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# Phenolic Compounds in Tea: Phytochemical, Biological, and Therapeutic Applications

*Jyoti V. Vastrad, Pratikhya Badanayak and Giridhar Goudar*

## Abstract

Phenolic compounds are one of the major and most complex groups of phytochemicals found among plant kingdom. Structurally they comprise of aromatic ring along with one or more hydroxyl groups. Based on the structure they are divided into subgroups such as phenolic acids, flavonoids, tannins, coumarins, lignans, quinones, stilbenes and carotenoids. Plant polyphenols are gaining popularity as a result of their potent antioxidant properties and notable effects in the prevention of oxidative stress-related diseases. Extraction, identification and characterisation of phenolic compounds from various plant sources has become a major area of health and medical research in the recent years. The major bioactive compounds responsible for tea's health benefits are thought to be phenolics. Catechin derivatives make up the majority of the phenolic compounds found in tea, and though flavonols and phenolic acids are also present in smaller amounts. The bioactivity of the compounds has been linked to a lower risk of serious illnesses like cancer, cardiovascular disease, and neurodegenerative disease. This chapter covers phenolic extraction, purification, analysis and quantification, as well as their antioxidant properties in different varieties of tea leaves.

**Keywords:** Tea leaf, phenolic compound, tannin, flavonoids, antioxidant, health benefits

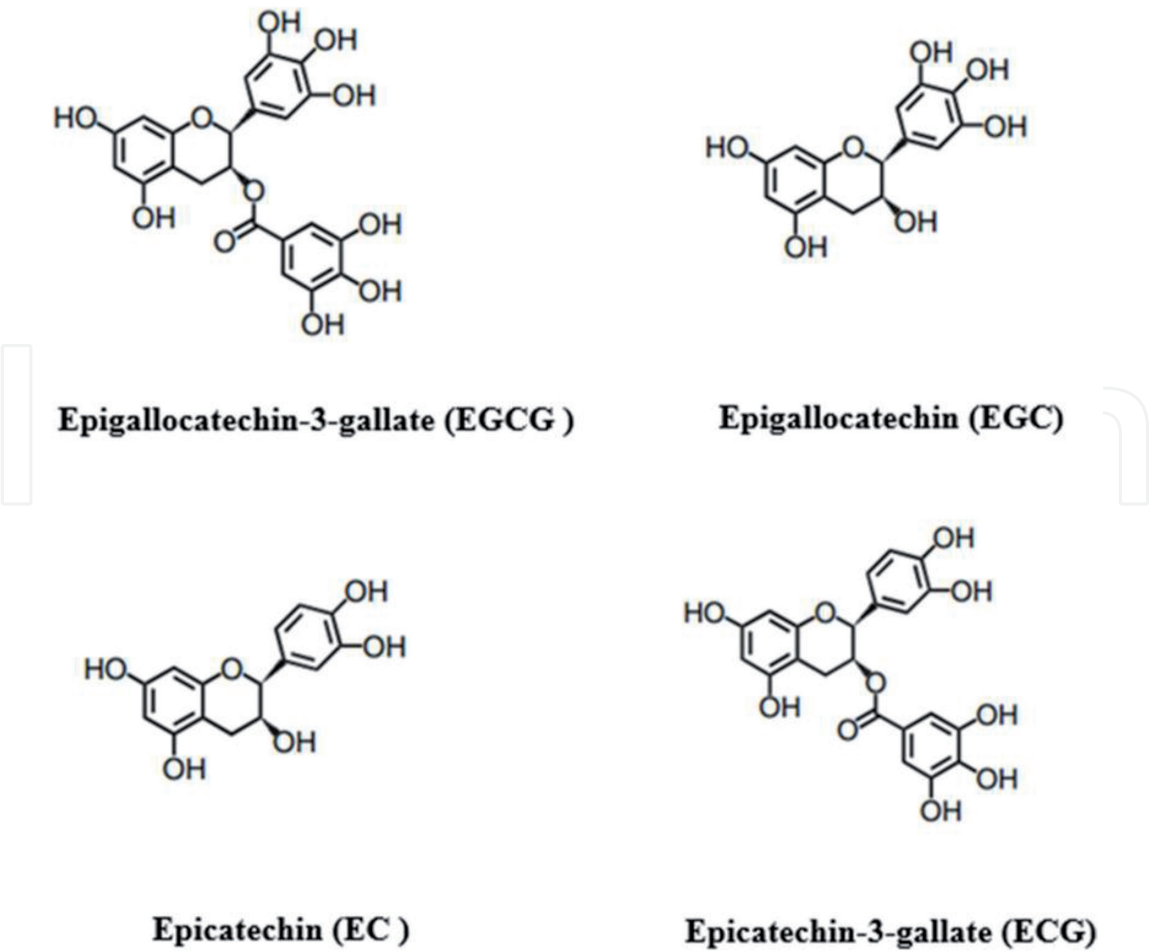
## 1. Introduction

Tea, which is prepared from the leaves of the *C. sinensis*, and is the second most popular beverage in the world, after water. Green tea, oolong tea, and black tea are made primarily from the young green shoots of the tea plant [1]. Only the young, top leaves and the unopened leaf bud are used in fine teas, which is one of their distinguishing characteristics. As a result, immature, light-green leaves are preferred for tea production, whereas mature and old leaves, which have a darker green colour, are unsuitable due to their unpleasant flavour. Tea beverages are classified as green (unfermented), white (lightly fermented), oolong (semi-fermented), or black (fermented) based on their manufacturing method (fully fermented) [2, 3]. It is cultivated in more than 50 countries of the world and the main producers of tea are China (2,473,443 t) and India (1,325,950 t) as per 2017 statistics (**Table 1**) [7].

