Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 1, 2021, Pages. 5661 - 5671
Received 15 December 2020; Accepted 05 January 2021.

# Structural and Beneficial Aspects of Tea (*Camellia sinensis*) Flowers

**Sudipta Kumar Sil[1]*, Nabankur Mukherjee[2], Sayanti Bagchi[3] , Santanu Gupta[4] , Kuhely Ganguli[5]**

[1]Professor, Department of Botany, University of Gour Banga, Malda, West Bengal - 732103 (corresponding author)

[2] Former research scholar, Department of Botany, University of Gour Banga, Malda, West Bengal - 732103 & presently post-doc researcher, TRA, Nagrakata,W.B.

[3]Assistant Professor, Department of Botany, Yogoda Satsang Palpara Mahavidyalaya, Palpara, Purba Medinipur, West Bengal- 721458

[4]Assistant Professor, Department of Botany, Malda College, Malda, West Bengal-732101

[5]Research Scholar, Department of Botany, University of Gour Banga, Malda, West Bengal - 732103

RUNNING TITLE: Structure and Benefits of Tea Flower

## Abstract

Tea is an economical plant for North East India and some parts of South India. Flower morphology is important to plant breeding as they provide important information on flower nature. There are three variety of tea races found in India. China variety i.e. *Camellia sinensis*, Assam variety i.e. *Camellia asamica*, Cambod variety *Camellia asamica sub. lasiocalyx.* Three varieties have different flower morphology by which variety could be identified. Flowering normally starts in monsoon and fruiting starts in early winter.

## Keywords

Actinomorphic, Anthesis, Corolla, Gibberellic acid, Pollination, Pserphid, Tea

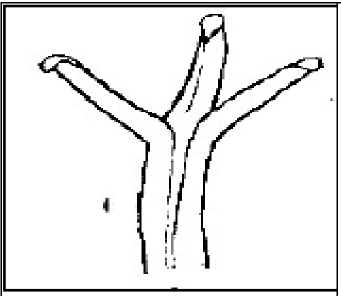
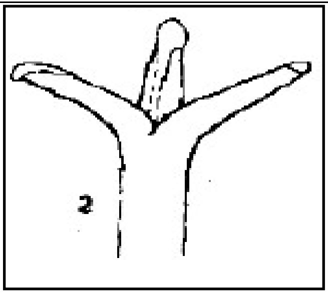
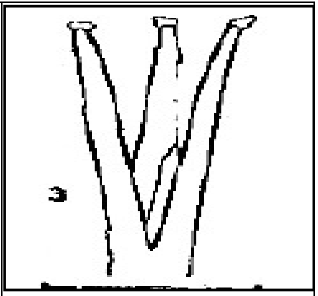
## Introduction

### Floral morphology

Tea flowers are actinomorphic i.e. they can be divided into single plane. Wu was the first one to describe morphology of tea flowers. He reported variation between china variety flowers. According to him, classification should be done on the basis of central placenta not by parietal placenta. There are two whorls in the calyx and there are two to four whorls in corolla (Ramasubramanian, 2005).

Tea also can be classified on the basis of the styles. In an study it was revealed that In *camellia sinenis* i.e. China variety styles are more united than others. In *Camellia asamica* i.e. in Assam variety styles are less united than *sinenis* but more than its sub species *lasiocalyx* i.e. cambod. Finally *Camellia asamica sub. lasiocalyx* normally exhibits least united style structure (Curr, 1962).

Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 1, 2021, Pages. 5661 - 5671
Received 15 December 2020; Accepted 05 January 2021.

| | | |
|---|---|---|
|  |  |  |
| *Camellia sinensis* | *Camellia asamica* | *Camellia asamica* var. *lasiocalyx* |

**Pollination**

Tea can exhibits both self and cross fertilization. Pollen grains may be triangular to spherical. In an research result showed a flower can have near about 80% viable pollen (Tsou, 1997; Iqbal and Wijesikare, 2002). Pollination occur through small insects mostly by 'pserphid'. This insects have a short flying range. Through keeping distance between two flowering plants chances of cross pollination can be lowered.

Flower buds are visible through out the year. Flowering normally occurs after July/August. But it can vary depends on agroclimate zone. Seed set up starts after September. Sometimes two three flowering peaks also can be observed in a season. Mature seeds can be observed collected from November to February. Anthesis occurs normally during the morning sunshine from 7.30 to 9.00 A.M. Petal unfurling can continue till noon (Ariyarathna*et.al*., 2011).

