

Comparison of physico-chemical quality of different strawberry cultivars at three maturity stages

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Abstract

Comparison of physico-chemical quality of strawberry fruit cv. Praratchatan 60, 72 and 80 at 25, 50 and 75% color break was investigated. Strawberry fruit cv. Praratchatan 60 and 72 had prominent numbers of conic-shaped fruit which were 77.78 and 62.22%, respectively, while moderate numbers were found in strawberry fruit cv. Praratchatan 80 (46.67%). Fruit weights and fruit sizes in terms of width, length and thickness were different among three cultivars. Strawberry fruit characteristics and chemical properties also varied among cultivars and color break stages which appeared in the surface color, flesh color, firmness, soluble solids content (SSC), titratable acidity (TA) and vitamin C content. Strawberry fruit cv. Praratchatan 60 had the highest total soluble phenolics (TSP) and antioxidant activity (AA). Besides, AA from crude extracts of three strawberry cultivars notably correlated to their TSP (correlation coefficient (R) of 0.976). Furthermore, strawberry fruit harvested at 75% color break had higher SSC, vitamin C and anthocyanin content while being lower in firmness, TA, TSP and AA compared to those harvested at 25 and 50% color break.

Keywords

Strawberry fruit

Color break

Maturity stages

Antioxidant activity

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Introduction

Among berry fruit market demands, strawberries are popular for consumers due to their favorable appearances and desirable flavors (Mitcham, 2004). Complex mixture of different metabolites and trace components greatly contribute to unique taste and tartness, especially the flavor of newly-developed strawberry cultivars, which are mainly influenced by the optimal mixture of esters, aldehydes and sulfur compounds (Zabetakis and Holden, 1997; Ayala-Zavala *et al.*, 2004; Zhang *et al.*, 2009). Strawberries are abundant in natural antioxidants such as ascorbic acid, phenolic acids, anthocyanin, flavonoids and glutathione that express a high level of radical scavenging activity and help against oxidative-related diseases in human (Block *et al.*, 1992; Wang *et al.*, 1996; Heinonen *et al.*, 1998; Jin *et al.*, 2011). There are multiple factors that considerably affect fruit nutrition value and characteristics, including cultivating technique, soil nutrition, planting site, weather condition and degree of ripeness (May and Pritts, 1990; Haffner *et al.*, 1998). In addition, the fruit cultivar is also considered as a key factor that contributes to the differences in chemical quality and fruit shape, for example, ascorbic acid and

anthocyanin content were dependent on cultivar and ripening degree (Haffner *et al.*, 1998; Cordenunsi *et al.*, 2005).

Therefore, the ultimate aim of this study was to compare the morphological characteristics and postharvest quality of strawberry fruit cv. Praratchatan 60, 72 and 80, the commercially-developed cultivars for highland growers in Thailand under The Royal Project Foundation on which number of previous studies has been found to be very limited.

Materials and Methods

Materials

Strawberry fruit (*Fragaria x ananassa* Duch.) cv. Praratchatan 60, 72 and 80 at three different maturity stages as determined by their color break: 25 (1/4 red), 50 (1/2 red) and 75% (3/4 red), were harvested from Maehae Royal Project Development Center, Chiang Mai, Thailand. Then, all one-thousand-two-hundred-and-sixty strawberry fruit (one-hundred-and-forty from each color break stage in each cultivar) were neatly separated and packaged in perforated plastic boxes and transported to Postharvest Technology Research Center, Department of Plant Science and Soil Science, Chiang Mai University by refrigerated

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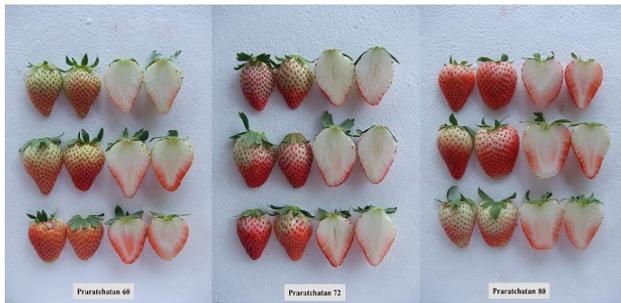


Figure 1. Three different strawberry fruit cultivars (cv. Praratchatan 60, 72 and 80)

truck ($10 \pm 1^\circ\text{C}$).