Phenolic acids, terpenoids, flavonoids, alkaloids, tannins, and phytosterols are the major bioactive constituents in the plant leaves [8]. Tea chemical composition depends on the cultivars, environmental factors and different manufacturing process [9]. Flavonoids like flavanols (flavan-3-ols), flavonols, flavones, flavanones, and anthocyanidins are important components of tea leaves, accounting for up to 30% of the dry weight of the leaves [10, 11]. Catechins which are group of flavan-3-ols are the major bioactive compounds in fresh tea leaves, among them epicatechin (EC),

Compounds	Green tea	Black tea	Black tea infusion
Protein	15	15	Trace
Amino acids	4	4	3.5
Fibre	26	26	0
Carbohydrates	7	7	4
Lipids	7	7	Trace
Pigments	2	2	Trace
Minerals	5	5	4.5
Phenolic compounds	30	5	4.5
Oxidised phenolic compounds	0	25	4.5

**Table 1.**  
*Composition (%) of green, black and infusion [4–6].*



**Figure 1.**  
*The main phenolic compounds of tea polyphenols [12].*

epigallocatechin (EGC), epicatechin gallate (ECG), epigallocatechin gallate (EGCG), catechin and gallic acid are majorly found (**Figure 1**) [13, 14].

Tea is widely acknowledged to have numerous health benefits, including antioxidant activity, anti-inflammatory activity, anti-microbial effects, and anti-carcinogenic effects when consumed regularly. The phenolic compounds in tea are thought to be responsible for these effects. As a result, tea phenolics are thought to be valuable phytochemicals and received a great deal of attention [15].

## 2. Different types of tea

Type of tea produced depends on the various fermentation processes, white tea (sundried fresh leaves), green tea (heated or steamed fresh leaves), and black tea (fermented leaves) [16]. Among different tea types, black tea is produced highest about 76–78%, followed by green tea (20–22%) and oolong tea (2%) accounting for worldwide production [17].

