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REVIEW

COMPARISON OF POMELO (*CITRUS MAXIMA*) GROWN IN CHINA AND THAILAND

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KEYWORDS

climate, commercial cultivars, fruit characteristics, lycopene, naringin, sensory evaluation

HIGHLIGHTS

- China is the largest producer of pomelo globally.
- Chinese pomelos are adapted to subtropical climates and Thai pomelos to tropical climates.
- Guanxi pomelo is a popular cultivar in China and Thong Dee is the most popular in Thailand.
- Naringin is the most abundant flavonoid in Chinese and Thai pomelos.
- Fruity, sweet, sour, juicy and overall flavor attributes are important in consumer preference.

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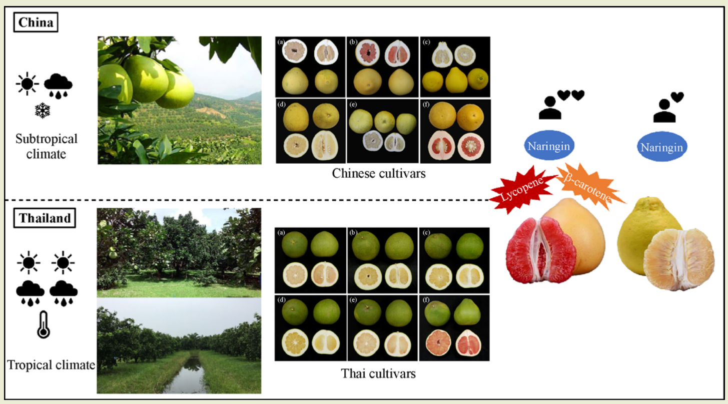
GRAPHICAL ABSTRACT



ABSTRACT

Pomelo is a member of the genus *Citrus* that is a key contributor to the breeding of modern citrus cultivars. China is the largest producer of pomelo and one of the top five pomelo exporting countries. Pomelos from Thailand are also well-known for their excellent quality and flavor and are ranked in the top ten export countries. This review introduces pomelo planting locations and conditions in China and Thailand. The characteristics and qualities of some commercial pomelo cultivars in China and Thailand are summarized to introduce them to international consumers and to document their similarities and dissimilarities. Data on bioactive compounds and antioxidant capacity are also included for most Chinese and Thai pomelos to highlight how they differ in this aspect because consumers are increasingly interested in healthier foods. In addition, the sensory perception in terms of aroma, flavor, texture and taste attributes, consumer perspective and preferences are discussed.

1 INTRODUCTION

Citrus fruits are the leading fruit crops worldwide. The three major citrus crops in terms of production and consumption are orange (*Citrus sinensis*), mandarin (*Citrus reticulata*), and grapefruit/pomelo (*Citrus paradisi*/*Citrus maxima*). According to the world citrus production report in 2019/2020, orange had the highest production rate at 48 Mt followed by mandarin at 32 Mt and grapefruit/pomelo at 7 Mt[1]. Pomelo and grapefruit are aggregated together because of their similar appearance. However, more than 50% of the production of this group is pomelo produced in China. China, the possible center of origin of pomelo[2], is the largest producer of pomelo globally[1]. In 2018/2019, China produced 4.9 Mt of pomelo representing 70% of global production with 0.2 Mt (4% of the total production) exported at a value of 193 million USD[3,4]. Large areas of Asia have a suitable climate for growing pomelo. Even though there have been many attempts to introduce desirable pomelo cultivars from Asia to Europe and the USA, there have been few successes in producing good quality fruits outside Asia[2,5]. In Asia, cultivars of pomelo are classified into three groups comprising Chinese cultivars which are suitable for subtropical climates, Thai cultivars which are the best tropical cultivars, and Indonesian cultivars which are very variable and sometimes inferior[2]. The reason why Indonesian pomelo is variable and of low quality may be because it is mostly grown from seeds as home garden plants just for use in festivals such as New Year.

