

Nutritional value, phytochemistry, health benefits, and potential food applications of *Pouteria campechiana* (Kunth) Baehni: A comprehensive review

Thi Van Thanh Do^{a,*}, Wildan Suhartini^b, Chi Uyen Phan^c, Zhengwei Zhang^d, Gulden Goksen^e, Jose M. Lorenzo^{f,g,*}

^a Department of Food Science and Technology, University of Nebraska—Lincoln, Lincoln, Nebraska, USA

^b Study Program of Food Technology, Department of Production and Industrial Technology, Sumatera Institute of Technology, Lampung 35365, Indonesia

^c Department of Chemical Technology and Environment, The University of Danang – University of Technology and Education, 48 Cao Thang St., Danang 550000, Viet Nam

^d School of Food and Drug, Shenzhen Polytechnic, No.7098, Liuxian Avenue, Shenzhen 518055, Guangdong Province, China

^e Department of Food Technology, Vocational School of Technical Sciences at Mersin Tarsus Organized Industrial Zone, Tarsus University, Mersin 33100, Turkey

^f Centro Tecnológico de la Carne de Galicia, Avda. Galicia nº 4, Parque Tecnológico de Galicia, San Cibrao das Viñas, 32900 Ourense, Spain

^g Universidade de Vigo, Área de Tecnología de los Alimentos, Facultad de Ciencias de Ourense, 32004 Ourense, Spain

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ABSTRACT

Today, people around the world put more time and effort into exploring healthy foods and herbal medicines for improving health and disease prevention. Foods are expected to render physiological benefits beyond their traditionally nutritional value. An immense number of food components with medicinal activities beside nutrients have been found in various natural plants. *Pouteria campechiana* has been distributed throughout Central America, the Caribbean, some regions of Southeast Asia, and areas of Africa. Fruit of *P. campechiana* contains a broad spectrum of nutrients and plant bioactives. *P. campechiana* is utilized by local people as a useful medicinal resource for several therapeutic treatments. This paper provides a comprehensive review of *P. campechiana* from updated research literature. Botanical information, nutrient values, phytochemistry, as well as bioactivities are covered. The processes, proposals for product development, and toxicity of *P. campechiana* are also discussed.

1. Introduction

The genus *Pouteria* consist of approximately 235 species, including several edible fruit species such as *Pouteria campechiana*, *Pouteria viridi*, *Pouteria lucuma*, and *Pouteria sapota*. *Pouteria campechiana* (Kunth) Baehni, known as “canistel” is native to Mexico and Central America, and belongs to the family Sapotaceae in the order Ericales (Jo, Kim, Kim, Cheon, & Kim, 2016; Niu et al., 2018). It has been known since pre-

Columbian times as evidenced by images of the fruit on woven cloth and clay vessels (Martin & Malo, 1978). This species was brought into cultivation in the Philippines from Cuba by Spaniards between 1912 and 1915 and was introduced to Taiwan from the Philippines in 1929. It can now be found in many countries such as Sri Lanka, America, China, Vietnam, Thailand, and Indonesia. The edible pulp of *P. campechiana* fruit has a sweet taste and boiled egg yolk-like texture. *P. campechiana* fruit can be eaten fresh and also processed in the form of sweets,

* Corresponding authors at: Department of Food Science and Technology, University of Nebraska—Lincoln, Lincoln, Nebraska, USA (T.V.T. Do). Centro Tecnológico de la Carne de Galicia, Avda. Galicia nº 4, Parque Tecnológico de Galicia, San Cibrao das Viñas, 32900 Ourense, Spain (J.M. Lorenzo).

E-mail addresses: tdo9@huskers.unl.edu, dothivanthanh91@gmail.com (T.V.T. Do), jmlorenzo@ceteca.net (J.M. Lorenzo).

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puddings, milkshakes, ice cream, jam, and pie. The latex extracted from the tree is a main ingredient to produce chicle in Central America. Studies have showed that the fruit pulp contains high levels of carbohydrates, amino acids, carotenoids, polyphenolics, flavonoids, vitamins B and C, and is a rich source of minerals (Sethuraman et al., 2020). Parts of this plant have been used in traditional medicine for centuries. The decoction from *P. campechiana* bark is utilized as an antipyretic in Mexico and to treat skin blisters and soreness in Cuba. Unripe fruit is taken for controlling diarrhea. The leaves are reported to be anti-inflammatory and *P. campechiana* seeds are also used as a remedy for ulcers (Manthra et al., 2019). Modern pharmacological investigations have demonstrated that ingredients from *P. campechiana* show a broad spectrum of pharmacological actions including antimicrobial, anti-obesity, anti-inflammatory, and antioxidant activities (Chan-Zapata et al., 2018; Elsayed, El-Tanbouly, Moustafa, Abdou, & El Awdan, 2016). Sangeetha, Pratheeba, Ragavendran, and Natarajan (2019) confirmed that the compound myricitrin (58) isolated from leaf extract possessed a significant toxic effect against both *Aedes aegypti* and *Culex quinquefasciatus* mosquitoes at all stages. Other research also found that the aqueous extract of *P. campechiana* leaf effectively fabricates titanium dioxide nanoparticles from titanium dioxide with anti-mosquito activity on *Aedes aegypti* (Narayanan et al., 2021). These results indicated that *P. campechiana* leaves have potential to prevent the spread of mosquito-borne diseases to humans and other vertebrates.

To the best of our knowledge, this paper is the first time information on *P. campechiana* has been compiled by summarizing the existing literature as of December 2022 regarding botanical characteristics, phytochemistry, nutritional composition, biological activities, and toxicity issues. The review also elucidates the storage, processes, and product development of *P. campechiana*. Hopefully, this information will be helpful in the future research of this plant for food and medicine, as well as consumer understanding.

2. Botany of *P. Campechiana*

According to Vozzo (2002) and Lim (2013), *P. campechiana* (Fig. 1) is a medium sized, erect, evergreen tree with a 8–20 m height and a 25–60 cm diameter trunk. The leaves are alternate and gathered as whorls at the tips of the branches, elliptical to oblanceolate or obovate, 6 to 25 cm long, and 2.5 to 8 cm wide, glossy with bright green and bluntly pointed at the apex, more sharply tapered at the base. Every part of the tree is rich in white gummy latex (Gou & Liu, 2016). Flowers are small, about 1 cm, green white-colored, fragrant, solitary or clustered, born in the leaf axils or at the leafless nodes on 5–12 mm long pedicels with multiple stamens (Deng et al., 2013). *P. campechiana* flowers are bisexual with very short pistil style. Fruit is a berry, variable in shape and size, round,

ovoid, subglobose, spindle, often with pointed apex, up to 7–12.5 cm long by 4–7.5 cm wide. Immature and unripe fruit is green, hard, and abundant in white latex. The ripe fruit skin turns pale orange-yellow or golden-yellow, the pulp is soft, dry to mealy, and has a musky flavor with a few fine fibers. The seeds are 2–5.3 cm long and 1.25–3.2 cm wide, ovoid to globose with pointed ends, glossy and chestnut-brown except for a curved ventral side which is dull light-brown to greyish-white. The plant begins to yield flowers and fruits between 4 and 5 years of age (Vozzo, 2002). There is considerable variation regarding the time of flowering and fruiting among its growing locations. Fruit generally ripens about 5–6 months after flowering (Pushpakumara, 2020). The fruit is mature for harvest from August through October in Mexico (Vozzo, 2002) while in Taiwan it begins to mature in December (Deng et al., 2013). *P. campechiana* fruit ripens in July and November in China but in Vietnam the fruit ripens in May and September. Tropical and subtropical climates with 1800 m of altitude and frequent rains are good for cultivation (Andrade et al., 2002).

P. campechiana is commonly known as “canistel” in Cuba, Brazil, and Costa Rica, “tiesa” in the Philippines (Padilla, Saddul, & Laborde, 2016), “danhuang guo” in China (Shao-feng, 2013), “kanisuteru” in Japan (Suda et al., 2005), “lêkima” in Vietnam (Nguyen, Nguyen, & Nguyen, 2019), but it also receives a variety of different popular names in some countries such as “caca De Niño”, “cozticzapoti”, and “cucumu” in Mexico, “lavalu” and “ratalawulu” in Sri Lanka, “lamut kahamen”, “khe maa”, and “to maa” in Thailand, “sawo mentega”, “sawo ubi”, and “alkesah” in Indonesia, and “eggfruit”, “canistel”, and “yellow sapote” in the United States (Lim, 2013). *Pouteria campechiana* (Kunth) Baehni is the only accepted name for the plant in report of “The Plant List” (<https://www.theplantlist.org>) in relation to other 32 synonyms. According to “CABI” (<https://www.cabi.org>), *P. campechiana* only has one other scientific name: *Lucuma nervosa* A. DC.

3. Nutritional composition and phytochemistry

3.1. Nutrient constituents

P. campechiana fruit is a rich source of carbohydrates, dietary fiber, protein, fat, and vitamins including C, A, and B-group vitamins (Awang-Kanak & Bakar, 2018). Minerals contained in *P. campechiana* fruit are potassium, sodium, calcium, magnesium, phosphorus, copper, iron, manganese, and zinc. The nutrient constituents found in the pulp of *P. campechiana* fruit are summarized in Table 1. Potassium had the highest content with 2990 mg/kg compared with other minerals in *P. campechiana* fruit. Heavy metals such as lead, cadmium, and chromium were also found in the fruit with low levels of 0.09, 0.008, and 0.01 mg/kg, respectively (Jing-ru, 2009). It was reported that the ripe

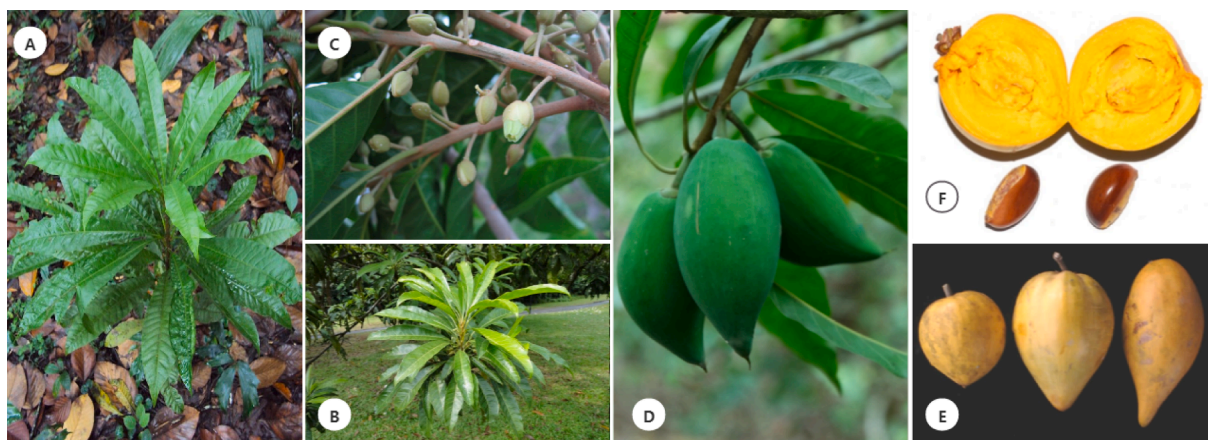


Fig. 1. *P. campechiana*: seedling (A), leaves are whorled at the end of branch (B), flower buds and flower (C), immature fruits (D), different varieties of fruit (E), longitudinal sections of a ripe fruit and its seeds (F).

Table 1
Proximate, mineral, and vitamin composition of *P. campechiana* fruit.