Morphological characteristics

Strawberry fruit from each color break stage in each cultivar were inspected and counted by appearance according to eight morphological categories, namely: oblate, globose, globose conic, conic, long conic, necked, long wedge and short wedge. Then the results were calculated and presented in percentage of fruit shape.

Fruit sizes were measured by determination of fruit width, length and thickness using vernier caliper and expressed in centimeter unit (cm). All fruit from three cultivars and three color break stages were weighed by fine balance, which was expressed in gram unit (g).

Fruit surface and flesh color measurements

The surface and flesh colors at the midsection of each of fifteen fruit from each batch were measured using a chromameter (CR-300, Konica Minolta, Japan), and the measurements were expressed as L^* value (lightness of objective; range from 0 to 100), a^* value (negative value indicates green while positive value indicates red color), b^* value (higher positive b^* value indicates yellowish color). Fruit surface and flesh colors were presented in Chroma (color saturation; range from 0 to 60) and Hue angle (editorial angle of color; range from 0° to 360°) which were obtained from calculation of a^* and b^* values according to following formulas:

$$\text{hue angle} = \arctangent (b^*/a^*) \quad (1)$$

$$\text{Chroma} = (a^{*2} + b^{*2})^{1/2} \quad (2)$$

Fruit firmness

Fifteen fruit from each batch were measured for fruit firmness by a hand puncture tester fitted with a 5.0 mm diameter flathead of 10 mm long probe (capacity of 1 kg). Each fruit from each cultivar and color break stage was punctured once at its midsection. Fruit firmness was presented in kilogram

unit (kg).

Soluble solids content (SSC), titratable acidity (TA) and vitamin C content

Twenty-five fruit from each cultivar and color break stage were randomly divided into 5 replications. Then they were homogenized by blender and manually squeezed with cheese cloth filtration. The squeezed juice was used to measure SSC using digital refractometer PR-101 (Atago Co. Ltd., Tokyo, Japan). TA was measured by diluting each 10 ml aliquot of strawberry juice in 90 ml of distilled water and titrating to pH 8.2 with 0.1 N NaOH. TA was expressed in percentage equivalent of titratable citric acid. Determination of vitamin C content was carried out by 2,6-dichlorophenol-indophenol visual titration assay (Ranganna, 1986). Ten ml aliquot of strawberry juice was added into 90 ml of 0.4% oxalic acid solution and filtered through filter paper Whatman® No.1, 10 ml sample was taken and titrated to the end point (solution immediately turned pink and stayed up to 15 seconds) with 0.04% 2,6-dichlorophenol-indophenol solution. Vitamin C content was expressed in milligrams per 100 gram fresh weight (mg/100 gFw).

Analysis of antioxidant activity (AA) and total soluble phenolics (TSP)

AA of strawberry extract was determined by 2,2-diphenyl-1-picrylhydrazyl (DPPH, Sigma Chemicals Co., St. Louis, USA) radical scavenging activity assay (DPPH assay) according to Manthey (2004) with some modifications. Twenty five fruit samples from each cultivar and color break stage were randomly divided into 5 replications. Then they were frozen by liquid nitrogen and immediately blended by a coffee blender. Five grams of powder sample were extracted by 20 ml absolute methanol under dark conditions for 1 hour. Then, homogenates were filtered using filter paper Whatman No.1 and diluted for 25 times with the extraction solution. Final crude extract was obtained from the filtration of solution with $0.45 \mu\text{m}$ nylon filter. For antioxidant activity assay, 400 μl of crude extract was added into 2 ml of DPPH solution and incubated at room temperature under dark conditions. The absorbance at 517 nm of the solution was immediately measured after 1 hour incubation time with a spectrophotometer (Spectro23, LaboMed, Inc., U.S.A.) using a mixture of 2 ml DPPH solution with 400 μl absolute methanol as a control. AA was calculated by using standard antioxidant activity from gallic acid and expressed in μg gallic acid equivalent per gram fresh weight ($\mu\text{gGAE/gFw}$).

TSP was determined by Folin-Ciocalteu colorimetric assay according to Sellappan et al. (2002) with some modifications using Folin-Ciocalteu's phenol reagent or FCR (Merck, Germany). Fifty μ l of aforementioned final crude extract was added into a mixture of 50 μ l of absolute methanol, 1 ml of distilled water, 375 μ l of Na_2CO_3 solution and 125 μ l of Folin-Ciocalteu's phenol reagent. The mixture was incubated at room temperature under dark conditions, and the absorbance at 765 nm of the solution was immediately measured after 2 hours of incubation time, using the mixture of mentioned solution without sample extract as a control. The absorbance was used to calculate the amount of TSP with standard content obtained from standard gallic acid and expressed in μ g gallic acid equivalent per gram fresh weight (μ gGAE/gFw).