In China, the area suitable for pomelo is in the south, a subtropical zone. The major pomelo growing area had average temperatures ranging from 16.8 to 21.1°C and average rainfall of 970 to 1610 mm in 2014. According to the Global Agricultural Information Network Report[6,7], the largest pomelo producing regions are Fujian, Guangdong, Guangxi, Sichuan, Hunan, Jiangxi, Zhejiang, and Yunnan (Table 1).

Pomelo is one of the top ten economic fruit crops in Thailand. Production in 2018 was 147 kt (only 3% of Chinese production) with 26 kt exported at a value of 17 million USD[6–8]. Most of Thailand has a tropical wet and dry or savanna climate type. The average annual temperature and rainfall in Samut Songkhram Province are representative of tropical savanna at 27.6°C and 1161 mm. Nakhon Si Thammarat Province, representative of the tropical monsoon climate, has average annual temperature and rainfall of 27.2°C and 2292 mm[8] (Table 1). Pomelo can grow in all regions of Thailand. Sixty of 76 Thai provinces have pomelo production. The major producing provinces are Pichit, Kanchanaburi, Samut Songkhram, Chiang Rai, Nakhon Pathom, Nakhon Nayok, Nakhon Si Thammarat, Prachinburi, Chaiyaphum and Chainat[9] (Table 1). China is a major importer of Thai pomelos.

Table 1 Comparison of factors related to pomelo cultivation in China and Thailand

Factor	China	Thailand
Climatic zone	Subtropics	Tropics
Annual rainfall	970–1610 mm[a]	1161–2292 mm[b]
Annual Temperature	17–21°C[c]	27–28°C[d]
Flowering time	February–March	1st time: January–March 2nd time: August–October
Harvesting time	October–January	1st time: August–September 2nd time: March–April
Harvesting fruit age	6.0–6.5 month	6.5–8.0 month
Most production provinces (% production rate)		
⩾ 20	Fujian, Guangdong	Pichit
10–20	Guangxi	Kanchanaburi, Samut-Songkhram
5–10	Sichuan, Hunan	Chiang Rai, Nakhon Pathom, Nakhon Nayok, Nakhon Si-Thammarat
1–5	Jiangxi, Zhejiang, Yunnan, Hubei	Prachinburi, Chaiyaphum, Chainat

Note: [a]Range of average rainfall and [c]temperature in 2014 in Dapu County of Guangdong; Pingle County of Guangxi; Pinghe County of Fujian; and Nanbu County of Sichuan, the major cultivation areas of pomelo in China. [b]Range of average rainfall and [d]temperature in 2019 for Samut Songkhram and Nakhon Si Thammarat, representative provinces of the central (tropical savanna) and southern (tropical monsoon) regions of Thailand.

It is therefore important to know how Thai and Chinese pomelos differ, why they have diversified even though they likely share the same origin, and how Thai and Chinese pomelos are perceived by consumers. This review compares three aspects of Thai and Chinese pomelos: (1) commercial cultivars with fruit characteristics and quality; (2) bioactive compounds and antioxidant capacity; and (3) sensory attributes and consumer preference.

2 COMMERCIAL CULTIVARS WITH FRUIT CHARACTERISTICS AND QUALITIES

Both countries have many pomelo cultivars. Some are only locally grown or recognized at specific locations (landrace cultivars) and others are grown widely and favored by most people (commercial cultivars).

Most commercial pomelo cultivars in China are grown in Fujian, Guangdong, Guangxi, Hunan, Sichuan, and Yunnan. Some cultivars have been grown for centuries but due to their desirable flavor they are still highly favored commercial cultivars, e.g., Anjiang, Guanxi, Shatian and Wendan. Moreover, there are some new cultivars that are mutants of these old cultivars that possess desirable characteristics, and have become popular and commercially grown, e.g., Hongrou, Huangjin and Sanhong, and these are bud mutants of cv. Guanxi. The fruit characteristics and qualities of Chinese commercial cultivars are as follows.