Components	Content/100 g	24.40 g ^b	29.57 ^b g	Components	Content/100 g	4.01 g ^a	Components	Content/100 g	23.2 mg ^b	468 ^a mg
Carbohydrate	40.19 g ^a	—	—	Glucose	3.30 g ^a	—	Calcium	2.24 mg ^b	—	—
Water	52.96 g ^b	64.00 g ^b	54.44 ^b g	Fructose	2.70 g ^a	3.92 g ^a	Magnesium	7.04 mg ^b	11.7 mg ^b	443 ^a mg
Protein	1.16 g ^a	0.71 g ^b	8.75 ^b g	Raffinose	—	0.29 g ^a	Potassium	—	299 mg ^b	568 ^a mg
Fiber	2.12 g ^a	9.11 g ^b	2.77 ^b g	Maltose	—	ND	Iron	0.31 mg ^b	0.52 mg ^b	1641 ^a mg
Fat	4.97 g ^a	1.04 g ^b	4.74 ^b g	Vitamin B ₁	—	—	Sodium	—	11.1 mg ^b	271 ^a mg
Ash	0.71 g ^a	0.78 g ^b	2.92 ^b g	Vitamin B ₂	—	—	Copper	0.01 mg ^b	<0.02 mg ^b	0.58 ^a mg
Energy	879.27 ^a kJ	538.7 kJ ^b	819.77 kJ	Vitamin B ₃	—	—	Manganese	0.02 mg ^b	0.13 mg ^b	—
Total sugar	21.6 g ^a	—	—	Vitamin C	6.00 mg ^a	187 mg ^b	Zinc	0.08 mg ^b	0.28 mg ^b	0.16 ^a mg
Sucrose	15.6 g ^a	—	—	Vitamin A	—	—	Phosphorus	—	21.8 mg ^b	—
Reference	(Sethuraman et al., 2020)	(G.-h. Fang, Dong, Zhan, Xu, & Wang, 2018)	(Kubola et al., 2011)	Reference	(Sethuraman et al., 2020)	(G.-h. Fang et al., 2018)	Reference	(G.-h. Fang et al., 2018)	(Jing-ru, 2009)	(Nur et al., 2022)

ND: not detectable; ^a: Values expressed on the basis of dry weight; ^b: Values expressed on the basis of fresh weight.

P. campechiana fruit pulp contained 21.6 g/100 g dry weight (DW) of total sugar with sucrose being the main sugar (Sethuraman et al., 2020). According to Gao et al. (2019), the weight, size, and organic acid content of *P. campechiana* fruit varied depending on the growing area. The medium ripe fruit (green/yellow = 1/3) harvested at the altitudes of 695, 756, and 848 m had the weight of 110.67, 107.19, and 148.90 g with total organic acid contents of 38.66, 42.71, and 47.52 mg/g, respectively. This indicated that there was an increase in the organic acid amount when the altitude increased. The authors also reported that the total organic acid content comprising of tartaric acid, malic acid, citric acid, and gallic acid of the fruit decreased during storage at room temperature. The vitamin C content of *P. campechiana* fruit pulp in Bandarawela of Sri Lanka and in Bangladesh was 0.53 and 0.61 mg/g fresh weight (FW), respectively (Mallawaarachchi, Madhujith, & Pushpakumara, 2019; Mehraj, Sikder, Mayda, Taufique, & Uddin, 2015) while in Nakon Phamon province of Thailand it was 1.87 mg/g FW (Kubola, Siriamornpun, & Meeso, 2011). Chang, Lee, Lin, and Chen (1998) found that among 41 local Taiwanese fruits, *P. campechiana* fruit pulp had the highest dietary fiber content with 8.6 g/100 g DW. Cellulose accounted for almost 40% of the total dietary fiber content, followed by soluble dietary fiber, insoluble non-cellulose polysaccharide, and lignin with about 29, 17, and 14% respectively in the fruit pulp. Fourteen fatty acids were identified in the *P. campechiana* fruit pulp: palmitic acid, oleic acid, myristic acid, and linolenic acid were the predominant fatty acids (Marzuki, Hamid, & Wahab, 2018; Yahya & Wahab, 2017). Ma, Sheng, Wang, and Liu (2019) investigated nutritional composition and volatile oil profile of *P. campechiana* seed. The content of water, ash, starch, protein, fat, reducing sugar, and vitamin C found in the seed was 7.46, 2.22, 13.89, 1.12, 6.27, 0.46, and 0.002 g/100 g DW, respectively. The seed contained 8 essential amino acids and 10 non-essential amino acids. Further studies clarified the difference in nutritional composition among seed, fruit pulp, and leaf (Costa, Wondracek, Lopes, Vieira, & Ferreira, 2010; Pai & Shenoy, 2020). Costa et al. (2010) confirmed that the total lipid value in the seed (4.62 g/100 g DW) was higher than that in the fruit pulp (0.61 g/100 g DW), however, the water content in the fruit pulp (49.50 g/100 g FW) was higher than that in the seed (47.25 g/100 g FW). The acid-soluble ash content was greater than the water-soluble ash content in *P. campechiana* leaves while in the fruit pulp the acid-soluble ash content was lower than the water-soluble ash content (Pai & Shenoy, 2020).

3.2. Phytochemistry of *P. Campechiana*

The main phytochemical constituents isolated from *P. campechiana* are carotenoids, phenolic acids, flavonoids, stilbenes, and volatiles (Kubola et al., 2011; Pai & Shenoy, 2020; Sangeetha et al., 2019). Other chemical constituents known to be present in this plant such as terpenes, glycosides, sterol, and alkanes are also discussed in detail below. A summary of the phytochemical constituents present in *P. campechiana* is shown in Table 2.

3.2.1. Phenolic compounds

Phenolic compounds in plants such as phenolic acids, flavonoids, stilbenes, coumarins, and tannins play an important role as reducing agents, free radical scavengers, and singlet oxygen quenchers. J. Ma, Yang, Basile, and Kennelly (2004) first identified and quantified polyphenolic antioxidants in fruits of three *Pouteria* species using high performance liquid chromatography (HPLC) and selected ion monitoring liquid chromatography-mass spectrometry (SIM LC-MS) analysis. Seven polyphenol antioxidants were detected in *P. sapota* and *P. viridis*. However, only four polyphenols were present in *P. campechiana*. The content of individual polyphenolic antioxidants was 1.04 ppm for (+)-catechin (52), 2.82 ppm for myricitrin (58), 5.62 ppm for (+)-gallicocatechin (54), and 16.85 ppm for gallic acid (71). From the investigation of 19 Thai wild fruits (Kubola et al., 2011), phytochemicals including 6 phenolic acids and 6 flavonoids in ripe *P. campechiana* fruit pulp were identified

Table 2
Chemical compounds identified in *P. campechiana*.

No.	Phytochemical classification	Extraction solvent	Content	Part(s) of plant	Reference (s)
Amino acids					
(1)	Alanine	Water	1.82 mg/g DW	Seeds	(Ma et al., 2019)
(2)	Arginine	Water	2.27 mg/g DW	Seeds	(Ma et al., 2019)
(3)	Aspartic acid	Water	3.20 mg/g DW	Seeds	(Ma et al., 2019)
(4)	Cysteine	Water	0.05 mg/g DW	Seeds	(Ma et al., 2019)
(5)	Glutamic acid	Water	5.06 mg/g DW	Seeds	(Ma et al., 2019)
(6)	Glycine	Water	1.32 mg/g DW	Seeds	(Ma et al., 2019)
(7)	Histidine	Water	1.10 mg/g DW	Seeds	(Ma et al., 2019)
(8)	Isoleucine	Water	0.55 mg/g DW	Seeds	(Ma et al., 2019)
(9)	Leucine	Water	1.80 mg/g DW	Seeds	(Ma et al., 2019)
(10)	Lysine	Water	0.68 mg/g DW	Seeds	(Ma et al., 2019)
(11)	Methionine	Water	0.19 mg/g DW	Seeds	(Ma et al., 2019)
(12)	Phenylalanine	Water	0.80 mg/g DW	Seeds	(Ma et al., 2019)
(13)	Proline	Water	0.94 mg/g DW	Seeds	(Ma et al., 2019)
(14)	Serine	Water	1.28 mg/g DW	Seeds	(Ma et al., 2019)
(15)	Threonine	Water	0.70 mg/g DW	Seeds	(Ma et al., 2019)
(16)	Tryptophan	Water	0.02 mg/g DW	Seeds	(Ma et al., 2019)
(17)	Tyrosine	Water	0.35 mg/g DW	Seeds	(Ma et al., 2019)
(18)	Valine	Water	0.82 mg/g DW	Seeds	(Ma et al., 2019)
Carotenoids					
(19)	Antheraxanthin	Mixture of hexane, ethanol, acetone, and toluene	—	Fruit pulp	(Evangelista-Lozano et al., 2021)
(20)	<i>cis</i> - Violaxanthin	Cold acetone	*	Fruit pulp	(Costa et al., 2010)
(21)	<i>cis</i> - ζ - Carotene	Cold acetone	—	Fruit pulp	(Costa et al., 2010)
(22)	Lutein	Acetone	ND ^b	Fruit pulp	(E. Murillo et al., 2010)
(23)	Neoxanthin	Cold acetone	19270 $\mu\text{g/g DW}$ ^a	Fruit pulp	(de Lanerolle et al., 2008)
		Cold acetone	*	Fruit pulp	(Costa et al., 2010)
(24)	Phytofluene	Cold acetone	6.5 $\mu\text{g/g}$	Fruit pulp	(Costa et al., 2010)
(25)	<i>trans</i> - Violaxanthin	Cold acetone	*	Fruit pulp	(Costa et al., 2010)
(26)	<i>trans</i> - ζ - Carotene	Cold acetone	9.1 $\mu\text{g/g}$	Fruit pulp	(Costa et al., 2010)
(27)	Violaxanthin	Cold acetone	1151 $\mu\text{g/g DW}$ ^a	Fruit pulp	(de Lanerolle et al., 2008)
		Mixture of hexane, ethanol, acetone, and toluene	—	Fruit pulp	(Evangelista-Lozano et al., 2021)
				Fruit peel	(Evangelista-Lozano et al., 2021)
(28)	Xanthophyll	Mixture of hexane, ethanol, acetone, and toluene	3.88 $\mu\text{g/g}$ ^d	Fruit Peel	(Evangelista-Lozano et al., 2021)
		Mixture of hexane, ethanol, acetone, and toluene	1.32 $\mu\text{g/g}$ ^d	Fruit pulp	(Evangelista-Lozano et al., 2021)
(29)	Zeaxanthin	Acetone	19.7 $\mu\text{g/g FW}$	Fruit pulp	(E. Murillo et al., 2010)
		Mixture of hexane, ethanol, acetone, and toluene	—	Fruit pulp	(Evangelista-Lozano et al., 2021)
				Fruit peel	(Evangelista-Lozano et al., 2021)
(30)	β -Carotene	Cold acetone	156 $\mu\text{g/g DW}$ ^a	Fruit pulp	(de Lanerolle et al., 2008)
		Cold acetone	7.10 $\mu\text{g/g}$	Fruit pulp	(Costa et al., 2010)
		Mixture of hexane, ethanol, acetone, and toluene	—	Fruit pulp	(Evangelista-Lozano et al., 2021)
(31)	β -Carotene 5,6-epoxide	Cold acetone	7.90 $\mu\text{g/g}$	Fruit pulp	(Costa et al., 2010)
(32)	β -Cryptoxanthin	Cold acetone	1106 $\mu\text{g/g DW}$ ^a	Fruit pulp	(de Lanerolle et al., 2008)
(33)	ζ -Carotene	Cold acetone	ND	Fruit pulp	(de Lanerolle et al., 2008)
Fatty acids					
(34)	Arachidonic acid	Ethanol	0.6%	Fruit pulp	(Yahya & Wahab, 2017)
(35)	Behenic acid	Ethanol	< 0.1%	Fruit pulp	(Yahya & Wahab, 2017)
(36)	Capric acid	Ethanol	1.2 %	Fruit pulp	(Yahya & Wahab, 2017)
(37)	Caproic acid	Ethanol	0.1%	Fruit pulp	(Yahya & Wahab, 2017)
(38)	Caprylic acid	Ethanol	3.1%	Fruit pulp	(Yahya & Wahab, 2017)
(39)	<i>cis</i> - Linoleic acid	Ethanol	2.4%	Fruit pulp	(Yahya & Wahab, 2017)
(40)	<i>cis</i> - Linolenic acid	Ethanol	14.1%	Fruit pulp	(Yahya & Wahab, 2017)
(41)	<i>cis</i> - Oleic acid	Ethanol	19.1%	Fruit pulp	(Yahya & Wahab, 2017)
(42)	Lauric acid	Ethanol	3.9%	Fruit pulp	(Yahya & Wahab, 2017)
(43)	Lignoceric acid	Ethanol	3.0%	Fruit pulp	(Yahya & Wahab, 2017)
(44)	Myristic acid	Ethanol	16.1%	Fruit pulp	(Yahya & Wahab, 2017)
(45)	Palmitic acid	Ethanol	24.5%	Fruit pulp	(Yahya & Wahab, 2017)
(46)	Palmitoleic acid	Ethanol	4.4%	Fruit pulp	(Yahya & Wahab, 2017)
(47)	Stearic acid	Ethanol	3.3%	Fruit pulp	(Yahya & Wahab, 2017)
(48)	<i>trans</i> - Linoleic acid	Ethanol	< 0.1%	Fruit pulp	(Yahya & Wahab, 2017)
(49)	<i>trans</i> - Linolenic acid	Ethanol	< 0.1%	Fruit pulp	(Yahya & Wahab, 2017)
(50)	<i>trans</i> - Oleic acid	Ethanol	< 0.1%	Fruit pulp	(Yahya & Wahab, 2017)
Flavonoids					
(51)	Apigenin	Methanol/HCl (100:1, v/v)	0.88 mg/g DW	Fruit	(Kubola et al., 2011)
(52)	Catechin	Methanol	1.04 ppm	Fruit	(J. Ma et al., 2004)
		Methanol	3.62 mg/100 g FW	Fruit	(Adiyaman et al., 2016)
(53)	Epicatechin	Methanol	3.57 mg/100 g FW	Fruit	(Adiyaman et al., 2016)

