The albedo and segment walls are white and are separated easily from the pulp. The pulp is quite large, brownish-yellow (honey colored) and clinging tightly together. The flavor is sweet and slightly sour with crisp and juicy but not watery texture. TSS is 11.4%–12.6%, TA 0.66%–0.72% and ascorbic acid 43.8–50.1 mg·(100 mL)$^{-1}$. Seeds are large but few in number[35–38] (Fig. 2(c)).

2.10 Kao Tangkwa

Kao Tangkwa is a well-known cultivar in Chainat Province. It is also grown in other provinces near Chainat including Nakhon Sawan and Uthai Thani. The fruit is oblate, medium-sized at 14–16 cm in diameter and 0.9–1.6 kg in weight. It has smooth green rind and fine oil glands. The albedo and segment walls are white. The juice sacs are large with a clear honey color and clinging tightly together. This cultivar is sweet with mild acidic, crisp, dry and not watery, having a TSS of 10.8%–11.4%, TA of 0.44%–0.66% and ascorbic acid content of 48.8–66.0 mg·(100 mL)$^{-1}$. It has a few seeds[36–38] (Fig. 2(d)).

2.11 Tha Khoi

Tha Khoi is a cultivar that originated and is widely grown in Pichit Province. This cultivar is sold on the domestic market and is also exported, especially to China. The fruits are quite large, globose in shape with a neck that is not obvious. The fruit diameter is about 15–18 cm, weighing 0.7–0.8 kg. The rind is rough with yellow green and large oil glands. The albedo is pinkish, thick and fluffy having a unique aroma that is processed to produce flavorful candy, a famous product of Pichit Province. The pulp and segment wall are also pink. The juice sacs are slightly long and clinging tightly together. Tha Khoi is juicy and sour with a mild sweet taste. It has moderately low sugar and high acid with a TSS of 8.69%–9.39%, TA of 0.83%–0.78% and ascorbic acid content of 37.0–55.1 mg·(100 mL)$^{-1}$. It contains a few seeds and is sometimes seedless[35,36,38,39] (Fig. 2(e)).

2.12 Tab Tim Siam

Tab Tim Siam or Daeng Siam, a ruby-red pomelo, is a local cultivar in Nakhon Si Thammarat Province that has recently become a commercial cultivar. It is now famous in Thailand and export markets. The fruit of Tab Tim Siam is large, pyriform, weighing 1.8 – 2.0 kg and 16–22 cm in diameter. Its rind has soft velvet hairs, light green and thin at 0.7–1.1 cm thick. The albedo and segment walls are quite red. The pulp is pink to ruby red with soft, sweet, juicy, and flavorful aroma. The juice contains a TSS of 9.7%–12.7%, TA of 0.29%–0.42% and ascorbic acid of 68.2±3.11 mg·(100 g)$^{-1}$ fresh weight (FW) . It has a few seeds or is seedless[37,40,41] (Fig. 2(f)).

3 BIOACTIVE COMPOUNDS AND ANTIOXIDANT CAPACITY

3.1 Carotenoids

Carotenoids or tetraterpenoids are pigments producing bright yellow, red and orange colors in plants. Generally, based on the flesh color, pomelo falls into two main groups, white- to yellowish-fleshed and pink- to red-fleshed, though greenish or orange flesh is also found. The difference in color results from

Fig. 2 Thai commercial pomelo cultivars: (a) Thong Dee, (b) Kao Yai, (c) Kao Numphueng, (d) Kao Tangkwa, (e) Tha Khoi, and (f) Tab Tim Siam.

differences in carotenoid composition. At maturity the main pigments of red-fleshed pomelo are lycopene and β-carotene but these are quite low in white-fleshed cultivars in which other carotenoids are dominant. The common Chinese red-fleshed pomelos are Hongrou, Huangjin and Sanhong, which are all bud mutants of cv. Guanxi (white-fleshed). Liu et al.[42] and Jiang et al.[43] report that lycopene and β-carotene were found in abundance in red-fleshed sweet pomelo (Hongrou) with 5–6 times higher lycopene than β-carotene. Conversely, Huangjin with orange pulp had β-carotene as the predominant compound at 35 times higher than lycopene whereas those were quite low or non-detectable in cv. Guanxi (Table 2). Also, there are many other red-fleshed pomelos in China, e.g., Chuhong, Chuzhou Early Red and Fengdu/Shanyuan, which are rich in lycopene and β-carotene, especially Chuhong (Table 2). Xu et al.[46] show that cv. Fengdu had much higher lycopene and β-carotene than cv. Hongrou. The lycopene and β-carotene contents of some other white-fleshed pomelos are quite low or not present, thus other carotenoid compounds are found as in cvs Yuhuan and Feicui. Xu et al.[47] report that lutein (73.9 $ng \cdot g^{-1}$ DW) and phytoene (73.6 $ng \cdot g^{-1}$ DW) were the main flavonoid compounds in cv. Yuhuan followed by zeaxanthin (21.7 $ng \cdot g^{-1}$ DW) and β-carotene (10.7 $ng \cdot g^{-1}$ DW) with lycopene not detected. However, in cv. Feicui (pale green-fleshed) only violaxanthin was detected at about 1 $\mu g \cdot g^{-1}$ DW[44] (Table 2).

There are fewer red-fleshed cultivars in Thailand than in China. The main red-fleshed commercial cultivars are Tab Tim Siam, Tha Khoi and Thong Dee. Thong Dee (pink-fleshed), the most abundant cultivar in Thailand, has high concentrations of

Table 2 Major carotenoid concentrations in flesh or juice of Chinese and Thai pomelo cultivars

Cultivar	Flesh color	Lycopene	β-Carotene	Lutein	Zeaxan-thin	Phytoene	Viloaxanthin	β-Cryptoxan-thin	Unit	Reference
Chinese pomelo										
Chuhong	Red	~ 450	~ 50			~ 50	~ 1		$\mu g \cdot g^{-1}$ (DW)	[44]
Feicui	Pale green						~ 1		$\mu g \cdot g^{-1}$ (DW)	[44]
Guanxi	White	~ 1							$\mu g \cdot g^{-1}$ (FW)	[42]
		~ 10	~ 2						$\mu g \cdot g^{-1}$ (FW)	[43]
Hongrou/Red-fleshed Sweet	Red	5.83±0.44	1.54±0.10						$\mu g \cdot g^{-1}$ (FW)	[42]
		~ 240	~ 40						$\mu g \cdot g^{-1}$ (FW)	[43]
		55.5±1.13	41.1±2.24						$\mu g \cdot g^{-1}$ (DW)	[45]
		5.26±0.17	2.19±0.14						$\mu g \cdot g^{-1}$ (DW)	[46]
		41.1±2.24	72.2±17.1	trace					$\mu g \cdot g^{-1}$ (juice)	[15]
Fengdu/Shanyuan	Red	92.2±1.94	27.3±0.68						$\mu g \cdot g^{-1}$ (DW)	[46]
Huangjin	Orange	~ 10	~ 350						$\mu g \cdot g^{-1}$ (FW)	[43]
			219						$\mu g \cdot g^{-1}$ (juice)	[16]
Yuhuan	White		0.011	0.074	0.022	0.074			$\mu g \cdot g^{-1}$ (DW)	[47]
Chuzhou Early Red	Red	16.1	6.32		0.17	1.74			$\mu g \cdot g^{-1}$ (DW)	[47]
Majia	Red	~ 40							$\mu g \cdot g^{-1}$ (DW)	[27]
Thai pomelo										
Tab Tim Siam	Red	196	~ 2.3	~ 0.1		~ 6	~ 0.2	~ 5	$\mu g \cdot g^{-1}$ (FW)	[48]
		~ 4	~ 4.5						$\mu g \cdot g^{-1}$ (DW)	[49]
Thong Dee	Pink	2.88±0.87	0.26±0.08						$\mu g \cdot g^{-1}$ (FW)	[29]
		13.8–64.6	2.82–3.51	0.12–0.17		12.2–13.4	nd	0.18–0.37	$\mu g \cdot g^{-1}$ (FW)	[28]
Kao Namphueng	Light yellow	0.067±0.035	0.089±0.024						$\mu g \cdot g^{-1}$ (FW)	[29]
Manee Esan	Red	68.7	22.4						$\mu g \cdot g^{-1}$ (FW)	[50]

Note: nd, not detected.

lycopene at 2.88–64.6 $\mu g \cdot g^{-1}$ DW and β-carotene at 0.26–3.51 $\mu g \cdot g^{-1}$ DW[28,29]. However, the yellow-fleshed cv. Khao Namphueng has lower concentrations of lycopene (67±35 $ng \cdot g^{-1}$ DW) and β-carotene (89±24 $ng \cdot g^{-1}$ DW)[29]. In the ruby-red-fleshed cultivar Tab Tim Siam, lycopene is the predominant pigment with a particularly rich content of 196 $\mu g \cdot g^{-1}$ DW followed by phytoene, β-cryptoxanthin and β-carotene at 6.0, 5.0 and 2.3 $\mu g \cdot g^{-1}$ DW, respectively[48] (Table 2). Also, a new pomelo cultivar Manee Esan recently discovered in the north-east region has a heavy red pulp with high concentrations of lycopene at 68.7 $\mu g \cdot g^{-1}$ DW and β-carotene at 22.4 $\mu g \cdot g^{-1}$ DW[50] (Table 2). Of the red-fleshed pomelo cultivars in Thailand, Tab Tim Siam has the highest lycopene content with its deep red flesh. However, comparing it with Chinese pomelos, it is not always as high as that of cv. Chuhong (Table 2).

