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunlit fruit</td>
<td>23 33</td>
<td>3.44 4.21</td>
<td>2.02 1.76</td>
<td>5.46 5.97</td>
<td>226 241</td>
<td>0.18 0.29</td>
</tr>
<tr>
<td>Non-treated fruit</td>
<td>0 5</td>
<td>3.39 4.17</td>
<td>2.08 1.98</td>
<td>5.47 6.15</td>
<td>158 232</td>
<td>0.18 0.23</td>
</tr>
<tr>
<td>Significance**</td>
<td>**</td>
<td>**</td>
<td>NS NS NS NS NS NS NS NS NS NS NS NS NS NS ** ** ** ** ** ** **</td>
<td>0.18 0.23 0.23 0.33 104 509 463 129 630 578</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a Total is sum of citric acid and malic acid.
b CE indicates a chlorogenic acid equivalent.
c C3G, C3R and total indicate a cyanidin 3-glucoside, a cyanidin 3-rutinoside and sum of them, respectively.
d TE indicates an alpha-tocopherol equivalent.
e Sunlit fruit is exposed to sunlight for 22–28 days by cutting off the shoot with leaves around the fruit.
f NS, * and ** indicate a non-significant and a significant difference with $P < 0.05$ and a significant difference with $P < 0.01$ by the $t$-test, respectively (n = 7–10 in 2003, n = 3 in 2004).
in sunlit fruit and non-treated fruit in the contents of organic acid and \( \beta \)-carotene. Sunlit fruit had a significantly higher level of sorbitol content (1.43 times) than non-treated fruit in 2003. They also had significantly higher contents of phenolics (1.15 times) and total anthocyanin (sum of cyanidin 3-glucoside and cyanidin 3-rutinoside, 8.09 times) in 2004 and a higher level of antioxidant activity (1.17–1.24 times) in both years than non-treated fruit. The use of two types of reflecting film under the outer canopy for 40 days did not influence the development of the bright red color (Table 6). Reflectivity was under 21% of direct sunlight in photon flux density and UV light.

**Discussion**

In previous studies, we reported that organic components, such as citric acid, sorbitol, \( \beta \)-carotene, and phenolics, and antioxidant activity in the Japanese apricot fruit were influenced by the blooming day, harvest time, fruit size, and ripening period (Oe, 2006, 2007, 2008). Generally, the phenolics of fruit are influenced by the soil conditions (Kubota and Kudo, 1992), temperature (Tomana et al., 1979; Yamada et al., 1988), rootstock (Kubota et al., 1993a), girdling (Kubota et al., 1993b), tree vigor (Kubota et al., 1993c), use of plant growth regulator (Kondo and Gemma, 1993; Kondo et al., 2001; Matushima et al., 1989), and light conditions. Irradiation with ultraviolet light plays an important role in the coloration and synthesis of anthocyanin in many types of fruit. The \( \beta \)-carotene contents in spinach and lettuce are reported to be enhanced by high light intensity (Oyama et al., 1999). We were interested in the characteristics of Japanese apricot ‘Nanko’ fruit, which become partially red under sunlight, we investigated the effect of cultivation on blushing, the levels of organic components, and antioxidant activity.

Our results indicated that blushed fruit had higher levels of citric acid, sorbitol, phenolics, and antioxidant activity in flesh (with skin) than non-blushed fruit. Significant reductions in the expression of the red color, phenolic content, and antioxidant activity were found when fruit were shaded from UV light for about three weeks before harvest. Shading from sunlight reduces the anthocyanin content in apple (Awad et al., 2000; Saito, 1995) and antioxidant activity in the skin of lemon and apple (Kondo et al., 2003). The red coloration of mangos is improved with high light intensity (Sasaki and Utsunomiya, 2002), and light is essential in the anthocyanin synthesis of eggplant (Matsuzoe et al., 1999). Further, UV light plays an important role in the anthocyanin synthesis of apple (Arakawa, 1988, 2000; Kubo et al., 1988), sweet cherry (Arakawa, 1993; Kataoka et al., 1996), peach (Kataoka and Beppu, 2004), and grape (Kataoka et al., 2003). UV-B irradiation enhanced the phenolic content of harvested apple fruit (Lancaster et al., 2000), and UV-C irradiation enhanced the phenolic content and antioxidant activity of harvested strawberry fruit (Erkan et al., 2008). Our results showed that UV light contributed profoundly to the expression of red, phenolic content, and antioxidant activity in Japanese apricot fruit. Although we did not determine the contents of hydroxycinnamic acids, which are known to have the capacity to shield underlying tissues from harmful UV-radiation, in this study, it has been proved that hydroxycinnamic acids synthesis was enhanced by direct solar radiation in bilberry leaves (Jaakola et al., 2004), sweet potato leaves (Islam et al., 2003), and apples (Rudell and Mattheis, 2002). Since Ozaki et al. (2009) reports that the main phenolic compounds are hydroxycinnamic acid and its derivatives in Japanese apricot ‘Nanko’ fruit, it could be inferred that the content of hydroxycinnamic acids would have been enhanced by UV irradiation. Although fruit coloration was also inhibited by high temperature (Tomana, 1979; Yamada and Shibayama, 2006), we confirmed that there was no difference in fruit covered with UV cut-off film and fruit covered with a plastic bag (UV permeable) in their surface temperatures, and fruit covered with a plastic bag blushed; therefore, the reason for the lack of red color in covered fruit is not considered to be enhanced temperature.