(continued on next page)

Table 2 (continued)

No.	Phytochemical classification	Extraction solvent	Content	Part(s) of plant	Reference (s)
(54)	Gallocatechin	Methanol	5.62 ppm	Fruit	(J. Ma et al., 2004)
(55)	Kaempferol	Methanol/HCl (100:1, v/v)	0.78 mg/g DW	Fruit	(Kubola et al., 2011)
(56)	Luteolin	Methanol/HCl (100:1, v/v)	13.98 mg/g DW	Fruit	(Kubola et al., 2011)
(57)	Myricetin	Ethanol	—	Leaves; Seeds	(Elsayed et al., 2016)
		Methanol/HCl (100:1, v/v)	55.67 mg/g DW	Fruit	(Kubola et al., 2011)
(58)	Myricitrin	Methanol	2.82 ppm	Fruit	(J. Ma et al., 2004)
(59)	Myricetin-3-O- α -L-rhamnoside	Ethanol	—	Leaves; Seeds	(Elsayed et al., 2016)
(60)	Myricetin-3-O- β -galactoside	Ethanol	—	Leaves; Seeds	(Elsayed et al., 2016)
(61)	Quercetin	Ethanol	—	Leaves; Seeds	(Elsayed et al., 2016)
		Methanol	14.78 mg/100 g FW	Fruit	(Adiyaman et al., 2016)
		Methanol/HCl (100:1, v/v)	23.15 mg/g DW	Fruit	(Kubola et al., 2011)
(62)	Rutin	Methanol/HCl (100:1, v/v)	20.64 mg/g DW	Fruit	(Kubola et al., 2011)
Flavonoid glycosides					
(63)	Myricetin 3-O- α -rhamnopyranoside	Ethyl acetate	—	Leaves	(Hernandez et al., 2008)
(64)	Quercetin 3-O- α -rhamnopyranoside	Ethyl acetate	—	Leaves	(Hernandez et al., 2008)
(65)	Quercetin 3-O- β -arabinopyranoside	Ethyl acetate	—	Leaves	(Hernandez et al., 2008)
(66)	Taxifolin 3-O- α -arabinofuranoside	Ethyl acetate	—	Leaves	(Hernandez et al., 2008)
(67)	Taxifolin 3-O- α -rhamnopyranoside	Ethyl acetate	—	Leaves	(Hernandez et al., 2008)
(68)	trans-taxifolin 3-O- α -arabinopyranoside	Ethyl acetate	—	Leaves	(Hernandez et al., 2008)
Phenolic acids					
(69)	Caffeic acid	Methanol	4.62 mg/100 g FW	Fruit	(Adiyaman et al., 2016)
		Methanol/HCl (100:1, v/v)	5.56 mg/g	Fruit	(Kubola et al., 2011)
(70)	Ferulic acid	Methanol	6.76 mg/100 g FW	Fruit	(Adiyaman et al., 2016)
		Methanol/HCl (100:1, v/v)	50.73 mg/g	Fruit	(Kubola et al., 2011)
(71)	Gallic acid	Ethanol	—	Leaves; Seeds	(Elsayed et al., 2016)
		Methanol	16.85 ppm	Fruit	(J. Ma et al., 2004)
		Methanol	15.35 mg/100 g FW	Fruit	(Adiyaman et al., 2016)
		Methanol/HCl (100:1, v/v)	1.36 mg/g	Fruit	(Kubola et al., 2011)
(72)	Protocatechuic acid	Ethanol	—	Leaves; Seeds	(Elsayed et al., 2016)
		Methanol/HCl (100:1, v/v)	5.14 mg/g	Fruit	(Kubola et al., 2011)
(73)	Vanillic acid	Methanol/HCl (100:1, v/v)	15.48 mg/g	Fruit	(Kubola et al., 2011)
(74)	p-Cormaric acid	Methanol/HCl (100:1, v/v)	8.84 mg/g	Fruit	(Kubola et al., 2011)
Stilbenoids					
(75)	Ampelopsin A	Ethyl acetate	—	Leaves	(Hernandez et al., 2008)
(76)	Ampelopsin B	Ethyl acetate	—	Leaves	(Hernandez et al., 2008)
(77)	Balanocarpol	Ethyl acetate	—	Leaves	(Hernandez et al., 2008)
(78)	Hopeaphenol	Ethyl acetate	—	Leaves	(Hernandez et al., 2008)
(79)	Vaticaphenol A	Ethyl acetate	—	Leaves	(Hernandez et al., 2008)
(80)	ϵ -viniferin diol (Betulifol B)	Ethyl acetate	—	Leaves	(Hernandez et al., 2008)
Triterpenoids					
(81)	Corosolic acid	Ethanol	—	Leaves	(Ren et al., 2019)
(82)	Euscaphic acid	Ethanol	—	Leaves	(Ren et al., 2019)
(83)	Fatty acid ester of betulinic acid	Ethyl acetate	—	Stem bark	(Ragasa et al., 2011)
(84)	Fatty acid ester of oleanolic acid	Ethyl acetate	—	Stem bark	(Ragasa et al., 2011)
(85)	Maslinic acid	Ethanol	—	Leaves	(Ren et al., 2019)
(86)	Ursolic acid	Ethanol	—	Leaves	(Hussein, 2016)
(87)	24-nor-13,27-cycloursane-type triterpenoid (Lucumic acid A)	Ethanol	—	Leaves	(Ren et al., 2019)
(88)	24-nor-ursane triterpenoid (Lucumic acid B)	Ethanol	—	Leaves	(Ren et al., 2019)
(89)	4(R),23-epoxy-2 α ,3 α ,19 α -trihydroxy-24-norurs-12-en-28-oic acid	Ethanol	—	Leaves	(Ren et al., 2019)
(90)	2 α ,3 α ,19 α ,23-tetrahydroxy-13 α ,27-cyclours-11-en-28-oic acid	Ethanol	—	Ethanol	(Ren et al., 2019)
(91)	2 α , 3 α , 19 α , 23 tetrahydroxyursolic acid	Ethanol	—	Leaves	(Hussein, 2016)
(92)	2 α ,3 β ,19 α -trihydroxy-24-norursa-4(23),12-dien-28-oic acid	Ethanol	—	Ethanol	(Ren et al., 2019)
(93)	3 β , 28- dihydroxy-olean-12-enyl fatty acid ester	Ethyl acetate	—	Stem bark	(Ragasa et al., 2011)
Volatile compounds and essential oils					
(94)	1-Chlorononadecane	Ethanol	2.15%	Seeds	(Ma et al., 2019)

(continued on next page)

Table 2 (continued)

No.	Phytochemical classification	Extraction solvent	Content	Part(s) of plant	Reference (s)
(95)	1-Iodoheptadecane	Ethanol	1.51%	Seeds	(Ma et al., 2019)
(96)	2-(Ethylthio)ethanol	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(97)	2-Methylbutanoic acid	Diethyl ether	0.03 mg/kg	Fruit pulp	(Pino, 2010)
(98)	2-Methyl-Z,Z-3,13-octadecadienol	Ethanol	1.20%	Seeds	(Ma et al., 2019)
(99)	2-Pentadecanone	Diethyl ether	0.26 mg/kg	Fruit pulp	(Pino, 2010)
(100)	2-Tridecanone	Diethyl ether	0.10 mg/kg	Fruit pulp	(Pino, 2010)
(101)	3-Methyl-2-buten-1-ol	Diethyl ether	0.21 mg/kg	Fruit pulp	(Pino, 2010)
(102)	3-Methyl-tetradecane	Ethanol	1.45%	Seeds	(Ma et al., 2019)
(103)	22-Tricosenoic acid	Ethanol	0.56%	Seeds	(Ma et al., 2019)
(104)	Benzoic acid	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(105)	Dimethyl sulfide	Diethyl ether	tr ^c	Fruit pulp	(Pino, 2010)
(106)	Eicosane	Ethanol	3.32%	Seeds	(Ma et al., 2019)
(107)	Erucylamide	Ethanol	4.26%	Seeds	(Ma et al., 2019)
(108)	Ethyl 2-methylbutanoate	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(109)	Ethyl 3-hydroxyoctadecanoate	Diethyl ether	1.03 mg/kg	Fruit pulp	(Pino, 2010)
(110)	Ethyl butanoate	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(111)	Ethyl dodecanoate	Diethyl ether	1.41 mg/kg	Fruit pulp	(Pino, 2010)
(112)	Ethyl decanoate	Diethyl ether	0.14 mg/kg	Fruit pulp	(Pino, 2010)
(113)	Ethyl hexanoate	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(114)	Ethyl isobutanoate	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(115)	Ethyl octadecanoate	Diethyl ether	0.74 mg/kg	Fruit pulp	(Pino, 2010)
(116)	Ethyl octanoate	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(117)	Ethyl pentadecanoate	Diethyl ether	0.12 mg/kg	Fruit pulp	(Pino, 2010)
(118)	Ethyl tetradecanoate	Diethyl ether	1.81 mg/kg	Fruit pulp	(Pino, 2010)
(119)	Ethyl (E)-cinnamate	Diethyl ether	1.32 mg/kg	Fruit pulp	(Pino, 2010)
(120)	Ethyl (E)-crotonate	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(121)	Geranyl acetone	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(122)	Glyceryl monooleate	Ethanol	0.79%	Seeds	(Ma et al., 2019)
(123)	Isobutyl acetate	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(124)	Hentetracontanol	Ethanol	1.66%	Seeds	(Ma et al., 2019)
(125)	Hexacosane	Ethanol	1.54%	Seeds	(Ma et al., 2019)
(126)	Hexacosene	Ethanol	0.54%	Seeds	(Ma et al., 2019)
(127)	Hexadecanoic acid	Ethanol	8.16%	Seeds	(Ma et al., 2019)
(128)	Isobutyl 2-hydroxypropanoate	Diethyl ether	0.80 mg/kg	Fruit pulp	(Pino, 2010)
(129)	Isobutyl acetate	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(130)	Limonene	Diethyl ether	0.21 mg/kg	Fruit pulp	(Pino, 2010)
(131)	Linalool	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(132)	Methyl 2-hydroxy-3-methylpentanoate	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(133)	Methyl 2-hydroxy-4-methylpentanoate	Diethyl ether	4.74 mg/kg	Fruit pulp	(Pino, 2010)
(134)	Methyl 2-hydroxyisopentanoate	Diethyl ether	0.20 mg/kg	Fruit pulp	(Pino, 2010)
(135)	Methyl 2-methylbutanoate	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(136)	Methyl dodecanoate	Diethyl ether	0.07 mg/kg	Fruit pulp	(Pino, 2010)
(137)	Methyl hexadecanoate	Diethyl ether	1.25 mg/kg	Fruit pulp	(Pino, 2010)
(138)	Methyl hexanoate	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(139)	Methyl octadecanoate	Diethyl ether	0.05 mg/kg	Fruit pulp	(Pino, 2010)
(140)	Methyl oleate	Ethanol	0.43%	Seeds	(Ma et al., 2019)
(141)	Methyl pentadecanoate	Ethanol	0.38%	Seeds	(Ma et al., 2019)
(142)	Methyl tetradecanoate	Diethyl ether	0.51 mg/kg	Fruit pulp	(Pino, 2010)
(143)	Methyl (E)-2-decenoate	Diethyl ether	0.03 mg/kg	Fruit pulp	(Pino, 2010)
(144)	Methyl (E)-2-octenoate	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(145)	Methyl (E)-cinnamate	Diethyl ether	0.55 mg/kg	Fruit pulp	(Pino, 2010)
(146)	Mono (2-ethylhexyl) phthalate	Ethanol	6.64%	Seeds	(Ma et al., 2019)
(147)	Oleic acid	Ethanol	10.47%	Seeds	(Ma et al., 2019)
(148)	Pentacosane	Ethanol	1.38%	Seeds	(Ma et al., 2019)
(149)	S-Methyl 2-propenethioate	Diethyl ether	2.48 mg/kg	Fruit pulp	(Pino, 2010)
(150)	S-Methyl thiobutanoate	Diethyl ether	1.20 mg/kg	Fruit pulp	(Pino, 2010)
(151)	Tricosane	Ethanol	0.86%	Seeds	(Ma et al., 2019)
(152)	Tetracosane	Ethanol	3.19%	Seeds	(Ma et al., 2019)
(153)	Tetradecanoic acid	Ethanol	0.40%	Seeds	(Ma et al., 2019)
(154)	Triacotane	Ethanol	1.63%	Seeds	(Ma et al., 2019)
(155)	Triacetyl acetate	Ethanol	0.52%	Seeds	(Ma et al., 2019)
(156)	(E)-Nerolidol	Diethyl ether	0.07 mg/kg	Fruit pulp	(Pino, 2010)
(157)	(E)-β-Ionone	Diethyl ether	0.02 mg/kg	Fruit pulp	(Pino, 2010)
(158)	(E)-β-Ocimene	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(159)	(E,E)-α-Farnesene	Diethyl ether	0.02 mg/kg	Fruit pulp	(Pino, 2010)
(160)	p-Cymene	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(161)	α-Terpineol	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(162)	α-Thujene	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
(163)	γ-Nonalactone	Diethyl ether	0.21 mg/kg	Fruit pulp	(Pino, 2010)
(164)	γ-Terpinene	Diethyl ether	tr	Fruit pulp	(Pino, 2010)
Others					
(165)	2-Pentene, 3-ethyl-4,4-dimethyl-	Methanol	—	Fruit	(Pai & Shenoy, 2020)
(166)	3-Deoxy-d-mannoic lactone	Methanol	—	Fruit	(Pai & Shenoy, 2020)
(167)	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl-	Methanol	—	Fruit	(Pai & Shenoy, 2020)
(168)	11,14,17-Eicosatrienoic acid, methyl ester	Methanol	—	Leaves	(Pai & Shenoy, 2020)

