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Short Communication

Fruit quality and antioxidant capacity of six Thai mango cultivars

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ABSTRACT

Fruits of six Thai mango (*Mangifera indica* L.) cultivars ('Okrong', 'Nuan Chan', 'Thongdum', 'Namdokmai No. 4', 'Namdokmai Si-Thong' and 'Yaigrum') were analyzed for their quality characteristics and antioxidant capacity. Sucrose was the main sugar in the mango fruit. Carotenoids were higher in 'Thongdum', (15 mg/100 g dry weight; DW) than other cultivars. The total flavonoids and total phenolics were in the ranges 33–67 mg/100 g DW and 8–22 mg/100 g DW, respectively. The antioxidant capacity was in the range 23–68 mg/(±)-6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid (Trolox) equivalents per·100 g DW and was positively correlated with the flavonoid and phenolic contents, suggesting that these compounds mainly contribute to the antioxidant activity of mango fruits. There were genotypic differences in the antioxidant contents. Thai mangoes have great potential as an antioxidant source.

Introduction

Mango (*Mangifera indica* L.) is one of the most popular tropical fruits and is widely produced in the world for its attractive color, good taste and high level of health-beneficial compounds; it has been reported to contain significant amounts of pigments such as chlorophylls and carotenoids (Grundhofer et al., 2001). Carotenoids such as β-carotene are an important dietary source of vitamin A (Haskell, 2012; Tang, 2012). Mango fruits also contains vitamin E as well as ascorbic acid, the main biologically active form of vitamin C (Charoensiri et al., 2009; Liu et al., 2013).

In recent years, phenolic compounds have attracted research interest for their strong antioxidative action against reactive oxygen species. Gallic acid and quercetin are the major phenolic compounds in mango fruits (Robles-Sanchez et al., 2009; Liu et al., 2013), and increase with fruit ripening (Kim et al., 2009; Palafox-Carlos et al., 2012). Several studies have attempted to examine the antioxidant capacity of mango fruit skin (Ajila et al., 2007a, 2007b) or flesh (Palafox-Carlos et al., 2012; Liu et al., 2013). Kim et al. (2010) demonstrated that extracts of skin and flesh of mango protected human cells from oxidative stress induced by hydrogen peroxide and had an antiproliferative effect on human cell cancer lines. Therefore, mango fruit has great potential as an antioxidant source.

Thailand is one of the world's major producers of mango after India and China (FAOSTAT, 2013). Previous studies reported that several Thai mango cultivars were rich in β-carotene, with contents in the range 6.54–11.25 mg·100 g^{-1} dry weight (DW) (Vasquez-Caicedo et al., 2005). Many studies have attempted to verify the abundance of phytochemical compounds in mango cultivars from the USA (Shivashankara et al., 2004; Liu et al., 2013), Brazil (Gonzalez-Aguilar et al., 2007; Ribeiro et al., 2008) and Mexico (Palafox-Carlos et al., 2012; Ornelas-Paz et al., 2008); however, there are –a few reports on cultivars from Thailand. The antioxidant capacity of Thai mango cultivars has also been little studied.

The purpose of this study was to evaluate the fruit quality, phytochemical compound accumulation and antioxidant capacity of several Thai mango cultivars.

Materials and methods

Plant materials

Fruit of six Thai mango cultivars were purchased during the 2014 harvest season from a local market in Bangkok, Thailand:

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Table 1
Fruit quality of mango cultivars.