3.2 Flavonoids

The flavonoids in pomelo are flavanones, flavones and flavonols. The flavanones are the most common group. The most abundant type of flavanone in pomelo is naringin followed by hesperidin and neohesperidin. Xu et al.[51] evaluated the flavanones in Chinese pomelo cvs Mi and Siji and found that naringin was highest at 108–125 $mg \cdot L^{-1}$ juice followed by hesperidin (21–42 $mg \cdot L^{-1}$ juice)) and neohesperidin was lowest in Miyou and not detected in Sijiyou (Table 3). Likewise, Xi et al.[52], Zhang et al.[54,55] analyzed the flavonoids in various pomelo cultivars and showed that naringin was the predominant compound in almost all cultivars studied followed by neohesperidin. Hesperidin was detected in some cultivars at similar concentration to neohesperidin, e.g., 24-14, Huayingshan, Liangpin, Meiweishatian and Wentan, while in some cultivars neither neohesperidin nor hesperidin was detected, e.g., 14-13, Cuixiangtian, Dongfengzao, Guanxi, and Yuhuan. Of the local cultivars studied by Xi et al.[52], Anjiangxiang and Dayongjuhuaxin contained the highest amounts of naringin though less than cv. Chandler, a hybrid from the United States.

Similarly, Thai pomelo cultivars have naringin as the most abundant flavanone at up to 40%–60% of the total flavonoids. Hesperidin and neohesperidin were also found in some studies with different concentrations and orders depending on cultivar[36,41,57] even though they were not detected in some studies[59,62] (Table 3). However, the most important flavanone is naringin. Numerous studies have investigated the naringin content in commercial pomelo cultivars and have found different cultivars with the highest concentration. In Pichaiyongvongdee and Haruenkit[36], the order of cultivars from the highest to the lowest naringin content were, Pattavee (386 $mg \cdot L^{-1}$ juice) and Tha Khoi (381 $mg \cdot L^{-1}$ juice) > Kao Yai (365 $mg \cdot L^{-1}$ juice) > Kao Tangkwa (243 $mg \cdot L^{-1}$ juice), as stated in Wattanasiritham et al.[59], Kao Yai from Chiang Mai Province (524 $\mu g \cdot g^{-1}$ FW) > Tha Khoi (500 $\mu g \cdot g^{-1}$ FW) > Kao Namphueng (444 $\mu g \cdot g^{-1}$ FW) > Kao Yai from Nakhon Pathom Province (350 $\mu g \cdot g^{-1}$ FW) > Kao Tangkwa (201–241 $\mu g \cdot g^{-1}$ FW), as described in Chaiwong et al.[58], Tab Tim Siam (768 $\mu g \cdot g^{-1}$ FW) > Kao Namphueng, Kao Tangkwa, Kao Yai and Thong Dee (364–415 $\mu g \cdot g^{-1}$ FW), and in Mäkynen et al.[57], Tha Khoi (41.3 $mg \cdot g^{-1}$ DW) > Kao Tangkwa (40.7 $mg \cdot g^{-1}$ DW) > Tab Tim Siam (26.3 $mg \cdot g^{-1}$ DW) (Table 3). Even though not all the same commercial cultivars were compared in each study, it seems that Tha Khoi is the Thai cultivar highest in naringin concentration followed by Tab Tim Siam. However, the differences in quality and quantity of flavonoids depends not only on the cultivar but also on stage of maturity and growing region with different environments and management affecting the naringin in pomelo[58,59]. Additionally, the extraction method and equipment used can affect the detection of flavonoids in pomelo[63].

3.3 Antioxidant capacity

Antioxidant capacity is an important parameter indicating the health benefits of foods. Antioxidant activity can be examined by numerous methods including 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity, ferric reducing-antioxidant power (FRAP) assay and superoxide radical-scavenging activity (SRSA). The DPPH assay is generally used in plant biochemistry to measure the ability of plant constituents to scavenge free radicals. The DPPH radical can be reduced by reaction with antioxidants that can donate hydrogen[64]. FRAP is used to evaluate the capacity of the sample to reduce the ferric complex to the ferrous form[65] and SRSA for measuring the superoxide anion radical-scavenging ability of the sample[66].

Different plant species and cultivars have heterogeneous phytochemical profiles resulting in different biological properties, especially antioxidant activity[67,68]. Likewise, the antioxidant capacity varies among pomelo cultivars as shown in Table 4. Comparing Chinese pomelo cultivars, Xi et al.[52] showed that the cultivar having the highest antioxidant value was different using different methods, i.e. DPPH, FRAP and SRSA (Table 4). Therefore, an overall antioxidant potency composite (APC) index calculated from all methods was used and it indicated that the cultivar with the highest antioxidant capacity was cv. 28-19 followed by cvs Qi and Jintanglv with APC values of 88.6, 88.2 and 87.2, respectively. For some other cultivars, Xu et al.[51] analyzed DPPH and FRAP in cv. Mi and Siji pulp extracts (Table 4). They found that both methods indicated that Mi had higher antioxidant capacity than Siji.

Table 3 Major flavonoid concentrations in flesh or juice of Chinese and Thai pomelo cultivars

Cultivar	Naringin	Hesperidin	Neohesperidin	Unit	Reference
Chinese pomelo					
Mi	109±0.03	42.2±1.27	6.71±0.97	$mg \cdot L^{-1}$ (juice)	[51]
Siji	126±0.80	21.8±0.36	nd	$mg \cdot L^{-1}$ (juice)	[51]
Wentan	2430±123	26.3±3.43	16.5±0.98	$\mu g \cdot g^{-1}$ (FW)	[52]
Liangping	1160±68	11.4±1.09	16.4±1.87	$\mu g \cdot g^{-1}$ (FW)	[52]
Liangping No.1	~ 3000	nd	nd	$\mu g \cdot g^{-1}$ (FW)	[53]
Huayingshan	974±56.9	0.80±0.02	1.93±0.05	$\mu g \cdot g^{-1}$ (FW)	[52]
Hongxin	2390±67	nd	19.8±1.43	$\mu g \cdot g^{-1}$ (FW)	[52]
Meiweishatian	2310±89	29.9±1.54	24.1±2.37	$\mu g \cdot g^{-1}$ (FW)	[52]
Gaopu	1360±76	nd	32.4±3.82	$\mu g \cdot g^{-1}$ (FW)	[52]
Shatian	2150±122	nd	19.3±1.70	$\mu g \cdot g^{-1}$ (FW)	[52]
	164–198			$mg \cdot L^{-1}$ (juice)	[54]
	155±13.9	nd	nd	$mg \cdot L^{-1}$ (juice)	[55]
Gulaoqianshatian	~ 9000	trace	nd	$\mu g \cdot g^{-1}$ (DW)	[53]
Wanbai	1280±90	nd	9.43±0.65	$\mu g \cdot g^{-1}$ (FW)	[52]
Dayongjuhuaxin	3120±55	nd	7.53±0.34	$\mu g \cdot g^{-1}$ (FW)	[52]
24-14	2180±119	13.5±0.78	14.3±0.77	$\mu g \cdot g^{-1}$ (FW)	[52]
14-13	1440±46	nd	nd	$\mu g \cdot g^{-1}$ (FW)	[52]
Chandler	4010±147	nd	12.7±0.40	$\mu g \cdot g^{-1}$ (FW)	[52]
Dongfengzao	971±56.3	nd	nd	$\mu g \cdot g^{-1}$ (FW)	[52]
Zaoshu	1580±77	nd	30.7±2.65	$\mu g \cdot g^{-1}$ (FW)	[52]
Zuoshi	1350±98	nd	13.3±0.72	$\mu g \cdot g^{-1}$ (FW)	[52]
Qi	1100±77	nd	19.5±0.99	$\mu g \cdot g^{-1}$ (FW)	[52]
Guanxi	892±34.6	nd	nd	$\mu g \cdot g^{-1}$ (FW)	[52]
	136±11.2	nd	nd	$mg \cdot L^{-1}$ (juice)	[55]
	61–139			$mg \cdot L^{-1}$ (juice)	[54]
	~ 7000	nd	nd	$\mu g \cdot g^{-1}$ (DW)	[53]
Dianjiangbai	~ 2000	nd	nd	$\mu g \cdot g^{-1}$ (DW)	[53]
Menglunzao	2350±122	nd	9.16±0.82	$\mu g \cdot g^{-1}$ (FW)	[52]
Tongxian	2110±161	nd	21.3±2.55	$\mu g \cdot g^{-1}$ (FW)	[52]
Libo	1970±66	nd	12.6±1.32	$\mu g \cdot g^{-1}$ (FW)	[52]
Linnanshatiao	1390±55	nd	38.6±3.61	$\mu g \cdot g^{-1}$ (FW)	[52]
Sijipao	992±76.6	nd	10.8±0.78	$\mu g \cdot g^{-1}$ (FW)	[52]
Jintanglv	1280±102	nd	22.8±2.44	$\mu g \cdot g^{-1}$ (FW)	[52]
Shisheng	2380±133	nd	10.4±0.91	$\mu g \cdot g^{-1}$ (FW)	[52]
Guanxiang	735±55.8	nd	12.0±1.09	$\mu g \cdot g^{-1}$ (FW)	[52]
28-19	2370±210	nd	44.7±1.54	$\mu g \cdot g^{-1}$ (FW)	[52]
Anjiangxiang	3130±128	nd	25.6±0.93	$\mu g \cdot g^{-1}$ (FW)	[52]
Guokui	1770±24.0	nd	12.4±0.07	$\mu g \cdot g^{-1}$ (FW)	[52]
Yuhuan	32.6±1.82	nd	nd	$mg \cdot L^{-1}$ (juice)	[55]
Cuixiangtian	21.8±0.94	nd	nd	$mg \cdot L^{-1}$ (juice)	[55]

