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An overview of the chemical constituents, pharmacological properties, and safety evaluation of *Camellia sinensis* flowers

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ABSTRACT

The young leaves of *Camellia sinensis* (L.) Kuntze are most-studied *in vitro* and *in vivo* with little attention on other parts of the plant. This overview is focused on the chemical constituents and pharmacological properties of the lesser-known flowers of *C. sinensis* with brief descriptions on their morphology, reproductive biology, and uses. Studies on the chemical constituents and pharmacological properties of *C. sinensis* flowers are on flower buds and not on open flowers. Chemical compounds found in tea flowers include flavonols, catechins, polysaccharides, saponins, proteins, alkaloids, spermidine derivatives, and anthocyanins. Major pharmacological properties of *C. sinensis* flowers include hypoglycemic, anti-cancer, antioxidant, hypolipidemic, modulation of gut health, antimicrobial activities, and anti-inflammatory activities. Other pharmacological properties are hepatoprotective, immunoregulatory, β-amyloid aggregation inhibitory, gastroprotective, nephroprotective, anti-obesity, anti-allergic, anti-cholesterol, pancreatic lipase inhibitory, melanin synthesis inhibitory, and non-alcoholic fatty liver disease activities. The potentials and challenges of development of health supplements and other commercial products from tea flowers are discussed.

INTRODUCTION

The tea plant *Camellia sinensis* (L.) Kuntze belongs to the family Theaceae. The species has two varieties, namely, *C. sinensis* var. *sinensis* (China tea) and *C. sinensis* var. *assamica* (Assam tea) [1,2]. The former is grown in China, Japan and Taiwan, while the latter predominates in South and Southeast Asia, including Australia and Africa. Tea is mostly planted in the highlands and rarely in the lowland [2].

Tea var. *sinensis* is an evergreen, multi-stemmed shrub that grows up to 3 m in height while tea var. *assamica* can grow up to 10−15 m tall with one main stem [1,3]. Under cultivation, young leaves of *C. sinensis* are regularly picked and tea plants are pruned and trained to a low profusely branching and spreading bush of 1.0−1.5 m in height. Leaves are alternate and obovate-lanceolate in shape with a short petiole, serrate margin, and pubescent on the lower surface. In var. *sinensis*, leaves are dark green, leathery, narrower, and marginal veins are indistinct. In var. *assamica*, leaves are lighter green, thinly leathery, wider, and longer, with distinct marginal veins. Tea flowers are axillary, occurring as single flowers or as clusters of 2−4 flowers and emit a mildly sweet fragrant. Flower petals are white or light pink and stamens bear many yellow anthers (Fig. 1a). Styles are free (var. *sinensis*) or partly fused (var. *assamica*) with stigmatic lobes [1,3]. Between varieties of *C. sinensis*, flowers possess different morphology and fruit yield [4]. Phenotypic traits include pistil length, stamen length, and stigma width.

In China, tea flower buds are produced in May with flowers blooming from September to December [5]. In Sri Lanka, flowering periods of *C. sinensis* occur from February to April, and from July to November [6]. The tea plant is a facultative outbreeder, i.e., cross-pollination results in a higher fruit set than self-pollination [7]. Most pollen has the ability to germinate on the cross-pollinated stigma [4].

Flies and bees have been observed to be the pollinators of the tea plant and fruiting is from February to May [8]. Another study in Sri Lanka reported that the major flowering season is from September to December and the major fruiting season occurs from April to August [9]. Tea flowers can be classified into four development stages, namely, green or young

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buds, white or mature buds (Fig. 1b), half-open flowers, and full bloom flowers (Fig. 1a) [10]. The yield of tea flowers varies from 3−12 tons/ha/year [11], with 8.8 tons/ha/year as the average [5]. It has been estimated that China produces 4−12 million tons of tea flowers each year [5,11]. An added advantage of removing the tea flowers is that the yield and quality of tea leaves are enhanced by ~30% the following year [11].

Previously, tea plantations in China were focused on producing tea from the young leaves [5]. Tea flowers were discarded or sprayed with chemicals to induce foliage production and not floral growth. Plant growth regulators such as ethephon, paclobutrazol, and chlormequat have shown to be effective in promoting the abscission of tea flower buds and flowers in tea plantations [12].