Cultivar	Fresh weight (g)	Length (cm)	Diameter (cm)	TSS (°Brix)	TA (%)
'Okrong'	152.9 ± 4.0^{c,*}	9.7 ± 0.1^{d}	6.0 ± 0.1^{c}	20.3 ± 0.9^{cd}	0.2 ± 0.0^{bc}
'Nuan Chan'	286.5 ± 12.5^{b}	15.0 ± 0.4^{ab}	6.7 ± 0.1^{b}	21.2 ± 0.6^{bc}	0.1 ± 0.0^{c}
'Thongdum'	311.2 ± 10.8^{b}	11.7 ± 0.1^{c}	7.4 ± 0.1^{a}	23.5 ± 0.5^{a}	0.3 ± 0.0^{ab}
'Namdokmai No.4'	401.9 ± 7.1^{a}	15.7 ± 0.1^{a}	7.8 ± 0.1^{a}	18.9 ± 0.2^{d}	0.4 ± 0.0^{a}
'Namdokmai Si-Thong'	414.3 ± 19.1^{a}	14.8 ± 0.1^{b}	7.7 ± 0.1^{a}	20.1 ± 0.3^{cd}	0.3 ± 0.0^{ab}
'Yaigrum'	174.3 ± 4.6^{c}	9.6 ± 0.1^{d}	6.9 ± 0.1^{b}	23.1 ± 0.2^{ab}	0.1 ± 0.0^{c}

TSS = total soluble solids, TA = titratable acids.
*Values within a column followed by the same lowercase letter are not significantly different at $p < 0.05$ using Tukey-Kramer's multiple comparison test. Data are shown as mean ± SE ($n = 10$).

Table 2
Skin color of mango cultivars.

Cultivars	L*	a*	b*	C	Hue
'Okrong'	71.0 ± 0.9^{b,†}	1.6 ± 0.5^{d}	43.2 ± 0.9^{b}	43.2 ± 0.9^{b}	92.2 ± 0.7^{b}
'Nuan Chan'	77.7 ± 0.5^{a}	4.8 ± 0.3^{b}	47.3 ± 0.7^{a}	47.5 ± 0.7^{a}	84.2 ± 0.4^{c}
'Thongdum'	48.4 ± 1.1^{c}	−12.8 ± 0.3^{e}	25.3 ± 1.4^{d}	28.4 ± 1.3^{d}	117.3 ± 1.4^{a}
'Namdokmai No.4'	78.1 ± 0.2^{a}	3.2 ± 0.5^{b}	38.5 ± 0.4^{c}	38.7 ± 0.4^{c}	85.2 ± 0.7
'Namdokmai Si-Thong'	77.7 ± 0.4^{a}	7.2 ± 0.3^{a}	41.0 ± 0.8^{bc}	41.7 ± 0.8^{bc}	80.1 ± 0.3^{e}
'Yaigrum'	77.9 ± 0.9^{a}	0.7 ± 0.7^{c}	48.4 ± 0.6^{a}	48.4 ± 0.7^{a}	89.1 ± 0.8^{c}

L* = lightness, a* = green to red color, b* = blue to yellow color, C = chroma and hue = hue angle.
†Values within a column followed by the same lowercase letter are not significantly different at $p < 0.05$ using Tukey-Kramer's multiple comparison test. Data are shown as mean ± SE ($n = 8–10$).