**Biological functions of Tea Flower**

Tea flowers possesses many functional metabolites related to polysaccharides, catechins and saponins. Catechins and polysaccharides are responsible for the antioxidant abilities of tea flower. Tea flower polysaccharides have equivalent amount of polysaccharides as tea leaves.

Li *et.al*. reported that tea flowers have acute and subchronic toxic effects on rats (Li *et.al*, 2011). Crude tea polysaccharides

**Genetics of tea flowering**

The process of flower induction and development involves an intricate physiological process comprising of numerous endogenous as well as extraneous factors (Liu *et al*, 2017). During the past decade, molecular and genetic mechanisms involved in tea flower induction, differentiation and development have been inferred. Floral induction has been found to be influenced by the expression of genes such as gibberellic acid intensive dwarf 1B (GID1B) and GID1C, gibberrelin 3-oxidase 1 (GA3ox1), GIGANTEA (GI), pseudo-response regulator (PRR7) and flowering locus T (FT), whereas expression of genes such as leafy (LFY), pound-floolish (PNF) and pennywise (PNY) were correlated with floral bud formation (Liu *et al*, 2020). 207 unigenes and transcription factors such as WRKY, ERF, MYB, bHLH and

Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 1, 2021, Pages. 5661 - 5671
Received 15 December 2020; Accepted 05 January 2021.

MADS-box have been particularly identified with flowering-associated roles in tea (Liu *et al*, 2017).

Tea flower differentiation and development includes various processes. The tubulin-encoding *Tua1* and pollen coat protein (*Pcp*) genes have been observed to promote pollen tube growth (Fang et al, 2006) and anther development (Ye *et al*, 2008) in tea. Pollen tube elongation in tea flowers is also regulated via the nitric oxide (NO) pathway under low temperature stress by the CAMTA TFs, COBRA-like genes and phosphatidylinositol-4-kinase (PI4K) (Pan *et al*, 2016).

Moreover, major genes responsible for total catechin content in tea flowers such as chalcone synthase (CH2) and flavonol synthase (FLS) were found to be highly expressed during early flowering stage, while genes such as phenylalanine ammonia lyase (PAL1) and flavonoid 3'-hydroxylase (F3'H1) were expressed in the late flowering stage and negatively correlated with the total catechins content in the flowers (Sun *et al*, 2019). As is evident, aroma compound formation during tea flowering increases. This occurs due to the increasing activity of hydrolytic enzymes such as glycosidases (Watanabe *et al*, 1993; Hayashi *et al*, 2004). Consequently, flavor precursors formed during anthesis are converted to volatile compounds leading to the gradual development of unique odors (Watanabe *et al*, 1993).

**Bioactivities**

Antioxidant

Tea flowers have a considerable amount of catechins, comparable to the leaves (Lin *et al*, 2003), which in turn contributes to the antioxidant activity of tea flower extract. Ethanol extracts of tea flowers were found to exhibit high scavenging activity against hydroxyl radical ($IC_{50}$ = 19.7 µg/mL) and DPPH radical ($IC_{50}$ = 47.6 µg/mL)(Yang *et al*, 2007). Isolation and purification of catechins showed the high concentration of EGCG and ECG in tea flowers contributing immensely to its antioxidant activity (Yang *et al*, 2009). The method used for extraction of bioactive compounds from flowers also influence their antioxidant efficiency. Flower extract obtained through super critical extraction (SFE) method was found to retain volatiles (Xia *et al*, 2018) which would otherwise have been degraded due to higher temperatures used for extraction in other processes (Shi *et al*, 2018). In addition to catechins, tea flower polysaccharides also contribute to its antioxidant property (Wang *et al*, 2012).