In this study, blushed fruit exposed to sunlight from an early growth stage had higher levels of citric acid and total organic acid than non-blushed fruit, although there was no difference in the index of ripeness, such as fruit size, diameter index, firmness, and skin color b* value or the content of malic acid, between blushed and non-blushed fruit. In Japanese apricot fruit, the citric

<table>
<thead>
<tr>
<th>Average of blushed area (%)</th>
<th>Photon flux density (µmol·m(^{-2})·s(^{-1}))</th>
<th>Reflectivity (%)</th>
<th>Ultraviolet (W·m(^{-2}))</th>
<th>Reflectivity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White film without holes</td>
<td>0</td>
<td>368 a</td>
<td>21</td>
<td>8.1 a</td>
</tr>
<tr>
<td>Silver film with holes</td>
<td>0</td>
<td>328 a</td>
<td>19</td>
<td>6.3 b</td>
</tr>
<tr>
<td>Non-treatment</td>
<td>0</td>
<td>36 b</td>
<td>2</td>
<td>1.3 c</td>
</tr>
<tr>
<td>Direct sunlight</td>
<td>—</td>
<td>1738</td>
<td>—</td>
<td>41.8</td>
</tr>
</tbody>
</table>

\( ^a \) Photon flux density and ultraviolet light are measured at 40 cm above ground and ultraviolet is range of 290 to 390 nm. Reflectivity is degree of 40 cm above ground/degree of direct sunlight × 100.

\( ^b \) Different letters indicate a significant difference with \( P < 0.05 \) by the Tukey’s test (n = 24).

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**Table 6.** Effect of various reflecting films on blushing of fruit and their reflectivity of photon flux density and ultraviolet.
acid content increases, and the malic acid content decreases with maturity (Kakiuchi et al., 1985; Oe et al., 2006), and larger fruit have higher contents of citric acid and malic acid than smaller fruit on the same harvest day (Oe et al., 2006). Blushed fruit exposed to sunlight from an early growth stage may be rich in citric acid and total organic acid. The reason for this phenomenon seems to be an increased carbohydrate level as a result of exposure to sunlight, since it is known that fruit has a photosynthetic function (Matsui, 1989); however, blushed fruit exposed to sunlight by cutting off the shoot with leaves around the fruit for only 3–4 weeks were not rich in citric acid and total organic acid; thus, exposing the fruit to sunlight more than 4 weeks before harvest may be necessary to increase the citric acid content. On the other hand, fruit covered with transparent ultraviolet cut-off film had higher contents of citric acid and β-carotene in 2005 than uncovered fruit. The reason for these phenomena is assumed to be that the high temperature in covering film accelerates fruit maturity, since contents of citric acid and β-carotene increase with maturity and maturity progresses earlier at higher temperatures in Japanese apricot fruit (Suzuki et al., 1995).

We investigated whether the methods for accelerating coloring used in other fruit species would be effective for Japanese apricot. The cultivation technique of exposing fruit to sunlight was used for the purpose of producing colored fruit, for example, by laying reflecting film under a canopy of mandarin, persimmon, peach, sweet cherry, and fig or by picking leaves from the trees of apple (Oba et al., 1996), sweet cherry, and persimmon. When Japanese apricot fruit were exposed to direct sunlight by laying reflective film under an outer canopy for 40 days was ineffectual for blushing on Japanese apricot ‘Nanko’ fruit. This result indicated that the levels of sunlight and UV light obtained by the use of reflecting film, under 21% of direct sunlight, were insufficient to increase the blushing degree in ‘Nanko’ fruit.

These findings showed that bright blushed fruit was rich in phenolics and antioxidant activity and that ultraviolet light played an important role in blushing and increasing phenolic content in Japanese apricot ‘Nanko’ fruit. In a future study, determination of the phenolic compounds enhanced by UV light will be necessary.

**Literature Cited**


Kondo, S. and H. Gemma. 1993. Relationship between abscisic acid (ABA) content and maturation of the sweet cherry. J.