In recent years, tea flowers in China have been used to manufacture food, beverage, and cosmetics [5]. Tea flowers are dried (Fig. 1c) and consumed as a tea beverage when steeped in hot water [13]. The drying process involves hot-air drying or in combination with microwave drying [14,15]. Beverage produced from white or mature flower buds is the best, yielding a tea that is bright orange-yellow in color, and has a flowery or chestnut aroma, and a sweet and mellow taste. Black tea produced from tea leaves has been scented with dried tea flowers [16]. A fermentation technology for producing cider from tea flowers has been formulated [17]. Tea flowers can also be used to make a weak alkaline soap with a creamy white color and tea flower fragrance [18]. The tea flower soap has a strong ability in cleaning and protecting the skin. A facial cream from tea flower has been formulated and patented in China [19]. In Japan, tea flowers have been used as preservative for traditional soya products such as miso (fermented soybean paste) and tsukudani (boiled food in sweetened soy sauce) [20]. Honeybees (*Apis mellifera*) pollinating tea flowers are known to produce quality honey [21]. The honey contains theanine, a very rare amino acid derived from tea flowers. Furthermore, the nectar of tea flower has the highest concentration of caffeine that the activated the brain function of honeybees to produce the honey.

In the past 15 years or so, tea flowers have generated scientific and commercial interest [11]. The importance of this alternative resource has led to the establishment of the International Institute of Tea Flowers in Japan and the International Research and Development Center of Tea Flowers in China. In 2013, the Ministry of Health of China has recognized tea flowers as a new food source.

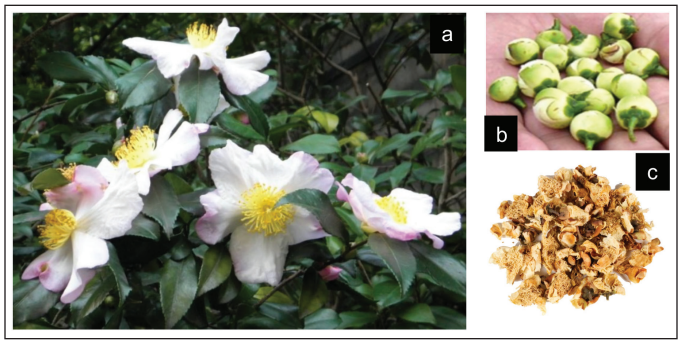


Figure 1. Fresh flowers of *C. sinensis* bear white petals with a pinkish tinge and produce numerous yellow stamens (a), white or mature flower buds (b), and dried tea flowers (c).

Most review articles on the chemical constituents and pharmacological properties of *C. sinensis* are focused on its young leaves [22–24], with little attention on other parts of the plant. This article is confined to the lesser-known flowers of *C. sinensis* with some emphasis on their chemical constituents, pharmacological properties, and safety evaluation. Their morphology, reproductive biology, and uses are briefly mentioned.

CHEMICAL CONSTITUENTS

Chemical compounds reported in tea flowers include catechins, polysaccharides, saponins, proteins, alkaloids, spermidine derivatives, flavonol glycosides, and anthocyanins [25,26]. The aqueous extract of tea flowers contains carbohydrates (34%), crude proteins (28%), phenolic compounds (12%), and saponins (2.8%) [26].

In recent years, tea flower polysaccharides (TFPS) have attracted great interest because of their α-glucosidase inhibitory and α-amylase inhibitory activities [11,27]. In general, the molecular weights of TFPS are greater than polysaccharides of tea leaves. Tea flowers contain acid polysaccharides, comprising rhamnose, arabinose, galactose, glucose, xylose, mannose, galacturonic acid, and glucuronic acid [11,27].

Isolated from tea flowers are flavonols (kaempferol, kaempferol glycosides, quercetin, quercetin glycosides, myricetin glycoside, and rutin), and catechins (catechin, epicatechin, gallocatechin, gallocatechin gallate, epigallocatechin, catechin gallate, epicatechin gallate, and epigallocatechin gallate) [11,28−30]. The total concentration of epicatechin gallate and epigallocatechin gallate was 70% of the total concentration of catechins in the ethanol tea flower extract [31]. The contents of total catechins and caffeine ranged from 10 to 38 mg/g and from 3 to 8 mg/g, respectively [32]. The contents of catechins in tea leaves are generally more than 12% higher than those in tea flowers [11].