(continued on next page)

Table 2 (continued)

No.	Phytochemical classification	Extraction solvent	Content	Part(s) of plant	Reference (s)
(169)	16-Octadecenoic acid, methyl ester	Methanol	—	Leaves	(Pai & Shenoy, 2020)
(170)	Aspidocarpine	Methanol	—	Leaves	(Pai & Shenoy, 2020)
(171)	Calendin	Methanol	—	Leaves	(Pai & Shenoy, 2020)
(172)	d-Glycero-d-galacto-heptose	Methanol	—	Fruit	(Pai & Shenoy, 2020)
(173)	Dibutyl phthalate	Methanol	—	Leaves	(Pai & Shenoy, 2020)
(174)	Dimethylamine, N-(neopentyloxy)-	Methanol	—	Fruit	(Pai & Shenoy, 2020)
(175)	Di-n-octyl phthalate	Acetone	—	Leaves	(Sangeetha et al., 2019)
(176)	DL-Arabitol	Methanol	—	Fruit	(Pai & Shenoy, 2020)
(177)	Glycerin	Methanol	—	Fruit	(Pai & Shenoy, 2020)
(178)	Hexatriacontane	Acetone	—	Leaves	(Sangeetha et al., 2019)
(179)	Kaur-16-ene	Methanol	—	Leaves	(Pai & Shenoy, 2020)
(180)	N-(2-Cyanoethyl)-N-methylacetamide	Methanol	—	Leaves	(Pai & Shenoy, 2020)
(181)	N, N- dimethyl-O-(1-methyl-butyl)-hydroxylamine	Methanol	—	Fruit	(Pai & Shenoy, 2020)
(182)	Octacosane	Acetone	—	Leaves	(Sangeetha et al., 2019)
(183)	Pentadecyl propan-2-yl sulfite	Acetone	—	Leaves	(Sangeetha et al., 2019)
(184)	Pentyl acetate	Methanol	—	Fruit	(Pai & Shenoy, 2020)
(185)	Phytol, acetate	Methanol	—	Leaves	(Pai & Shenoy, 2020)
(186)	Spinasterol	Ethyl acetate	—	Stem bark	(Ragasa et al., 2011)
(187)	Stigmast-5-en-3-ol, (3beta)-	Methanol	—	Fruit	(Pai & Shenoy, 2020)
(188)	Tetracosane	Acetone	—	Leaves	(Sangeetha et al., 2019)
(189)	β-D-Glucopyranoside, methyl	Methanol	—	Fruit	(Pai & Shenoy, 2020)

^a : Sample harvested in home garden of Peradeniya, Sri Lanka.

^b : <0.1 µg /g.

^c : < 0.01 mg/kg.

^d : immature fruit (green color); ND: not detectable;*: Content of violaxanthin and neoxanthin is 196 µg/g; tr: Trace.

and the contents determined. Ferulic acid (70) showed the highest content among the phenolic acids while myricetin (57) possessed the highest content among the flavonoids. Adiyaman et al. (2016) examined the difference in phenolic composition between *Averrhoa carambola* and *P. campechiana* fruits. The *P. campechiana* fruit extract under 80% methanol extraction at a solid-to-liquid ratio of 1:3 found 6 phenolic compounds, namely gallic acid (71), ferulic acid (70), caffeic acid (69), catechin (52), epicatechin (53), and quercetin (61). The total phenolic and flavonoid contents of *P. campechiana* fruit extract obtained were 152.45 mg gallic acid equivalent (GAE)/100 g FW and 109.73 mg quercetin equivalent (QE)/100 g FW while those of *Averrhoa carambola* fruit extract under the same extraction conditions were 161.56 mg GAE/100 FW and 72.00 mg QE/100 g FW, respectively. Pai and Shenoy (2020) found the methanolic extract from *P. campechiana* fruit contained 602.60 mg GAE/100 g DW of total phenolic content (TPC) and 1697.00 mg QE/100 g DW of total flavonoid content (TFC). The discrepancy of total phenolic and flavonoid amounts between the two above-mentioned studies may be due to difference in applied analysis methods, culture environment, and maturity stage of the fruit. Sunila and Murugan (2017) elucidated the total phenolics and flavonoids of *P. campechiana* fruit at different maturity stages. There were 6 stages based on weeks after pollination (WAP) involving 4 WAP (stage 1), 8 WAP (stage 2), 12 WAP (stage 3), 16 WAP (stage 4), 20 WAP (stage 5), and 24 WAP (stage 6). The findings pointed out that the TFC constantly increased during the process of fruit development while the TPC increased from stage 1 to stage 3 and then started to decline at stage 4.

Total phenolic and flavonoid contents differ in fruit, leaf, and, parts of fruit according to some reports (Hidayah, Fitriansyah, Aulifa, Dewi, & Barkah, 2020; Kong, Khoo, Prasad, Chew, & Amin, 2013; Pai & Shenoy, 2020). Quantitative analysis of phytochemicals in *P. campechiana* conducted by Pai and Shenoy (2020) revealed that the TPC and TFC in *P. campechiana* leaf was higher than that in *P. campechiana* fruit. Moreover, total tannin in the leaf showed a higher value with 167.02 mg tannic acid equivalent (TAE)/g DW compared to the total tannin in the fruit with 6.05 mg TAE/g DW. Kong et al. (2013) investigated phytochemicals in several extracts from *P. campechiana* seed, pulp, and peel of *P. campechiana* fruit. Out of three solvents, including water and 70% methanol, extracting solvent of 70% ethanol exhibited the highest phenolic and flavonoid contents in all parts of the fruit. The ethanol

extract from the peel contained the highest TPC with 2304.7 mg GAE/100 g DW while the pulp extract had the highest TFC with 6414.03 mg rutin equivalent (RE)/100 g DW. The 70% ethanol leaf extract also had the highest TPC, followed by the extracts of peel, seed, and pulp of the fruit (Hidayah et al., 2020). The leaf extract also showed the highest value for TFC, followed by extracts of the seed, pulp, and peel. Some studies agreed with the findings of Hidayah et al. (2020). For instance, Suda et al. (2005) reported that the TPC in *P. campechiana* seed was found to be a higher value in both acetone and 80% ethanol extracts as compared to the TPC in pulp extracts. In both ethanol and aqueous extracts, the highest amount of phenolics was found in the peel followed by the pulp (Nur, Khan, Biswas, Hossain, & Amin, 2022). Between 60% ethanol and 70% ethanol, the extracting solvent of 60% ethanol showed higher polyphenol extraction efficiency in fruit pulp using an ultrasonic-assisted extraction method (Marzuki et al., 2018; Yahya & Wahab, 2017). It goes without saying that freeze drying is a means for retaining sensory, nutritional, and functional properties of foods (Oyinloye & Yoon, 2020). Anjo et al. (2021) considered phytochemical characteristics in dehydrated *P. campechiana* pulp using two different drying techniques. Freezing-dried and oven-dried samples showed an insignificant difference in TPC with 4.56 and 5.19 mg GAE/g while there was a significant difference in TFC with 0.38 and 0.68 mg QE/g, respectively under methanol extraction at a solid-to-liquid ratio of 1:10.

The studies above found the leaf of *P. campechiana* has a remarkably high amount of flavonoid and phenolic contents compared to other parts. Identification of chemical compounds in the leaves plays a crucial role in specifying its biological activities. Six stilbenes and six flavonoid glycosides were isolated and identified in the ethyl acetate extract of *P. campechiana* leaves (Hernandez, Villaseñor, Joseph, & Tolliday, 2008). The stilbenes identified were ampelopsin A (75), ampelopsin B (76), balanocarpol (77), ε-viniferin diol (80), hopeaphenol (78), vaticaphenol A (79). Elsayed et al. (2016) identified phytochemicals in *P. campechiana* leaf and seed. They found the 70% ethanolic extracts from the leaves and seeds contained 6 compounds: protocatechuic acid (72), gallic acid (71), quercetin (61), myricetin (57), myricetin-3-O-α-L-rhamnoside (59), and myricetin-3-O-β-galactoside (60).

3.2.2. Carotenoids

Total carotenoid content in *P. campechiana* fruit pulp samples grown

in different regions of Sri Lanka ranged from 1.87 to 23.47 mg/g DW (de Lanerolle, Priyadarshani, Sumithraarachchi, & Jansz, 2008). These samples exhibited differences in the contents of carotenoid components and neoxanthin was found to be the predominant carotenoid in the pulp. The research of Costa et al. (2010) confirmed that neoxanthin (23) and violaxanthin (27) were the main carotenoids, followed by ζ -carotene (33), β -carotene 5,6-epoxide (31), β -carotene (30), and phytofluene (24) in fruit pulp harvested in the Federal district, Brazil. *P. campechiana* was determined to be a good source of zeaxanthin (29) at a remarkable level (19.7 μ g/g) among Panamanian wild fruits (E. Murillo, Meléndez-Martínez, & Portugal, 2010). It has been reported that zeaxanthin offers protective effects on eye, skin, liver, and cardiovascular health (A. G. Murillo, Hu, & Fernandez, 2019). Therefore, consumption of this fruit might provide significant health benefits to humans. In the latest study, (Anjo et al., 2021) indicated that both fruit pulp samples treated with freeze drying and thermal drying resulted in a difference of carotenoid content with 1.00 mg/g and 0.88 mg/g, respectively. The lower content for thermal drying was explained as being due to degradation of carotenoid compounds caused by temperature and oxygen exposure for a long 7-hour drying process.