(*Continued*)

Cultivar	Naringin	Hesperidin	Neohesperidin	Unit	Reference
Shuijingmi	988±78.7	553±33.1	nd	$\mu g \cdot g^{-1}$ (FW)	[56]
Thai pomelo					
Tab Tim Siam	26310±440	nd	29920±180	$\mu g \cdot g^{-1}$ (DW)	[57]
	768±32.1			$\mu g \cdot g^{-1}$ (FW)	[58]
	2.65±0.06	0.56±0.02	0.09±0.01	$mg \cdot L^{-1}$ (juice)	[41]
Tha Khoi	41290±430	nd	36790±250	$\mu g \cdot g^{-1}$ (DW)	[57]
	500	nd	nd	$\mu g \cdot g^{-1}$ (FW)	[59]
	4430			$\mu g \cdot g^{-1}$ (DW)	[60]
	381±67.2	2.15±0.11	2.18±0.32	$mg \cdot L^{-1}$ (juice)	[36]
Thong Dee	8130±130	10080±120	10760±30	$\mu g \cdot g^{-1}$ (DW)	[57]
	364±31			$\mu g \cdot g^{-1}$ (FW)	[58]
	254–388			$\mu g \cdot g^{-1}$ (FW)	[61]
	261	nd	nd	$\mu g \cdot g^{-1}$ (FW)	[59]
	349±54.9	nd	nd	$mg \cdot L^{-1}$ (juice)	[36]
Kao Namphueng	2340±110	22780±330	14760±150	$\mu g \cdot g^{-1}$ (DW)	[57]
	411±20.9			$\mu g \cdot g^{-1}$ (FW)	[58]
	444	nd	nd	$\mu g \cdot g^{-1}$ (FW)	[59]
	323±43.6	nd	0.59±0.04	$mg \cdot L^{-1}$ (juice)	[36]
Kao Yai	11900±210	12040±120	25400±120	$\mu g \cdot g^{-1}$ (DW)	[57]
	415±25.0			$\mu g \cdot g^{-1}$ (FW)	[58]
	350–524	nd	nd	$\mu g \cdot g^{-1}$ (FW)	[59]
	365±82.9	nd	nd	$mg \cdot L^{-1}$ (juice)	[36]
Kao Tangkwa	40650±390	nd	nd	$\mu g \cdot g^{-1}$ (DW)	[57]
	392±17.4			$\mu g \cdot g^{-1}$ (FW)	[58]
	201–241	nd	nd	$\mu g \cdot g^{-1}$ (FW)	[59]
	243±33.6	nd	nd	$mg \cdot L^{-1}$ (juice)	[36]
Kao Hom	263			$\mu g \cdot g^{-1}$ (FW)	[59]
Kao Pan	295	nd	nd	$\mu g \cdot g^{-1}$ (FW)	[59]
	316±34.5	nd	nd	$mg \cdot L^{-1}$ (juice)	[36]
Pattavee	386±80.2	nd	nd	$mg \cdot L^{-1}$ (juice)	[36]

Note: nd, not detected.

Nevertheless, by comparing DPPH in cvs Mi and Siji there seemed to be less antioxidant capacity than in the local pomelos studied by Xi et al.[52] (Table 4).

Turning to Thai pomelos, Pichaiyongvongdee and Haruenkit[36] evaluated antioxidant activity using DPPH and FRAP assays in seven pomelo cultivars comprising Kao Numphueng, Kao Pan, Kao Tangkwa, Kao Yai, Pattavee, Tha Khoi, and Thong Dee. Tha Khoi had the highest antioxidant ability followed by Thong Dee (Table 4). This corresponded with total polyphenol contents (1.50 and 1.37 $mg \cdot mL^{-1}$ gallic acid, respectively). Likewise, Mäkynen et al.[57] evaluated six of the seven commercial pomelo cultivars of Pichaiyongvongdee and Haruenkit[36] including Tab Tim Siam instead of Kao Pan and Pattavee. The ranking of cultivars differed depending on the antioxidant analysis method. Using DPPH, they were ranked Kao Yai > Thong Dee > Tab Tim Siam but FRAP gave the sequence Kao Numphueng > Kao Yai > Kao Tangkwa, and with SRSA, Kao Tangkwa > Thong Dee > Tha Khoi (Table 4). From these results, the FRAP assay conformed more to the total phenolic content than the other methods, with