Caffeine and theobromine are purine alkaloids found in tea flowers with highest contents in the stamens and petals of flower buds [33]. The contents of caffeine are 23.6 and 24.2 kBq/g and the contents of theobromine are 20 and 9.7 kBq/g, respectively [34]. Four spermidine derivatives (tricoumaroyl, triferuoyl, feruoyl dicoumaroyl, and coumaroyl diferuoyl spermidines) have been isolated from tea flowers for the first time [35]. The content of tricoumaroyl spermidine, the major compound, is highest in flower buds (181 μg/g) reducing to 92 μg/g in open flowers. Recently, hydroxycinnamic acid amides (phenolamides) have been reported from tea flowers [36]. All 12 varieties of tea flowers studied possessed *p*-coumaroyl-spermidine.

Triterpene oligoglycosides or triterpenoid saponins, namely, floratheasaponins (FTS) A−J chakasaponins (CKS) I−VI, and floraasamsaponins (FAS) I−VIII have been isolated from flowers of *C. sinensis* [10,11,37−41]. FTS A−C and J have been reported from Japan; FTS A−I and CKS I−VI from China; FTS A−F and CKS I−III from Taiwan; and FAS I−VIII from India (Fig. 2). Another group of triterpenoid saponins

with highly-substituted oxygen functional groups has been identified as chakasapogenins (CKA) I−III [42]. The contents of saponin in tea flowers range from 9.5 to 79 mg/g [39]. Maximal accumulation of saponins occurs in the green bud stage [10].

The following are some characteristic features of the triterpenoid saponins (Fig. 2). All FTS A−J possess a galactopyranosyl (Gal) component at R^6, a H component at R^3 and R^4 with the exception of FTS I and FTS H that has an acetyl (Ac) component at R^3 and R^4. Oxyangeloyl (OAng) dominates R^1 with the exception of FTS G that has an oxytigloyl (OTig) component instead. FTS C and F have 2 methylbutyryl (2MB) at R^2 not found in other FTS.

1. Among CKS I−VI possess a H and Gal component at R^4 and R^6, respectively. OTig and H dominate R^1 and R^3 except for CKS IV and CKS VI that have a H and Ac component, respectively.
2. All FAS I−VIII have a H and Rha component at R^4 and R^7, respectively. Ac dominates R^2 except FAS VIII that has a H component instead.

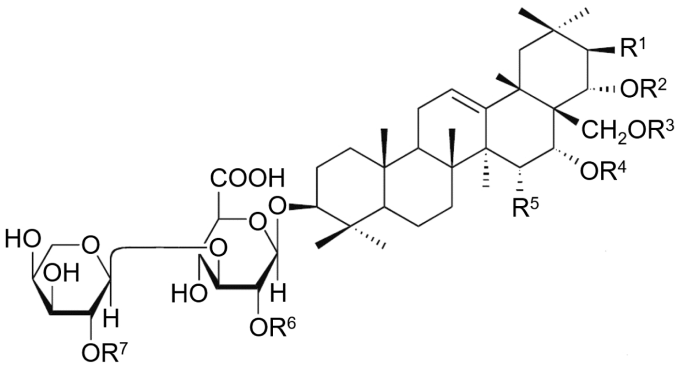
The pink color of tea flowers was attributed to cyanidin-3-*O*-glucoside, an anthocyanin isolated from the pink petals [41,42]. Earlier studies have reported the presence of cyanidin *O*-syringic acid, petunidin 3-*O*-glucoside, and pelargonidin 3-*O*-*β*-D-glucoside in pink tea flowers [43,44]. Supercritical carbon dioxide extraction of tea flowers accounted for 86.6% of the essential oil with nonadecane (18.7%) and heneicosane (12.2%) as major volatile components [45].

