Phytochemical Screening and Fruit Quality of Commercial Eggplants

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Abstract

Ten commercial eggplant cultivars and two allies were collected from Northeastern region of Thailand in order to examine fruit quality and screen for selected phytochemicals. Eggplants were classified into three species including *Solanum torvum*, *S. violaceum* and *S. melongena*. There were 10 cultivars in *S. melongena* (commercial eggplants) containing cv. 'Makhuea kai tao khaw', 'Makhuea khuen', 'Makhuea pro chao phraya', 'Makhuea pro look lai', 'Makhuea pro muang', 'Makhuea tor lae kaew', 'Makhuea tor lae khaw', 'Makhuea yao kaew', 'Makhuea yao khaw', and 'Makhuea yao muang'. The analysis indicated that there were significant differences ($p \leq 0.05$) in fruit quality traits including color, thickness, hardness, TSS and moisture. All samples could be divided into three groups based on fruit color including white, purple, and green groups. The commercial eggplants had more thickness than *S. torvum* and *S. violaceum*, but these two species had more TSS contents than commercial eggplants. The results of phytochemical screening showed that *S. torvum* tended to have higher alkaloid, tannin, saponin and steroid contents from the staining technique. Furthermore, 'Makhuea yao muang' showed the highest DPPH radical scavenging capacity (49.33%) compared to all others. The principal component and cluster analysis based on correlation of fruit traits and phytochemicals showed that all commercial eggplants were clustered in the same group. The correlation analysis indicated that TSS contents positively correlated with saponin and steroid, while TSS contents negatively correlated with thickness and moisture contents. As this study, commercial eggplants showed higher fruit quality and antioxidant activity than related species.

Keywords: eggplant; *Solanum* spp.; fruit quality; phytochemicals; antioxidant activity
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1. Introduction

Solanum L., one of the largest genera of Solanaceae, consists of 1,400 species and is cosmopolitan [1, 2]. The geographic distribution of these species is in all continents, especially in Central and South America [3-5]. Twenty-two species of *Solanum* are found in Thailand and about half of them are found in other countries [6]. Although *Solanum* are reported as poisonous and non-edible plants, some species play an important role in food and agriculture including spice, herb, food ingredient, insecticide, and fungicide. Moreover, they have been also used in medicinal ingredients to treat asthma, bruise, cough, diarrhea, fever, headache, and rheumatic fever [4, 7-9].

Eggplants (*Solanum melongena* L.) are a domestic vegetable of the genus *Solanum* that has the worldwide gross production value in 2016 of about 38,373.83 million US$ and of about 6.39 million US$ in Thailand [10]. Within Asia, they are cultivated over areas that extend from northeast India and Burma to Southwest China, Vietnam, Laos, and Northern Thailand [11]. Increasingly, eggplants are grown worldwide about 2,644,517 hectares and widely cultivated in China (59.41%), India (27.72%), Egypt (1.82%), Indonesia (1.66%), and Turkey (0.97%) [12] because they are annual plants, well adapt to various environments, and diverse in color, shape and size based on varieties [11, 13]. Besides being good sources of nutrients, eggplants also contain several bioactive compounds including alkaloids, phenolic compounds, anthocyanin, antioxidants, and flavonoids [14-21]. These secondary compounds can attribute to the traditional medicinal efficacy in analgesic activity [22], antimicrobial [23, 24], and antioxidant [25, 26].

Eggplants and wild species are the important sources of basic ingredients in Thai food and components in herbal medicine [7, 27-29]. There are many eggplant cultivars for domestic production in Thailand, but little information regarding the comparison between fruit quality and phytochemical screening among commercial eggplants in Thailand has been reported. Thus, the objectives of this study were to evaluate the fruit quality and phytochemical profiles of commercial eggplants.

2. Materials and Methods

2.1 Materials

The samples of commercial eggplants and allies were collected in Sakon Nakhon province, Northeastern region of Thailand. All fruits were harvested at commercial maturity stages after flowering at 7-10 days. The fruits were kept in polyethylene bag and transferred to laboratory at Kasetsart University, Chalermphrakiat Sakon Nakhon Province Campus within 2 h after harvest. All fruits were cleaned with tap water and then air-dried at room temperature for 30 min. Five replications (3 fruits per replicate) of each cultivar were taken to determine quality attributes. The fruits were then sliced and dried in hot air oven at 70ºC. The dried samples were kept in hermetically sealed plastic bags to determine phytochemicals screening and antioxidant activity.

2.2 Fruit quality evaluation of eggplant samples

The peel colors of eggplants were measured using a HunterLab Miniscan EZ 4500L colorimeter (Hunter Associates Laboratory Inc.; Reston, VA, USA). The L^*, a^*, b^* and hue values of the fruits were recorded from colorimeter. The peel colors were measured at three different positions of fruit such as top, middle and bottom. The texture of eggplants was measured using a Hardness Tester No.510-1 Model FHR-1 (Nippon Optical Works Co., Ltd., Japan). The maximum force of measurement was recorded as the fruit hardness and the data were expressed as newton unit. The thickness of fruit flesh (from exocarp to outer layer of endocarp) was determined using a vernier calipers. The total soluble solids (TSS) content of fruit was measured using a Milwaukee instrument MR series hand refractometer (Milwaukee, USA) and expressed as ^{o}Brix.