### 2.1 Black tea

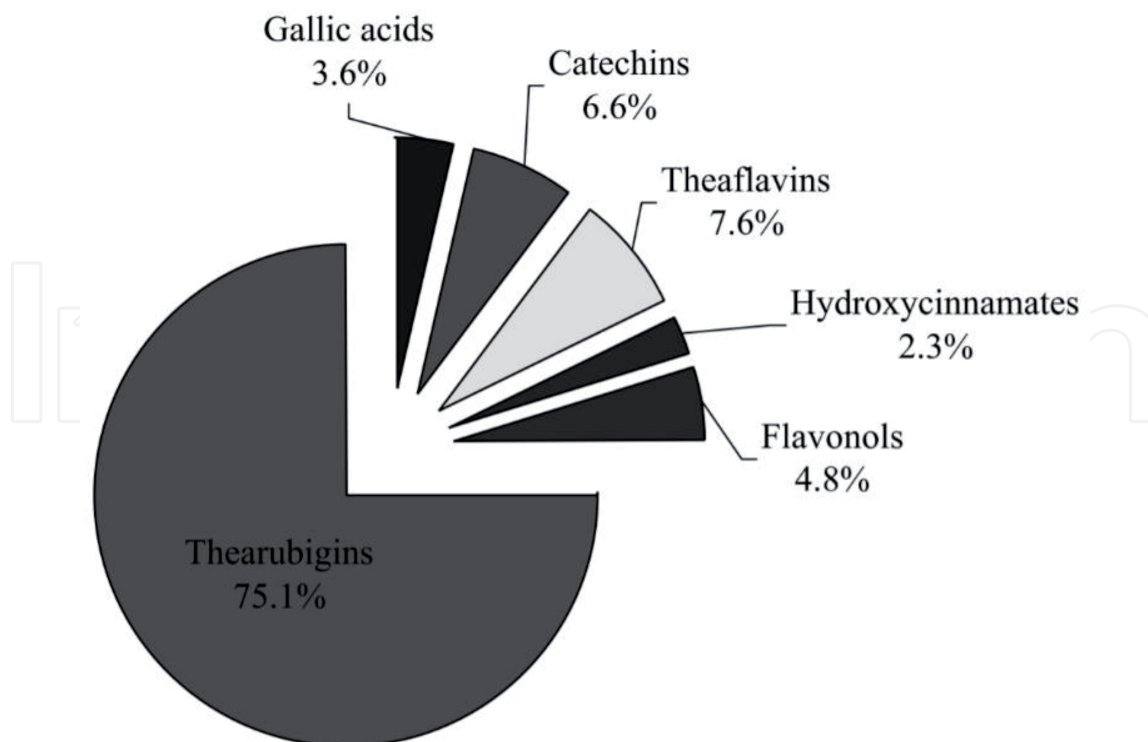
Black tea which is prepared from the young tender shoots of *C. sinensis* is consumed widely as a non-alcoholic beverage. It is most popular in India, Europe and North America [18]. The phenolic composition of black tea differs significantly from green tea due to the fermentation process resulting in the formation of condensation and oxidation products such as thearubigins and theaflavins, which might be due to the action of polyphenol oxidases (PPO) [19, 20]. In comparison to green tea, 85% of catechin in black tea is transformed into theaflavin-3,3'-digallate and thearubigin [21]. Astringency and brightness of tea is due to theaflavins, whereas colour and mouthfeel is because of thearubigins [18]. Theaflavins and thearubigins (2 to 6%) account for catechin content of 3 to 10% (w/w) of 10 to 20% (w/w) of the dry weight of black leaves (**Figure 2**) [18].

Rechner et al. [22] has reported numerous *in vitro* and *in vivo* effects of tea polyphenols, including antioxidant, anticarcinogenic, and hypolipidemic properties. The bioavailability and metabolism of individual polyphenolic constituents of black tea (flavan-3-ols, flavonols, hydroxybenzoic acids, hydroxycinnamates) in humans have been reported by Liebert et al. [23]. Rababah et al. [24] show that a cup of black tea, as it is traditionally brewed in the UK, is an excellent source of polyphenols, containing up to six different classes of polyphenols and having higher antioxidant activity than other dietary sources. Treatment of the black tea brew with simulated gastric juice resulted in a significant increase in the identified theaflavins, implying partial cleavage of thearubigins in the gastric lumen environment. As a result, black tea can be considered a good source of polyphenols and/or antioxidants [25].

### 2.2 Green tea

Green tea is prepared by leaves of *C. sinensis* which after harvest are heated with rolling immediately for inactivating the polyphenol oxidase (PPO) enzyme which is responsible for oxidation of tea catechins into theaflavins and thearubigins. Green tea is prepared by steaming of fresh leaves and drying at higher temperature to avoid the polymerisation and oxidation of polyphenols [26].