2.1 Guanxi

Guanxi is the most popular commercial cultivar in China. It is extensively grown in Pinghe County, Zhangzhou City, Fujian Province, the largest producer of this cultivar with production of 1.2 Mt representing 40% of Chinese total production[10] together with some production in Sichuan Province[11]. Guanxi pomelo, an old cultivar that has been grown for more than 500 years, is consumed locally and also exported to Canada, the EU, and Russia[12]. Guanxi pomelo fruit is pyriform with golden-orange-colored, delicate, thin and smooth rind. The albedo and segment walls are white and the flesh is pale yellow. The pulp is tender, crisp and juicy. The taste is sweet to moderately sour with 9.17%–11.6% total soluble solids (TSS), 0.73%–1.01% titratable acidity (TA) and 48.9–52.0 mg·(100 mL)$^{-1}$ vitamin C (ascorbic acid). Its fruit is seedless[12,13] (Fig. 1(a)).

Guanxi has produced a series of mutant cultivars with different color of either fruit flesh or peel through selection of natural mutations in the field. Hongroumiyou, a red-fleshed pomelo, is a high-quality spontaneous bud mutant of cv. Guanxi. This cultivar matures in late September to early October which is 20–25 days earlier than its maternal cultivar (Fig. 1(b)). Huangjin-miyou, an orange-yellow fleshed pomelo, is also one of the bud mutants of cv. Guanxi. It has a unique orange-yellow flesh containing high β-carotene and its texture is fine, tender, crisp, and juicy. Sanhong is another bud mutant of cv. Guanxi. It is different from its sister mutants in that its albedo and segment walls are pink. The flesh is red, tender, crisp, and juicy. These three mutant cultivars consist of 10.6%–11.7% TSS, 0.54%–0.87% TA and 34.3–40.5 mg·(100 mL)$^{-1}$ ascorbic acid. They are seedless cultivars[11,14–16].

2.2 Shatian

Shatian is an elite pomelo cultivar and is also an old cultivar. It originated in Rong County of Guangxi. Shatian is grown mainly in Guangdong, Guangxi, and Hunan in China. Its fruit is pyriform, weighing 1.1–1.5 kg. The rind is orange-yellow, fairly rough, medium thick and sometimes difficult to peel. The albedo and segment walls are white. The pulp is pale yellow and fine, tender and juicy in texture. Its flavor is sweet with slightly acidic taste containing a high TSS of 10.2%–16.1%, TA of 0.24%–0.45% and ascorbic acid content of 123 mg·(100 mL)$^{-1}$. It is a seedy cultivar with about 100 seeds per fruit[17–19] (Fig. 1(c)).

2.3 Wendan

Wendan is an old cultivar in Zhejiang and Fujian Provinces. Its

Fig. 1 Chinese commercial pomelo cultivars: (a) Guanxi, (b) red-fleshed Guanxi, (c) Shatian, (d) Anjiang, (e) Shuijing, and (f) Majia.

fruit is medium size, pyriform or high oblate weighing 0.5–1.5 kg. The rind is pale yellow and easily peeled. The pulp is yellow, tender, fragrant, moderately sweet and sour with TSS $\geqslant$ 10.0%, TA $\leqslant$ 0.9% and TSS/TA $\geqslant$ 11.1. This cultivar has a unique flavor and high edible proportion of $\geqslant$ 55.0% and is seedless. An early fragrant cultivar from Zhejiang, pomelos from Zhangzhou, Fujian Province, Siji and Yuhuan have also been selected from cv. Wendan[20,21].

2.4 Anjiang

Anjiang, a fragrant pomelo, is an old pomelo from Hongjiang County in Huaihua City, Hunan Province. It is believed to have been grown for more than 2000 years. Anjiang pomelo has a large fruit of 1.0–1.5 kg, being pyriform with yellow-green rind. Its flesh is light yellow and crystal like with the famous qualities of crisp, tender, juicy, sweet, and mild sour taste. The pulp contains high sugar and nutrients with a TSS of up to 15.2% and ascorbic acid as high as 158 $mg \cdot (100\ g)^{-1}$[22] (Fig. 1(d)).