Anticancer

The anti-tumour and anti-cancerous activity of tea flowers have been recorded extensively in the last decade. Inhibitory effectson growth oftransplanted S180 in addition to prolonged mice survival, promotion of plasma interleukin-2, interferon-γ levels and improvement of the T-lymphocyte subsets CD4+ and CD4+/CD8+ percentages was observed after 10 day continued administration of tea flower polysaccharides (TFPS). Furthermore, TFPSalsosignificantly enhanced delayed-type hypersensitivity response and macrophage phagocytosis (Han *et al*, 2010).The water extracts of tea flowers from six different species of *Camellia* – *Camellia japonica*, *Camellia tenuifolia*, *Camellia oleifera*, 2 savoury *Camellias* and *Camellia sinensis*, were used to test the anti-proliferative and

Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 1, 2021, Pages. 5661 - 5671
Received 15 December 2020; Accepted 05 January 2021.

apoptotic effects in human breast cancer MCF-7 cells. The water extract of *Camellia sinensis* was found to be the most active among all the test species, which may be attributed to the presence of (−)-epigallocatechin-3-gallate and (−)-epigallocatechin in *Camellia sinensis*which were absent in other species(Way *et al*, 2009).In another study (Xu *et al*, 2012), various fractions of hot water extracts of tea flowers containing crude fractions of tea flower polysaccharides (TFPS) were found to possess inhibitory activity on the growth of human gastric cancer BGC-823 cells.Wang *et al* (2017) evaluated the anti-cancerousproperties of tea flower saponins(TFS) using human ovarian cancer cell lines.They demonstrated that TFS produced significant anti-proliferative effects against A2780/CP70 and OVCAR-3 cells by inducing p53-dependent apoptosis and S phase arrestvia inhibition of the expression of Cdc25A, Cdk2, and CyclinD1 and upregulation of Cyclin E and Cyclin A.

Antiinflammatory

Tea flowers were found to possess adequate amount of anti-inflammatory properties. Chen *et al* (2012) found that administration of tea flower extract effectively inhibited lipopolysaccharide-induced liver inflammation in mice. Furthermore, the concentration of nitric oxide (NO), tumour necrosis factor-$\alpha$ (TNF-$\alpha$) and interleukin-1$\beta$ (IL-1$\beta$) mRNA were found to markedly reduce in mice with immunological liver inflammation after treatment with tea flower extract.

Antiobesity

Due to the adoption of urban lifestyle by most people, obesity has become an ever increasing issue of concern in the present age. Tea has been well known for ages to counteract obesity (Westerterp-Plantenga, 2010; Rains *et al*, 2011; Heber *et al*, 2014). In recent times, a methanolic extract of tea flowers has also been found to inhibit increase in body weight and visceral fat content in high-fat diet-fed mice (Hamao*et al*, 2011). Particularly, the n-butanol (BuOH)-soluble fraction of the extract and its primary component, chakasaponins II, was found to reduce food intake in high-fat as well as normal diet-fed mouse. They have also been found to inhibit the levels of neuropeptide Y (NPY)mRNAin the hypothalamus. Moreover, chakasaponins II were found to release 5-hydroxytryptamine (5-HT) from the isolated ilea cells of mice, thus suppressing appetite signals.

Hypoglycemic

Hypoglycemic properties of tea has been well known for ages. Lately, the anti-diabetic properties of tea flowers have also been extensively worked upon and eventually revealed. Matsuda *et al* (2012) demonstrated the role of chakasaponins I–III (50 and 100 mg/kg) extracted from tea flower buds in significantly lowering glucose levels in olive oil or sucrose-loaded mice. Blood glucose levels in alloxan-induced diabetic mice was found to decline considerably by continuous oral administration of tea flower polysaccharides (Han *et al*, 2011a). Similar hypoglycemic effect of tea flower polysaccharides were observed in diabetic Sprague-Dawley mice induced by alloxan (Cai*et al*, 2011). Methanolic and n-butanol soluble fractions of tea flowers have been found to possess suppressive effects on serum glucose levels in sucrose-loaded mice. Specifically, floratheasaponins A, B and C present in the n-butanol soluble fraction have been shown to have hypoglycemic properties (Yoshikawa *et al*, 2008).

**References**

1. Ariyarathna HACK, Gunasekare MTK, Kottawa-Arachichige JD, Paskarathevan R, Ranaweera KK, Ratnayake M, Kumara JDBAP (2011) Morpho-physiological and phenological attributes of reproductive biology of tea (*Camellia sinensis* (L.) O. Kuntze) in Sri Lanka. Euphytica, 181: 203-215.

2. Ashihara H (2006) Metabolism of alkaloids in coffee plants. *Braz. J. Plant Physiol*., **18:** 1–8.https://doi.org/10.1590/S1677-04202006000100001

3. Balentine DA, Wiseman SA, and Bouwens LCM(1997) The chemistry of teafavonoids. *Crit. Rev. Food Sci. Nutr.,* **37:** 693-704.https://doi.org/10.1080/10408399709527797.