Green tea is a popular tea that is usually consumed as an infusion with a pleasant taste and is thought to have a positive effect on general health even at high doses of 8 to 16 cups per day [27]. Green tea leaves are high in bioactive compounds, especially



**Figure 2.**  
Mean percentile composition of different classes of polyphenols in consumer brews of different black teas [22].

phenolic compounds with antioxidant activity (**Figure 3**). Although recent studies have identified several other phenolic compounds at lower concentrations, particularly flavonols and phenolic acids, the increased proportion of catechins is related to biological functionality [29]. The stability of green tea flavanols depend on the intactness of the plant cell [16]. Green tea consumption has been shown in scientific studies to improve general health and reduce the risk of severe diseases. This is a trend with promising and positive results to help with body weight control [30], UV radiation protection, physical functional performance [27], oral health, bone health, and other physiological effects [23]. Specific diseases, including those with severe consequences, such as neurodegenerative and cardiovascular diseases, have received special attention.

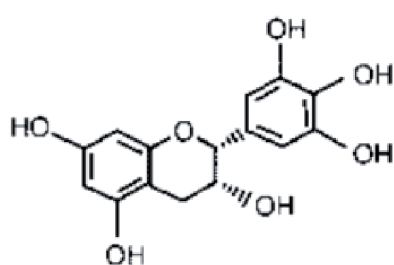
Green tea health benefits are linked to polyphenolic compounds, which have piqued the interest of the food industry and researchers [31]. Green tea can be used in the formulation of some products to boost antioxidant activity for nutritional or technological purposes. Several mechanisms, similar to those seen in biological structures, can be used to prevent lipid oxidation in food (e.g., free radical scavenging and metal-chelating activity). Lipid oxidation can change physical-chemical and sensory properties like colour, flavour, and taste. Among the many foods that require the use of antioxidants, meat and muscle products are particularly vulnerable to lipid oxidation, necessitating the addition of antioxidants to extend shelf life [23, 29, 32].

### 2.3 Oolong tea

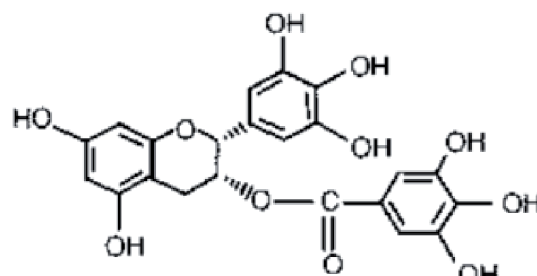
Oolong tea is a semi-fermented tea, which is less fermented than black tea. Young green shoots (usually the top three leaves of each branch) are freshly harvested in the early morning and allowed to wither in the sunlight for a few hours before undergoing the semi-fermentation process, in which tea leaves are oxidised, pan fired at 200°C, rolled into a ball shape, and then dried in a specialised oven at various desired temperatures [33].