3.2.3. Volatile compounds

Fruits produce a wide range of volatile compounds which earn their characteristic aromas and contribute to their flavor. Content and composition of volatile compounds are influenced by many factors including maturity stages, genetic and environmental factors, post-harvest handling, and storage (El Hadi, Zhang, Wu, Zhou, & Tao, 2013). The volatile constituents of *P. campechiana* fruit were identified and quantified by Pino (2010) using gas chromatography (GC) and GC–mass spectrometry (GC–MS) analysis. Forty-nine compounds were identified and the methyl 2-hydroxy-4-methylpentanoate (133) and S-methyl 2-propenethioate (149) were main volatiles in the ripe fruit. Total volatile content was 18.8 mg/kg determined by addition of a measured amount of internal standard to the sample prior to volatile isolation. In the findings of Ma et al. (2019), the *P. campechiana* seeds contained 22 volatile compounds. The predominant compounds were oleic acid (147), hexadecanoic acid (127), mono (2-ethylhexyl) phthalate (146), and erucylamide (107) with 10.47%, 8.16%, 6.64% and 4.22%, respectively. To date, studies on volatile compounds of *P. campechiana* have only been investigated by Ma et al. (2019) and Pino (2010). Therefore, more research is needed to cover and provide accurate and comprehensive data of volatile compounds in *P. campechiana*.

3.2.4. Others

Phytochemical investigation of the leaves of *P. campechiana* was conducted and led to the isolation of eight triterpenoids (Ren et al., 2019). Along with the six known triterpenoids isolated from the leaves, the two new substances found were 2 α ,3 β ,19 α -trihydroxy-24-nor-

13 α ,27-cycloursa-4(23),11-dien-28-oic acid (lucumic acid A) (87) and 1 β ,2 α ,3 α ,19 α -tetrahydroxy-24-norursa-4(23),12-dien-28-oic acid (lucumic acid B) (88) (Fig. 2). Lucumic acid A and B were given as trivial names by authors. The ethyl acetate extract from stem bark of *P. campechiana* was reported to include spinasterol (186) and the triterpenes namely, 3 β , 28-dihydroxy-olean-12-enyl fatty acid ester (93), a mixture of a fatty acid ester of oleanolic acid (84) and a fatty acid ester of betulinic acid (83) in a 0.3:1 ratio (Ragasa, Labacladoa, & Rideout, 2011). These triterpenes exhibited slight antimicrobial activity against some bacteria. The total alkaloid in the fruit extract (10.50%) was higher than that in leaf extract (6.44%) (Pai & Shenoy, 2020). The authors found the presence of sugar alcohols such as glycerin (177) and DL-Arabinitol (176) in *P. campechiana*. Fourier transform infrared (FT-IR) spectroscopy analysis was used by Manthra et al. (2019) to confirm the presence of alcohols, phenols, alkanes, amides, amino acids, carboxylic acids, nitro compounds, and amines in the methanol extract of *P. campechiana* bark. The other identified phytochemicals from *P. campechiana* are listed in Table 2 as additional information for future studies related to this plant.

4. Biological activities of *P. Campechiana*

Much research has indicated that *P. campechiana* has a wide variety of health-promoting properties including anti-oxidation, anti-inflammation, antimicrobial, immunomodulatory, and other activities. Fig. 3 briefly illustrates main mechanisms of action of *P. campechiana* on human health. However, a detailed discussion of findings is provided below.

4.1. Antimicrobial activity

Ma et al. (2019) and Vazhacharickal and Thomas (2018) showed that essential oil from *P. campechiana* seeds had potent antimicrobial activity against both Gram-positive and Gram-negative bacteria. In the findings of Ma et al. (2019), the essential oil appeared active against 4 microorganisms, namely *Micrococcus tetragenus*, *Bacillus cereus*, *Staphylococcus albus*, and *Escherichia coli* with zone of inhibition in the range of 11.03–16.23 mm. The essential oil presented no bacteriotoxicity against *Bacillus subtilis*. Another study of Ragasa et al. (2011) indicated that 3 β , 28-dihydroxy-olean-12-enyl fatty acid ester (93) and a mixture of a fatty acid ester of oleanolic acid (84) and a fatty acid ester of betulinic acid (83) which were isolated from ethyl acetate extract of the *P. campechiana* stem bark, slightly inhibited against the bacteria *Escherichia coli* and *Pseudomonas aeruginosa* and the fungi *Candida albicans* and *Trichophyton mentagrophytes*. Compound 93 was found to possess stronger antimicrobial activity than the mixture of compounds 83 and 84. The three compounds were inactive against *Bacillus subtilis*, *Staphylococcus aureus*, and *Aspergillus niger*. Vazhacharickal and Thomas

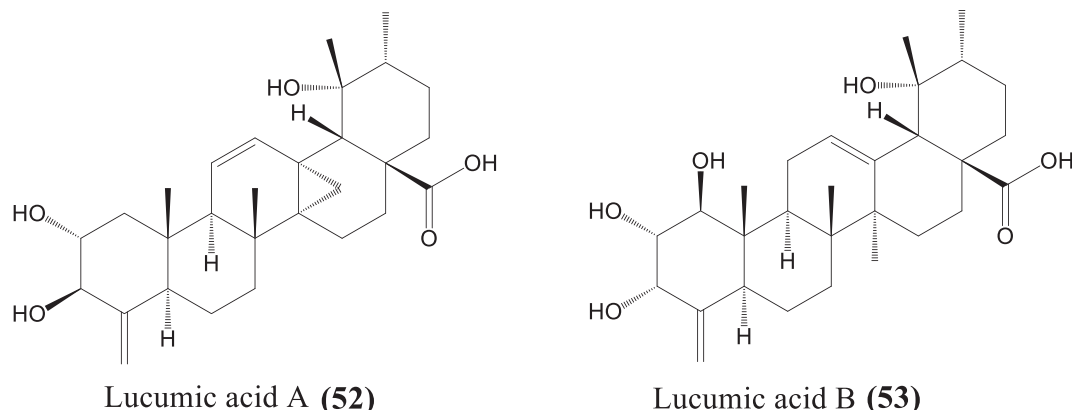


Fig. 2. Some chemical structures present in *P. campechiana*.

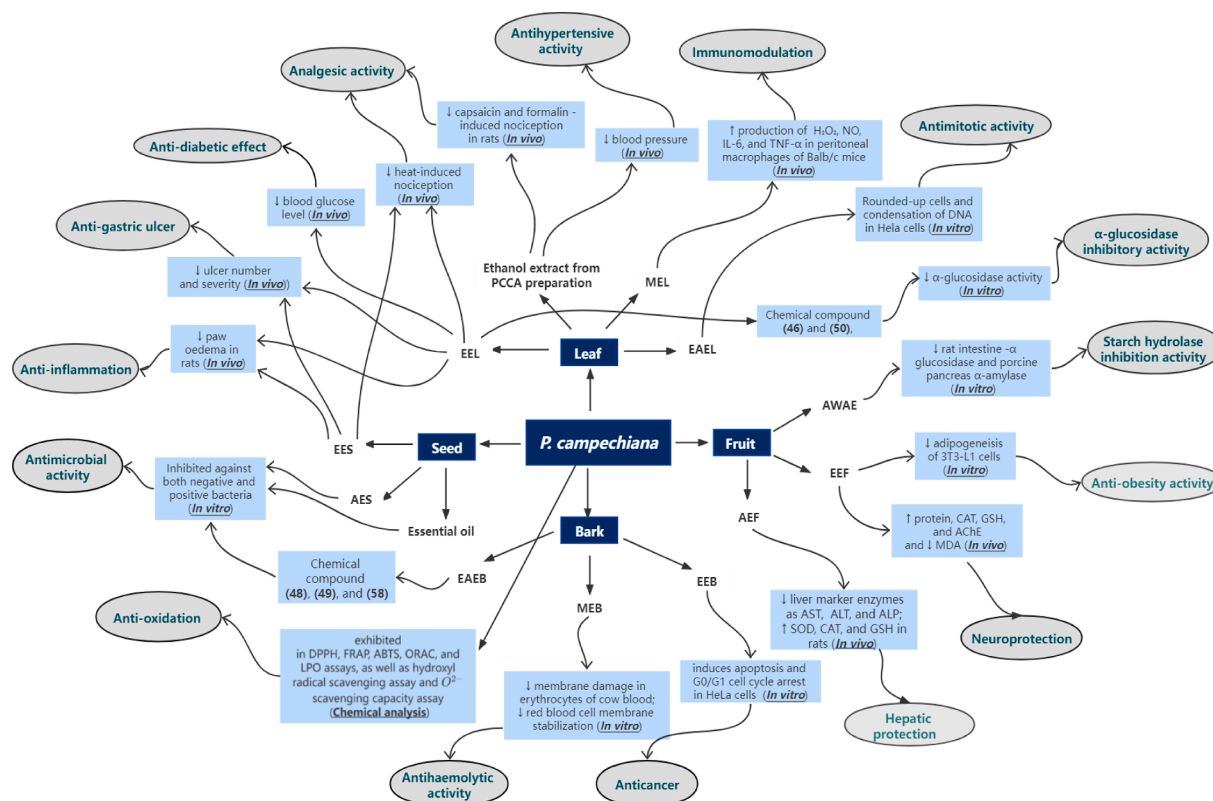


Fig. 3. Schematic representation of main mechanisms of action and outcomes of *P. campechiana* on health. Abbreviations: EAE – ethyl acetate extract from leaves; MEL – methanol extract from leaves; EEL – ethanol extract from leaves; AWAE – extract using acetone - water - acetic acid mixture from fruit; EEF – ethanol extract from fruit; AEF – aqueous extract from fruit; ethanolic extract from fruit; EES – ethanolic extract from bark; MEB – methanol extract from bark; EAB – ethyl acetate extract from bark; AES – aqueous extract from seeds; EES – ethanol extract from seeds; ↑ – increase, upregulation, enhancement, or stimulation compared to control; ↓ – decrease or inhibition compared to control; IL-6 – interleukin 6; TNF-α – tumor necrosis factor α; AChE – acetylcholinesterase; GSH – glutathione; CAT – catalase; MDA – malondialdehyde; ALP – alkaline phosphatase; AST – aspartate transaminase; ALT – alanine transaminase; SOD – superoxide dismutase; DPPH – diphenylpicrylhydrazyl radical scavenging; FRAP – ferric reducing antioxidant power; ABTS – 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid); LPO – lipid peroxidation; ORAC – oxygen radical absorbance capacity; PCCA – *P. campechiana*, *Chrysophyllum cainito*, *Citrus limonum*, and *Annona muricata* at a ratio of 1:1:1:1.

(2018) reported that the aqueous extract of *P. campechiana* seeds exhibited inhibitory potential against 5 bacteria including *Escherichia coli*, *Salmonella typhi*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Klebsiella pneumoniae* with the inhibition zone of 11, 10, 9, 11, and 9 mm, respectively. Silver, copper, and zinc nanoparticle solutions synthesized in the presence of the *P. campechiana* seed extract were found to have higher antibacterial activity compared to the nanoparticle solutions without supplementation of the seed extract. However, the effectiveness of antibacterial activity depended on the extract concentration added. The synthesized nano-ceria from leaves extract of *P. campechiana* showed antibacterial activity against *B. subtilis*, *S. aureus*, *P. syringae* and *P. aeruginosa*, but had no activity against *E. coli* (Navada, Nagaraja, D'Souza, Kouser, Nithyashree, et al., 2022a).