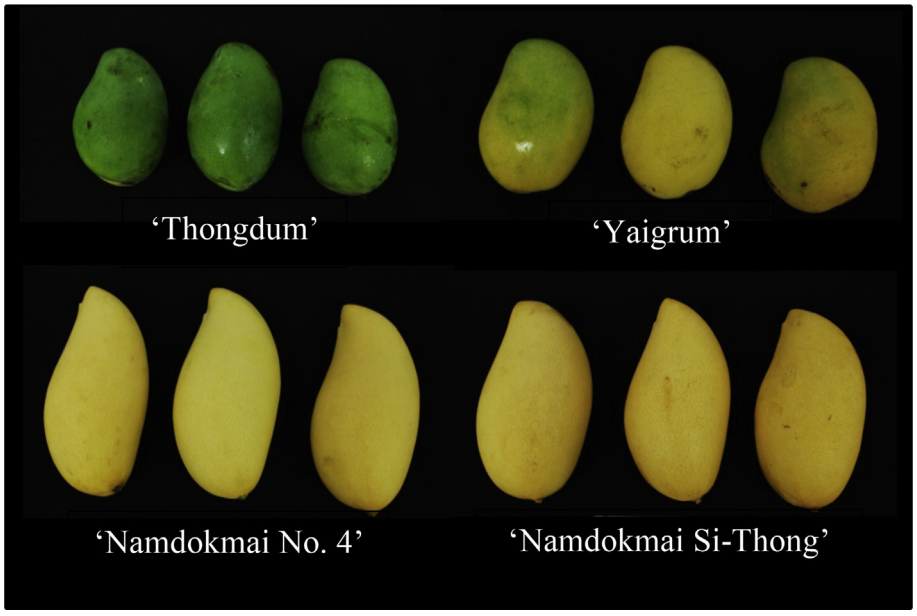

Fig. 1. Fruit skin color of Thai mango cultivars. (For interpretation of the references to color/colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Flesh color of four Thai mango cultivars.

Cultivars	L*	a*	b*	C	hue
'Thongdum'	67.5 ± 1.0^{b,†}	20.3 ± 1.1^{a}	66.3 ± 0.4^{a}	69.4 ± 0.5^{a}	73.0 ± 0.9^{b}
'Namdokmai No.4'	73.0 ± 0.9^{a}	6.1 ± 0.4^{c}	55.1 ± 0.7^{b}	55.5 ± 0.7^{c}	83.7 ± 0.0.3^{a}
'Namdokmai Si-Thong'	72.3 ± 0.5^{a}	7.0 ± 0.4^{bc}	57.1 ± 0.5^{b}	57.5 ± 0.5^{c}	83.0 ± 0.4^{a}
'Yaigrum'	72.0 ± 0.9^{a}	9.3 ± 0.6^{b}	64.9 ± 0.5^{a}	65.5 ± 0.5^{b}	81.8 ± 0.5^{a}

L* = lightness, a* = green to red color, b* = blue to yellow color, C = chroma and hue = hue angle.
†Values within a column followed by the same lowercase letter are not significantly different at $p < 0.05$ using Tukey-Kramer's multiple comparison test. Data are shown as mean ± SE ($n = 10$).

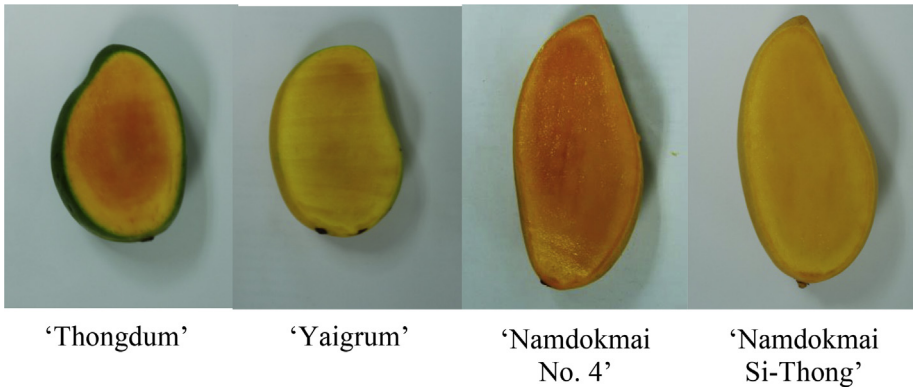

Fig. 2. Fruit flesh color of Thai mango cultivars. (For interpretation of the references to color/colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Individual sugar contents of mango fruits.

Cultivar	Fructose (g/100 g DW)	Glucose (g100 g DW)	Sucrose (g100 g DW)
'Okrong'	17.33 ± 6.15[a,*]	4.18 ± 0.67[ab]	31.58 ± 11.23[ab]
'Nuan Chan'	9.80 ± 0.95[a]	1.72 ± 0.80[b]	48.95 ± 9.27[ab]
'Thongdum'	13.06 ± 1.53[a]	5.39 ± 1.71[ab]	55.40 ± 1.43[a]
'Namdokmai No.4'	13.00 ± 2.84[a]	5.81 ± 0.91[ab]	19.04 ± 7.48[b]
'Namdokmai Si-Thong'	19.47 ± 0.34[a]	6.28 ± 0.33[a]	31.24 ± 1.22[ab]
'Yaigrum'	13.08 ± 1.71[a]	5.35 ± 0.64[ab]	28.13 ± 3.54[ab]

DW = dry weight.
*Values within a column followed by the same lowercase letter are not significantly different at $p < 0.05$ using Tukey-Kramer's multiple comparison test. Data are shown as mean ± SE ($n = 3$).