2.5 Shuijing

Shuijing or Ruili Crystal Honey is a famous pomelo produced in Ruili City, Yunnan Province. The favorable characteristics of this cultivar are early maturity, good quality and long storage life. It can be harvested in mid to late September matching the period of the Mid-autumn Festival and National Day, and is therefore very popular for giving as a present to relatives and friends. Ruili Honey pomelo is pyriform with yellow-green rind. Its flesh is white, juicy, sweet and sour, delicious, and has high nutrition value[23] (Fig. 1(e)).

2.6 Majia

Majia is a pomelo cultivar selected from a genetic variant of the local pomelo population of Majia Natural Village of Danan Town, Guangfeng District, Jiangxi Province[24]. It has been grown for hundreds of years and its production has developed rapidly. The planting area of Majia County in Shangrao City covered nearly 14,000 ha in 2016[25]. This cultivar has a large pyriform fruit with yellow rind. Its pulp is red, tender, juicy, and sweet or sour in taste with a TSS of 11.5%, TA of 0.45%[26] and ascorbic acid of about 45 $mg \cdot (100\ g)^{-1}$[27] (Fig. 1(f)).

Most commercial pomelo cultivars in Thailand can adapt to the environment. Their fruit flavor is quite stable leading to them being widely grown. However, the popularity of cultivars depends mainly on consumer preference. In the past, cvs Kao Hom, Kao Pan, and Kao Puang were popular. Sweeter cultivars such as cvs Kao Numphueng, Kao Tangkwa, and Kao Yai are now preferred. Therefore, cvs Kao Hom, Kao Pan, and Kao Puang are now less commonly grown and rarely found in markets. Red-fleshed cultivars contain larger amounts of the antioxidants lycopene and β-carotene than the white-fleshed cultivars[28,29] and the red color is more attractive, resulting in the increasingly popularity of red-fleshed pomelos. In Thailand, the current commercial cultivars are Kao Numphueng, Kao Tangkwa, Kao Yai, Tab Tim Siam, Tha Khoi, and Thong Dee.

2.7 Thong Dee

Thong Dee or Kao Thong Dee is the predominant commercial cultivar in Thailand sold in domestic, Asian, and the EU markets[30,31]. It can grow well in most regions occupying about 35% of the total planting area[32]. The most important production provinces are Nakhon Pathom, Prachinburi, Ratchaburi, and Samut Sakhon. The fruit of Thong Dee is oblate, medium size, 14–16 cm in diameter and 0.9–1.1 kg in weight. The rind is smooth green and the albedo and segment walls are pinkish. The flesh is pinkish at about 1 cm thick from outside and the rest is yellowish. The juice sacs cling tightly together but are separated easily from the segment wall, soft, very juicy and watery. This cultivar has a sweet and sour taste with 10.5%–11.9% TSS, 0.65%–0.73% TA and 57.6–74.7 $mg \cdot (100\ mL)^{-1}$ ascorbic acid. It is a seedy cultivar if grown with other cultivars in the same orchard[33–38] (Fig. 2(a)).

2.8 Kao Yai

Kao Yai is a famous cultivar produced in Samut Songkhram Province. Some other important provinces include Chiang Mai, Nakhon Pathom and Samut Sakhon. The fruit shape is globose with a neck that is not obvious. Its size is large at 14–19 cm in diameter and 1.2–2.3 kg in weight, reaching 3.0–4.0 kg in fertile soils. The rind is smooth light-yellow green with large oil glands. The albedo and segment walls are pinkish white while the pulp is yellowish to sometimes light-pinkish brown. Juice sacs are large, irregularly arranged, clinging tightly together, juicy but not watery. It is sweet and crisp with 10.5%–12.4% TSS, 0.47% TA and 50.3$\pm$1.25 $mg \cdot (100\ mL)^{-1}$ ascorbic acid and has a unique aroma. Seeds are quite large and numerous[34–38] (Fig. 2(b)).