Table 4 Antioxidant capacity of the flesh in Chinese and Thai pomelo cultivars

Cultivar	DPPH	FRAP	SRSA	Reference
Mi	37.7±1.07 (%)	510±4.0 ($mg \cdot L^{-1}$ AA)		[51]
Siji	35.8±0.95 (%)	442±3.3 ($mg \cdot L^{-1}$ AA)		[51]
Wentan	35.8±2.40 (%)	1.20±0.09 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	31.7±3.43 (% anion)	[52]
Liangping	29.3±3.21 (%)	0.97±0.08 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	33.7±2.89 (% anion)	[52]
Liangping No.1	9.39±0.31 ($mmol \cdot g^{-1}$ TE, DW)	18.6±0.59 ($mmol \cdot g^{-1}$ TE, DW)		[53]
Huayingshan	41.6±4.41 (%)	1.08±0.09 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	30.6±1.90 (% anion)	[52]
Hongxin	48.5±5.23 (%)	1.12±0.15 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	38.3±3.83 (% anion)	[52]
Meiweishatian	42.1±3.60 (%)	1.02±0.11 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	33.9±1.65 (% anion)	[52]
Gaopu	40.1±3.64 (%)	1.07±0.05 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	37.5±2.55 (% anion)	[52]
Shatian	37.2±2.65 (%)	1.00±0.07 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	25.8±2.87 (% anion)	[52]
Gulaoqianshatian	9.12±0.86 ($mmol \cdot g^{-1}$ TE, DW)	12.6±0.35 ($mmol \cdot g^{-1}$ TE, DW)		[53]
Wanbai	35.6±4.82 (%)	1.20±0.09 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	33.7±1.87 (% anion)	[52]
Dayongjuhuaxin	38.6±3.21 (%)	0.90±0.05 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	40.3±5.76 (% anion)	[52]
24-14	36.4±2.55 (%)	1.10±0.12 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	36.5±4.24 (% anion)	[52]
14-13	41.3±3.54 (%)	1.43±0.17 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	39.0±2.14 (% anion)	[52]
Chandler	46.0±4.67 (%)	1.30±0.07 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	43.4±3.80 (% anion)	[52]
Dongfengzao	43.2±5.12 (%)	1.24±0.10 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	42.9±4.34 (% anion)	[52]
Zaoshu	40.2±3.21 (%)	1.28±0.04 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	35.7±2.63 (% anion)	[52]
Zuoshi	42.6±4.65 (%)	1.22±0.07 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	42.4±3.77 (% anion)	[52]
Qi	48.5±5.41 (%)	1.43±0.13 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	44.8±3.81 (% anion)	[52]
Guanxi	47.3±4.90 (%)	1.10±0.10 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	42.9±2.90 (% anion)	[52]
	8.25±0.17 ($mmol \cdot g^{-1}$ TE, DW)	14.6±0.69 ($mmol \cdot g^{-1}$ TE, DW)		[53]
Menglunzao	40.2±3.76 (%)	1.02±0.09 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	38.6±1.54 (% anion)	[52]
Tongxian	35.4±2.63 (%)	0.97±0.08 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	39.7±3.66 (% anion)	[52]
Libo	45.4±4.43 (%)	0.90±0.07 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	41.4±5.89 (% anion)	[52]
Linnanshatiao	42.1±2.87 (%)	1.50±0.14 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	39.6±3.73 (% anion)	[52]
Sijipao	36.8±1.76 (%)	0.93±0.06 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	40.8±3.71 (% anion)	[52]
Jintanglv	49.3±5.76 (%)	1.55±0.14 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	39.7±2.75 (% anion)	[52]
Shisheng	39.1±2.65 (%)	1.02±0.06 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	33.8±1.99 (% anion)	[52]
Guanxiang	41.7±3.23 (%)	1.30±0.04 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	44.1±4.37 (% anion)	[52]
28-19	50.9±4.77 (%)	1.56±0.19 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	40.2±3.77 (% anion)	[52]
Anjiangxiang	32.2±2.55 (%)	1.21±0.09 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	38.2±3.79 (% anion)	[52]
Guokui	41.2±2.89 (%)	1.10±0.04 ($mmol \cdot L^{-1}$ $FeSO_4 \cdot 7H_2O$)	35.6±2.83 (% anion)	[52]
Shuijingmi	7.93±0.30 (%)	12.5±1.15 ($mmol \cdot g^{-1}$ TE, DW)		[56]
Dianjiangbai	10.7±0.35 ($mmol \cdot g^{-1}$ TE, DW)	18.0±1.28 ($mmol \cdot g^{-1}$ TE, DW)		[53]
Majia	~ 95 (%)	~ 0.52 (Abs. at 700 nm)		[27]
Tab Tim Siam	8.64±0.79 ($mg \cdot g^{-1}$ AA, DW)	66.5±1.25 ($mg \cdot g^{-1}$ AA, DW)	0.61±0.06 ($g \cdot g^{-1}$ TE, DW)	[57]
	~ 60 (%)			[49]
Tha Khoi	0.41±0.27 ($mg \cdot g^{-1}$ AA, DW)	68.0±1.06 ($mg \cdot g^{-1}$ AA, DW)	0.65±0.09 ($g \cdot g^{-1}$ TE, DW)	[57]
	8.34±0.05 (%)	37.0±1.31 ($mg \cdot g^{-1}$ TE, DW)		[60]

(*Continued*)

Cultivar	DPPH	FRAP	SRSA	Reference
	25.6±1.04 (%)	351±18.6 (mg·L^{-1} AA) 547±66.4 (mg·L^{-1} TE)		[36]
Thong Dee	11.0±0.99 (mg·g^{-1} AA, DW)	60.9±0.43 (mg·g^{-1} AA, DW)	0.72±0.03 (g·g^{-1} TE, DW)	[57]
	25.0±2.89 (%)	303±8.8 (mg·L^{-1} AA) 440±13.8 (mg·L^{-1} TE)		[36]
	0.411–0.643 (mg·g^{-1} TE, FW)	0.369–0.491 (mg·g^{-1} AA, FW)		[61]
Kao Namphueng	1.45±0.49 (mg·g^{-1} AA, DW)	109±1.25 (mg·g^{-1} AA, DW)	0.62±0.06 (g·g^{-1} TE, DW)	[57]
	22.2±0.71 (%)	193±14.1 (mg·L^{-1} AA) 284±22.1 (mg·L^{-1} TE)		[36]
Kao Yai	13.8±0.66 (mg·g^{-1} AA, DW)	78.1±0.26 (mg·g^{-1} AA, DW)	0.48±0.06 (g·g^{-1} TE, DW)	[57]
	17.0±0.74 (%)	214±6.3 (mg·L^{-1} AA) 317±9.9 (mg·L^{-1} TE)		[36]
Kao Tangkwa	6.34±0.63 (mg·g^{-1} AA, DW)	69.6±0.10 (mg·g^{-1} AA, DW)	0.80±0.14 (g·g^{-1} TE, DW)	[57]
	16.7±0.89 (%)	204±10.2 (mg·L^{-1} AA) 302±16.0 (mg·L^{-1} TE)		[36]
Kao Pan	10.8±1.00 (%)	124±2.6 (mg·L^{-1} AA) 177±4.0 (mg·L^{-1} TE)		[36]
Pattavee	18.4±2.07 (%)	235±6.2 (mg·L^{-1} AA) 351±9.7 (mg·L^{-1} TE)		[36]

Note: DPPH, 2,2-diphenyl-1-picrylhydrazyl free radical-scavenging assay; FRAP, ferric reducing antioxidant power assay; SRSA, superoxide anion radical-scavenging activity assay; AA, ascorbic acid; TE, Trolox; DW, dry weight; FW, fresh weight.

the order Kao Numphueng > Kao Yai > Tha Khoi (115, 114, and 111 mg gallic acid per g DW, respectively). However, antioxidant capacity does not always correspond to total phenolic content. Some studies have investigated antioxidant capacity in citrus fruit and found that total antioxidant capacity could be mainly contributed by phenolic compounds or ascorbic acid[69,70]. Arena et al.[69] and Xu et al.[51] showed that ascorbic acid, not phenolic compounds, was the major contributor to antioxidant capacity in citrus fruit. Additionally, lycopene, which is a main carotenoid pigment in red-fleshed pomelos, is also a strong antioxidant[71]. Moreover, the issue about which cultivar has the strongest antioxidant capacity is debatable because the antioxidant capacity of each cultivar can be altered by different growing environments and seasonal conditions[72,73]. There are also other factors such as maturity of the fruit, material preparation, and analysis methods that potentially lead to inconsistencies.

4 SENSORY ATTRIBUTES AND CONSUMER PREFERENCE

Consumer preference indicates that sensory qualities contribute to consumer decision-making in addition to price and freshness of fruit[74]. The sensory quality of a product is determined by use of sensory evaluation to obtain information about the sensitivity of the human senses in the five perspectives sight, smell, taste, touch, and sound[75]. Sensory evaluation can also be related to physiologic or biochemical evaluation to co-analyze qualities such as firmness and crunchiness to water soluble pectin level or firmness value by penetrometer, sweet and sour taste to sugars, organic acids or sugar/acid ratio, and bitter taste to naringin or limonin contents[76–78]. In addition, sensory evaluation can be used in quality control, product development and shelf-life research.

There are a large number of pomelo cultivars and each cultivar differs in its sensory characteristics including aroma, flavor and texture. Beyond cultivar, there are many factors affecting the biochemical constituents in the fruit which finally alter the sensory characteristics such as geographical origin, growing conditions, cultural practices, maturity at harvest, fresh-cut processing, and storage conditions and period[57,79]. In addition, postharvest storage can affect sensory change in each cultivar differently.