'Okrong', 'Nuan Chan', 'Thongdum', 'Namdokmai No.4', 'Namdokmai Si-Thong' and 'Yaigrum'. Fruits were immediately taken to the Quality Laboratory of the Biology Resources and Technology Department of King Mongkut's University of Technology Thonburi, Thailand for physical measurement and total soluble solids (TSS) and titratable acids (TA) analysis.

Physical measurement, total soluble solids and titratable acids

Ten fruits of each cultivar (except for eight fruits for 'Okrong') were weighed and sized. The skin and flesh colors were determined using a hand-held colorimeter (CR-400, Konica Minolta, Osaka, Japan) six times at the stem end, equatorial position and stylar end. Color was expressed as the mean of L* (lightness), a* (green to red), b* (blue to yellow), chroma and hue angle.

Fruit juice was obtained by squeezing the flesh and was used for TSS and TA measurements. TSS was measured using a refractometer (PAL-1, Atago, Tokyo, Japan) and expressed as °Brix. TA was determined by titrating with 0.1 N sodium hydroxide (NaOH) and expressed as percentage of citric acid.

Sugar analysis

Freeze-dried mango flesh (200 mg) was extracted in 0.5 mL 80% ethanol (volume to column for 20 min at 80 °C). The mixture was centrifuged at 10,000 × *g* for 10 min at 4 °C and the supernatant was recovered. The pellet was extracted again in 0.3 mL 80% ethanol with 0.2 mL 5% rhamnose added as an internal standard for 20 min at 80 °C. After the second centrifugation, the two supernatants were combined and dried under vacuum. Sample solutions were filtered through a 0.22 μm syringe filter prior to the sugars analysis using high performance liquid chromatography. Sugars were analyzed using a TSKgel Amide-80 (particle size: 5 μm, I.D. 4.6 × 250 mm, Tosoh, Tokyo, Japan) flushed with 1 mL/min of 75% acetonitrile at 80 °C. Glucose, fructose and sucrose were identified by comparison with the retention times of authentic standards and quantified by calculation of the area with the internal standard.

Carotenoid assays

Carotenoid, phenolic and antioxidant assays were carried out in the Horticulture Laboratory of the Faculty of Agriculture, Utsunomiya University, Utsunomiya, Japan. For carotenoid analysis, 1 g of freeze-dried flesh sample was ground with a mortar and pestle and put into an Erlenmeyer flask covered with aluminum foil. Then, 25 mL of extraction solution consisting of hexane:acetone:ethanol

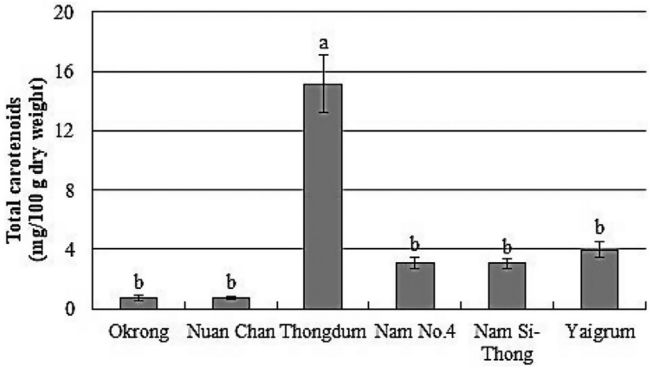

Fig. 3. Total carotenoids in fruit flesh of mango cultivars. Different lowercase letters indicate significant differences at $p < 0.05$ using Tukey-Kramer's multiple comparison test. Vertical error bars indicate ± SE ($n = 8–10$).