PHARMACOLOGICAL PROPERTIES

In Table 1, the major pharmacological properties of tea flowers are hypoglycemic (7), anti-cancer (7), antioxidant (4), hypolipidemic (4), modulation of gut health (3), antimicrobial (3), and anti-inflammatory (3) activities. There are two studies each on hepatoprotective and immunoregulatory activities of tea flowers. β-Amyloid aggregation inhibitory, gastroprotective, nephroprotective, anti-obesity, anti-allergic, anti-cholesterol, pancreatic lipase inhibitory, melanin synthesis inhibitory, and non-alcoholic fatty liver disease activities are minor pharmacological properties of tea flowers, represented by one study each.

SAFETY EVALUATION

A study on the safety evaluation of hot water TFE was conducted by Li *et al*. [75]. Mutagenicity of the TFE was assessed using the Ames test. Results showed that the extract (up to 5.0 mg/plate) had no mutagenic effect towards four tested strains of *Salmonella typhimurium*. In the acute toxicity study, a single dose of the flower extract (12 g/kg) was administered by gavage, and monitored for 14 days. In the sub-chronic toxicity study, the rats were administered with the extract by gavage at doses of 1, 2, and 4 g/kg daily for 13 weeks [75]. In the acute toxicity study, all animals gained weight, and appeared active and normal with LD_{50} value >12 g/kg. In the sub-chronic toxicity study, no dose-related effects on survival, growth, hematology, blood chemistry, organ weights, or pathologic lesions were observed. The results of the safety evaluation study showed that the TFE has no mutagenic potential and exhibits an extremely low acute and sub-chronic toxicity to animals.



Saponin	R^1	R^2	R^3	R^4	R^5	R^6	R^7
Floratheasaponin							
FTS A	OAng	Ac	H	H	H	Gal	Xyl
FTS B	OAng	Ang	H	H	OH	Gal	Xyl
FTS C	OAng	2MB	H	H	OH	Gal	Xyl
FTS D	OAng	Ac	H	H	H	Gal	Rha
FTS E	OAng	Ang	H	H	OH	Gal	Rha
FTS F	OAng	2MB	H	H	OH	Gal	Rha
FTS G	OTig	Ac	H	H	H	Gal	Rha
FTS H	OAng	Ac	H	Ac	H	Gal	Rha
FTS I	OAng	H	Ac	H	H	Gal	Rha
FTS J	OAng	Tig	H	H	OH	Gal	Xyl
Chakasaponin							
CKS I	OTig	Ac	H	H	H	Gal	Xyl
CKS II	OTig	Tig	H	H	OH	Gal	Xyl
CKS III	OTig	Ac	H	H	OH	Gal	Xyl
CKS IV	H	Tig	H	H	OH	Gal	Xyl
CKS V	OTig	Tig	H	H	OH	Gal	Rha
CKS VI	OTig	H	Ac	H	H	Gal	Xyl
Floraassamsaponin							
FAS I	OTig	Ac	Glc	H	H	Gal	Rha
FAS II	OAng	Ac	Glc	H	H	Gal	Rha
FAS III	OTig	Ac	H	H	OH	Glc	Rha
FAS IV	OTig	Ac	H	H	OH	Gal	Rha
FAS V	OAng	Ac	H	H	OH	Gal	Rha
FAS VI	OTig	Ac	H	H	H	Glc	Rha
FAS VII	OAng	Ac	H	H	H	Glc	Rha
FAS VIII	OTig	H	Ac	H	H	Glc	Rha

Figure 2. Types of acylated oleanane-type triterpene oligoglycosides isolated from flowers of *C. sinensis*. Ac = acetyl, Ang = angeloyl, CKS = chakasaponin, FAS, floraassamsaponin, FTS = floratheasaponin, Gal = galactopyranosyl, Glc = glucopyranosyl, MB = methylbutyryl, Rha = rhamnopyranosyl, Tig = tigloyl, and Xyl = xylopyranosyl.

Table 1. Bioactivities, effects, and mechanisms of extracts and bioactive compounds from flowers of *C. sinensis*.