4.2. Antioxidant effect

The antioxidant capacity of *P. campechiana* has been determined by multiple methods such as diphenyl-picrylhydrazyl (DPPH) radical scavenging, ferric reducing antioxidant power (FRAP), 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS), lipid peroxidation (LPO) assay, hydroxyl radical scavenging, superoxide radical scavenging, and nitric oxide radical scavenging tests (Aseervatham et al., 2014; Manthra et al., 2019). According to J. Ma et al. (2004), the ethyl acetate fraction of *P. campechiana* fruit had an IC₅₀ of 146.3 µg/mL in the DPPH assay, the lowest antioxidant capacity among the three *Pouteria* species studied. A couple of studies determined antioxidant potential of wild *P. campechiana* fruit along with many other wild fruits as a supplement to the antioxidant databases of plant food (Ikram et al., 2009;

Kubola et al., 2011). For example, among 58 Malaysian underutilized fruits, the antioxidant effect of the methanol extract from wild *P. campechiana* fruit showed 0.43 mM and 73.32% of scavenging activity using FRAP and DPPH analysis, respectively (Ikram et al., 2009). Kubola et al. (2011) pointed out that among 19 Thai wild fruits, the inhibition (%) of wild *P. campechiana* fruit was 92.15% in a wide range from 26.58% in *Ensete glauca* Roxb fruit to 98.97% in *Terminalia chebula* Retz fruit determined by DPPH assay. The extracts from 2 underutilized fruits, namely carambola (*Averrhoa carambola*) and *P. campechiana* were analyzed for their total phenolics and antioxidant potential (Adiyaman et al., 2016). The findings indicated that the carambola extract with higher TPC (161.56 mg GAE/100 g) resulted in higher antioxidant potential (91.77 mg ascorbic acid equivalent antioxidant capacity (AEAC)/100 g) while the *P. campechiana* extract with lower TPC (152.45 mg GAE/100 g) showed lower antioxidant capacity (87.21 mg AEAC/100 g) by DPPH determination. The antioxidant potential and total phenolic and flavonoid contents in *P. campechiana* fruit had a significantly positive correlation (Aseervatham et al., 2014; Waisundara, 2018). Malla-waarachchi et al. (2019) investigated antioxidant capacity of different fruit pulps from 4 underutilized fruits in Sri Lanka by using ABTS, and FRAP assays. The result showed that the aqueous extract of *Phyllanthus emblica* possessed the highest antioxidant potential, followed by *P. campechiana*, *Diospyros discolor*, and *Phyllanthus acidus* observed in both tests. To differentiate the antioxidant capacity in parts of *P. campechiana* fruit, Kong et al. (2013) conducted a study concerning different extracting solvents. The solvent of 70% ethanol exhibited highest antioxidant capacity in all parts of the fruit. However, there were no significant differences in antioxidant capacity among the extracts of

peel, pulp, and seed observed in DPPH testing. Another study determined that the seed possessed the strongest antioxidant potency with an IC₅₀ value of 0.5 µg/mL, followed by the leaf, peel, and pulp with IC₅₀ values of 0.8, 8.0, and 29.0 µg/mL, respectively (Hidayah et al., 2020). The discrepant findings of antioxidant capacity in *P. campechiana* may be due to growing region, maturity stage, extraction methods, and required applied analysis methods. *In vitro* antioxidant activity of methanolic extracts from *P. campechiana* bark and *Tricosanthes tricuspidata* leaves was screened by various antioxidant assays (Manthra et al., 2019). The authors found that the *P. campechiana* bark extract exhibited high anti-radical activity in ABTS, DPPH, PLO, hydroxyl radical scavenging, and superoxide radical scavenging activity with the IC₅₀ value of 9, 41.1, 82, 220, and 48.2 µg/mL, respectively, whereas the *Tricosanthes tricuspidata* leaf extract showed moderate activity with the IC₅₀ values of 47, 63.3, 161, 130, and 84 µg/mL, respectively. Pramod, Ratheesh, Jose, and Sumi (2020) confirmed that increasing the bark extract concentration resulted in an increase of antioxidant capacity.

4.3. Analgesic activity

Elsayed et al. (2016) first investigated analgesic activity of *P. campechiana* seed and leaf extracts based on the hot plate test in male albino Wistar rats. The rats were divided into 10 groups, 0.9% saline-administered rats (control group), indomethacin-administered rats (20 mg/kg) (positive control group), and 8 other groups which treated with ethanol extract from the seeds (EES), ethanol extract from the leaves (EEL), defatted ethanol fraction from the leaves (DEL), and hexane fraction from the leaves (HFL) at two doses of 100 and 200 mg/kg. The analgesic activity observed in the ethanolic extracts from leaves was more potent than that in the extracts from the seeds. Out of 10 groups, the group administered the EEL was found to have the highest analgesic effectiveness at both doses. The DEL exhibited stronger pain relief capacity compared to the HFL. A herbal preparation composed of leaves of 4 vegetal species *P. campechiana*, *Chrysophyllum cainito*, *Citrus limonum*, and *Annona muricata* at a ratio of 1:1:1:1 (PCCA) was assessed for its antinociceptive and antihyperalgesic properties (Déciga-Campos, Ortiz-Andrade, Sanchez-Recillas, Flores-Guido, & Ramírez Camacho, 2017). The ethanolic extract preparation was conducted with 2 nociceptive tests (capsaicin and formalin) in male Wistar rats. The results indicated that the systemic antinociceptive effect of the preparation with oral administration in range of 50–400 mg/kg was dose-dependent in the 1% formalin test which produced 66% antinociceptive response at 400 mg/kg. Similarly, a concentration-dependent antinociceptive effect was also found in the 0.2% capsaicin test with administration in range of 20–160 mg/paw. The decrease of capsaicin-induced nociception showed a maximum effect of 69.5% at 160 mg/paw. The report demonstrated antihyperalgesic effects of the herbal preparation and supported the reports of its effects in traditional use as in Mayan folk medicine.

4.4. *In vitro* α-amylase and α-glucosidase inhibitory activity

The hematite nanoparticles synthesized from *P. campechiana* leaf extract found to provide moderate inhibition of pancreatic α-amylase (Navada, Nagaraja, D'Souza, Kouser, Ranjitha, et al., 2022b). An increase in the concentration of the hematite nanoparticles increased the enzyme inhibition effect. In the findings of Waisundara (2018), *Flacourtia inermis* fruit possessed the highest carbohydrate hydrolase inhibitory activity, followed by *P. campechiana* fruit through analysis of α-amylase and α-glucosidase inhibitory activities among 5 local fruits in Sri Lanka. There was no observable correlation found between these hydrolase inhibitory activities and TPC which implied that this characteristic may not be supported by phenolic compounds. Ren et al. (2019) specified that corosolic acid (81) and maslinic acid (85) in *P. campechiana* leaf extract had weak α-glucosidase inhibitory activity with the inhibitory rate of 66.3% and 55.2%, respectively at the concentration of 50 µM.

4.5. Other activities

Sánchez-Recillas et al. (2018) used the same herbal preparation as the study of Déciga-Campos et al. (2017) for examining vasorelaxant and hypotensive activities. The PCCA extract induced a significant vasorelaxation with maximal effects of 65.78% at medium effective concentration (EC₅₀) of 463.43 µg/mL. The vasorelaxant effect of the PCCA was present in both endothelium-intact and endothelium-denuded aortic rings and this effect was in a concentration-dependent manner and was partially endothelium-dependent. Oral administration of the PCCA in male Wistar rats significantly decreased systolic blood pressure with 12%, 12.5%, and 10% at 200 mg/kg and 5.77%, 9.19%, and 10% at 300 mg/kg after 1, 3, and 5 h of the administration. The blood pressure returned to baseline after 7 h of administration at both doses. The methanol extract from *P. campechiana* leaves (MEL) was found to have an immunomodulatory effect on phagocytic activity, through the production of (nitric oxide) NO, hydrogen peroxide (H₂O₂), interleukin 6 (IL-6), and tumour necrosis factor α (TNF-α) in peritoneal murine macrophages of BALB/c mice (Chan-Zapata et al., 2018). In order to understand whether aqueous extract of *P. campechiana* fruit (AEF) could reduce acetaminophen-induced hepatic damage, the male Wistar rats were divided into different groups pre-treated with AEF at different concentrations (150 and 250 mg/kg) (Aseervatham et al., 2014). Treatment with AEF induced a significant decrease in the liver marker enzymes such as aspartate transaminase, alanine transaminase, and alkaline phosphatase and showed an increase in the antioxidant enzymes involving superoxide dismutase (SOD), catalase (CAT), and glutathione (GSH) in rats. The increase in activities of SOD, CAT, and level of GSH in the group administered with AEF at 250 mg/kg was equivalent to that in the positive control group treated with silymarin of 50 mg/kg. The results suggest that *P. campechiana* fruit extract has significant hepatoprotective effects against acetaminophen-induced hepatotoxicity. Angiogenesis is the result of the complex balance between proangiogenic and antiangiogenic factors and it initiates tumor growth, metastasis, and cancer progression (Pour, Hajek, Buchler, Maisnar, & Smolej, 2004). The report of Pulido and Gari (2017) showed that *P. campechiana* leaf extract possessed an inhibitory effect on angiogenesis. In comparison with an ibuprofen-treated positive control group, the potential of the inhibitory effect from the leaf extract was stronger in the chorioallantoic membrane of 12-day old duck embryo. Twelve compounds, ampelopsin A (75), ampelopsin B (76), balanocarpol (77), ε-viniferin diol (80), hopeaphenol (78), vaticaphenol A (79), taxifolin 3-O-α-arabinofuranoside (66), trans-taxifolin 3-O-α-arabinopyranoside (68), quercetin 3-O-α-rhamnopyranoside (70), myricetin 3-O-α-rhamnopyranoside (63), taxifolin 3-O-α-rhamnopyranoside (67), quercetin 3-O-β-arabinopyranoside (65) isolated from *P. campechiana* were evaluated for their antimitotic activity (Hernandez et al., 2008). Only ampelopsin B (76) was scored as positive in the primary screen and demonstrated characteristic cell rounding and condensation of DNA seen in HeLa cells arrested during mitosis. The authors suggested that compound 76 could act as a weak microtubule depolymerizer. In order to search for plant foods with anti-obesity activity in Okinawa prefecture, an *in vitro* investigation of the inhibitory activity on adipogenesis and the promotion of adipolysis a large scale study of 102 plant foodstuffs was conducted by Niwano et al. (2009). In their findings, *P. campechiana* fruit was found to be among 31 plant foodstuffs that exhibited 50% or more inhibition of adipogenesis in 3 T3-L1 cells while only 4 plant foodstuffs showed 50% or more stimulation of adipolysis of 3 T3-L1 cells. The anti-haemolytic activity of the methanol extract from *P. campechiana* bark (MEB) was examined by Manthra et al. (2019). The membrane damage induced by H₂O₂ in cow erythrocytes was inhibited by MEB at 34.66% and the maximal inhibition of hemolysis was obtained with 83.54% red blood cell membrane stabilization at a concentration of 500 µg/mL. At the same concentration, the standard butylated hydroxyl toluene (BHT) exhibited inhibition of hemolysis of 89.63%.

Tagne, Kengne, Doungue, Kemtsop, and Enyong (2020) evaluated the effect of *P. campechiana* fruit on aluminum chloride-induced Alzheimer's disease in albino rats. The results showed that the administration of aluminum chloride with 100 mg/kg twice a week during 42 days in the rats reduced total proteins, CAT, GSH, and acetylcholinesterase (AChE) activities and increased malondialdehyde (MDA). Supplementation at 200 and 400 mg/kg of ethanolic extract from *P. campechiana* fruit (EEF) and at 5% and 10% of fruit powder resulted in an increase of total proteins, CAT, GSH, and AChE and a decline of MDA in the aluminum chloride-treated rats. A greater neuroprotective effect was achieved at 400 mg/kg of the EEF and 10% of the fruit powder. The anti-diabetic effects of *P. campechiana* leaves were also investigated by Vishnupriya (2017). The ethanolic extract of *P. campechiana* leaves consumed at two concentrations (200 and 400 mg/kg) had a very significant impact on lowering the blood glucose level of alloxan-induced diabetic albino rats compared to the control group. However, increase in concentration of the leaf extract did not show a decrease in the blood glucose level; for example, the diabetic rat groups treated with 200 and 400 mg/kg showed blood glucose levels of 11.56 and 11.62 mmol/L, respectively on 21st days. Another study found that leaves and seeds of *P. campechiana* had anti-gastric ulcer and anti-inflammatory effects (Elsayed et al., 2016). Among different extracts and fractions, the EEL showed the highest anti-ulcer activity with 95.98% of ulcer number inhibition while the EES revealed the strongest anti-inflammatory effect with 85% of oedema inhibition in albino rats at a dose of 200 mg/kg. *P. campechiana* extract has been demonstrated to suppress the viability of cancer cell lines. Pramod et al. (2020) assessed the *in vitro* cytotoxicity of ethanolic extract of *P. campechiana* bark (EEB). Treatment with the EEB induced apoptosis and G0/G1 cell-cycle arrest associated with independent up-regulation of p21 (WAF1/CIP1) in HeLa cells. The hematite nanoparticles synthesized from *P. campechiana* leaf extract manifested the A549 lung cancer suppressive activity with a cell viability of 33.39% at 500 µg/mL (Navada et al., 2022b).