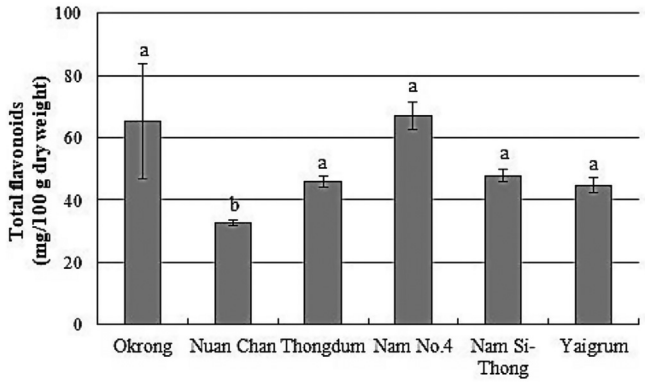

Fig. 4. Total flavonoids in fruit flesh of mango cultivars. Different lowercase letters indicate significant differences at $p < 0.05$ using Tukey-Kramer's multiple comparison test. Vertical error bars indicate ± SE ($n = 8–10$).

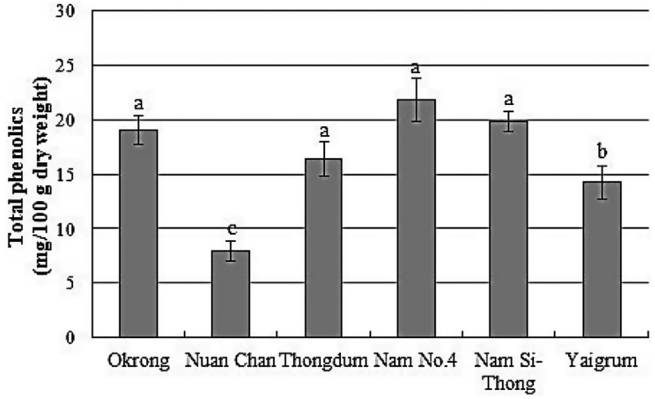

Fig. 5. Total phenolics in fruit flesh of mango cultivars. Different lowercase letters indicate significant differences at $p < 0.05$ using Tukey-Kramer's multiple comparison test. Vertical error bars indicate ± SE ($n = 8–10$).

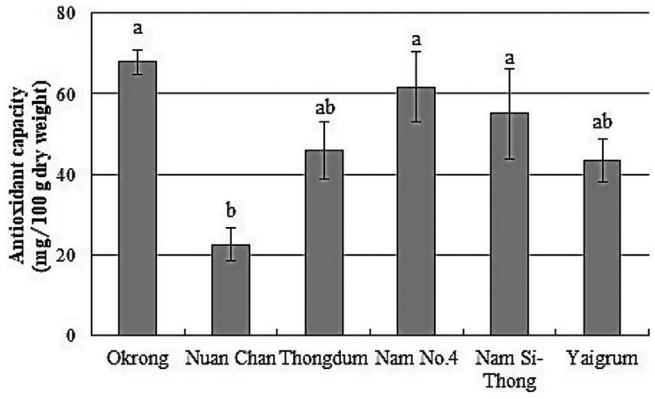

Fig. 6. Antioxidant capacity in fruit flesh of mango cultivars. Different lowercase letters indicate significant differences at $p < 0.05$ using Tukey-Kramer's multiple comparison test. Vertical error bars indicate ± SE ($n = 5$).

(2:1:1, by volume) was added and stirred. After mixing for 10 min, 5 mL of distilled water was added and stirred for 5 min. The hexane phase was used for measurement. The absorbance at 450 nm was measured using a spectrophotometer. The total carotenoids amount was calculated from the calibration curve and expressed as milligrams per 100 g dry weight (mg/100 g DW) of β-carotene.