Bioactivity	Effect and mechanism	Reference
Hypoglycemic	Polysaccharides from both hot water and boiling water TFE and TLE exhibited stronger GI than AI activities.	[27]
	Saponins from the butanol fraction of methanol TFE exhibited potent inhibitory effects on ethanol and indomethacin-induced gastric mucosal lesions in rats and on serum glucose elevation in sucrose-loaded rats. The gastroprotective and hypoglycemic activities were attributed to FTS A−C.	[46]
	TFPS exhibited strong GI of 83% and displayed stronger proliferation on mice splenic lymphocytes than tea leaf polysaccharides.	[47]
	TFP-2, a polysaccharide fraction from TFE, inhibited GI and AI, and also significantly decreased in blood glucose levels of alloxan-induced diabetic mice.	[48]
	CKS I–III from the methanol TFE significantly inhibited increase in plasma TG and glucose levels in sucrose-loaded mice at 50 and 100 mg/kg.	[49]
	Polysaccharides from ethanol TFE reduced blood glucose in alloxan-treated rats by protecting against oxidative damage and by inhibiting digestive enzymes activities.	[50]
	Bee pollen from flowers of *C. sinensis* inhibited glucose uptake and transport by interacting with glucose transporters in human intestinal Caco-2 cells.	[51]
Anti-cancer	Against MCF-7 breast cancer cells and among TFE water extracts from six different *Camellia* species, TFE from *C. sinensis* was the most active, attributed to ECG and EGCG, not detected in other species.	[52]
	Two purified fractions of TFPS-1 and TFPS-3 inhibited BGC-823 gastric cancer cells by 83% and 81%, at 200 µg/ml, respectively. Weaker inhibition (59%) was displayed by TFPS and TFPS-2 fractions.	[53]
	From the methanol TFE, strong growth inhibition in IC_{50} values was exhibited by FTS A against HSC-2 (4.6 µM) and HSC-4 (6.2 µM) oral squamous cancer cells, by MKN-45 (4.5 µM) against gastric cancer cells, and by CKS I against HSC-2 (4.6 µM) oral squamous cancer cells. Antiproliferative mechanisms involved induction of apoptotic cell death *via* activation of caspase-3/7.	[54]
	Tea flower saponins displayed significant anti-proliferative effects on A2780/CP70 and OVCAR-3 ovarian cancer cells by inducing p53-dependent apoptosis and S-phase arrest.	[55]
	Saponins (CKS I and IV) from the methanol TFE inhibited the growth and proliferation of A2780/CP70 and OVCAR-3 cisplatin-resistant ovarian cancer cells by inducing apoptosis *via* the intrinsic pathway.	[56]
	A standardized saponin extract from the aqueous TFE induced S phase cell cycle arrest and apoptosis in A2780/CP70 ovarian cancer cells *via* the Akt-MDM2-p53 signaling pathway.	[57]
	Tea flower saponins induced autophagy in OVCAR-3 ovarian cancer cells by activation of the ERK pathway and ROS generation.	[58]
Antioxidant	The ethanol TFE and its ethyl acetate fraction possessed potent antioxidant activity. The strong DPPH FRS activity was attributed to EGCG and ECG.	[28]
	The ethyl acetate fraction of ethanol TFE exhibited the highest quenching activity towards hydroxyl radicals (SC_{50} = 11.6 µg/ml), followed by the ethanol extract (SC_{50} = 19.7 µg/ml).	[31]
	The hydroxyl radical scavenging effect of ethanol TFE was stronger than that of vitamin E and 75% ethanol fresh tea leaf extract.	[32]
	The essential oil from tea flowers exhibited stronger DPPH FRS ability than essential oils from geranium and peppermint, but weaker than the essential oil from clove.	[45]
Hypolipidemic	Among the flavonol glycosides isolated from the methanol TFE, CFS B was found to possess oleic acid-albumin-induced lipid accumulation inhibitory activity in HepG2 cells. Chakaflavonoside B, a new flavonol, was found to inhibit lipid accumulation.	[30]
	FAS A−C from the butanol fraction of methanol TFE inhibited serum TG levels in olive oil-treated mice.	[37]
	CKS I–III from the methanol TFE inhibited plasma TG after loading olive oil in mice.	[49]
Modulation of gut health	Polysaccharides from tea flowers modulated gut health and promoted the growth of gut microbiota.	[59]
	Polysaccharides from tea flowers maintained the intestinal health in mice by improving intestinal adaptive immune tolerance.	[60]
	Polysaccharides from tea flowers had prebiotic effects on gut microbiota in healthy persons and in patients with inflammatory bowel syndrome.	[61]
Antimicrobial	The ethyl acetate TFE inhibited *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Candida albicans*, and *Candida parapsilosis* growth with a DIZ of 17.3, 15.0, 19.0, and 21.3 mm, respectively.	[62]
	Solvent free supercritical fluid extract of tea flowers displayed strong antifungal (20−27 mm) and appreciable antibacterial (7−12 mm) activities at minimum concentrations of Q1 mg/ml.	[63]
	The outstanding antifungal activity of aqueous TFE was displayed using 6.4 mg/ml against *Aspergillus flavus*. Inhibition exceeded 90% after 24 hours of incubation.	[64]