Anthocyanin content

Anthocyanin content was determined by an extraction of ethanolic hydrochloric solution (1.5 N HCl : 95% $\text{C}_2\text{H}_5\text{OH}$ = 1.5 : 8.5) according to Ranganna (1986) with some modifications. One gram of frozen-blended sample from the aforementioned experimental unit of AA and TSP analysis was added into 40 ml of ethanolic hydrochloric solution and incubated under dark conditions for 5 hours. Then the solution was filtered by paper filter (Whatman No.1) and bleached the infiltrated sample again by 40 ml of extraction solution. The solution was finally made up to 100 ml by ethanolic hydrochloric solution. Subsequently, the solution was measured for absorbance at 535 nm using ethanolic hydrochloric solution as a control. Anthocyanin content was presented in milligram per 100 gram fresh weight (mg/100 gFw).

Shelf life

Strawberry fruit from each color break stage in each cultivar were packaged in perforated plastic box containing 20 fruit (3 replications were made up, total 60 fruit were used). Subsequently, all samples were stored at 5°C, 75-80% relative humidity (RH). Microbial and fungal incidences were used to determine strawberry shelf life. Unaccepted box of produce was determined when only a single fruit in the box appeared with microbial and/or fungal infestation.

Results and Discussion

Fresh weight and Fruit size

Table 1 shows the characteristics of three strawberry cultivars. Strawberry fruit cv. Praratchatan

80 had longer width than cv. Praratchatan 60 but was not significantly different from cv. Praratchatan 72. Still, strawberry fruit cv. Praratchatan 72 had the longest length compared to cv. Praratchatan 60 and 80. Nonetheless, there was no statistical difference in fruit thickness among the three cultivars. In case of fruit fresh weight, strawberry fruit cv. Praratchatan 72 and 80 had higher fresh weight than that of cv. Praratchatan 60. Three color break stages had no influence on fruit length, thickness and fresh weight but only for fruit width that a significant difference was noted. Strawberry fruit at 75% color break had longer width than fruit at 25% color break. Cultivar, climate and cultivation practices mainly influence strawberry fruit size. During color development, strawberry fruit constantly enlarged its size by 14% from unripe to fully-ripe stage due to fruit core's cell enlargement phenomenon (Childers, 1981; Avigdori-Avidov, 1986). Nogata et al. (1993) also found that fresh weight of strawberry fruit cv. Toyonoka slightly increased upon its fully-red color development.

Strawberry morphology

Table 2 shows the results of morphological shape from three strawberry cultivars at three color developmental stages. Strawberry fruit cv. Praratchatan 60 and 72 showed similar results of fruit appearances which were mainly distributed in conic shape with the rest varied among globose conic, long conic, necked, long wedge and short wedge shapes while strawberry fruit cv. Praratchatan 80 eventually exhibited only conic and long wedge shapes at 25, 50 and 75% color break. Cultivar is the major factor affecting strawberry fruit formation and postharvest quality (Cordenunsi et al., 2003). Interestingly, the results from this study implied that strawberry fruit cv. Praratchatan 60 and 72 had similar growing characteristics while cv. Praratchatan 80 had different fruit formation development. However, climate change during cultivation, especially at the time of fruit growth and development, also affected fruit formation, for example, short day-length could induce oblate shape. In addition, improper relative humidity, drought and insect infestation during pollination and fertilization can also contribute to mal-formative effects (Ayala-Zavala et al., 2004; Cordenunsi et al., 2005).