Aroma is the first sense of consumption. Its profile can be reflected by the study of volatile constituents. Zhang et al.[17] analyzed the volatile profile of Chinese pomelo cvs Shatian and Guanxi from different regions using solid-phase microextraction (SPME) and gas chromatography-mass spectrometry (GC-MS). They found that cv. Guanxi was more complicated in volatile composition and had higher concentrations than cv. Shatian. Cultivar Guanxi contained 11 aldehydes while cv. Shatian had only two. Hexanal (grass, tallow and fat odors) was the major aldehyde primarily contributing to the overall aroma of the two cultivars according to the very high odor actvity values (OAV). In addition, *E*-2-octenal and *E*-2-nonenal (green, nut, fat, orris and cucumber aroma) detected in cv. Guanxi were part of the overall aroma with OAV > 1. The primary alcohol was hexanol devoted to the green scent to the overall aroma in both cultivars while ethyl acetate was an ester also detected in both cultivars but it was the major ester in cv. Shatian providing a pineapple flavor. Cultivar Guanxi showed a different aroma derived from butyl butanoate instead of ethyl acetate. For terpenes, limonene (citrus and mint flavor) was the major terpene in cv. Shatian while *cis*-linalool oxide (flower odor), β-myrcene (balsamic, must and spice scents) and limonene were the major terpenes in cv. Guanxi. The concentrations of all these terpenes and also linolool (flower and lavender flavor) in both cultivars were above their thresholds (Table 5). Moreover, the volatile profiles of Chinese (cvs Honey Pink and Honey White) and Thai (cvs Thong Dee and Kao Yai) pomelo juices were compared using headspace-SPME and GC-MS coupled with a flame ionization detector. Limonene (citrus odor) was found in all cultivars but it was predominant in Thai cultivars, especially in cv. Thong Dee (30 times more than in Chinese cultivars). On the other hand, Chinese cultivars were rich in *cis*-3-hexanol and hexanol (green odor), especially in cv. Honey Pink. Octanol was detected in smaller amounts only in these Chinese cultivars while α-terpineol was found only in cv. Thong Dee. No alcohols were present in cv. Kao Yai. In addition, nootkatone (grapefruit and fruity citrus odor) was abundant only in cv. Thong Dee. In terms of the main aldehyde, acetaldehyde (fruity odor) was predominant in cv. Kao Yai instead of hexanal (grass odor)[80] (Table 5). It therefore seems that Thai cultivars have stronger fruity and citrus odors while Chinese cultivars contain higher green and grass odors.

For sensory analysis, Zhu et al.[78] evaluated three Chinese pomelo cultivars, Dongshizou, Huangjin and Sanhong, for their metabolites and sensory attributes. New technologies and techniques were used in their study such as electronic nose, electronic tongue and fuzzy comprehensive sensory evaluation. D-limonene was the most abundant terpene in the pomelos. Cultivars Sanhong and Huangjin were quite similar in their aromas with higher D-limonene and hexanal (key aroma compound with the highest OAV) than in cv. Dongshizou with camphene instead as the key aroma. For taste attributes, cv. Dongshizou had the highest sourness, aftertaste, sweetness, umami and saltiness. Astringency attribute was predominant in cvs Huangjin and Sanhong. Not only astringency, bitterness and richness were also the highest intensity in cv. Huangjin pulp

Table 5 Sensory descriptions of Chinese and Thai pomelo cultivars

Cultivar	Sensory description	Reference
Chinese pomelo		
Guanxi	High hexanal (key aroma) (grass, tallow and fat aroma) *E*-2-octenal (green, nut, and fat aroma) *E*-2-nonenal (orris and cucumber aroma) High pentanol (OAV < 1) Hexanol (green aroma) Butyl butanoate (fruity aroma) High *cis*-linalool oxide (flower aroma) High β-myrcene (balsamic, must, and spice aroma) High limonene (citrus and mint aroma) Linolool (flower and lavender aroma)	[17]
Shatian	High hexanal (key aroma) (grass, tallow and fat aroma) Hexanol (green aroma) High ethyl acetate (pineapple aroma) High limonene (citrus and mint aroma) Linolool (flower and lavender aroma)	[17]
Honey Pink	Limonene Very high *cis*-3-hexanol Very high hexanol Octanol Acetaldehyde High Hexanal	[80]
Honey White	Limonene High *cis*-3-hexanol High hexanol Octanol Acetaldehyde Hexanal	[80]
Huangjin	High D-limonene High hexanal (key aroma) Highest aroma intensity High astringency, bitterness, and richness Third most satisfying taste	[78]
Sanhong	High D-limonene High hexanal (key aroma) High astringency Second most satisfying taste	[78]
Dongshizou	Lower D-limonene High camphene (key aroma) High sourness, aftertaste-A, sweetness, umami, and saltiness First most satisfy taste	[78]

(*Continued*)

Cultivar	Sensory description	Reference
Thai pomelo		
Thong Dee	Very high limonene	[80]
	Cis-3-hexanol	
	Hexanol	
	α-terpineol	
	Nootkatone	
	Hexanal	
	Trace of acetaldehyde	
	High glossiness	[79]
	High citrus, pomelo, floral, and overall sweet aroma and flavor	
	High viny, orange peel, and overall sour aroma	
	High overall sour flavor	
	High moisture release	
	Low hardness and firmness	
Tab Tim Siam	High floral and overall sweet aroma and flavor	[79]
	High viny flavor	
	High orange peel flavor and aftertaste	
	High chewiness and fibrous	
	High bitter taste and bitter aftertaste	
	High astringent and particles	
	Low pomelo aroma and flavor	
	Low overall sour flavor	
	Low sour taste	
KaoYai	High limonene	[80]
	High acetaldehyde	
	No hexanal	
	No alcohols	
	High viny and over all sour flavor	[79]
	High hardness and firmness	
	Low sweet taste and sweet aftertaste	
Kao Numphueng	High sweet taste	[79]
	Low orange peel flavor and aftertaste	
	Low bitter taste	
	Low astringent and particles	
Kao Tangkwa	High over all sour flavor	[79]
	Low viny flavor	
	Low chewiness	
	Low bitter taste	

Note: OAV, odor activity value.

(Table 5). From all taste attributes they found that sourness, astringency, bitterness and richness had a variable importance value of > 1 and were the important attributes discriminating the three cultivars. Cultivar Dongshizou, with the highest score in the fuzzy comprehensive sensory evaluation, had the most satisfying taste followed by cvs Sanhong and Huangjin. However, cv. Huangjin had the strongest aroma (Table 5). They also found that the most important attributes contributing to consumer preference were sweetness, sourness, fruitiness, juiciness and overall flavor. Rosales and Suwonsichon[79] studied sensory characteristics in the commercial Thai cultivars Kao Namphueng, Kao Tangkwa, Kao Yai, Tab Tim Siam, and Thong Dee. Relying on sensory descriptive analysis, a lexicon consisting of 30 sensory attributes of pomelo was developed describing aroma, flavor and texture. They showed that the red-fleshed cultivars (Tab Tim Siam and Thong Dee) were more flavorful with higher intensities for floral, overall sweet and citrus aroma and flavor, viny aroma and moisture release than the yellow-fleshed cultivars (Kao Namphueng, Kao Tangkwa, and Kao Yai) (Table 5). This also correlated well with the aldehyde content, the key volatile characterizing citrus flavor, found in pink-fleshed pomelo juice at twice the amount of yellow-fleshed pomelo juice[81]. However, in terms of texture, the yellow-fleshed pomelos, especially cv. Kao Yai, were harder and firmer than both cvs Tab Tim Siam and Thong Dee. This is possibly related to the characteristics of their juice sacs. Moreover, cv. Tab Tim Siam had the most bitter taste and orange-peel flavor and aftertaste, which contrasted with cv. Kao Namphueng. Chaiwong et al.[58] found that the concentration of naringin, a bitter taste phenolic compound, was more distinctive in cv. Tab Tim Siam than in these four cultivars. In addition, cv. Tab Tim Siam had high chewiness and fibrousness whereas it was low in pomelo aroma and flavor and overall sour flavor. Glossiness, orange-peel aroma, overall sour aroma and pomelo aroma and flavor were described for cv. Thong Dee. Cultivar Kao Tangkwa had low chewiness and a viny flavor (Table 5). Changes in sensory characteristics were also examined in their study. During storage these precut pomelo cultivars were placed on polystyrene foam trays, wrapped in polyethylene film and kept at 5°C and 85% RH for a week. Most sensory changes during storage occurred in yellow-fleshed pomelos. They declined in some characteristics of aroma, flavor and taste while red-fleshed cultivars which are more flavorful maintained their quality during storage. They therefore have more potential for export than the yellow-fleshed cultivars.

Studies on Chinese and Thai pomelos[78,79] indicate that the most important sensory characteristics related to consumer preference are sweetness, sourness, juiciness, fruitiness, floral flavor and overall flavor. Astringency and bitterness are main attributes by which cultivars are distinguished. The differences between Chinese and Thai pomelos were determined by comparing Chinese Red Honey and Tab Tim Siam. In terms of taste, cv. Red Honey has a mild sweet taste at first then a bitter aftertaste while cv. Tab Tim Siam has an overwhelming sweetness followed by a trace of sourness. The pulp of cv. Red Honey is dry, rough and scattered but that of cv. Tab Tim Siam is succulent, fine, soft and clinging together. However, the pulp color of cv. Tab Tim Siam is not evenly red as in cv. Red Honey. It is red at the outside but yellow in the center of each segment[82].