2.3 Moisture content determination

Moisture content analysis was examined using the modified method of Kasikawattana *et al*. [30]. The eggplants were sliced into thin pieces and 20 g of sample was taken to determined moisture content. The samples were dried in hot air oven at 70^{o}C for 48 h or until sample weight was stable. The percentage of moisture content was calculated using the equation shown below.

$$\text{Moisture content (\%)} = [(\text{flesh weight (g)} - \text{dry weight (g)})/\text{flesh weight}] \times 100 \quad (1)$$

2.4 Phytochemical screening of commercial eggplants

2.4.1 Crude extracts preparation

The samples were dried in a hot air oven at 40^{o}C and ground in a blender. Powder samples (6 g) were soaked in 50 ml of absolute ethanol for 7 days in the dark at ambient temperature. The samples were then filtered with a Whatman filter paper no. 42 and the filtrate was evaporated using a rotary vapor BUCHI R-200 (BÜCHI Labortechnik AG, Switzerland) at 40^{o}C and 100 atm for 30-45 min. The crude extracts were collected and kept in an amber bottle at 4^{o}C [31] for further analysis.

2.4.2 Phytochemical screening

The crude extract was examined qualitatively for their phytochemical components within 5 days after extraction to reveal the presence of some secondary metabolites. The results were presented as + (light color), ++ (moderate color), +++ (dark color), and – (non-color changes) based on the color intensity with standard methods [32].

(1) Alkaloid testing: The alkaloids were determined using the modified method of Djaafar and Ridha [32]. One ml of Dragendoff's reagent was mixed with 50 mg of crude extracts. The mixture was shaken and incubated at room temperature for 10 min. The appearance of orange precipitate showed the positive result.

(2) Tannin testing: Tannin testing was conducted according to Kumar *et al*. [31] with slight modification. A 50 mg of crude extract in each sample was mixed with 0.5 ml of 70% nitric acid. Tannin presence was observed when the color of mixture was formed from reddish to yellow.

(3) Saponin testing: Saponin was evaluated using a foam test adopted from Kumar *et al*. [31]. One ml of distilled water was mixed with 50 mg of crude extract and vigorously shaken for 30 s. Persistent froth forming indicated the presence of saponin.

(4) Steroid testing: Steroid was determined by Liebermann-Burchard's test [33]. Crude extract (50 mg) was mixed with 0.2 ml of glacial acetic and 0.2 ml of concentrated sulfuric acid. The formation of a green solution showed steroid presence.

2.5 Antioxidant activity determination

The antioxidant activity was determined using DPPH (2, 2-Diphenyl-1-picrylhydrazyl) radical scavenging activity assay described by Brand-Williams *et al*. [34]. Six grams of sample powder was extracted with 99.8% ethanol and then filtered with a Whatman filter paper no. 42. One µl of aqueous filtrate of extract was added into 3 ml of DPPH solution (200 µM dissolved in 80% ethanol). The mixture was incubated at room temperature and under dark condition for 30 min. The absorbance of the solution was measured at 515 nm by the T60 UV-VIS spectrophotometer (PG Instruments Limited, United Kingdom). The antioxidant activity was expressed as the percentage of DPPH free radical scavenging using the following formula.

$$\text{DPPH free radical scavenging activity (\%)} = [(A_0\text{-}A_1)/A_0] \times 100 \quad (2)$$

A_0 = the wavelength absorbance at 0 min
A_1 = the wavelength absorbance at 30 min

2.6 Data analysis

The variance and mean differences of data were statistically analyzed value using ANOVA and the means were compared using the Least Significant Difference (LSD) with Statistix 8.0 program (Analytical Software; Tallahassee, FL, USA) at the significant level $p \leq 0.05$. The correlation and cluster analysis based on fruit quality and phytochemical properties were examined by PAST ver. 3.25 [35]. The relative qualitative differences of phytochemicals were scored from the comparison of presence/absence based on color intensity. The phytochemical presences were given scores ranging from 0 to 3. A value of 3 represented an abundant presence, while values of 2 and 1 were assigned to apparently moderate and slightly presence, respectively. A value of 0 means that the phytochemical was not detected in this study.