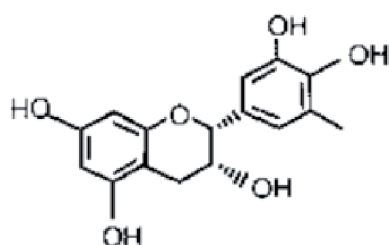
### A: Major green tea polyphenols



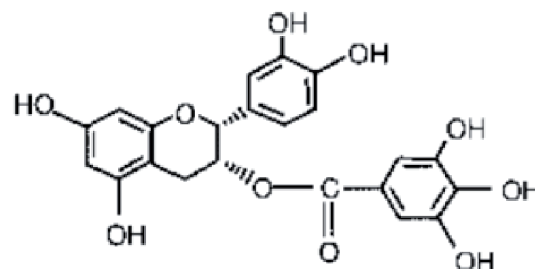
**(-)-Epigallocatechin**



**(-)-Epigallocatechin-3-gallate**

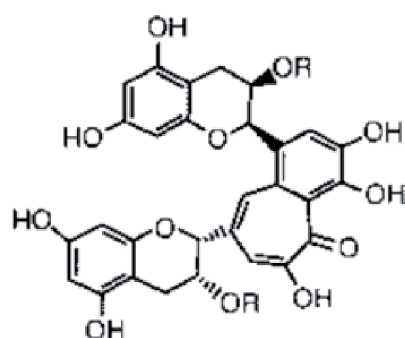


**(-)-Epicatechin**

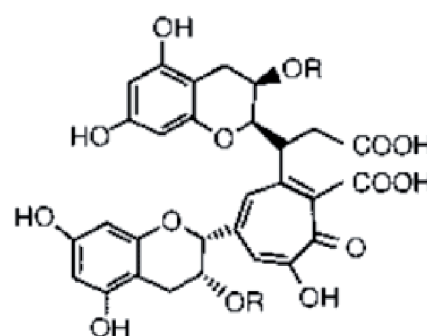


**(-)-Epicatechin-3-gallate**

### B: Major black tea polyphenols



**Theaflavins**



**Thearubigins**

**Figure 3.**  
Major green tea polyphenols [28].

The partial fermentation of oolong tea produces polymerised polyphenols such as procyanidins (condensed tannins) which is unique to the limited time of oxidation process. Oolong tea contain both properties of green tea and black tea with catechins and theaflavins, however it contains half the content epigallocatechin-3-gallate in comparison to green tea [19, 34]. The components of oolong tea are classified in **Table 2**.

Oolong tea, which has a taste and colour between green and black tea, is primarily produced in China's Fujian [33] and Guangdong provinces [37], as well as in Taiwan [38]. Oolong tea absorbs a lot of moisture from the air after a long time in storage, so it needs to be refined by drying on a regular basis. In general, old oolong tea refers to oolong teas that have been stored for more than five years and refined annually through a professional drying process. Experientially, the longer oolong tea is stored and gradually oxidised, the better it tastes and has beneficial effects on human health. As a result, fermentation (oxidation) and drying are two critical steps in the production of oolong tea [39].

Wang et al. [37] discovered that the main bioactive compounds in oolong tea, such as phenolics and flavonoids, have remarkable antioxidant activity and inhibitory

Compounds	Contents (mg/g)	
	Oolong tea	Green tea
Flavon-3-ol without galloyl moiety		
Catechin	10	5
Gallocatechin	30	43
Epigallocatechin	6	25
Epicatechin	2	8
Flavon-3-ol without galloyl moiety		
Catechin gallates	7	5
Epicatechin gallates	3	6
Epigallocatechin gallates	14	29
Gallocatechin gallates	16	19
Allocatechin gallates	1.85	—
Gallic acid	2.19	—
Caffeine	64	53
Polymerised	33.65	—
Total polyphenols	99.32	—

**Table 2.**  
*Components of oolong and green tea [35, 36].*

potential on the growth of 4 T1 murine breast cancer cells in vitro. Thus, after further research, the phenolic enriched extracts of Tieguanyin tea are expected to have a potential application in the food and pharmaceutical industries. More alike, it has similar constituent of green tea.

3. Phenolic composition in different tea types

The tea leaves are good source of several polyphenols and oxidative enzymes, hence they are selected for preparation of different types of the tea. These tea polyphenols are basically tea flavonoids, earlier known as tannins. The catechins of flavonoid group are the predominant polyphenols of fresh tea, which account for 12–24% of dry weight. Other than catechins, the tea leaves also contain other polyphenols such as phenolic acids, anthocyanidin and flavonols along with their glycosides [40, 41]. Depending on the harvesting season, cultivars, cultivation conditions and manufacturing process the polyphenolic content varies in different types of tea. The major catechins in tea leaves are (–)-epigallocatechin gallate (EGCG; 9170–14900 mmol/100 g leaf), (–)-epi-gallocatechin (ECC; 8060–17900 mmol/100 g leaf), (–)-epicatechin gallate (ECG; 1400–2350 mmol/100 g leaf [42]. The catechin content in different tea types vary depending on fermentation process, green tea produced without fermentation contain highest amount of catechins among which EGCG is the major catechin found. Considering EGCG as an abundant catechin in all tea types, as the fermentation process is increased in different tea types the EGCG content decreased in different tea types; green tea (70.2 mg/100 g), oolong tea (34.48 mg/100 g), and black tea (9.36 mg/100 g) [43].