Fruit surface and flesh color

In fruit surface color, three strawberry cultivars showed no difference in L^* value whereas significant differences were found in chroma and hue angle. Strawberry fruit cv. Praratchatan 60 had the highest chroma value with cv. Praratchatan 72 and 80. For

Table 1. Results of fruit size and weight of three strawberry cultivars

Treatments	Fruit size and weight			
	Fresh weight (g)	Length (cm)	Thickness (cm)	Width (cm)
Factor 1: Cultivar				
Praratchatan 60	16.72±3.10 ^b	4.05±0.27 ^b	3.11±0.24	3.43±0.25 ^b
Praratchatan 72	19.15±3.89 ^a	4.40±0.40 ^a	3.11±0.28	3.50±0.32 ^{ab}
Praratchatan 80	19.10±3.80 ^a	3.95±0.28 ^c	3.18±0.23	3.51±0.26 ^a
Factor 2: Color break				
25 %	17.79±3.63	4.11±0.42	3.11±0.27	3.44±0.28 ^b
50 %	18.32±3.77	4.17±0.40	3.14±0.25	3.47±0.27 ^{ab}
75 %	18.86±4.05	4.13±0.39	3.15±0.25	3.53±0.28 ^a
Factor 1	*	*	ns	*
Factor 2	ns	ns	ns	*
Factor 1×2	ns	ns	ns	ns

Note: Means with different letters in the same column differ significantly ($P < 0.05$)

*= significant, ns=not significant

Table 2. Results of strawberry fruit shape from three strawberry cultivars at three different color break stages

Morphological shapes	Cultivar Praratchatan 60			Cultivar Praratchatan 72			Cultivar Praratchatan 80		
	Color break (%)			Color break (%)			Color break (%)		
	25	50	75	25	50	75	25	50	75
Oblate	0.00±0.00 ^c	0.00±0.00 ^c	0.00±0.00 ^e	0.00±0.00 ^f	0.00±0.00 ^d	0.00±0.00 ^f	0.00±0.00 ^e	0.00±0.00 ^d	0.00±0.00 ^d
Globose	0.00±0.00 ^c	0.00±0.00 ^c	0.00±0.00 ^e	0.00±0.00 ^f	0.00±0.00 ^d	0.00±0.00 ^f	0.00±0.00 ^e	0.00±0.00 ^d	0.00±0.00 ^d
Globose conic	0.00±0.00 ^c	0.00±0.00 ^c	3.33±0.00 ^d	0.00±0.00 ^f	0.00±0.00 ^d	0.00±0.00 ^f	0.00±0.00 ^e	0.00±0.00 ^d	0.00±0.00 ^d
Conic	76.67±6.67 ^a	80.00±6.67 ^a	76.67±3.34 ^a	60.00±0.00 ^a	60.00±6.67 ^a	66.67±0.00 ^a	36.67±0.00 ^b	50.00±0.00 ^a	53.33±0.00 ^a
Long conic	13.33±3.34 ^b	13.33±0.00 ^b	10.00±0.00 ^b	13.33±0.00 ^c	16.67±0.00 ^b	10.00±0.00 ^c	13.33±0.00 ^c	6.67±0.00 ^c	0.00±0.00 ^d
Necked	3.33±0.00 ^c	3.33±0.00 ^c	0.00±0.00 ^e	3.33±0.00 ^e	6.67±0.00 ^c	13.33±3.34 ^b	0.00±0.00 ^e	0.00±0.00 ^d	0.00±0.00 ^d
Long wedge	3.33±0.00 ^c	3.33±0.00 ^c	3.33±0.00 ^d	16.67±3.34 ^b	13.00±0.00 ^b	6.67±0.00 ^d	43.33±0.00 ^a	43.33±3.34 ^b	40.00±3.33 ^b
Short wedge	3.33±0.00 ^c	0.00±0.00 ^c	6.67±0.00 ^c	6.67±0.00 ^d	3.33±0.00 ^{cd}	3.33±0.00 ^e	6.67±3.34 ^d	0.00±0.00 ^d	6.67±0.00 ^c
C.V. (%)	21.08	18.87	9.43	9.43	18.87	9.43	9.43	9.43	9.42

Note: Means with different letters in the same column differ significantly ($P < 0.05$).

hue angle, strawberry fruit cv. Praratchatan 60 and 72 showed higher value than that of cv. Praratchatan 80. Three color break stages similarly influenced L^* value and hue angle, the trends showed that both values decreased according to the red color development while chroma increased with red color development (Table 3). The color results clearly related to anthocyanin contents (Table 4). The increase of anthocyanin content (from color break 25 to 75%) affected the decrease of fruit surface lightness (L^*) and the increase of fruit surface red color saturation (chroma) (McGuire, 1992).