4. Cai X, Wang YF, Mao FF, Lan YU, Liu CX, Zhang H and Wei XL (2011)Hypoglycemic and hyperglycemia-prevention effects of crude tea flower polysaccharide. *Modern Food Science & Technology*, *27*(3), 262-266 (in Chinese). https://doi.org/10.13982/j.mfst.1673-9078.2011.03.002.

5. Chen BT, Ki WX, He RR, Li YF, Tsoi B, Zhai YJ and Kurihara H (2012) Anti-inflammatory effects of a polyphenols-rich extract from tea (*Camellia sinensis*) flowers in acute and chronic mice models. *Oxid. Med. Cell Longev*.,Vol. 2012, Article ID 537923. https://doi.org/10.1155/2012/537923

6. Chen YY, Fu XM, Mei X, Zhou Y, Du B, Tu YY and Yang ZY (2016) Characterization of functional proteases from flowers of tea (*Camellia sinensis*) plants. *J. Funct. Foods*, **25:** 149–159. https://doi.org/10.1016/j.jff.2016.05.017

7. Chen YY, Zhou Y, Zeng LT, Dong F, Tu YY and Yang ZY (2018) Occurrence of functional molecules in the flowers of tea (*Camellia sinensis*) plants: Evidence for a second resource. *Molecules,* **23(4):** 790.https://doi.org/10.3390/molecules23040790.
8. Curr. (1962) Tea Classification Revised, Sci. July, 1962.

9. Dong F, Yang ZY, Baldermann S, Kajitani Y, Ota S, Kasuga H, Imazeki Y, Ohnishi T, Watanabe N (2012)Characterization of L-phenylalanine metabolism to acetophenone and 1-phenylethanol in the flowers of *Camellia sinensis* using stable isotope labeling. *J. Plant Physiol*, **169:** 217–225.https://doi.org/10.1016/j.jplph.2011.12.003

10. Dong F, Zhou Y, Zeng LT, Peng QY, Chen YY, Zhang L, Su XG, Watanabe N and Yang ZY (2016) Elucidation of differential accumulation of 1-phenylethanol in flowers and leaves of tea (*Camellia sinensis*) plants. Molecules, **21:** 1106. https://doi.org/10.3390/molecules21091106

11. Facchini PJ, Hagel J and Zulak KG (2002)Hydroxycinnamic acid amide metabolism: physiology and biochemistry.*Can. J. Bot*., **80:** 577–589.https://doi.org/10.1139/b02-065

12. Fang WP, Jiang C, Yu M, Ye AH and Wang Z (2006). Differentially expression of *Tua1*, a tubulin-encoding gene, during flowering of tea plant *Camellia sinensis* (L.) O. Kuntze using cDNA amplified fragment length polymorphism technique. *ActaBiochimicaetBiophysicaSinica*, **38(9):** 653-662. https://doi.org/10.1111/j.1745-7270.2006.00202.x.

13. Hamao M, Matsuda H, Nakamura S, Nakashima S, Semura S, Maekubo S,WakasugiS and Yoshikawa M (2011). Anti-obesity effects of the methanolic extract and chakasaponins from the flower buds of *Camellia sinensis* in mice. *Bioorg. Med. Chem.,* **19(20):** 6033-6041. https://doi.org/10.1016/j.bmc.2011.08.042.

14. Han Q, Ling ZJ, He PM and Xiong CY (2010). Immunomodulatory andantitumor activity of polysaccharide isolated from tea plant flower. *Prog. Biochem. Biophys*.,**37(6):** 646-653. https://doi.org/10.3724/SP.J.1206.2009.00656.

15. Han Q, Yu QY, Shi J, Xiong CY, Ling ZJ and He PM (2011a) Molecularcharacterization and hypoglycemic activity of a novel water-solublepolysaccharide from tea (*Camellia sinensis*) flower. *Carbohydr. Polym.*,**86(2):** 797-805. https://doi.org/10.1016/j.carbpol.2011.05.039.

16. Han Q, Yu QY, Shi J, Xiong CY, Ling ZJ and He PM (2011b) Structuralcharacterization and antioxidant activities of 2 water-soluble polysaccharidefractions purified from tea (*Camellia sinensis*) flower. *J. Food Sci.*,**76(3):** C462-C471. https://doi.org/10.1111/j.1750-3841.2011.02063.x.