(Continued)

Bioactivity	Effect and mechanism	Reference
Anti-inflammatory	Both TFE and tea leaf extract exerted their strong NO inhibitory effects in LPS-induced RAW 264.7 cells.	[32]
	Inhibition of NO production in LPS-activated RAW264.7 cells by TFE was attributed to CKA III.	[65]
	The hot water TFE possessed potent anti-inflammatory effects in acute and chronic mice models. Mechanism of the effects were associated with suppression of NO production and expression of TNF-α and IL-1β mRNA.	[66]
Hepatoprotective	The ethanol TFE prevented the increase of ALT and SGOT levels, reduced the formation of MDA, and enhanced the activities of SOD and GPx in CCl_4-induced liver injury mice.	[53]
	A water-soluble polysaccharide fraction from the methanol TFE protected against liver LPO induced by bromobenzene in mice by increasing the activity of SOD and total antioxidant capacity, and attenuating the enhancement of MDA content.	[67]
Immunoregulatory effects	The ameliorating effect of TFE on Cy-induced immuno-suppression and hepatic injury in mice was associated with the modulatory effect of the extract on the gut microbiota.	[26]
	TFPS had immunoregulatory effects in Cy-induced immuno-suppressed mice by improving intestinal barrier and activating the colonic TLR4/MyD88/NF-κB p65 and JAK2/STAT3 pathways.	[59]
Aβ aggregation inhibitory	FAS III, IV, and VII from the n-butanol fraction of methanol TFE, significantly inhibited aggregation of Aβ with 73%, 69%, and 57% inhibition, respectively.	[41]
Gastroprotective	Saponins from the butanol fraction of methanol TFE exhibited potent inhibitory effects on ethanol- and indomethacin-induced gastric mucosal lesions in rats. The gastroprotective activities were attributed to FTS A–C.	[46]
Nephroprotective	Methanol extracts of tea buds and/or flowers exerted nephroprotective activities by ameliorating renal dysfunction, lipid peroxidation and antioxidant enzyme suppression.	[68]
Anti-obesity	The methanol TFE inhibited body weight gain and weight of visceral fats in high fat-diet and/or TSOD mice. CKS II inhibited gastric emptying as well as food intake in high fat-diet and normal diet mice.	[69]
Anti-allergic	From the methanol TFE, FTS A–F displayed anti-allergic activity by inhibiting the release of Hex A from RBL-2H3 cells. Strongest activity was observed in FTS A–C with inhibitory effects of 62%, 57%, and 61%, respectively.	[70]
Anti-cholesterol	The anti-cholesterol activities of flowers from three albino tea cultivars and one non-albino tea cultivar were compared. Yujinxiang, an albino cultivar, exhibited stronger activity in decreasing the micellar cholesterol solubility. Among the four samples, cholesterol esterase inhibition and bile salt binding were insignificantly different.	[71]
Pancreatic lipase inhibitory	CKS I–III from the butanol fraction of methanol TFE accelerated the effects on gastrointestinal transit in mice and inhibited porcine pancreatic lipase with IC_{50} values of 150–530 μM.	[72]
Melanin synthesis inhibitory	An ethanol TFE inhibited melanin synthesis in α-MSH stimulated B16-F10 melanoma cells by normalizing the expression of genes that are essential for melanin synthesis.	[73]
Non-alcoholic fatty liver disease	The TFE inhibited oleic acid-induced hepatic steatosis in HepG2 cells by promoting lipid degradation and protecting the liver from NAFLD through the reduction of ROS stress.	[74]