3. Results and Discussion

3.1 Morphological traits of eggplant samples

All collected samples of *Solanum* were classified into 3 species based on Zhi-yun *et al.*'s classification [3] including *S. torvum* Swartz. (Makhuea Phuang), *S. violaceum* Ortega (Ma Waeng Ton), and *S. melongena* L. with 10 cultivars containing *S. melongena* cv. 'Makhuea kai tao khaw', 'Makhuea khuen', 'Makhuea pro chao phraya', 'Makhuea pro look lai', 'Makhuea pro muang', 'Makhuea tor lae kaew', 'Makhuea tor lae khaw', 'Makhuea yao kaew', 'Makhuea yao khaw', and 'Makhuea yao muang'. The members in species of *S. melongena* were commercial eggplants. Most of collected samples in this research were glabrous and non-prickly, except for *S. violaceum.* They could be divided into 3 groups based on their shape (Figure 1 and Table 1) composing of (1) elongated shape: *S. melongena* cv. 'Makhuea yao kaew', 'Makhuea yao khaw' and 'Makhuea yao muang' (2) oval shape: *S. melongena* cv. 'Makhuea kai tao khaw', 'Makhuea khuen', 'Makhuea pro chao phraya', 'Makhuea pro look lai' and 'Makhuea pro muang' and (3) round shape: *S. torvum, S. violaceum, S. melongena* cv. 'Makhuea tor lae kaew' and 'Makhuea tor lae khaw'.

From the color data (Figure 1 and Table 1), all samples could be classified into three groups depended on fruit color including (1) white group with brightness value (L^*) = 79.53-84.39 and hue angle between 44.77-47.87 such as *S. melongena* cv. 'Makhuea kai tao khaw', *S. melongena* cv. 'Makhuea tor lae khaw', *S. melongena* cv. 'Makhuea yao khaw', (2) purple group with a^* = 18.80-35.50 and hue angle between 316.23-320.64 such as *S. melongena* cv. 'Makhuea pro muang' and *S. melongena* cv. 'Makhuea yao muang', and (3) green group with a^* = -18.60 to -7.00 and hue angle 64.08-71.84 and this group could further be separated into 2 subgroups, i.e. (3.1) light green subgroup such as *S. torvum*, *S. melongena* cv. 'Makhuea tor lae kaew', and *S. melongena* cv. 'Makhuea yao kaew', and (3.2) green with white striped eggplant subgroup such as *S. violaceum, S. melongena* cv. 'Makhuea khuen', *S. melongena* cv. 'Makhuea pro chao phraya', and *S. melongena* cv. 'Makhuea pro look lai'.

The results confirmed that *Solanum* was a very diverse genus in terms of fruit size, shape and color [36, 37]. Color quality evaluation of eggplants and allies presented the color divergence in each sample based on CIE L^*, a^*, b^* and hue values [38]. The L^* indicated the lightness from black (0) to white (100). Therefore, white eggplants showed higher L^* value than did the eggplants of other colors. The value of a^* meant the green-red component with green in the negative value ($a^* < 0$) and red in the positive value ($a^* > 0$). This is a reason that the purple eggplants represented the positive a^*, whereas green and white groups showed the negative a^*.

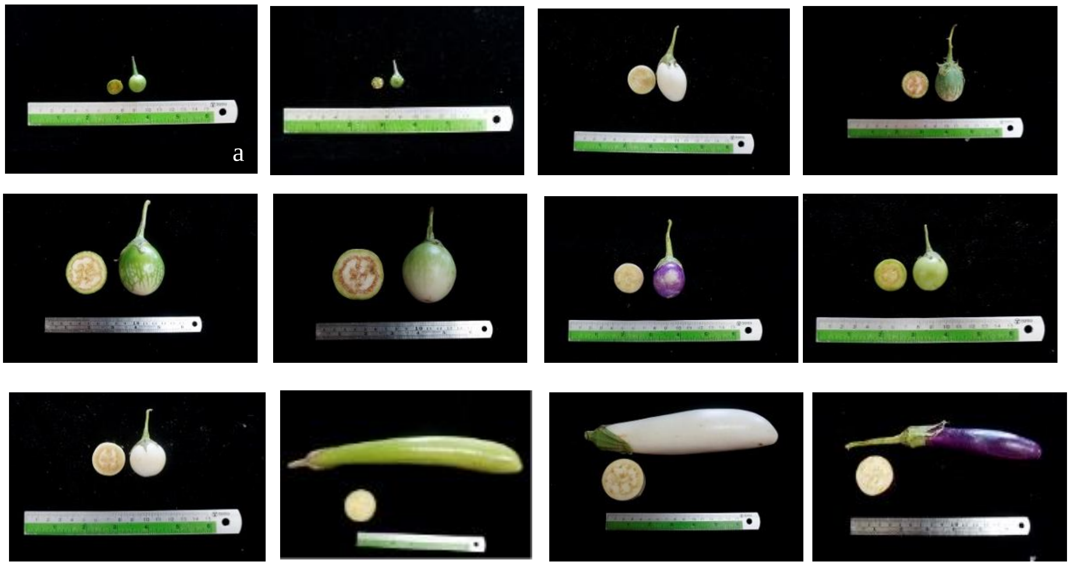

Figure 1. Morphological traits of commercial eggplants and related species (a) *S. torvum*, (b) *S. violaceum*, (c) *S. melongena* cv. ‘Makhuea kai tao khaw’, (d) *S. melongena* cv. ‘Makhuea khuen’, (e) *S. melongena* cv. ‘Makhuea pro chao phraya’, (f) *S. melongena* cv. ‘Makhuea pro look lai’, (g) *S. melongena* cv. ‘Makhuea pro muang’, (h) *S. melongena* cv. ‘Makhuea tor lae kaew’, (i) *S. melongena* cv. ‘Makhuea tor lae khaw’, (j) *S. melongena* cv. ‘Makhuea yao kaew’, (k) *S. melongena* cv. ‘Makhuea yao khaw’, and (l) *S. melongena* cv. ‘Makhuea yao muang’