17. Heber D, Zhang Y, Yang J, Ma JE, Henning SM, Li Z (2014) Green tea, black tea, and oolong tea polyphenols reduce visceral fat and inflammation in mice fed high-fat, high-sucrose obesogenic diets. *J.Nutr*., **144(9):**1385-93. https://doi.org/10.3945/jn.114.191007

18. Hayashi S, Yagi K, Ishikawa T, Kawasaki M, Asai T, Picone J, Turnbull C, Hiratake J, Sakata K, Takada M, Ogawa K and Watanabe, N. (2004). Emission of 2-phenylethanol from its □-D-glucopyranoside and the biogenesis of these compounds from [2H8] L-phenylalanine in rose flowers. *Tetrahedron*, **60(33):** 7005-7013. https://doi.org/10.1016/j.tet.2003.10.130.

19. Iqbal MCM, Wijesekare KB (2002) Cells of the connective tissue differentiate and migrate into pollen sacs. Nturwissenchaft 89:39–42.

20. Joshi R, Poonam and Gulati, A (2011a) Biochemical attributes of tea flowers(*Camellia sinensis*) at different developmental stages in the Kangra region of India. *SciHortic-Amsterdam*, **130(1):** 266-274. https://doi.org/10.1016/j.scienta.2011.06.007.

21. Joshi R, Poonam, Saini R, Guleria S, Babu GDK, Kumari M and Gulati A(2011b) Characterization of volatile components of tea flowers (*Camelliasinensis*) growing in Kangra

by GC/MS. *Nat. Prod. Commun*.,**6(8):**1155-1158. https://doi.org/10.1177/1934578X1100600829.

22. Li F, Dong C, Yang T, Ma J, Zhang S, Wei C, Wan X and Zhang Z (2019) Seasonal theanine accumulation and related gene expression in the roots and leaf buds of tea plants (*Camellia sinensis* L.). *Front Plant Sci*., **10:**1397. https://doi.org/10.3389/fpls.2019.01397

23. Lin YS, Wu SS and Lin JK (2003) Determination of tea polyphenols and caffeine in tea flowers (*Camellia sinensis*) and their hydroxyl radical scavenging and nitric oxide suppressing effects. *J. Agric. Food Chem.,* **51(4):**975-980. https://doi.org/10.1021/jf020870v.
24. Liu F, Wang Y, Ding Z, Zhao L, Xiao J, Wang L and Ding S (2017) Transcriptomic analysis of flower development in tea (*Camellia sinensis*. (L.)). *Gene,* **631:** 39-51. https://doi.org/10.1016/j.gene.2017.08.013.

25. Liu Y, Hao X, Lu Q, Zhang W, Zhang H, Wang L,Yang Y, Xiao B and Wang X (2020) Genome-wide identification and expression analysis of flowering-relatedgenes reveal putative floral induction and differentiation mechanisms in tea plant (*Camellia sinensis*). *Genomics*, **112(3):** 2318-2326.https://doi.org/10.1016/j.ygeno.2020.01.003

26. Matsuda H, Hamao M, Nakamura S,Kon'I H, Murata M and Yoshikawa M (2012) Medicinal flowers. XXXIII.Anti-hyperlipidemic and anti-hyperglycemic effects of chakasaponins I-III and structure of chakasaponin IV from flower buds of Chinese tea plant (*Camellia sinensis*). *Chem. Pharm. Bull*., **60:**674–680.https://doi.org/10.1248/cpb.60.674

27. Matsuda H, Nakamura S, Morikawa T, Muraoka O and Yoshikawa M (2016) New biofunctional effects of the flower buds of *Camellia sinensis* and its bioactive acylatedoleanane-type triterpene oligoglycosides. *J. Nat. Med.,* **70(4):** 689-701.
a. https://doi.org/10.1007/s11418-016-1021-1.

28. Mondal TK , Rawal HC , Bera B , Kumar PM , Choubey M , Sahab G, Das B , Bandyopadhyay T , Ilangod RVJ, Sharma TR , Barua A , Radhakrishnand B and Singh NK (2019) Draft genome of a popular Indian tea genotype TV-1 [*Camellia assamica L.(O).* Kuntze]. http://dx.doi.org/10.1101/762161

29. Morikawa T, Lee IJ, Okugawa S, Miyake S, Miki Y, Ninomiya K, KitagawaN, Yoshikawa M and Muraoka O (2013a) Quantitative analysis of catechin,flavonoid, and saponin constituents in "tea flower", the flower buds of *Camelliasinensis*, from different regions in Taiwan. *Nat. Prod. Commun*.,**8(11):** 1553-1557. https://doi.org/10.1177/1934578x1300801114.