Flavonoid, phenolic and antioxidant capacity assays

Extraction was carried out following the method of Palafox-Carlos et al. (2012) with slight modification. One gram of freeze-dried flesh samples was ground using a mortar and pestle and extracted in 5 mL of 80% methanol containing 2% formic acid. The homogenate was sonicated for 30 min followed by centrifuging at 9000 × *g* for 25 min at 5 °C. The supernatant was collected into a new tube and the precipitate once again extracted with 5 mL of extraction solution following the method described above. The two supernatants were mixed and stored at −20 °C until analysis.

The total flavonoid content was determined following the method of Kim et al. (2003). One milliliter of methanolic solution was mixed with 4 mL of distilled water and 0.3 mL of 5% sodium nitrite was added. After 5 min, 0.3 mL of 10% aluminum chloride was added. After 6 min, 2 mL of 1 N NaOH was added followed by 2.4 mL of distilled water and mixed vigorously. The absorbance at 510 nm was recorded using a spectrophotometer. The total flavonoid content was expressed as milligrams per 100 g dry weight (mg/100 g DW) of catechin equivalents.

The total phenolics content was measured according to Liu et al. (2013) with slight modification. A 0.5 mL sample of methanolic solution (diluted in water) was mixed with 0.5 mL of Folin-Ciocalteu's reagent. After 5 min, 1.8 mL of 7.5% sodium carbonate was added and mixed and then allowed to stand for 60 min at room temperature. The absorbance was recorded at 765 nm and the total phenolics content was expressed as milligrams per 100 g dry weight (mg/100 g DW) of gallic acid equivalents.

The antioxidant capacity was determined using the 2,2-diphenyl-1-picryl-hydrazyl (DPPH) method as described by Palafox-Carlos et al. (2012) with modification. The stock solution was prepared by mixing 2.5 mg of DPPH with 100 mL of pure methanol. A 0.2 mL sample of methanolic solution was mixed with 2.8 mL of DPPH solution. Then, the mixture was allowed to stand for 30 min in darkness at room temperature. After 30 min, the absorbance at 517 nm was recorded using a spectrophotometer and the antioxidant capacity was expressed as milligrams per 100 g dry weight (mg/100 g DW) of (±)-6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid (Trolox) equivalents.

Statistical analysis

All data were subjected to analysis of variance, and significant differences of the means were evaluated using Tukey-Kramer's multiple comparison test (Statcel3, OMS, Tokyo, Japan).

Results and discussion

Fruit size, skin and flesh color

Based on individual fruit weight and size, 'Okrong' and 'Yaigrum' were small-fruited cultivars with mean weights of 152 g and 174 g, respectively; 'Thongdum' and 'Nuan Chan' were medium-fruited with mean weights of 311 g and 287 g, respectively and 'Namdokmai No. 4' and 'Namdokmai Si-Thong' were large-fruited cultivars with mean weights of 401 g and 414 g, respectively (Table 1).

The skin color analysis of cultivars is shown in Table 2. Lightness (L*) values were in the range 71–78, with the exception of 'Thongdum' with 48.4. The a* and b* values were −12.8 and 25.3, respectively, in 'Thongdum' indicating that this cultivar remained green even as the fruit ripened (Table 2, Fig. 1). In contrast, the other cultivars had positive a* values and high b* values, indicating their yellow color (Fig. 1). The C* value and hue angle were also low and high, respectively, in 'Thongdum'. This is interesting as chlorophyll degradation occurs generally during fruit ripening, resulting in a