Table 1. Fruit shape, fruit color and color parameters of commercial eggplants

	Fruit shape	Fruit color	Color parameters			
			*L**	*a**	*b**	h^o
S. torvum	R	G	43.38^{h}±2.93	-15.66^{f}±2.31	34.82^{b}±1.98	71.84^{b}±2.89
S. violaceum	R	G/W	24.99^{i}±3.15	-7.00^{d}±3.56	21.97^{de}±15.71	65.37^{b}±3.36
cv. ‘Makhuea kai tao khaw’	O	W	79.53^{b}±0.64	-1.37^{c}±0.32	17.79^{ef}±0.53	44.77^{c}±0.90
cv. ‘Makhuea khuen’	O	G/W	51.98^{ef}±2.31	-9.50^{de}±0.64	26.66^{cd}±1.31	64.08^{b}±1.70
cv. ‘Makhuea pro chao phraya’	O	G/W	68.43^{c}±1.05	-11.18^{e}±0.35	26.78^{cd}±2.02	67.54^{b}±1.46
cv. ‘Makhuea pro look lai’	O	G/W	45.73^{gh}±5.03	-14.96^{f}±0.79	34.35^{bc}±1.42	70.83^{b}±1.42
cv. ‘Makhuea pro muang’	O	P	49.62^{fg}±2.86	18.80^{b}±2.45	-8.15^{g}±1.08	316.23^{a}±1.25
cv. ‘Makhuea tor lae kaew’	R	G	60.48^{d}±1.69	-15.71^{f}±0.75	39.13^{b}±0.88	68.26^{b}±0.88
cv. ‘Makhuea tor lae khaw’	R	W	79.55^{b}±1.08	-1.86^{c}±0.17	14.62^{ef}±0.27	46.88^{c}±0.51
cv. ‘Makhuea yao kaew’	E	G	54.00^{e}±2.96	-18.60^{g}±1.38	48.87^{a}±1.11	68.22^{b}±1.55
cv. ‘Makhuea yao khaw’	E	W	84.39^{a}±0.97	-2.00^{c}±0.07	13.30^{f}±1.14	47.87^{c}±0.62
cv. ‘Makhuea yao muang’	E	P	14.86^{j}±2.30	35.50^{a}±2.26	-19.68^{h}±2.03	320.64^{a}±27.82
F-test			**	**	**	**
C.V. (%)			4.65	-45.61	22.62	7.86

Note: E = elongate, O = oval, R = round, G =green, G/W = green with white stripes, P = purple, W =white, Y = yellow

The *b** meant the blue-yellow component with blue in the negative value and yellow in the positive value [38]. Moreover, the hue value represented a color appearance parameter that was used to explain the quality of color. The results reported that hue angle was related to eggplant colors including purple group (h^o > 310), green group (h^o = 64.08-71.84), and white group (h^o = 44.77-47.87). Since blue-yellow color was not found in these samples, the *b** value was not considered for classification in this analysis.

3.2 Fruit quality evaluation of eggplants

There were significant differences ($p \leq 0.05$) in fruit quality traits as shown in Table 2, which was in agreement with Gajewski and Arasimowicz [39] who reported that the quality of eggplant fruits could be affected by cultivars and maturity stage. *S. violaceum* and *S. torvum* had less flesh thickness than commercial eggplants because of morphological diversity and genetic traits [36, 37]. Commercial eggplants were bred to obtain a larger fruit for economic value adding [40, 41]. The average of hardness value in this study was 8.29 N. The highest hardness was found in *S. melongena* cv. 'Makhuea tor lae khaw' (9.41 N), whereas *S. melongena* cv. 'Makhuea yao kaew' had the lowest value (6.26 N). These differences were due to fruit peel properties such as toughness and thickness [42]. Oval and round shaped eggplants were crispy, while *S. torvum*, *S. violaceum* and elongated eggplants were tough. The crispiness and toughness were factors that affected the hardness value of eggplants. The crispy eggplants had higher hardness value than tough eggplants. Moreover, hardness value also depended on the postharvest and storage conditions. The longer storage periods resulted in more fruit ripening, causing the hardness value to be lower [39].