2.9 Kao Numphueng

Kao Numphueng is a widely grown cultivar in Nakhon Pathom, Ratchaburi, and Samut Sakhon Provinces together with Thong Dee. Fruits are large with a globose shape and smooth green rind. The average fruit size is about 1.8 kg and 17–19 cm in diameter.

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

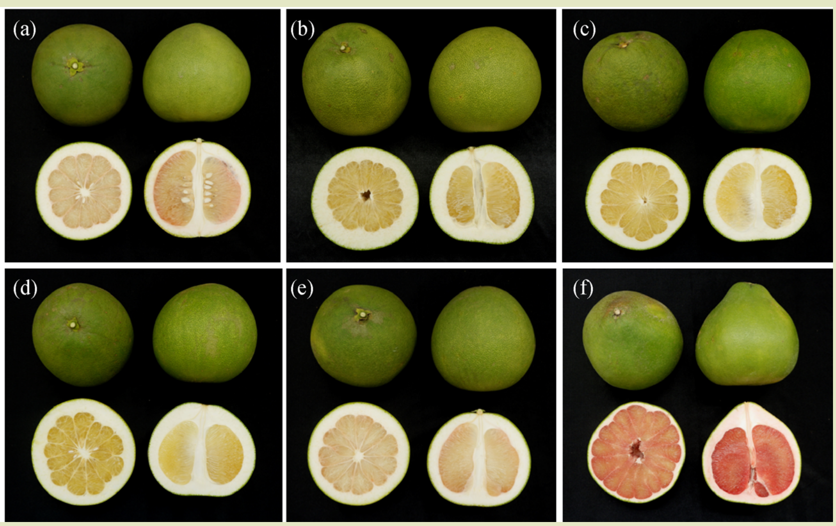


Fig. 2 Thai commercial pomelo cultivars: (a) Thong Dee, (b) Kao Yai, (c) Kao Numphueng, (d) Kao Tangkwa, (e) Tha Khoi, and (f) Tab Tim Siam.

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 μg·g^{-1} DW and β-carotene at 0.26–3.51 μg·g^{-1} DW[28,29]. However, the yellow-fleshed cv. Khao Namphueng has lower concentrations of lycopene (67±35 ng·g^{-1} DW) and β-carotene (89±24 ng·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 μg·g^{-1} DW followed by phytoene, β-cryptoxanthin and β-carotene at 6.0, 5.0 and 2.3 μg·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 μg·g^{-1} DW and β-carotene at 22.4 μg·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·L^{-1} juice followed by hesperidin (21–42 mg·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·L^{-1} juice) and Tha Khoi (381 mg·L^{-1} juice) > Kao Yai (365 mg·L^{-1} juice) > Kao Tangkwa (243 mg·L^{-1} juice), as stated in Wattanasiritham et al.[59], Kao Yai from Chiang Mai Province (524 μg·g^{-1} FW) > Tha Khoi (500 μg·g^{-1} FW) > Kao Namphueng (444 μg·g^{-1} FW) > Kao Yai from Nakhon Pathom Province (350 μg·g^{-1} FW) > Kao Tangkwa (201–241 μg·g^{-1} FW), as described in Chaiwong et al.[58], Tab Tim Siam (768 μg·g^{-1} FW) > Kao Namphueng, Kao Tangkwa, Kao Yai and Thong Dee (364–415 μg·g^{-1} FW), and in Mäkynen et al.[57], Tha Khoi (41.3 mg·g^{-1} DW) > Kao Tangkwa (40.7 mg·g^{-1} DW) > Tab Tim Siam (26.3 mg·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.

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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.

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