Flavonoids are phenolic compounds that are divided into several sub-classes: anthocyanidins, flavanones, flavanols, flavones, flavonols, and isoflavones. These sub-classes

share a basic structure of 15 carbons with a three-carbon bridge connecting two aromatic rings in the C6–C3–C6 configuration. Along with flavonoids, phenolic acids, which are divided into hydroxybenzoic acids and hydroxycinnamic acids, are an important group. Gallic acid, also known as 3,4,5-trihydroxybenzoic acid, has a relatively simple structure. This compound serves as the foundation for hydroxybenzoic acids and other derivatives with antioxidant activity, such as ellagic acid [44–46]. The hydroxycinnamic acid derivatives, on the other hand, have p-coumaric acid as the basic structure, which is formed by an aromatic ring with one hydroxy substitution and one propenoic acid.

In tea leaves almost 20 different flavonols and their glycosides have been detected which include quercetin, kaempferol, and myricetin which account for 2–3% of the water-soluble extractive in green tea [47, 48]. The main flavonol glycosides found in tea are rutin, quercetin glycoside and kaempferol glycoside with 0.05–0.15%, 0.2–0.5% and 0.16–0.35%, respectively of dry weight [47]. The other group of phenolic compounds found in tea are phenolic acids which account for 5% of tea leaf dry weight. The major phenolic acids found in tea are gallic acid, chlorogenic acid and theogallin which account for 0.5–1.4%, 0.3% and 1–2%, respectively of dry weight content. Whereas ellagic acid and m-digallic acid are found in trace amounts. These phenolic acids act as precursors of catechin gallate and in association with other polyphenols have an effect on the astringency of tea beverage [40, 41]. Anthocyanidins and leucoanthocyanidins are another group of phenolic compounds in fresh tea leaves with 2–3% of dry weight content. Anthocyanidins such as cyanidin, pelargonidin, delphinidin and tricetinidin are approximately 0.01% of dry weight in tea leaves, however they may reach up to 1.0% in processed tea which gives a purple colour to the tea preparation with some bitterness [40, 41].

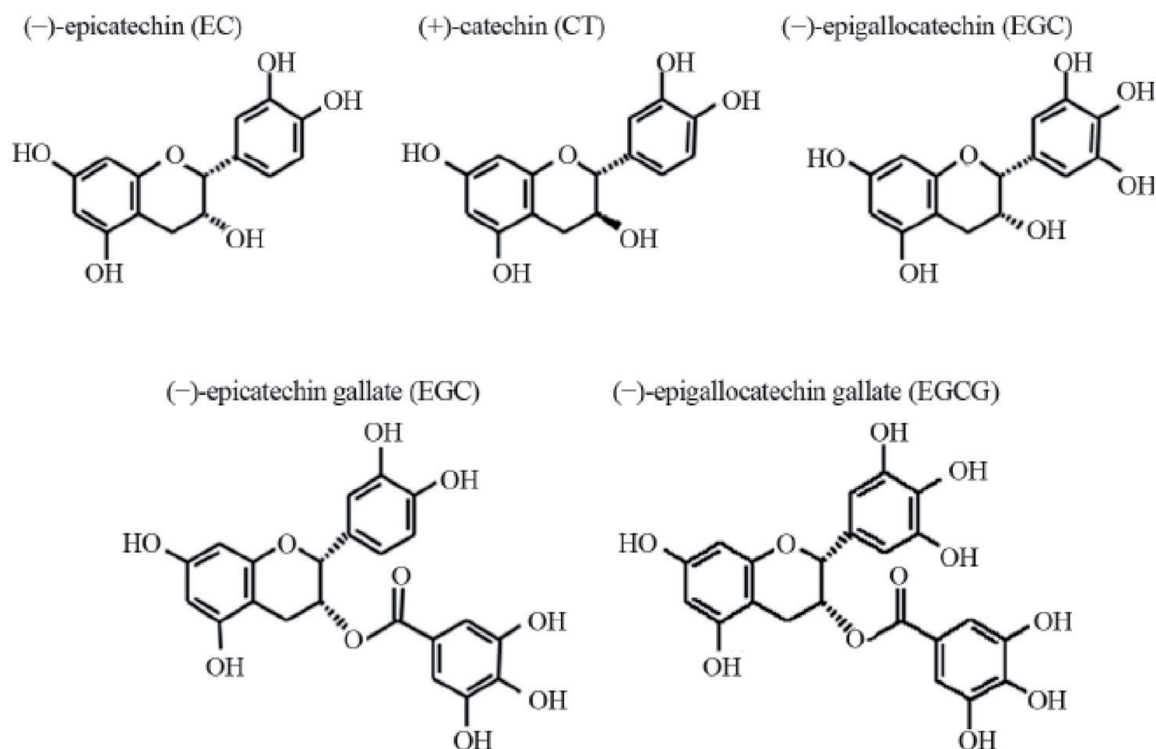
Infusions of black tea contain relatively high levels of catechins, ranging from 102 to 418 mg of total catechins/L [49]. The four major tea catechins are enzymatically oxidised and converted to various oxidation products containing black tea polyphenols during tea fermentation. Characteristic pigments of these oxidation products are typically classified into two major groups: theaflavins and thearubigins [48, 50]. Theaflavin content of black tea leaves ranges between 0.8 and 2.8 percent, depending on fermentation conditions. Thearubigins, on the other hand, can account for up to 60% of the solids in black tea infusions [50]. In black tea, theaflavin, theaflavin 3-gallate, theaflavin 3'-gallate, and theaflavin 3,3'-digallate are the main theaflavins formed by the reaction of quinones derived from a simple catechin and a gallic acid [48]. With relative molecular masses ranging from 700 to 40,000 Da, thearubigins remain ambiguous, and little is known about their chemical structures [48, 50]. Aside, from these unidentified colourless oxidation products, tea fermentation produces a plethora of other unidentified colourless oxidation products.