Table 2. Hardness, thickness, TSS and moisture contents in eggplants and allies

	Thickness (cm)	Hardness (N)	TSS (°Brix)	Moisture (%)
S. torvum	$0.11^{d}\pm0.00$	$8.00^{b}\pm1.54$	$15.13^{a}\pm0.35$	$82.36^{e}\pm0.95$
S. violaceum	$0.10^{d}\pm0.31$	$7.91^{b}\pm2.77$	$10.93^{b}\pm1.62$	$79.99^{f}\pm0.84$
cv. 'Makhuea kai tao khaw'	$0.39^{c}\pm0.07$	$8.90^{a}\pm0.42$	$5.13^{ef}\pm0.41$	$92.41^{a}\pm0.42$
cv. 'Makhuea khuen'	$0.48^{bc}\pm0.52$	$8.83^{a}\pm2.95$	$5.93^{e}\pm0.26$	$84.35^{d}\pm0.43$
cv. 'Makhuea pro chao phraya'	$0.47^{bc}\pm0.07$	$8.91^{a}\pm0.52$	$5.07^{ef}\pm0.26$	$91.07^{a}\pm0.92$
cv. 'Makhuea pro look lai'	$0.57^{ab}\pm0.09$	$7.69^{b}\pm2.82$	$5.80^{e}\pm0.41$	$91.77^{a}\pm0.48$
cv. 'Makhuea pro muang'	$0.37^{c}\pm0.05$	$8.90^{a}\pm0.35$	$7.06^{d}\pm0.88$	$91.14^{a}\pm0.76$
cv. 'Makhuea tor lae kaew'	$0.35^{c}\pm0.08$	$9.35^{a}\pm3.06$	$5.20^{ef}\pm0.56$	$88.40^{c}\pm0.76$
cv. 'Makhuea tor lae khaw'	$0.36^{c}\pm0.06$	$9.41^{a}\pm0.31$	$7.93^{c}\pm1.10$	$89.07^{bc}\pm0.37$
cv. 'Makhuea yao kaew'	$0.66^{a}\pm0.12$	$6.26^{c}\pm0.36$	$4.60^{fg}\pm0.63$	$92.25^{a}\pm0.64$
cv. 'Makhuea yao khaw'	$0.58^{ab}\pm1.24$	$7.59^{b}\pm0.46$	$4.07^{g}\pm0.26$	$91.21^{a}\pm2.21$
cv. 'Makhuea yao muang'	$0.41^{c}\pm0.16$	$7.67^{b}\pm0.61$	$5.33^{ef}\pm0.62$	$90.64^{ab}\pm0.31$
F-test	**	**	**	**
C.V. (%)	31.25	7.52	11.20	1.76

Note: In each column, different superscripts represent significant differences ($p \leq 0.05$).

Total soluble solid (TSS) of eggplants and related species were in range of 4.07-15.13°Brix (Table 2). The highest TSS was found in *S. torvum* (15.13°Brix) and the lowest TSS was shown in *S. melongena* cv. 'Makhuea yao khaw' (4.07°Brix). The moisture contents of eggplants and allies were higher than 80%. The highest moisture content was recorded in *S. melongena* cv. 'Makhuea kai tao khaw' (92.41%) and the lowest moisture content was found in *S. violaceum* (79.99%). The results showed that all cultivars of *S. melongena* had lower TSS contents than other species. A cause of different TSS contents in each sample was the variety of species and cultivars [43]. Contrarily, all eggplant cultivars in this study had more moisture contents than *S. torvum* and *S. violaceum*. These results were coincident with Koundinya *et al*. [43], who reported that average of moisture content in eggplants ranged from 84.60-90.40%.

3.3 Phytochemical screening in commercial eggplants

The results of phytochemical screening of eggplants and related species are shown in Table 3. Abundant alkaloids were found in *S. torvum, S. violaceum, S. melongena* cv. 'Makhuea kai tao khaw', *S. melongena* cv. 'Makhuea khuen', *S. melongena* cv. 'Makhuea pro muang', and *S. melongena* cv. 'Makhuea yao khaw'. A large amount of saponin was also observed in *S. torvum*.

Table 3. Phytochemical screening of some samples

	Alkaloids	Tannins	Saponins	Steroids
S. torvum	+++	+++	+++	+++
S. violaceum	+++	-	++	++
cv. 'Makhuea kai tao khaw'	+++	++	+	-
cv. 'Makhuea khuen'	+++	-	+	++
cv. 'Makhuea pro chao phraya'	++	-	+	-
cv. 'Makhuea pro look lai'	++	-	++	-
cv. 'Makhuea pro muang'	+++	-	++	-
cv. 'Makhuea tor lae kaew'	++	-	+	+
cv. 'Makhuea tor lae khaw'	+	-	++	-
cv. 'Makhuea yao kaew'	++	-	++	++
cv. 'Makhuea yao khaw'	+++	++	+	-
cv. 'Makhuea yao muang'	++	-	++	-

Note: +++ = abundant presence, ++ = moderate presence, + = slightly presence, - = absence

Moreover, tannin existed in *S. torvum, S. melongena* cv. 'Makhuea kai tao khaw', and *S. melongena* cv. 'Makhuea yao khaw'. Steroids were found in *S. torvum, S. violaceum*, *S. melongena* cv. 'Makhuea khuen', *S. melongena* cv. 'Makhuea yao kaew', and *S. melongena* cv. 'Makhuea tor lae kaew', respectively.