Table 3 shows the differences in flesh color of three strawberry cultivars at each developmental stage. The L^* value of strawberry fruit cv. Praratchatan 60 and 72 was higher than that of cv. Praratchatan 80 while cv. Praratchatan 60 expressed the highest chroma. Hue angle was significantly different among three cultivars. The highest hue angle of flesh color was found in cv. Praratchatan 72, followed by cv. Praratchatan 60, then 80. Three

color break stages showed different results which apparently corresponded to red color development and anthocyanin contents as shown in Table 4. Flesh color lightness decreased upon fruit ripeness while contrasting results were found in chroma (McGuire, 1992). Holcroft and Kader (1999) and Li *et al.* (2001) found that strawberry fruit accumulated anthocyanin in both external and internal tissues and the accumulation rate rapidly increased when fruit color developed from 50% color break (half red) to 100% color break (fully-red).

Fruit firmness

Firmness of strawberry fruit cv. Praratchatan 60 was higher than that of cv. Praratchatan 72, but not significantly different from cv. Praratchatan 80. The firmness effect can vary among cultivars in which higher firmness may be caused by the increase of pectin viscosity within fruit flesh (Werner and Frenkel, 1987; Watkins *et al.*, 1999). Likewise, Cordenunsi *et al.* (2003) compared postharvest

Table 3. Comparative results of surface color, flesh color and firmness of three strawberry cultivars

Treatments	Surface color			Flesh color			Firmness (Kg)
	L*	Chroma	Hue angle (°)	L*	Chroma	Hue angle (°)	
Factor 1: Cultivar							
Praratchatan 60	56.43±7.49	41.06±6.12 ^a	60.50±16.71 ^a	72.01±3.02 ^a	15.27±4.18 ^a	83.13±17.96 ^b	0.50±0.20 ^a
Praratchatan 72	56.43±10.29	36.44±11.54 ^b	57.73±21.36 ^a	72.57±1.91 ^a	13.23±2.15 ^b	90.88±7.83 ^a	0.43±0.24 ^b
Praratchatan 80	57.42±8.45	37.76±12.30 ^b	50.11±16.52 ^b	71.15±2.45 ^b	13.78±3.43 ^b	78.12±9.96 ^c	0.49±0.25 ^{ab}
Factor 2: Color break							
25 %	66.60±4.10 ^a	26.93±6.45 ^c	77.78±13.19 ^a	72.38±2.12 ^a	12.32±1.71 ^c	94.64±8.00 ^a	0.68±0.16 ^a
50 %	55.05±5.17 ^b	39.56±5.67 ^b	48.53±10.16 ^b	72.09±2.21 ^a	13.66±2.58 ^b	83.12±11.30 ^b	0.50±0.16 ^b
75 %	48.64±4.77 ^c	48.77±4.75 ^a	42.23±16.52 ^c	71.26±3.12 ^b	16.31±4.27 ^a	74.37±12.89 ^c	0.24±0.13 ^c
Factor 1	ns	*	*	*	*	*	*
Factor 2	*	*	*	*	*	*	*
Factor 1×2	*	*	*	*	*	*	ns

Note: Means with different letters in the same column differ significantly ($P < 0.05$).

*= significant, ns=not significant

quality of five strawberry cultivars during storage at 6°C, 95% RH and discovered that cultivar was the most important factor for determining postharvest quality, especially fruit texture and tartness. Besides, Moore and Sistrunk (1981) found that planting temperature, land elevation, fruit maturity, fruit size and moisture content of strawberry fruit directly influenced fruit firmness. In this study, in terms of fruit maturity, strawberry fruit at 25% color break had the highest firmness, followed by fruit at 50 and 75% color break, respectively (Table 3). Azodanlou *et al.* (2004) suggested that during red color development, cell wall-related compounds called pectin substances were continuously degraded and decomposed by protopectinase group and led to the loss of fruit firmness but not tartness.

Soluble solids content (SSC), titratable acidity (TA) and vitamin C content

In Table 4, strawberry fruit cv. Praratchatan 80 had the highest SSC compared with cv. Praratchatan 72 and 60. Moreover, fruit at 75% color break consisted of higher SSC than fruit at 25% color break. Cordenunsi *et al.* (2003) suggested that an accumulation of soluble sugars considerably varied among cultivars. Besides, high growing temperature induced low accumulation of SSC and organic acids since such a high temperature literally induced higher respiration rate (Ayala-Zavala *et al.*, 2004; Shin *et al.*, 2007). Nonetheless, SSC accumulation was notably higher in mature fruit. Likewise, Spayd and Morris (1981) reported that strawberry fruit cv. Cardinal and A-5344 at fully red development had higher SSC than fruit at half red stage.