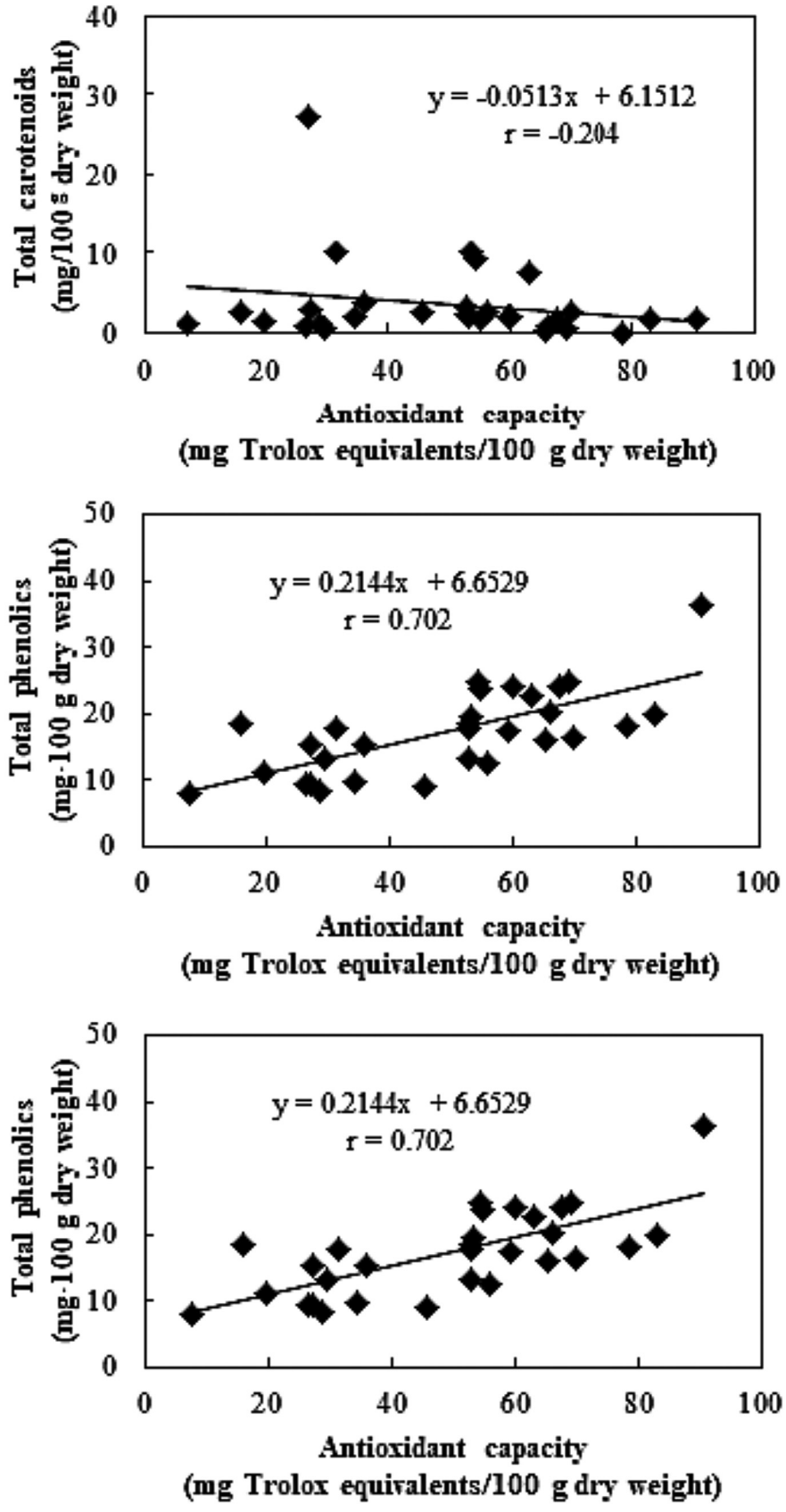

Fig. 7. Relationship between antioxidant capacity and total carotenoids, total flavonoids and total phenolics of mango fruit flesh, where ** indicates significant at $p < 0.01$ using Pearson's correlation test ($n = 5$).

yellow color (Palafox-Carlos et al., 2012). For the flesh color, 'Thongdum' had the lowest L* value and hue angle and the highest a* value compared with the other cultivars (Table 3). Fig. 2 shows the flesh color of four of the six cultivars. Skin color has been considered as a parameter to estimate the carotenoid content in flesh (Ornelas-Paz et al., 2008) and its maturity; however, the current results showed that in some cultivars such as 'Thongdum', skin color cannot be used to determine fruit ripening.