The different existences of phytochemicals do not only affect on genetic diversity of eggplants, but also on different organs, age, cultivation, harvesting, and storage [44, 45]. Phytochemical variations in eggplant extracts were distinct from related eggplant extracts. The analysis showed that the presences of alkaloids, tannins, saponins, and steroids were more abundant in *S. torvum* than others. According to Koomson *et al*. [46], ethanolic extracts of *S. torvum* fruits were a source of alkaloids, tannins, and saponins. Most of *Solanum* are bitter because of the presences of alkaloid, especially glycoalkaloids. However, alkaloid compounds found in eggplants are edible. Otherwise, 14 % of glycoalkaloid levels of *S. melongena* were considered as toxic [47]. Although alkaloids are toxic and cause diarrhea, they are known to be analgesic property [23], inhibit microbial activity and prevent plants from microbial pathogens [48, 49]. Tannins are a kind of water-soluble polyphenol that are astringent and bitter. Tannins also have antimicrobial, anti-inflammatory and wound healing properties [50, 51]. From the results of the screening tests, the commercial eggplant tested expressed non or moderately tannin presence compared with *S. torvum*. This is because of the breeding and selection program to reduce astringent and bitter flavor in commercial eggplants. Saponins are glycosides that have soapy characteristic and have properties of coagulating red blood cells, antimicrobial and anti-cancer activity [52, 53]. These phytochemical screening of ethanolic extracts of eggplant give confidence for folkloric uses and further development in plant breeding.

3.4 DPPH radical scavenging activity

The DPPH radial-scavenging activity of different eggplants is shown in Figure 2. The coefficient of variation for this statistical analysis was 6.38 and percentages of scavenging activity in all samples were significant difference ($p \leq 0.05$). The analysis revealed that *S. melongena* cv. 'Makhuea yoa muang' had the highest antioxidant activity. This might be related to anthocyanin contents in eggplants. Anthocyanin has been reported to be an effective antioxidant [54, 55] and belongs to flavonoid group [56]. More anthocyanin has been commonly found in the purple pigment than other pigments [54]. Moreover, anthocyanin was not in the peel of green or white eggplants [57, 58]. In this study, we only used absolute ethanol extraction solvent, which unlikely affected the DPPH result. Do *et al*. [59] reported that 100% ethanol was the most effective extraction solvent for antioxidant activity, phenolic and flavonoid compounds. As observed in the present study, the different peel color of *Solanum* displayed the

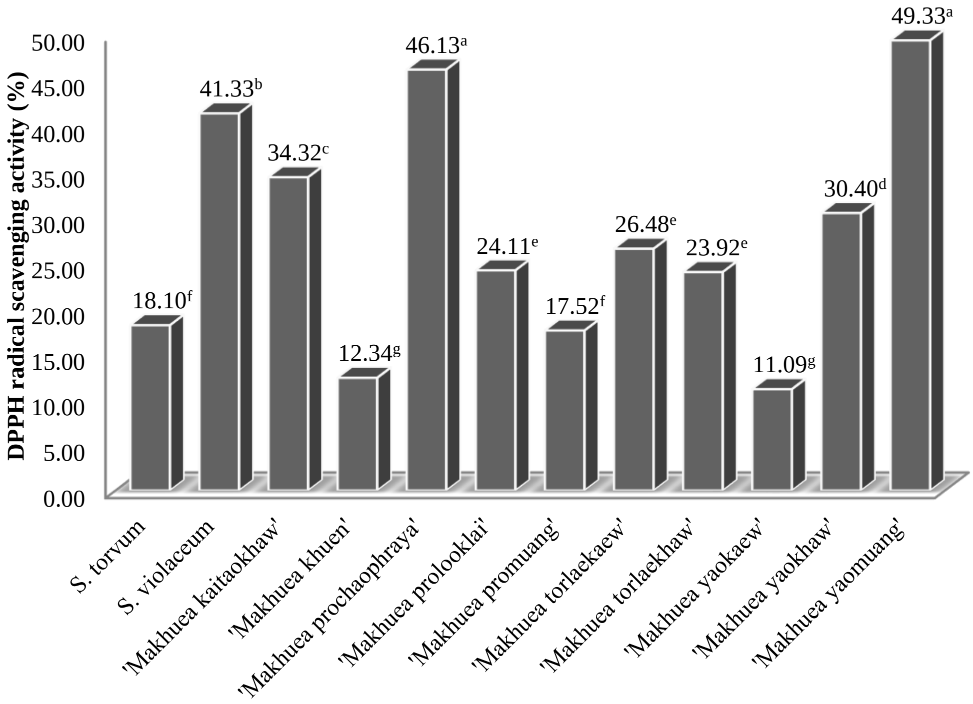

Figure 2. The DPPH radical scavenging activity of commercial eggplants

distinctions of antioxidant activity, which was in agreement with Somawathi *et al*. [60], who reported that purple eggplant exhibited the greatest DPPH radical scavenging activity.