Most consumers in Thai markets like cvs Kao Namphueng and Thong Dee which are grown in all regions of Thailand and have high productivity. Cultivar Thong Dee has excellent eating quality. It has a balanced sweet and sour taste with soft and juicy pulp meeting consumer preferences for juicy and fresh fruit. Cultivar Kao Namphueng has a sweet slightly sour taste and crisp and dry pulp meeting consumer preferences for crisp and non-watery fruit. In addition, cv. Tab Tim Siam is currently the most popular cultivar with its ruby-red, sweet, soft and juicy flesh. However, suitable planting areas for this cultivar are quite limited in the southern region resulting in a fairly low production volume. Nevertheless, with an attractive price (2–3 times higher than other cultivars) many farmers from all regions try to produce this cultivar leading to higher production and more opportunities for domestic and international market penetration in the future. Thai pomelos are consumed domestically and also exported to many countries. The export volume in 2016–2018 increased by 38% (from 19 to 26 kt) with an average market share of 21% of the total production[9,83]. China is the largest market in terms of export value with an average share at 54% followed by Vietnam at 25% and Hong Kong at 15% and the exports to China showed an increasing trend by 79% (from 5.6 to 10.0 million USD in 2016–2018)[83]. Chinese consumers prefer red-fleshed pomelo because they perceive red as a sign of luck and prosperity. Red-fleshed pomelo is favored for consumption during the Chinese Mid-autumn Festival, usually held around August or September and before the pomelo season in China (October to November). Fortuitously, this matches the pomelo season in Thailand. China has therefore imported large quantities of pomelos from Thailand. In the past, Kao Puang was the main cultivar exported to China but currently Tab Tim Siam, Tha Khoi and Thong Dee are the major cultivars marketed as “Thai red-fleshed pomelo”. In terms of flavor, Chinese admire Thai pomelo as one of the most four famous pomelos in the world (Duwei Wendan and Pingshan pomelo from Fujian, Shatian pomelo from Guangxi, and Thai pomelo). Chinese consumers love Thai pomelo for its glossy, large, juicy and sweet juice sacs. They enjoy pomelo as fresh fruit, ‘pomelo spicy salad’ or ‘*Yum Som-O* (Thai)’ which is also a very popular dish from Thailand[84]. Some other markets such as Canada, Laos, Myanmar, Singapore and United Arab Emirates are served but are of less importance with slow growth[83]. Export of Thai pomelos to EU markets increased from very low values during 2016–2018 to about 1.7% of the total export value in 2019[83,85]. However, exports to EU countries are uncertain due to limitations in marketing and phytosanitary standards concerning citrus canker (*Xanthomonas campestris* (all strains pathogenic to citrus))[30,31]. In addition to phytosanitary considerations, food safety and consistency of fruit quality also limit the export of Thai pomelos. Citrus canker and greening diseases, citrus leaf miner, fruit fly and thrips are the major reasons for excessive agrochemical applications and sometimes the residues exceed the regulatory limits. Inconsistency of fruit quality, especially flavor, is also affected by different growing locations, harvesting times and climate change[86]. In the EU and US, consumers prefer juicy, sweet and sour pomelos that are like grapefruit as these are more familiar to them, and they almost exclusively require red-fleshed cultivars high in carotenoids[87]. Thong Dee is therefore the cultivar most favored by Thai and international consumers[31].

5 CONCLUSIONS

China is the world largest source of pomelo fruit in terms of production volume and genetic diversity. Thailand ranks number two for pomelo production in Asia and Thai pomelo is particularly famous for its high quality. Even though Chinese and Thai pomelo may have common origins, they have diverged in many ways. Pomelo in China is grown in a subtropical climate. The average temperature and rainfall are lower than in Thailand which is in the tropics. The pomelo cultivars in China therefore flower and are harvested once per year while pomelo cultivars in Thailand can flower all year round but usually flower twice with two main harvests each year. However, Thai cultivars take a two weeks to two months longer to reach full maturity than Chinese cultivars. Most Chinese pomelos have a pyriform shape, with orange-yellow or light greenish-yellow, smooth, clear rind and crisp, juicy, non-watery, sometimes coarse and granulated, pulp. In contrast, Thai pomelos are mostly globose in shape with yellow-green or light green rind and are tender, juicy and with quite watery pulp. Another important aspect are bioactive compounds and antioxidant capacity. Generally, red-fleshed pomelos contain higher lycopene and β-carotene contents than white-fleshed fruit, and naringin is the predominant flavonoid. As far as sensory attributes and consumer aspects are concerned, most consumers prefer red-fleshed pomelo with their attractive color and high antioxidant capacity. In addition to appearance, internal qualities such as fruitiness, sweetness, sourness, juiciness and overall flavor are important in consumer preference for particular cultivars. Thai cultivars Tab Tim Siam and Thong Dee are red-fleshed and the best for aroma, flavor, and juiciness, and are favored by both domestic and international consumers. Cultivar Guanxi is the most popular Chinese pomelo both domestically and abroad. It is white-fleshed and possesses a more complicated aroma than cv. Shatian

Overall, knowing more Chinese and Thai pomelos would be useful for pomologists, plant breeders, food scientists, and pomelo industries. They can use this information to determine future research priorities, to identify the strengths and weaknesses of the pomelo production processes to make targeted improvements, to quantify characteristics of important pomelo cultivars to assist breeding, to create new products from pomelo or develop functional foods, and finally to promote the development of the pomelo industry worldwide.

Acknowledgements

This work was supported by the National Key Research and Development Program of China (2018YFD1000100), the National Natural Science Foundation of China (31925034, 31860536, and 31872052), and the fundamental research funds for the central universities. We thank Dr. Taveesak Sangudom, the Director of the Academic Section, the Horticultural Research Institute, Department of Agriculture, Thailand for his suggestions and information regarding Thai pomelo cultivars and cultivation.

Compliance with ethics guidelines

Warangkana Makkumrai, Yue Huang, and Qiang Xu declare that they have no conflict of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

REFERENCES

1. United States Department of Agriculture (USDA). Citrus: world markets and trade. *USDA,* 2020
2. Martin F W, Cooper W C. Cultivation of neglected tropical fruits with promise. Part 3: the pummelo. *Agricultural Research Service, US Department of Agriculture,* 1977
3. Trade Map (TM), List of exporters for the selected product: 080540 Fresh or dried grapefruit. 2020. Available at TM website on November 11, 2020
4. United States Department of Agriculture (USDA). Citrus: world markets and trade. *USDA,* 2017
5. Morton J F. Pummelo. In: Morton J F, ed. Fruits of warm climates. Maimi, Florida: *Creative Resource Systems, Inc.*, 1987, 147–151 ISBN: 0-9610184-1-0
6. Global Agricultural Information Network (GAIN). Citrus annual: China's citrus production expected to Fall. USA: *GAIN*, 2016
7. Global Agricultural Information Network (GAIN). citrus annual: citrus area in China continues to expand. USA: *GAIN*, 2018
8. Climate-data (CD). Climate Thailand: Weather by month for Thailand. Available at CD website on April 23, 2020
9. Information Technology & Communication center-Department of Agricultural Extension (ITC-DOAE). Pummelo: cultivation in 2018. *ITC-DOAE*, 2019. Available at ITC-DOAE website on May 10, 2020 (in Thai)
10. Li L J, Hong P, Chen F, Sun H, Yang Y F, Yu X, Huang G L, Wu L M, Ni H. Characterization of the aldehydes and their transformations induced by uv irradiation and air exposure of white guanxi honey pummelo (*Citrus grandis* (L.) Osbeck) essential oil. *Journal of Agricultural and Food Chemistry,* 2016, **64**(24): 5000–5010
11. Wang Y, Fu X K, He W, Chen Q, Ma J Y, Wang X R. Effect of bagging on fruit quality of three pummelo (*Citrus grandis* Osbeck) cultivars. In: IOP Conference Series. *Earth and Environmental Science*, 2019, **330**(3): 032051
12. China Intellectual Property Information Network (CIPIN). Guanxi pomelo. *China Intellectual Property News*, 2018. Available at CIPIN website on May 10, 2020
13. Taste atlas (TA). Guanxi Mi You. Available at TA website on May 18, 2020
14. Wang Y, He W, Fu X, Chen Q, Wang X. Effect of on-tree storage on fruit quality of three pummelo (*Citrus grandis* Osbeck) cultivars. In: IOP Conference Series. *Earth and Environmental Science,* 2019, **330**(3): 032052
15. Huang X Z, Lu X M, Lu X K, Chen X M, Lin H Q, Lin J S, Cai S H. Hongroumiyou, a new red fleshed pomelo cultivar. *Journal of Fruit Science,* 2007, **24**(1): 123–124 (in Chinese)
16. Lu X K, Lin Q H, Lin Y J, Zhang J T, Zhang S M, Li C S. 'Huangjinmiyou', a new orange-yellow fleshed pomelo cultivar. *Journal of Fruit Science*, 2013, **30**(5): 900–902 (in Chinese)
17. Zhang M, Li L, Wu Z, Wang Y, Zang Y, Liu G. Volatile composition in two pummelo cultivars (*Citrus grandis* L. Osbeck) from different cultivation regions in China. *Molecules,* 2017, **22**(5): 716
18. Li Z J. Effect of bagging on the fruit quality of Shatianyou pummelo cultivar. *South China Fruits,* 1999, **28**(2): 21 (in Chinese)
19. China daily (CD). Shatian pummelo. City of Hechi, Guanxi, 2014. Available at CD website on June 22, 2020
20. Chen J W, Pan Z X, Huang S X, Wang Z W, Li X, Zhang D Z, Wu W H, Liu S J, He H X. Method for controlling fruit cracking of *Citrus grandis* (L .) Osbeck. CV. Duweiwendan through interstocks. Google Patents, 2016. Available at Google Patents on June 14, 2020