Sugar concentration and titratable acids

The 'Thongdum' and 'Yaigrum' cultivars had the highest TSS, while 'Namdokmai No. 4' had the lowest (Table 1). The fructose content was in the range 10–20 g/100 g DW. The glucose content (2–6.3 g/100 g DW) was lower than for fructose; the highest glucose content was in 'Namdokmai Si-Thong' and lowest in 'Nuan Chan'. The sucrose content was higher than for the other sugars, with a range of 19–55.4 g/100 g DW (Table 4). Sucrose has been reported to be the predominant sugar in mango fruit, followed by fructose (Krishnamurthy et al., 1971; Liu et al., 2013).

Acidity (measured using the titration method) was relatively lower in the small-sized cultivars (Table 1). Malic, citric and ascorbic acids have been reported as the main organic acids in mango fruit (Liu et al., 2013; Tovar et al., 2001). The TSS and TA values in the Thai cultivars were higher and lower, respectively, compared with cultivars from China ('Tainong No. 1', 'JinHwang') and the USA ('Irwin', 'Keitt') reported by Liu et al. (2013); and cultivars from Brazil ('Haden', 'Tommy Atkins', 'Palmer', 'Uba') reported by Ribeiro et al. (2007).

Carotenoid, flavonoid and phenolic compounds

Carotenoids are synthesized via the isoprenoid pathway, while flavonoids and phenolics are products of the shikimate pathway (Tanaka et al., 2008). Mango fruits accumulate carotenoid and phenolic compounds during fruit development (Palafox-Carlos et al., 2012). Carotenoids are the main pigments responsible for the yellow-to-orange color of mature mango fruit. The total carotenoid content in the flesh in the current study was in the range 0.7–15.1 mg/100 g DW and was significantly higher in 'Thongdum' (Fig. 3). This result was in agreement with the flesh color parameter for this cultivar, which had the highest a* and b* values and a deep orange color (Table 2, Fig. 2).

The total flavonoid content was in the range 32.6–67.0 mg/100 g DW (Fig. 4), while the total phenolic content was 7.9–21.8 mg/100 g DW (Fig. 5). The levels of carotenoid, flavonoid and phenolic compounds varied between cultivars, suggesting genotypic differences in the accumulation of these bioactive compounds.

Antioxidant capacity

The antioxidant capacity expressed as Trolox equivalents (mg/100 g DW) was high in 'Okrong', 'Namdokmai No. 4' and 'Namdokmai Si-Thong', followed by 'Thongdum', 'Yaigrum' and 'Nuan Chan' (Fig. 6). The cultivars containing a high concentration of flavonoids and phenolics exhibited high antioxidant capacity (Figs. 4–6). Antioxidant capacity was positively correlated with flavonoid and phenolic compounds but not carotenoids (Fig. 7). The correlation coefficients were 0.729 and 0.702 ($p < 0.01$) between antioxidant activity and the total flavonoid content and total phenolic content, respectively. Polyphenolic compounds mainly contribute to antioxidant capacity in mango fruits (Ma et al., 2011). Phenolic compounds commonly accumulate in fruit, have great ability to scavenge free radical (Zhishen et al., 1999) and consequently can reduce oxidative damage (Kim et al., 2010).

In this study, the antioxidant capacity was determined using DPPH scavenging assay, which is a commonly used assay in foods (Pérez-Jiménez et al., 2008). However, some reports have failed to detect antioxidant activity of carotenoids using this assay (Corral-Aguayo et al., 2008; Liu et al., 2008; Muller et al., 2011) as was also found in the present study (Fig. 7). Therefore, further study using other methods is needed to verify antioxidant capacity in Thai mango cultivars.

Conflict of interest

The authors declare there are no conflicts of interest.

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