3.5 Correlation analysis between fruit quality and phytochemical properties

The correlation analysis of some fruit quality and phytochemical properties using principal component analysis (PCA) showed that variations of cultivars in eggplants affected physical and chemical properties. The examination found that the first principal component (PC1) and the second principal component (PC2) presented the variance of variables as 54.974%. The variance of first principal component was 38.286% comprising TSS, alkaloid, tannin, saponin, and steroid. The variance of second principal component was 16.688% including h^o value, hardness, TSS, and DPPH radical scavenging activity (Table 4). The correlations between principal component and eggplant cultivars are shown in Figure 3 and the correlation coefficients between fruit quality components and phytochemical properties are presented in Table 5. The TSS parameter was found to positively correlate with saponin and steroid presences with correlation coefficients of 0.75 and 0.64, respectively. TSS is a parameter that determines certain solids dissolved within a substance, and TSS value is often used to indicate the sweetness in fruit as sugar content [61, 62]. As saponin and steroid are mostly presented in glycoside forms containing an aglycone unit linked to sugar molecules [63, 64], a high TSS content correlated to an abundance of saponin and steroid in fruit. From the results, species that had abundant steroids and saponin also had high TSS values. On the other hand, the TSS parameter was negatively correlated with thickness and moisture contents. These analyses are in agreement with Rashidi *et al*.'s report [65] that the correlation between TSS and water content followed a linear regression. Thus, the more water content is, the less TSS content in fruit will be. Notably, DPPH radical scavenging activity did not correlate with either fruit quality or phytochemical properties in this study.

Table 4. Total variation and eigenvalue of eggplants based on principal component analysis

Characters	PC1	PC2	PC	Eigenvalue	% variance	Cumulative % variance
h^o value	-0.075	0.256	1	3.829	38.286	38.286
Thickness	-0.410	-0.444	2	1.669	16.688	54.974
Hardness	-0.036	0.546	3	1.484	14.844	69.818
TSS	0.484	0.122	4	1.185	11.853	81.671
% Moisture	-0.441	-0.147	5	0.823	8.231	89.902
Alkaloid	0.231	-0.096	6	0.773	7.739	97.641
Tannin	0.240	-0.154	7	0.142	1.416	99.057
Saponin	0.321	-0.078	8	0.061	0.606	99.663
Steroid	0.412	-0.302	9	0.031	0.310	99.973
DPPH activity	-0.110	0.522	10	0.003	0.027	100.00

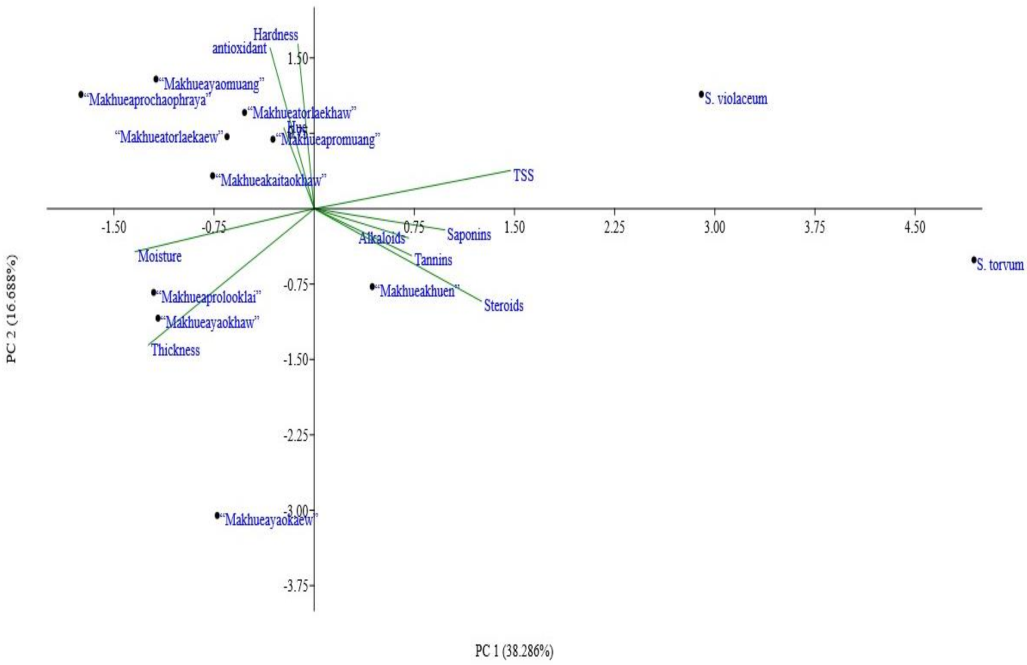

Figure 3. PCA projection for physical and chemical traits of eggplants and related species

Cluster analysis based on correlation data using UPGMA method presented the Cohen's correlation as 0.81. All samples could be classified into two major groups (Figure 4), the first group consisted of the non-eggplant group including *S. torvum* and *S. violaceum*, and the second group comprised all cultivars of *S. melongena* or the eggplant group. *Solanum torvum* and *S. violaceum* were clustered into the same group because both species exposed the small fruit with ample or moderate presences of alkaloids, saponins and steroids. The members within *S. melongena* group could be divided into three subgroups based on morphological and chemical traits, except for *S. melongena* cv. 'Makhuea yao kaew'. The first subgroup was classified by fruit color comprising *S. melongena* cv. 'Makhuea pro muang' and *S. melongena* cv. 'Makhuea yao muang' since these two eggplants were purple (h^o = 316.23-320.64). The second subgroup was isolated from other eggplants based on tannin presences. The members in second subgroup were *S. melongena* cv. 'Makhuea kai tao khaw' and *S. melongena* cv.