30. Morikawa T, Miyake S, Miki Y, Ninomiya K, Yoshikawa M and Muraoka O(2012) Quantitative analysis of acylatedoleanane-type triterpene saponins,chakasaponins I-III and floratheasaponins A-F, in the flower buds of *Camelliasinensis* from different regional origins. *J. Nat. Prod***., 66(4):** 608-613.
a. https://doi.org/10.1007/s11418-012-0627-1.

31. Morikawa T, Ninomiya K, Miyake S, Miki Y, Okamoto M, Yoshikawa M andMuraoka O (2013b)Flavonol glycosides with lipid accumulation inhibitoryactivity and simultaneous quantitative analysis of 15 polyphenols and caffeine inthe flower buds of *Camellia sinensis* from different regions by LCMS. *FoodChem.,* **140(1-2):** 353-360. https://doi.org/10.1016/j.foodchem.2013.02.079.

32. Nagata T and Sakai S (1984) Differences in caffeine, flavanols and amino acids contents in leaves of cultivated speciesof *Camellia*. *Jpn. J. Breed*.,**34:** 459–467.https://doi.org/10.1270/jsbbs1951.34.459

33. Ohta T, Nakamura S, Nakashima S, Matsumoto T, Ogawa K, Fujimoto K,Fukaya M, Yoshikawa M and Matsuda H (2015)Acylatedoleanane-type triterpene oligoglycosides from the flower buds of *Camellia sinensis* var. *assamica*. *Tetrahedron,* **71(5):** 846-851. https://doi.org/10.1016/j.tet.2014.12.049.

34. Ohta T, Nakamura S, Matsumoto T, Nakashima S, Ogawa K, Matsumoto T, Fukaya M, Yoshikawa M and Matsuda H (2017) Chemical structure of an acylatedoleanane-type triterpene oligoglycoside and anti-inflammatory constituents from the flower buds of *Camellia sinensis*. *Nat. Prod.Commun.,***12(8):** 1193-1196. https://doi.org/10.1177/1934578X1701200811.

35. Pan J, Wang W, Li D, Shu Z, Ye X, Chang P and Wang Y (2016) Gene expression profile indicates involvement of NO in *Camellia sinensis* pollen tube growth at low temperature. *BMC Genomics,* **17(1):** 809.https://doi.org/10.1186/s12864-016-3158-4.

36. Rains TM, Agarwal S and Maki KC (2011)Antiobesity effects of green tea catechins: a mechanistic review. *J.Nutr.Biochem*.,**22(1):**1-7.
37. https://doi.org/10.1016/j.jnutbio.2010.06.006

38. Ramasubramanian, B. Studies on variability, genetic divergence and crop improvement in tea (*Camellia assamica* (masters) wight ) , Thesis. Department of Botany, University of Calicut, Kerala, 2005.

39. Rawal HC , Mazumder A, Borchetia S , Bera B , Soundararajan S, Ilango RVJ , Barooah AK , Singh NK , Mondal TK (2020) Comparative analysis of chloroplast genomes indicated different origin for Indian Tea (*Camellia assamica*) cv TV-1 as compared to Chinese tea. http://dx.doi.org/10.1101/762161

40. Shi L, Gu Y, Wu D, Wu X, Grierson D, Tu Y and Wu Y (2018) Hot air drying of tea flowers: effect of experimental temperatures on drying kinetics, bioactive compounds and quality attributes. ***Int J Food SciTechnol,*** **54(2): 526-535.**https://doi.org/10.1111/ijfs.13967

41. Sugimoto S, Yoshikawa M, Nakamura S and Matsuda H (2009) Medicinal flowers. XXV. Structures of floratheasaponin J and chakanoside II from Japanese tea flower, flower buds of *Camellia sinensis*. *Heterocycles*, **78(4):** 1023-1029.https://doi.org/10.3987/com-08-11568.
42. Sun LT, Wang Y, Ding ZT and Liu F (2019)The dynamic changes of catechins and related genes in tea (*Camellia sinensis*) flowers. *Acta Physiol. Plant,* **41(2):** 30. https://doi.org/10.1007/s11738-019-2822-0.