21. Baidu Encyclopedia (BE). Duwei Wendan pomelo. Available at BE website on May 27, 2020 (in Chinese)
22. Baidu Encyclopedia (BE). Anjiang pummelo. Available at BE website on October 10, 2020 (in Chinese)
23. Zhou X Y, Zhou D G, Zhu C H, Li J X, Wang Z R, Peng Z L, Yue J Q, Gao J Y. Fruit quality of crystal honey pomelo with different tree ages. *Journal of Southern Agriculture,* 2018, **49**(5): 938–943 (in Chinese)
24. Cao L X. The investigation of pummelo germplasms and the origin analysis of Majiayou in Guangfeng, Jiangxi Province. Dissertation for the Master's Degree. Wuhan: *Huazhong Agricultural University*, 2012 (in Chinese)
25. Yu J T. Study on the development of famous and special agricultural products in Jiangxi province—above example of Raomajia grapefruit. Dissertation for the Master's Degree. Nanchang: *Nanchang University*, 2018 (in Chinese)
26. Nie Z P, Huang Q, Chen C Y, Wan C P, Chen J Y. Chitosan coating alleviates postharvest juice sac granulation by mitigating ROS accumulation in harvested pummelo (*Citrus grandis* L. Osbeck) during room temperature storage. *Postharvest Biology and Technology,* 2020, **169**: 111309
27. Nie Z, Wan C, Chen C, Chen J. Comprehensive evaluation of the postharvest antioxidant capacity of Majiayou pomelo harvested at different maturities based on PCA. *Antioxidants,* 2019, **8**(5): 136
28. Buaban P, Beckles D M, Mongkolporn O, Luengwilai K. Lycopene accumulation in pummelo (*Citrus maxima* [Burm.] Merr.) is influenced by growing temperature. *International Journal of Fruit Science,* 2019, **20**(2): 149–163
29. Charoensiri R, Kongkachuichai R, Suknicom S, Sungpuag P. Beta-carotene, lycopene, and alpha-tocopherol contents of selected Thai fruits. *Food Chemistry,* 2009, **113**(1): 202–207
30. Fresh Partners Thailand (FPT). Fresh Partners—Department of Agriculture Thailand Pomelo pilot project. Available at FPT website on January 28, 2021
31. Sutthachaidee W, Kuosuwan B, Kiranantawat B. Pomelo export logistics process: modern factors of efficiency (the case of wiang kaen district, chiang rai province, Thailand). *E3S Web of Conferences,* 2020, **164**: 03006
32. Chomchalow N, Somsri S, Songkhla P N. Marketing and export of major tropical fruits from Thailand. *AU Journal of Technology,* 2008, **11**(3): 133–143
33. Duangthong T. Pummelo cultivation. Bangkok: *Extension and Training Office*, *Kasetsart University*, 1999 (in Thai)
34. Kore V T, Tawade S S, Chakraborty I. Variation in pummelo cultivars: a review. *Imperial Journal of Interdisciplinary Research,* 2017, **3**(1): 1804–1812
35. Kasetloongkim. Varieties and characteristics of pummelo. Available at Kasetloongkim website on April 21, 2020 (in Thai)
36. Pichaiyongvongdee S, Haruenkit R. Investigation of limonoids, flavanones, total polyphenol content and antioxidant activity in seven thai pummelo cultivars. *Witthayasan Kasetsat Witthayasat,* 2009, **43**(3): 458–466
37. Paradonnuwat U.Pummelo planting technology for export. Bangkok: *Department of Plant Pathology, Faculty of Agriculture, Kasetsart University*, 2010 (in Thai)
38. Leelawatana K. Comparative studies of physical and chemical characteristics of seven pummelo culitvars (Citrus maxima Merr.). Dissertation for the Master's Degree. Bangkok: *Kasetsart University*, 1991 (in Thai)
39. Department of Intelectual Property (DIP). Announcement for geographical indication registration: Tha Khoi pummelo. Bangkok: *DIP*, 2018 (in Thai)
40. Kongsri S, Nartvaranant P. Fruit morphological characteristics and fruit quality of pomelo cv. Tabtim Siam grown in Nakhon Pathom and Nakhon Si Thammarat Provinces. *Journal of Thai Interdisciplinary Research Review,* 2019, **14**(1): 5–11
41. Kaewsuksaeng S, Sangwanangkul P. Nutritional values and bioactive compound contents in Citrus family locally cultivated in southern Thailand. Bangkok: *The Thailand Research Fund*, 2012 (in Thai)
42. Liu W N, Ye Q, Jin X Q, Han F Q, Huang X Z, Cai S H, Yang L. A spontaneous bud mutant that causes lycopene and β-carotene accumulation in the juice sacs of the parental Guanxi pummelo fruits (*Citrus grandis* (L.) Osbeck). *Scientia Horticulturae,* 2016, **198**: 379–384
43. Jiang C C, Zhang Y F, Lin Y J, Chen Y, Lu X K. Illumina® sequencing reveals candidate genes of carotenoid metabolism in three pummelo cultivars (*Citrus maxima*) with different pulp color. *International Journal of Molecular Sciences,* 2019, **20**(9): 2246
44. Yan F, Shi M, He Z, Wu L, Xu X, He M, Chen J, Deng X, Cheng Y, Xu J. Largely different carotenogenesis in two pummelo fruits with different flesh colors. *PLoS One,* 2018, **13**(7): e0200320
45. Lu X K, Lin Q H, Lu X M, Zhang S M, Li C S, Ye X F. Comparision on carotenoid compositions and contents in different sweet pomelos. *Fujian Journal of Agricultural Sciences,* 2012, **27**(7): 723–727
46. Xu J, Tao N G, Liu Q, Deng X X. Presence of diverse ratios of lycopene/β-carotene in five pink or red-fleshed citrus cultivars. *Scientia Horticulturae,* 2006, **108**(2): 181–184
47. Xu C J, Fraser P D, Wang W J, Bramley P M. Differences in the carotenoid content of ordinary citrus and lycopene-accumulating mutants. *Journal of Agricultural and Food Chemistry,* 2006, **54**(15): 5474–5481
48. Tatmala N, Ma G, Zhang L, Kato M, Kaewsuksaeng S. Characterization of carotenoid accumulation and carotenogenic gene expression during fruit ripening in red colored pulp of 'Siam Red Ruby'pumelo (*Citrus grandis*) cultivated in Thailand. *Horticulture Journal,* 2020, **89**(3): 237–243
49. Promkaew P, Srilaong V, Wongs-Aree C, Pongprasert N, Kaewsuksaeng S, Kondo S. Lycopene synthesis and related gene expression in pummelo pulp increased in shade-grown fruit. *Journal of the American Society for Horticultural Science,* 2020, **145**(1): 60–66
50. Ianthaisong N, Nampila R, Techawongstien S. Lycopene and β-carotene content during growth of'Manee-Esan'pummelo

(*Citrus grandis* (L.) Osbeck) fruit. *Acta Horticulturae,* 2018, (1208): 443–446