As for TA, strawberry fruit cv. Praratchatan 60 had the highest TA among studied cultivars. Fruit at 25 and 50% color break had higher TA than fruit at 75% color break. Percentage of titratable acidity in

all cultivars ranged between 0.81 and 0.92 (Table 4). Organic acids and non-volatile compounds are the second most important components of strawberry flavor after SSC. Citric acid is considerably prominent in strawberry (Cordenunsi *et al.*, 2003). The obtained results had similar trends to Montero *et al.* (1996), who reported that strawberry fruit cv. Chandler at fully red stage or during senescing process had lower TA than unripe fruit. Azodanlou *et al.* (2004) also supported previous study by providing similar results: TA of strawberry fruit cv. Carezza, Darselect and Marmolada decreased accompanied by red color development.

In case of vitamin C content, strawberry fruit cv. Praratchatan 80 had the highest value. In addition, fruit at 75% color break contained higher vitamin C than that at 25% color break. Vitamin C has long been considered an important quality attribute of strawberry fruit (Shin *et al.*, 2007). Cultivars and pre-harvest climatic condition can be defined as the crucial factors affecting vitamin C biosynthesis and accumulation (Lee and Kader, 2000; Cordenunsi *et al.*, 2003). Spayed and Morris (1981) suggested that strawberry fruit cv. Cardinal had a higher rate of vitamin C accumulation when fruit reached its full maturity (fully-red). Furthermore, a recent study also indicated that ascorbic acid concentration was usually higher in ripe fruit compared to the unripe ones (Olsson *et al.*, 2004; Kafkas *et al.*, 2007).

Anthocyanin content, total soluble phenolics (TSP) and antioxidant activity (AA)

For anthocyanin analysis, there was no significant difference in anthocyanin content among three studied cultivars. In contrast, strawberry fruit from each color break showed an obvious difference. Strawberry fruit at 75% color break had the highest anthocyanin content, followed by fruit at 50 and 25% color break,

Table 4. Comparative results of soluble solids content, titratable acidity, vitamin C content, total soluble phenolics, antioxidant activity and shelf life of three strawberry cultivars

Treatments	Soluble Solids Content (%)	Titratable Acidity (%)	Vitamin C Content (mg/100gFW)	Total Soluble Phenolics (μ gGAE/gFW)	Antioxidant Activity (μ gGAE/gFW)	Anthocyanin Content (mg/100gFW)	Shelf Life (days)
Factor 1: Cultivar							
Praratchatan 60	8.24 \pm 0.44 ^c	0.92 \pm 0.06 ^a	63.73 \pm 3.98 ^b	3358.95 \pm 300.23 ^a	1291.32 \pm 178.17 ^a	1.59 \pm 0.82	8.80 \pm 0.94
Praratchatan 72	8.97 \pm 0.88 ^b	0.83 \pm 0.04 ^b	65.40 \pm 2.53 ^b	2442.44 \pm 304.83 ^b	958.86 \pm 189.32 ^b	1.39 \pm 0.75	8.20 \pm 0.77
Praratchatan 80	10.43 \pm 0.37 ^a	0.82 \pm 0.03 ^b	72.57 \pm 3.12 ^a	1779.53 \pm 180.12 ^c	635.94 \pm 92.11 ^c	1.34 \pm 0.98	8.60 \pm 0.98
Factor 2: Color break							
25 %	8.57 \pm 1.05 ^b	0.89 \pm 0.05 ^a	64.01 \pm 4.66 ^b	2751.29 \pm 723.44	1142.88 \pm 345.93 ^a	0.48 \pm 0.08 ^c	9.40 \pm 0.63 ^a
50 %	9.22 \pm 1.04 ^{ab}	0.89 \pm 0.06 ^a	67.59 \pm 3.78 ^{ab}	2525.30 \pm 760.94	914.58 \pm 274.14 ^{ab}	1.51 \pm 0.42 ^b	8.60 \pm 0.51 ^b
75 %	9.86 \pm 0.89 ^a	0.81 \pm 0.04 ^b	70.11 \pm 4.94 ^a	2304.33 \pm 644.96	828.65 \pm 252.07 ^b	2.33 \pm 0.33 ^a	7.60 \pm 0.51 ^c
Factor 1	*	*	*	*	*	ns	ns
Factor 2	*	*	*	ns	*	*	*
Factor 1 \times 2	*	ns	ns	ns	*	*	ns

Note: Means with different letters in the same column differ significantly ($P < 0.05$).