43. Tsou CH (1997) Embryology of the Theaceae-anther and ovule development of Camellia, Frankilinia and Schima. Am J Bot 84:369–381.

44. Wang H, Cui XX, Zhao XG, Gao S, Zhao JA and YuanZL (2015)Differences of biochemical constituents and contents of eight cultivars flowers of *Camellia sinensis*. *J. Essent. Oil-Bear. Plants*, **18(2):** 320-328. https://doi.org/10.1080/0972060x.2014.961036.

45. Wang L, Xu RJ, Hu B, Li W, Sun Y, Tu YY and Zeng XX (2010a) Analysis of free amino acids in Chinese teas and flower of tea plant by high performanceliquid chromatography combined with solid-phase extraction. *Food Chem.*,**123(4):** 1259-1266. https://doi.org/10.1016/j.foodchem.2010.05.063.

46. Wang YF, Yang ZW and Wei XL (2010b) Sugar compositions, alphaglucosidase inhibitory and amylase inhibitory activities of polysaccharides fromleaves and flowers of *Camellia sinensis* obtained by different extraction methods.*Int. J. Biol. Macromol*., **47(4):** 534-539.https://doi.org/10.1016/j.ijbiomac.2010.07.007.

47. Wang YF, Yu L and Wei XL (2012) Monosaccharide composition and bioactivityof tea flower polysaccharides obtained by ethanol fractional precipitation andstepwise precipitation. *CyTA-J. Food*, **10(1):** 1-4.https://doi.org/10.1080/19476337.2010.523901.

48. Wang YM, Ren N, Rankin, GO, Li B, Rojanasakul Y, Tu Y and Chen YC(2017) Anti-proliferative effect and cell cycle arrest induced by saponins extracted from tea (*Camellia sinensis*) flower in human ovarian cancer cells. *J. Funct. Foods*, **37:** 310-321. https://doi.org/10.1016/j.jff.2017.08.001.

49. Wan XC (2003) Tea Biochemistry, 3rd ed.; China Agriculture Press: Beijing, China, pp. 8–67.

50. Wan XC and Xia T (2015) Secondary Metabolism of Tea Plant, 1st ed.; Science Press: Beijing, China, pp. 39–64.(In Chinese)

51. Watanabe N, Watanabe S, Nakajima R, Moon JH, Shimokihara K, Inagaki J,Etoh H, Asai T, Sakata K and Ina K (1993) Formation of flower fragrancecompounds from their precursors by enzymic action during flower opening.*Biosci. Biotechnol. Biochem.*,***57*(7):** 1101-1106.https://doi.org/10.1271/bbb.57.1101.

52. Way TD, Lin HY, Hua KT, Lee JC, Li WH, Lee MR, Shuang CH andLin JK (2009) Beneficial effects of different tea flowers against human breast cancer MCF-7 cells. *Food Chem.*, **114(4):** 1231-1236. https://doi.org/10.1016/j.foodchem.2008.10.084.

53. Wei XL, Chen MA, Xiao JB, Liu Y, Yu L, Zhang H and Wang YF (2010) Composition and bioactivity of tea flower polysaccharides obtained by different methods. *Carbohydr. Polym*.,**79:** 418-422. https://doi.org/10.1016/j.carbpol.2009.08.030

54. Weng W (2004) Study on the main bioactive compounds of tea (*Camellia sinensis*)flower and its application perspectives. Master's thesis, Zhejiang University,Hangzhou, China.

55. Westerterp-Plantenga MS (2010) Green tea catechins, caffeine and body-weight regulation. *Physiol.Behav*.,**100(1):**42-6. https://doi.org/10.1016/j.physbeh.2010.02.005

56. Xia C, Tu Y, Yang Z, Jin Y and Xia H (2018) Antioxidant activity of essential oil of flowers of tea (*Camellia sinensis* L.) plants extracted by supercritical carbon dioxide, *J. Biomed. Sci*., **7(3:10)**. https://doi.org/10.4172/2254-609X.100089

57. Xu RJ, Ye H, Sun Y, Tu YY and Zeng XX (2012) Preparation, preliminarycharacterization, antioxidant, hepatoprotective and antitumor activities ofpolysaccharides from the flower of tea plant (*Camellia sinensis*). *Food Chem. Toxicol*., **50(7):** 2473-2480.https://doi.org/10.1016/j.fct.2011.10.047.