51. Xu G H, Liu D H, Chen J C, Ye X Q, Ma Y Q, Shi J. Juice components and antioxidant capacity of citrus varieties cultivated in China. *Food Chemistry,* 2008, **106**(2): 545–551
52. Xi W, Fang B, Zhao Q, Jiao B, Zhou Z. Flavonoid composition and antioxidant activities of Chinese local pummelo (*Citrus grandis* Osbeck.) varieties. *Food Chemistry,* 2014, **161**: 230–238
53. Chen Q, Wang D, Tan C, Hu Y, Sundararajan B, Zhou Z. Profiling of flavonoid and antioxidant activity of fruit tissues from 27 Chinese local citrus cultivars. *Plants,* 2020, **9**(2): 196
54. Zhang M, Nan H, Wang Y, Jiang X, Li Z. Comparison of flavonoid compounds in the flavedo and juice of two pummelo cultivars (*Citrus grandis* L. Osbeck) from different cultivation regions in China. *Molecules,* 2014, **19**(11): 17314–17328
55. Zhang M X, Duan C Q, Zang Y Y, Huang Z W, Liu G J. The flavonoid composition of flavedo and juice from the pummelo cultivar (*Citrus grandis* (L.) Osbeck) and the grapefruit cultivar (*Citrus paradisi*) from China. *Food Chemistry,* 2011, **129**(4): 1530–1536
56. Zhu C, Zhou X, Long C, Du Y, Li J, Yue J, Pan S. Variations of flavonoid composition and antioxidant properties among different cultivars, fruit tissues and developmental stages of citrus fruits. *Chemistry & Biodiversity,* 2020, **17**(6): e1900690
57. Mäkynen K, Jitsaardkul S, Tachasamran P, Sakai N, Puranachoti S, Nirojsinlapachai N, Chattapat V, Caengprasath N, Ngamukote S, Adisakwattana S. Cultivar variations in antioxidant and antihyperlipidemic properties of pomelo pulp (*Citrus grandis* [L.] Osbeck) in Thailand. *Food Chemistry,* 2013, **139**(1–4): 735–743
58. Chaiwong S, Thepphakọn T, Suanphairot S, Chusi R, Khunchan U. Evaluation of the active compounds in flavonoids and anthocyanins of Thongdee, Kao Numphueng, Kao Tangkwa, Kao Yai, and Tab Tim Siam pummelo cultivars grown in Thailand. Bangkok: *The Thailand Research Fund*, 2010 (in Thai)
59. Wattanasiritham L S, Taweesuk K, Ratanachinakorn B. Limonin and naringin in pummelos (*Citrus grandis* (L.) Osbeck). In Proc. 31st Congress on Science and Technology. Nakhon Ratchasima: *Suranaree University of Technology*, 2005 (in Thai)
60. Tonapram W. Study of bioactive compounds and antioxidant activities of fruit, fresh-cut and juice Thakhoi pomelo. Dissertation for the Master's Degree. Phitsanulok: *Naresuan University*, 2017 (in Thai)
61. Chaiwong S, Theppakorn T. Bioactive compounds and antioxidant capacity of pink pummelo (*Citrus grandis* (L.) Osbeck) cv "Thong dee" in Thailand. *Journal of the International Society for Southeast Asian Agricultural Sciences,* 2010, **16**(2): 10–16
62. Rouseff R L, Martin S F, Youtsey C O. Quantitative survey of narirutin, naringin, hesperidin, and neohesperidin in citrus. *Journal of Agricultural and Food Chemistry,* 1987, **35**(6): 1027–1030
63. Sudto K, Pornpakakul S, Wanichwecharungruang S. An efficient method for the large scale isolation of naringin from pomelo (*Citrus grandis*) peel. *International Journal of Food Science & Technology,* 2009, **44**(9): 1737–1742
64. Kumaran A, Joel Karunakaran R. In vitro antioxidant activities of methanol extracts of five *Phyllanthus* species from India. *Lebensmittel-Wissenschaft+Technologie,* 2007, **40**(2): 344–352
65. Contreras-Calderón J, Calderón-Jaimes L, Guerra-Hernández E, García-Villanova B. Antioxidant capacity, phenolic content and vitamin C in pulp, peel and seed from 24 exotic fruits from Colombia. *Food Research International,* 2011, **44**(7): 2047–2053
66. Jia Z S, Tang M C, Wu J M. The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. *Food Chemistry,* 1999, **64**(4): 555–559
67. Balasundram N, Sundram K, Samman S. Phenolic compounds in plants and agri-industrial by-products: antioxidant activity, occurrence, and potential uses. *Food Chemistry,* 2006, **99**(1): 191–203
68. Kim D O, Jeong S W, Lee C Y. Antioxidant capacity of phenolic phytochemicals from various cultivars of plums. *Food Chemistry,* 2003, **81**(3): 321–326
69. Arena E, Fallico B, Maccarone E. Evaluation of antioxidant capacity of blood orange juices as influenced by constituents, concentration process and storage. *Food Chemistry,* 2001, **74**(4): 423–427
70. Rapisarda P, Tomaino A, Lo Cascio R, Bonina F, De Pasquale A, Saija A. Antioxidant effectiveness as influenced by phenolic content of fresh orange juices. *Journal of Agricultural and Food Chemistry,* 1999, **47**(11): 4718–4723
71. Edge R, McGarvey D J, Truscott T G. The carotenoids as antioxidants–a review. *Journal of Photochemistry and Photobiology,* 1997, **41**(3): 189–200
72. Dhuique-Mayer C, Caris-Veyrat C, Ollitrault P, Curk F, Amiot M J. Varietal and interspecific influence on micronutrient contents in citrus from the Mediterranean area. *Journal of Agricultural and Food Chemistry,* 2005, **53**(6): 2140–2145
73. Yoo K M, Lee K W, Park J B, Lee H J, Hwang I K. Variation in major antioxidants and total antioxidant activity of Yuzu (*Citrus junos* Sieb ex Tanaka) during maturation and between cultivars. *Journal of Agricultural and Food Chemistry,* 2004, **52**(19): 5907–5913
74. Wong S S. Eu consumers preferences of fresh citrus fruit from different countries: Perception, attitude and willingness to pay. Dissertation for the Master's Degree. Florida: *University of Florida*, 2012
75. Institute of Food Technologists. Sensory evaluation guide for testing food and beverage products. *Food Technology,* 1981, **35**(11): 50–59
76. Makkumrai W, Anthon G E, Sivertsen H, Ebeler S E, Negre-Zakharov F, Barrett D M, Mitcham E J. Effect of ethylene and temperature conditioning on sensory attributes and chemical composition of 'Bartlett' pears. *Postharvest Biology and Technology,* 2014, **97**: 44–61
77. McIntosh C A, Mansell R L. Three-dimensional distribution of limonin, limonoate A-ring monolactone, and naringin in the fruit tissues of three varieties of *Citrus paradisi. Journal of*

Agricultural and Food Chemistry, 1997, **45**(8): 2876–2883

78. Zhu C H, Lu Q, Zhou X Y, Li J X, Yue J Q, Wang Z R, Pan S Y. Metabolic variations of organic acids, amino acids, fatty acids and aroma compounds in the pulp of different pummelo varieties. *Lebensmittel-Wissenschaft+Technologie*, 2020, **130**: 109445
79. Rosales C K, Suwonsichon S. Sensory lexicon of pomelo fruit over various cultivars and fresh-cut storage. *Journal of Sensory Studies*, 2015, **30**(1): 21–32
80. Vivian Goh R M, Lau H, Liu S Q, Lassabliere B, Guervilly R, Sun J, Bian Y, Yu B. Comparative analysis of pomelo volatiles using headspace-solid phase micro-extraction and solvent assisted flavour evaporation. *Lebensmittel-Wissenschaft+Technologie*, 2019, **99**: 328–345
81. Cheong M W, Liu S Q, Zhou W, Curran P, Yu B. Chemical composition and sensory profile of pomelo (*Citrus grandis* (L.) Osbeck) juice. *Food Chemistry*, 2012, **135**(4): 2505–2513
82. Thongthai N. Tubtim Siam pomelo, precious and rare, waiting for you to taste. Produce Report: Fresh Fruit, 2018. Available at Producer Report website on January 28, 2021
83. Office of Agricultural Economics (OAE). Export volume and value of 080540000001 pomelo. Thailand: *OAE*, 2020 (in Thai)
84. Lungporn. Thai pummelo is world-famous ... Chinese people are very like both eating fresh and the new menu "Pummelo spicy salad", 2016. Available at Kasetkaoklai websie on June 17, 2020 (in Thai)
85. Tridge. Pomelo season in China. Available at Tridge website on June 24, 2020
86. Chanpanya N. Pomelo. Thailand: *Department of Agriculture Extension (DOAE)*, 2020 (in Thai)
87. Abouzari A, Mahdi Nezhad N. The investigation of citrus fruit quality. Popular characteristic and breeding. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 2016, **64**(3): 725–740