A*β* = *β*-amyloid, AI = α-amylase inhibitory, Akt = protein kinase B, ALT = alanine aminotransferase, CCl_4 = carbon tetrachloride, CFS = chakaflavonoside, CKA = chakasapogenin, CKS = chakasaponin, Cy = cyclophosphamide, DIZ = diameter of inhibition zone, DPPH = 2,2-diphenyl-1-picrylhydrazyl, ECG = epicatechin gallate, EGCG = epigallocatechin gallate, ERK = extracellular signal-regulated kinase, FAS = floraassamsaponins, FRS = free radical scavenging, FTS = floratheasaponins, GI = α-glucosidase inhibitory, GMP = gastro-mucosa protective, GPx = glutathione peroxidase, Hex A = β-hexosaminidase, IL = interleukin, JAK2, Janus kinase 2, LPO = lipid peroxidation, LPS = lipopolysaccharide, MDA = malondialdehyde, MDM2 = mouse double minute 2, mRNA = messenger ribonucleic acid, MSH = melanocyte stimulating hormone, MSI = Melanin synthesis inhibitory, MyD88, myeloid differentiation factor 88, NAFLD = non-alcoholic fatty liver disease, NO = nitric oxide, ROS = reactive oxygen species, SC_{50} = 50% scavenging concentration, SGOT = aspartate aminotransferase, SOD = superoxide dismutase, STAT3, signal transducers and activators of transcription 3, TFE = tea flower extract, TFPS = tea flower polysaccharides, TG = triglyceride, TLE = tea leaf extract, TLR4, toll-like receptors 4, TNF = tumor necrosis factor, and TSOD = Tsumura Suzuki obese diet.

CONCLUSION

Some of the chemical components of tea flowers, such as flavonols, catechins, caffeine, and theanine, are similar to those of tea leaves, and they share similar health benefits. Much of the previous work on the chemical constituents and pharmacological properties of *C. sinensis* flowers was conducted by scientists from the Kyoto Pharmaceutical University in Japan. Acylated oleanane-type triterpene oligoglycosides or saponins were isolated and identified from TFE, and their bioactivities described. Bioactivities include anti-hyperlipidemic, anti-hyperglycemic, anti-obesity, and gastroprotective effects, together with anti-allergic, pancreatic lipase inhibitory, and β-amyloid aggregation inhibitory activities. Comparisons were made between the chemical constituents of tea flowers from Japan, China, Taiwan, and India.

Although commercial products such as functional food are being developed from tea flowers, some issues need to be addressed. They include the high cost of harvesting tea flowers that are only available periodically. We envisage that rapid, selective, and mechanized harvesting techniques need to be developed as the flowering season is short, and the picking of white or mature flower buds is preferred over open flowers.

Additionally, the cost of manufacturing tea flower products is high, requiring efficient drying, extraction, and isolation. Post-harvest drying has to be rapid and efficient as fresh flowers containing high moisture content would quickly turn brown due to oxidation of polyphenol oxidases.

The development of health supplements from tea flower buds is promising requiring clinical studies to ascertain their effectiveness, dosage, and side-effects. More studies on the safety evaluation of tea flowers are needed, although a preliminary study has shown that TFE has no mutagenic potential, and possesses an extremely low acute and sub-chronic toxicity to animals.

An added advantage of removing the tea flowers is that the yield and quality of tea leaves are enhanced the following year. The recognition of the importance of tea flowers is reflected in the established of the International Institute of Tea Flowers in Japan, and International Research and Development Center of Tea Flowers were established in China. Once considered a waste resource, tea flowers are now recognized as a new food source by the Minister of Health of China in 2013.

AUTHOR CONTRIBUTIONS

The author made substantial contributions to the conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. The author is eligible to be an author as per the International Committee of Medical Journal Editors (ICMJEs) requirements/guidelines.

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CONFLICT OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

ETHICAL APPROVALS

This study does not involve experiments on animals or human subjects.

DATA AVAILABILITY

All data generated and analyzed are included in this research article.

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