5. Processes and product development of *P. Campechiana*

5.1. Lactic acid production

To consider suitability of ripe *P. campechiana* fruit pulp for lactic acid production through fermentation, three *Lactobacillus* strains, *Lactobacillus plantarum*, *Lactobacillus acidophilus*, and *Lactobacillus casei* has been investigated (Umesh, Thazeem, & Vikas, 2016). The authors reported that after 4 days of fermentation, *L. casei* produced the greatest amount of lactic acid with 20.07 g/L, followed by *L. acidophilus* and *L. plantarum* with 19.84 and 18.91 g/L respectively. Regarding all the utilized strains, the L-lactic acid contributed to 20% of total lactic acid.

5.2. Powder and starch production

The benefits of powder production from *P. campechiana* are to increase shelf life, reduce the costs of transportation and storage, and extend the possibility of out-of-season availability. Moreover, dried powder from *P. campechiana* can be used as natural food colorant or for diversifying the supply of foods with different flavors and textures. Influences of different drying methods on chemical and physical properties and technological characteristics have been reported (Anjo et al., 2021; Nguyen et al., 2019). For example, among two drying methods, the freeze drying resulted in the powder of *P. campechiana* fruit pulp with higher carotenoid content, more intense color, and greater technological characteristics in comparison with thermal drying using an air circulation oven at 70 °C (Anjo et al., 2021). Similarly, Nguyen et al. (2019) concluded that the freeze drying produced better fruit pulp powder in terms of vitamin C (5.11 mg/100 g), total sugar (35.00%), and total carotenoid content (1.71 mg/100 g), while the hot air drying resulted in lower results with vitamin C (2.14 mg/100 g), total sugar (31.45%), and total carotenoid content (1.28 mg/100 g). Pretreatment

also has influence on quality characteristics of *P. campechiana* powder. Pre-soaking the fruit pulp in citric acid solution had a negative impact on the powder color although this pretreatment could eliminate the bitter taste. In contrast, pre-soaking in NaCl solution was better to eliminate the bitter taste and maintain the orange color of canistel fruit pulp powder (Pertiwi, Nurhalimah, & Aminullah, 2020). Amalia, Setiarto, Fitrilia, and Masyrifah (2021) found that the pre-blanching in water at 80 °C for 10 min for powder production from *P. campechiana* seeds reduced the swelling power of starch granules, accelerated the thickening, promoted retrogradation, decreased nutrient content, and broke the granule structures in the seed. Pertiwi, Sunarya, and Rohmayanti (2020) predicted the optimization of egg albumin and maltodextrin contents and water for producing a powder with 25% of overripe *P. campechiana* fruit pulp. In the findings, egg albumin of 16.88%, maltodextrin of 8.12%, and water of 50.00% were optimal conditions, which resulted in validated values of the yield of 61.20 %, moisture content of 7.09 %, and β -carotene content of 0.63 mg/kg in the powder.

Starch is a naturally occurring carbohydrate which is biodegradable, inexpensive, renewable and widely available in various plants (Dereje, 2021). It not only provides energy for animals and humans but is also the primary raw material for industries. In the food sector, starch is commonly used as food additives for functions such as gelling, stability, thickening, binding, and texture improvement. Both starches isolated from *P. campechiana* fruit pulp and seed have A-type crystal structure (He et al., 2021; Li et al., 2021). The A-type crystalline starch of *P. campechiana* seed showed a more tightly packed amorphous structure, higher supramolecular content density, and ordered arrangement helix configuration, resulting in a more compact crystalline structure than that of B-type crystalline sweetsop pulp starch (Li et al., 2023). In the findings of He et al. (2021), freeze and vacuum drying resulted in the appearance of cracks and debris in starch granules isolated from the pulp. In addition, the hot-air and freeze-drying process promoted starch gelatinization and decrease of double helix number. *P. campechiana* seed starch (PCSS) had higher amylose content and long/short range order, lower porosity, and smoother, smaller particle morphology than *P. campechiana* pulp starch (PCPS). This resulted in lower water absorption capacity (WAC), final viscosity, gel hardness, and gel adhesiveness of PCSS and higher pasting temperature, peak temperature, breakdown viscosity, and peak viscosity of PCPS (Li et al., 2021). According to Li et al. (2022), the relatively stronger intermolecular hydrogen bonding among glycosidic bonds and stronger van der Waals forces among the helices of PCSS lead to the formation of a high number of double helix or V-polymorph arrangements and dense nano-nodules in amylopectin clusters which is in contrast to PCPS. Pertiwi, Rajani, and Novidahlia (2022) considered effects of heat-moisture treatment on the native starch isolated from fully ripe *P. campechiana* pulp on the pasting profile, physicochemical, and crystallinity properties. The heat-moisture treatment for starch increased in the initial and peak temperatures of gelatinization, peak time, trough viscosity, setback, and final viscosity and decrease peak and breakdown viscosities. In addition, the treatment made a more tenuous structure and had higher crystallinity degree. Nevertheless, this heat-moisture treatment significantly reduced the yield, brightness, and amylose content of the starch. Based on these obtained properties, untreated starch was suitable for frozen food, whereas heat moisture treated starch can be applied in noodle processing and as a thickener (Pertiwi et al., 2022). Agama-Acevedo et al. (2022) found that resistant starches isolated from *P. campechiana* pulp and seed after cooking remained at 33.3 and 32.6 %, respectively. The cooked seed starch showed an increase in slowly digestible starch content while the cooked pulp starch had an increased content of rapidly digestible starch. Some studies suggested that *P. campechiana* seed starch may serve as a potential alternative for starch in staple crops because it was shown to have similar characteristics to jackfruit seed, cassava, and pea starch (Li et al., 2021; Li et al., 2022).

5.3. Extraction of polysaccharides

Plant polysaccharides have been used for industrial applications including pharmaceuticals, biomaterials, food stuff and nutrition, and biofuels. The pharmacological activities of plant polysaccharides are antioxidant activity, antitumor activity, antimicrobial activity, promotion of wound healing, and immunostimulatory activity (Li, Niu, Xing, & Wang, 2018). The research of Zhu, Chu, Wei, Zong, and Lu (2011) found

the content of water-soluble polysaccharides in *P. campechiana* seed was high at 8.66%. Ma et al. (2020) found that the use 95% ethanol solvent with a liquid-to-material ratio of 41 mL/g, ultrasonic temperature of 79 °C, and ultrasonic time of 69 min provided the optimal conditions for polysaccharide extraction from *P. campechiana* seed powder, resulting in the polysaccharide yield of 15.94%. The purified seed polysaccharide composed of glucose and mannose with a molar ratio of 86.65:4.62 contained $\rightarrow 4$)- α -D-Glc(1 $\rightarrow$ and $\rightarrow 6$)- α -D-Glc(1 $\rightarrow$ glycosidic bonds.

Table 3

Patent list of products containing components from *P. campechiana* and their stated health-promoting properties.

Application	Composition	Health prompting properties	Publish number	Publication year
Sausage	Pork, brown rice powder, mung bean powder, hawthorn leaf, disk flowers of sunflower, ginseng, five-leaf ginseng, Chinese ginseng, epimedium, <i>Ilex asprella</i> root, Chinese mesona, bluecrown passionflower, apple, <i>P. campechiana</i> fruit pulp, Asian palmyra palm fruit, blueberry fruit, and water.	—	CN103230038A	2013
Milk shake	<i>P. campechiana</i> fruit pulp, starfruit, milk, felwort, Chinese chestnut leaf, <i>Lysimachia christinae</i> Hance., dandelion, English walnut, galangal, caster sugar, watermelon powder, jujube flower honey, peach blossom, <i>Lactobacillus bulgaricus</i> , and water.	—	CN103262938A	2013
Dried bean curd	Soybean, wood ear, pea, a nutrition additive, sword bean, avocado, seaweed powder, sesame oil, <i>Colocasia esculenta</i> tuber, <i>P. campechiana</i> fruit pulp, whitebait, yellow peach, dragon fruit, oatmeal, sugarcane juice, <i>Achyranthis bidentatae</i> , <i>Caragana sinica</i> , <i>Monochoria vaginalis</i> , fresh ginger, Chinese violet and <i>Lindernia ruellioidea</i> .	Immunity enhancement and life extension	CN104146069A	2014
Tea	<i>P. campechiana</i> fruit pulp, caster sugar, ascorbic acid, citric acid, xanthan gum, sodium carboxymethyl cellulose, and sucrose fatty acid ester.	—	CN103564557A	2014
Biscuit	Sweet potato, sweet potato dietary fiber, purple rice, kudzu vine root, medlar, hawthorn, Chinese date, <i>P. campechiana</i> fruit pulp, carrot, soybean, black sesame, millet, pineapple, cow milk, rose.	—	CN104799317A	2015
Paste	Fresh jujube, whitebait, passion flower, litchi fruit, pollen pini, <i>Stauntonia latifolia</i> , bamboo seed, cress, beetroot powder, tamarindus, coconut meat, black potato, yam bean powder, pig blood curd, Chinese yam, <i>P. campechiana</i> , peach juice, selfheal, ginkgo leaf, <i>Lucid ganoderma</i> , <i>Astragalus membranaceu</i> , other raw materials.	—	CN105029354A	2015
Vitamin C	<i>P. campechiana</i> fruit pulp, citric acid, vitamin C, table sugar, sodium carboxymethyl cellulose, and water.	—	CN105146377A	2015
Powder	Honey, peach, <i>Pleurotus eryngii</i> , rye grain, watermelon peel, <i>Arctium lappa</i> L root, corn flour, <i>P. campechiana</i> fruit pulp, <i>Portulaca oleracea</i> , red cabbage, mangosteen, sweet potato stem, lotus seed powder, and yogurt.	—	CN104824501A	2015
Jam	<i>P. campechiana</i> fruit pulp, watermelon, maltose, white sugar, watermelon juice, jelly powder, and water.	Diuresis, digestive aid, cough suppressant, and hypolipidemic effect	CN104719701A	2015
Canned juice	<i>P. campechiana</i> fruit juice, watermelon juice, lemon juice, pear juice, salt, sodium alginate, citric acid, sodium citrate, calcium lactate, calcium gluconate, and sodium carboxymethyl cellulose	Digestive aid, producing refreshing effect to the mind, and sedative effect	CN104719790A	2015
Jam	<i>P. campechiana</i> fruit pulp, multivitamins, brown sugar, lemon juice, <i>Ganoderma lucidum</i> powder, and white vinegar.	—	CN105455081A	2016
Jam	<i>P. campechiana</i> fruit pulp, coconut meat, maltose, watermelon juice, and jelly powder.	—	CN105639545A	2016
Jelly	<i>P. campechiana</i> fruit pulp, flower of <i>Plumeria rubra</i> L. cv. <i>Acutifolia</i> , <i>Lycopodium japonicum</i> , agar, Chinese medicine powder, xylitol, water	Reducing phlegm, tonifying the kidney, refreshing the brain, promoting blood circulation, and strengthening the body	CN105533583A	2016
Milk	<i>P. campechiana</i> fruit pulp, soybean, napa cabbage, <i>Sorghum bicolor</i> , water, <i>Oviductus ranae</i> , <i>Panax quinquefolius</i> , flower of <i>Plumeria rubra</i> L. cv. <i>Acutifolia</i> , evening primrose, ginkgo, spearmint, high-fructose corn syrup, and sesame powder	—	CN106212703A	2016
Wine	<i>P. campechiana</i> fruit pulp, pectinase, yeast, and sulfur dioxide	—	CN105713765A	2016
Jelly	<i>P. campechiana</i> fruit pulp, agar, honey, citric acid, strawberry, milk, and water.	Strengthening bones, aiding digestion, and reducing phlegm	CN105558963A	2016
Candy	<i>P. campechiana</i> fruit pulp, <i>Lithospermum</i> , <i>Homalomena occulta</i> , root of <i>Inula nervosa</i> Wall., root and bark of <i>Litsea coreana</i> , white sugar, starch syrup, and water	Easing sore and pain in loin and legs	CN106666022A	2017
Yogurt	Flower of <i>Aglaia odorata</i> , <i>P. campechiana</i> fruit pulp, tamarind pulp, kudzu vine root, milk powder, lactic acid bacteria, and water.	Relieving dizziness and headache caused by alcohol consumption	CN106665836A	2017
Beverage	<i>P. campechiana</i> fruit pulp, passion flower, black bean, cashew nut, pumpkin juice, fish mint juice, honey, konjac flour, and water	Immunity enhancement	CN106261320A	2017
Healthy drink	<i>P. campechiana</i> fruit pulp, malt, noni, mulberry, goji berry, cape jasmine, white sugar, lactic acid bacteria and <i>Saccharomyces</i> , and water	Heat clearing, relieving summer-heat, anti-inflammation, appetizing.	CN107752019A	2017
Cake	<i>P. campechiana</i> fruit pulp, cake flour, sugar, evaporated milk, eggs, butter, sodium bicarbonate, baking powder, orange juice, edible oil, frosting.	—	PH22019000228Y1	2019
Ice cream	all-purpose cream, condensed milk, evaporated milk, ripe fruit pulp	—	PH22019000401Y1	2020
Cookie	<i>P. campechiana</i> fruit pulp, eggs, evaporated milk, butter, vanilla, wheat flour, sugar, and raisins.	—	PH22020050751U1	2021

With a molecular weight of 67.9 kDa and a strip structure with smooth surface determined by scanning electron microscopy, the purified polysaccharide showed strong scavenging capacity through DPPH, ABTS, hydroxyl radical, and superoxide radical assays. Polysaccharides of *P. campechiana* seeds could be exploited as a natural antioxidant. To date, there is only one study on the extraction of polysaccharides from *P. campechiana*, which was completed by Ma et al. (2020).