*= significance, ns=non significance

respectively. Anthocyanin content is an important parameter for attracting consumers and assessing fruit maturity of strawberry (harvesting index) (Cordenunsi *et al.*, 2005). Anthocyanin derivatives called pelargonium-3-glucoside and cyaniding-3-glucoside are major pigments found in most strawberry cultivars (Nunes *et al.*, 2002). An increase of anthocyanin concentration when strawberry ripens is a well-known phenomenon (Wang and Lin, 2000; Ferreyra *et al.*, 2007). Moreover, Ayala-Zavala *et al.* (2004) and Zhang and Watkins (2005) found that higher temperature and faster ripening can induce greater anthocyanin biosynthesis and accumulation.

TSP values from strawberry extracts were significantly different among the three cultivars. Extract from strawberry fruit cv. Praratchatan 60 had the highest TSP (3358 \pm 300.23 μ gGAE/gFW), followed by extracts from cv. Praratchatan 72 and 80, respectively. Nonetheless, TSP from strawberry fruit at 25, 50 and 75% color break showed no significant difference. Total phenolics of strawberry mainly consist of p-coumaric acids, ellagitannins, glycosylated derivatives of ellagic acid and anthocyanin (Häkkinen *et al.*, 1999). The accumulation of phenolic compounds depends on cultivars, geographical position, growing temperature and fruit moisture content (Cordenunsi *et al.*, 2003; Ayala-Zavala *et al.*, 2004). Furthermore, after phenolic biosynthesis, certain accumulation of the compounds in strawberry fruit can be maintained or changed after harvest (Kalt *et al.*, 1999; Ayala-Zavala *et al.*, 2004).

From Table 4, AA of strawberry extracts shows a similar trend to TSP, likely, an extract from strawberry fruit cv. Praratchatan 60 had the highest AA (1291.32 \pm 178.71 μ gGAE/gFW), followed by extracts from cv. Praratchatan 72 and 80, respectively.

Besides, extract from strawberry fruit at 25% color break had higher AA than fruit at 75% color break. Total flavonoids and phenolic concentrations are considered the foremost active antioxidant compounds in strawberry fruit (Ferreyra *et al.*, 2007; Shin *et al.*, 2008). Certain compounds effectively express high levels of antiradical and antiproliferative activities in oxidative-chain reactions (Meyers *et al.*, 2003). From our study, the different levels of AA from three cultivars were directly influenced by the different contents of TSP from strawberry extracts. After correlation analysis, it was found that AA and TSP were highly correlated since they provided correlation coefficient (R) of 0.976.

Shelf life

All cultivars had a similar duration of shelf lives under 5°C with 75-80% RH condition. On the other hand, fruit maturity notably influenced strawberry shelf life. Fruit at 25% color break had the longest storage life - up to 9 days, while fruit at 50 and 75% color break had 8 and 7 days, respectively. Strawberry is one of the most perishable commodities and susceptible to microbiological decay and physiological damage (Mitcham, 2004). Fruit at 25% color break had better overall quality and higher firmness than fruit at 75% red color development and, as a result, a longer storage life (Table 3, Table 4). The results corresponded to Nunes *et al.* (2006) who found that strawberry harvested at three quarters red ripening stage could be stored for longer periods with better color and firmness than fruit harvested at fully red stage. Short storage life might additionally be due to the decrease of pectin viscosity in mature fruit and as a consequence of deteriorative changes associated with the senescing process (Werner and Frenkel, 1987; Cordenunsi *et al.*, 2003).

Conclusion

Physical and chemical quality of strawberry fruit cv. Praratchatan 60, 72 and 80 were studied. Cultivars contributed to the differences in physical quality in terms of fruit length and shape. Both fruit surface and flesh colors of all studied cultivars had significant interactions with the degrees of ripeness and anthocyanin contents. Different cultivars directly affected SSC, TSP and AA, in which strawberry fruit cv. Praratchatan 60 exhibited the highest TSP and AA. Besides, AA from strawberry crude extracts were highly related to their TSP. Nonetheless, cultivars had minor effects on TA and vitamin C content while degrees of ripeness clearly influenced anthocyanin content and shelf life of all strawberry fruit.

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