58. Yang Z, Xu Y, Jie G, He P and Tu Y (2007) Study on the antioxidant activity of tea flowers (*Camellia sinensis*). *Asia Pac. J.Clin. Nutr*.,**16 (suppl 1):** 148-152.

a. https://doi.org/10.6133/APJCN.2007.16.S1.28

59. Yang ZY, Baldermann S and Watanabe N (2013) Recent studies of the volatile compounds in tea. *Food Res. Int*., **53:** 585-599. https://doi.org/10.1016/j.foodres.2013.02.011

60. Yang ZY, Dong F, Baldermann S, Murata A, Tu YY, Asai T and WatanabeN (2012) Isolation and identification of spermidine derivatives in tea (*Camellia sinensis*) flowers and their distribution in floral organs**.** ***J. Sci. Food Agric.***, **92(10):** 2128-2132. https://doi.org/10.1002/jsfa.5596.

61. Yang ZY, Tu YY, Baldermann S, Dong F, Xu Y and Watanabe N (2009) Isolation and identification of compounds from the ethanolic extract of flowers of the tea (*Camellia sinensis*) plant and their contribution to the antioxidant capacity. *LWT Food Sci. Technol.*, **42:** 1439–1443.https://doi.org/10.1016/J.LWT.2009.03.017

62. Yang ZY, Xu Y, Jie GL, He PM and Tu YY (2007) Study on the antioxidant activity of tea flowers (*Camellia sinensis*).*Asia Pac. J. Clin. Nutr*.,**16:** 148–152.https://doi.org/10.6133/APJCN.2007.16.S1.28

63. Ye AH, Yu M, Zhu L, Jiang CJ, Wang ZX, Wei CL and Li YY (2008) Transcriptional profiling by cDNA-AFLP and its modified cDNA-AFLP technique reveals gene expression of tea (*Camellia sinensis*) during flower bud development stage. *Acta Laser Biology Sinica,* **17(6):** 733-738. https://doi.org/10.3724/SP.J.1141.2008.00373.

64. Yoshikawa M, Wang T, Sugimoto S, Nakamura S, Nagatomo A, Matsuda H andHarima S (2008) Functional saponins in tea flower (Flower buds of *Camellia sinensis*): Gastroprotective and hypoglycemic effects of floratheasaponins and qualitative and quantitative analysis using HPLC. *YakugakuZasshi- J. Pharm. Soc. Jpn.,* **128(1):** 141-151.https://doi.org/10.1248/yakushi.128.141.

65. Yu XL and He Y (2018) Optimization of tea-leaf saponins water extraction and relationships between their contents and tea (*Camellia sinensis*) tree varieties. *Food Sci.Nutr.,* **6:** 1734-1740. https://doi.org/10.1002/fsn3.724.

66. Zhang L, Ho CT, Zhou J, Santos JS, Armstrong L and Granato D (2019)Chemistry and biological activities of processed *Camellia sinensis* teas: A comprehensive review. *Compr. Rev. Food Sci. Food Saf.*,**18:** 1474-1495.https://doi.org/10.1111/1541-4337.12479.

67. Zhen Y (2002) Tea: Bioactivity and Therapeutic Potential; CRC Press, Taylor and Francis: New York, NY, USA, p. 58.

68. Zhou Y, Dong F, Kunimasa A, Zhang Y, Cheng S, Lu J, Zhang L, Murata A, Mayer F, Fleischmann P, Watanabe N and Yang Z(2014)Occurrence of glycosidically conjugated 1-phenylethanol and its hydrolase β-primeverosidase in tea (*Camellia sinensis*) flowers. *J. Agric. Food Chem.*, **62:** 8042–8050. https://doi.org/10.1021/jf5022658

69. Zhou Y, Zhang L, Gui JD, Dong F, Cheng S, Mei X, Zhang LY, Li YQ, Su XG, Baldermann S, Watanabe N and Yang Z (2015)Molecular cloning and characterization of a short chain dehydrogenase showing activity with volatile compounds isolated from *Camellia sinensis*. *Plant Mol. Biol. Rep.*, **33:** 253–263.

70. https://doi.org/10.1007/s11105-014-0751-z