5.4. Carotenoid pigment extraction

Conventional methods such as Soxhlet extraction and maceration are utilized the most for natural colorant extraction. Juniarti (2016) investigated extraction of carotenoid pigment from *P. campechiana* fruit pulp using the maceration method. The 80% acetone concentration and maceration time of 4 days at solid-to-liquid ratio of 1:3 yielded the highest carotenoid content of 271.44 mg/g and pH of 4.87. The research of Huynh and Nguyen (2022) used different solvents including n-hexane, dichloromethane, mixture of n-hexane and dichloromethane (v/v = 1:1) at the solid-to-liquid ratios of 1:15, 1:20, 1:25, and 1:30 to extract pigment from *P. campechiana* pulp. The usage of the mixture of n-hexane and dichloromethane resulted in the highest yield. Although the solid-to-liquid ratio of 1:30 showed the highest yield among the applied ratios, the highest carotenoid content obtained was at the ratio of 1:15 which led to the greatest antioxidant capacity with 224.39 mmol Trolox equivalent/100 g DW. The pigment was the most stable at neutral pH. In an unconventional extraction method, carotenoid pigment in *P. campechiana* pulp powder was extracted using ultrasound assisted extraction (Z. Fang et al., 2013). The results found that the optimal extraction conditions within the experimental ranges were an extraction solvent of 70% ethanol, ultrasonic power of 200 W, temperature of 40 °C, extraction time of 20 min, and a liquid-to-solid ratio of 20:1.

5.5. Product development

P. campechiana fruit is usually consumed as a dessert, drink, and as salad ingredient. Applications of *P. campechiana* in foodservice industry are also offered as a wide variety of products such as vinegar (Gu & Sheng, 2011), tea, wine, yogurt, jam, candy, and cookies (Table 3). *P. campechiana* fruit pulp powder was used as a substitute for all-purpose flour in a cookie product (Paragados, 2014). Adding the fruit pulp powder at all levels (25%, 50%, 75%, 100%) significantly increased the acceptability of product in terms of aroma, texture, flavor, and overall acceptance compared to the control sample. However, there was no significant increase in terms of appearance. Butter supplemented with *P. campechiana* fruit pulp in order to enhance color and carotenoid content also exhibited the positive results in acceptability (Puspita, Kurniawan, & Aiboi, 2019; Puspita, Rahardjo, Sanubari, & Kurniawan, 2018). Padilla et al. (2016) established a standard recipe for *P. campechiana* polvoron and calculated the selling price of the product. The standard recipe described contained *P. campechiana* pulp powder, all-purpose flour, skim milk powder, brown sugar, and butter in a ratio of 40:13.34:26.66:13.34:6.66, respectively. The *P. campechiana* polvoron prepared by the standard recipe could sell at reasonable price of 7.45 Philippine peso per piece. A spicy snack prepared from rice flour mixed with *P. campechiana* fruit pulp powder was developed by Bulathkandage, Henadeera, and Jayapala (2016). The *P. campechiana* snack packed in polypropylene bags (300 gauge) at room temperature (28–30 °C) extended shelf life for 5 weeks. Panelists preferred the new snack product to the traditional snack that existed in the market. The mixture prepared from 90% ripe *P. campechiana* pulp powder and 10% modified cassava flour with 1% guar gum was considered the best composite flour among the designed formulas to produce snack noodles with high sensory acceptability (S. R. R. Pertiwi, Novidahlia, Aminullah, Rohmayanti, & Siwi, 2022). S. R. R. Pertiwi, Aminullah, Hutami, and Nirmala (2018) analyzed the effects of non-gluten type and pan size on the quality of steamed brownies. Three different flour groups, namely

mixture of *P. campechiana* pulp powder and corn flour, mixture of *P. campechiana* pulp powder and modified cassava flour, and mixture of *P. campechiana* pulp powder and tapioca flour in a ratio of 1:1 was added to other ingredients and steamed in different brownie pans (L × W × D, cm), namely small size (20 × 7 × 2), medium size (22 × 9 × 2), and large size (24 × 11 × 2). The best steamed brownies were prepared from the flour mixture of *P. campechiana* pulp powder and modified cassava flour using the small brownie pan. The best product contained 21.55% of moisture, 1.28% of ash, 4.16% of protein, 22.50 % of fat, 50.51% of carbohydrate, 1.75 % of dietary fiber, 1.11 mg/100 g of total β carotene, and had an energy of 1762.22 kJ/100 g. Processed cheeses have a distinct mild flavor evolved from the transformation of natural cheeses by melting and pasteurization with the support of emulsifying salts (Kelly, 2019). Using a combination of inulin (0.5%) and *P. campechiana* fruit pulp powder (3%) to produce processed cheese at formulas of 50% and 100% butter fat content reduction (Saraiva et al., 2020), the findings showed the *P. campechiana* fruit pulp powder and inulin supplementation resulted in softer processed cheese and improved color compared to the control formulation. The elastic behavior of 50% fat reduced formulation exhibited greater stability during heating than that of the 100% fat reduced formulation. Anjali et al. (2020) revealed *P. campechiana* fruit pulp powder as a rich source of antioxidants and when incorporated into ice cream, induced enhancement of color, flavor, and texture properties.

Topical anti-aging nanoemulsion with added *P. campechiana* fruit extract was tested by Yahya and Wahab (2017). A combination of high-speed homogenization and phase inversion temperature method was used to prepare the nanoemulsion. The particle size and polydispersity index of the nanoemulsion obtained were 179.40 nm and 0.262, respectively. The nanoemulsion was stable in centrifugal testing and at different storage temperatures (25 °C and 45 °C) for 45 days. Under such storage conditions, the pH of the nanoemulsion was in the range of 4–7 which could be applied to human skin. Personal care and cosmetic products such as hand-washing solutions, facial masks, and skin care creams could be developed from *P. campechiana*.

6. Storage of *P. Campechiana*

Fruits are a good source of vitamins and minerals in the diet. However, they start to degrade after harvesting because of high water content and richness in nutrients which attract spoilage microorganisms and pests. Investigation into the changes of quality and shelf life of post-harvest *P. campechiana* fruit, as well as proper storage conditions are important for reducing post-harvest losses and ensuring consumer safety. Adiyaman et al. (2013) found that cold storage at 4 °C in combination with packaging of 1% vented high density polyethylene bags (200 gauge), *P. campechiana* fruit pretreated with solution of calcium chloride and 2% sodium chloride had an extended shelf life (20 days) compared to the fruit pretreated with 1.5% potassium metabisulphite solution (17 days). The influence of harvesting stage and packaging materials on shelf-life of *P. campechiana* fruit was studied by Gomolmanee and Ketrosakul (2011). The fruits were classified into 4 groups according to harvest stage, M1 (green/yellow = 1/0), M2 (green/yellow = 3/1), M3 (green/yellow = 1/1), and M4 (green/yellow = 1/3). It was reported that after harvesting and being stored at an ambient temperature of 25 °C (85% RH), the total soluble solid contents of the 4 fruit groups packed with polypropylene, polyethylene, and polyvinyl chloride bags increased after 14 days of storage. Regarding storage at 10 °C (95% RH) in combination with the packings, *P. campechiana* fruits at M3 and M4 stages appeared yellow on 7th day of storage whereas the fruits at M1 and M2 stages could not turn yellow and ripen normally. A recent study investigated changes in the phytochemicals of *P. campechiana* fruit during storage at room temperature (Hien, Huong, & Thanh, 2019). *P. campechiana* fruit harvested after about 120–125 days of fructification, the contents of polyphenols, flavonoids, and tannins in the fruit decreased steadily, while the carotenoid content increased and reached

the highest content of 124.27 mg/g on 10th day during 12 days of storage.

7. Toxicity assessment

Studies on the safety and side effect evaluations for *P. campechiana* are limited although multiple biological activities have been reported. The ethanol extracts of PCCA herbal preparations were evaluated for their acute toxicity in rats at 5, 50, 300, or 2000 mg/kg/day for 14 days after oral administration (Sánchez-Recillas et al., 2018). The treated rats did not exhibit signs of toxicity such as tremors, convulsions, salivation, diarrhea, lethargy, sleep, and piloerection. There were no changes observed in the outer appearance including skin, fur, eyes, and mucous membranes. Levels of erythrocytes, platelets, hemoglobin, hematocrit, glucose, cholesterol, serum glutamic oxaloacetic transaminase, and serum glutamic pyruvic transaminase in the blood biochemical analysis of the treated rats showed no differences. However, the leukocyte level at dose of 5 mg/kg/day and the level of serum triglycerides at dose of 2000 mg/kg/day were significantly increased. To our knowledge, there are no studies available in literature reporting toxicity assessment except the report of Sánchez-Recillas et al. (2018). Thus, we propose researchers need to put more efforts into studying *P. campechiana* toxicity and safety.

8. Conclusion

P. campechiana is an underutilized plant that is worthy investigating due to its substantial biological activities and potential applications in the food industry. *P. campechiana* fruit has been shown to be rich in nutrients, vitamins including vitamin C, minerals, fiber, polyphenol compounds, flavonoids, and carotenoids. Environmental factors, growing area, harvesting time, and maturity stage at collection influence the content of nutrients and phytochemical composition. *P. campechiana* has been demonstrated to have health benefits for human beings through both *in vitro* and *in vivo* studies. However, these studies are still unclear and insufficient, and it is highly vital to specify active constituents and clarify underlying mechanisms of action to scientifically validate pharmacological applications. Clinical study of *P. campechiana* is also needed to explore efficacy. There is a gap in the research of polysaccharide extraction techniques from *P. campechiana* seed. Thus, we propose researchers need to put more efforts into studying polysaccharide extraction in terms of choosing extraction solvent and method, as well as biological activity and characterization of extracted polysaccharides from this plant seed and fruit pulp. *P. campechiana* is indigenous to Mexico and Central America, however, information and scientific literature on processes and product development are really limited. Therefore, food scientists and technologists in these locations need to make further progress in considering and developing products containing *P. campechiana* and evaluating the quality and sensory characteristics of the products. To date, only a few commercial *P. campechiana* products have been available on the market so we encourage the cosmetic and food manufacturers to conduct studies to develop more products for consumers.

The present article elucidated the botany, phytochemistry, and health benefits of *P. campechiana*, as well as its processes and product development trends. The knowledge of *P. campechiana* presented here serves as a resource for students and professionals seeking information or may facilitate prospective application of *P. campechiana* in the functional food, dietary supplementation, and pharmaceutical fields.

Ethical statements

This study did not involve human or animal subjects. Therefore, no approvals for human or animal research were necessary.

Declaration of Competing Interest

The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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