Table 5. Correlation coefficients between quality components and DPPH scavenging activity

	Thickness	Hardness	TSS	Moisture	Alkaloid	Tannin	Saponin	Steroid	DPPH
h°	-0.05	-0.03	-0.07	0.21	0.06	-0.28	0.27	-0.30	0.19
Thickness		-0.35	-0.84**	0.77**	-0.28	-0.28	-0.45	-0.42	-0.21
Hardness			0.03	-0.09	-0.10	-0.09	-0.37	-0.31	0.11
TSS				-0.78**	0.26	0.42	0.75**	0.64*	-0.13
Moisture					-0.36	-0.13	-0.34	-0.75**	0.05
Alkaloid						0.51	-0.07	0.35	-0.10
Tannin							0.17	0.24	-0.08
Saponin								0.42	-0.22
Steroid									-0.44

Note: * = significantly different at $p \leq 0.05$ level, ** = significantly different at $p \leq 0.01$ level

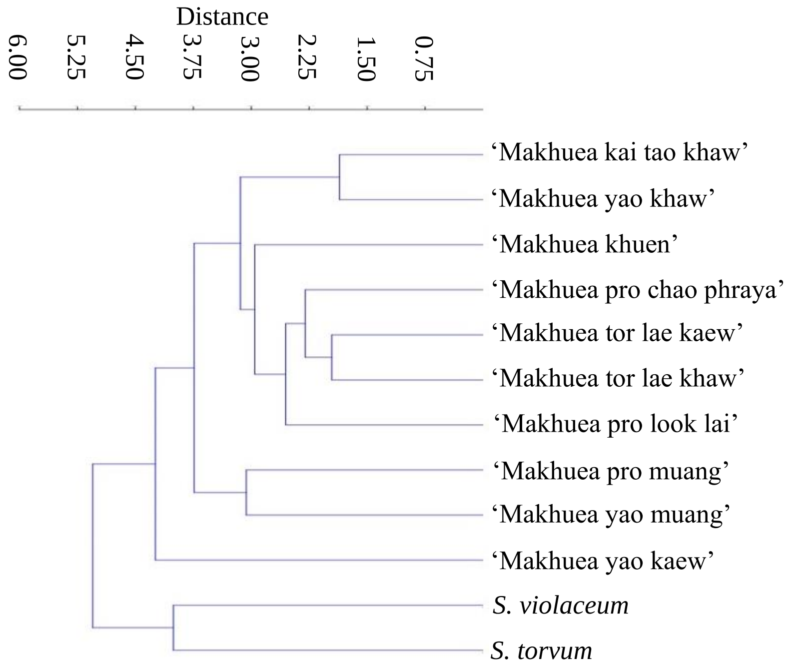

Figure 4. Dendrogram of commercial eggplants and related species using UPGMA clustering based on correlation matrix

'Makhuea yao khaw' The representatives in third subgroup involved *S. melongena* cv. 'Makhuea khuen', *S. melongena* cv. 'Makhuea pro chao phraya', *S. melongena* cv. 'Makhuea toe lae kaew', *S. melongena* cv. 'Makhuea tor lae khaw' and *S. melongena* cv. 'Makhuea pro look lai'. These eggplant cultivars were classified together because most of them were green fruit and lacked tannin. This analysis could interpret that fruit quality and phytochemical data could be used as a criterion to separate all cultivars of *S. melongena* from the two related species. Furthermore, fruit color and tannin presences were able to be a parameter for eggplant clustering.

4. Conclusions

The fruit quality of commercial eggplants and related species were significantly different. Peel color was distinct and it depended on main pigment content in eggplants. The maximum of L^* value was found in the white eggplant group. The highest a^* value was in *S. melongena* cv. 'Makhuea yao muang'. Moreover, commercial eggplants (*S. melongena*) presented more flesh thickness and moisture content than other species, whereas a high TSS was found in *S. torvum* and *S. violaceum*. The phytochemical screening showed that *S. torvum* was a good source of secondary metabolites including alkaloids, tannins, saponins, and steroids, while commercial eggplants presented moderate or slight phytochemical contents. All samples had the DPPH radical scavenging activity, while *S. melongena* cv. 'Makhuea yao muang' showed the highest activity. The correlation analysis between fruit quality and phytochemical data indicated a significant correlation between TSS content and saponin and steroid presence. Additionally, the examination could classify all cultivars of *S. molongena* from two related species using cluster analysis. In overall conclusion, commercial eggplants had higher fruit quality, phytochemical content, and antioxidant activity than *S. torvum* and *S. violaceum*. Future studies should be conducted to identify and quantify the phytochemical compounds in eggplants.

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