The polyphenols in green tea accounting for 40% of the dry leaf weight include different polyphenolic groups such as flavonols (quercetin, kaempferol and rutin), phenolic acids, leucoanthocyanins, caffeine and theanine [4]. Theanine is a non-protein amino acid which account for 1.5–3.0% of dry weight of tea leaf and is almost 50% of the total amino acids content in tea. The natural theanine in tea is usually in L-form which significantly contributes to the sweet taste in green tea infusions [41].

#### **4. Analysis of polyphenols in tea**

The high level of interest in green tea composition has been linked to antioxidant activity and, as a result, elevated phenolic content. Recently, a wide range of compounds





**Figure 4.** Chemical structures of the green tea polyphenols (–) -epicatechin (EC), (+) catechin (CT), (–) -epigallocatechin (EGC), (–) -epicatechin gallate (EGCg), and (–) epigallocatechin gallate (EGCG) [51].

have been identified, and several methods for identifying and quantifying these compounds have been developed. Some phenolic compound properties have been considered for identifying each class of phenolic compounds in several matrices. Because degradation of important phenolic compounds in green tea can reach 70% at temperatures lower than those used in gas chromatography, thermal sensitivity necessitates the use of liquid chromatography rather than gas chromatography [43]. The double bonds in the aromatic ring of phenolic allow for UV–visible spectrophotometric measurements. The maximum absorption evaluation indicates, at the very least, the subclass (e.g., flavanol, flavonol, and flavones) or supports the identification with a standard.

The distinct fragmentation pattern of each phenolic compound enables identification in mass analyzers or provisional identification for compounds lacking a standard, even for complex and high molecular weight compounds (**Figures 1, 3 and 4** depicts the phenolic structures present in different teas) [31, 44]. Given the aforementioned characteristics, liquid chromatography separation followed by spectrophotometry and/or mass spectrometry analysis can provide valuable information for the investigation of the phenolic profile in tea extracts. Other analyses were also carried out using nuclear magnetic resonance (NMR) to provide solid information on the phenolic profile of tea [44].

## 5. Health beneficial effects of tea

Epidemiological studies on the benefits of green tea consumption against major diseases, supported by *in vitro* and *in vivo* experiments have revealed promising protective effects. Catechins, the major phenolic constituents of green tea, are also the compounds linked to health benefits through modulation of relevant mechanisms altered by important diseases, as discussed in this section. Tea is high in antioxidants.

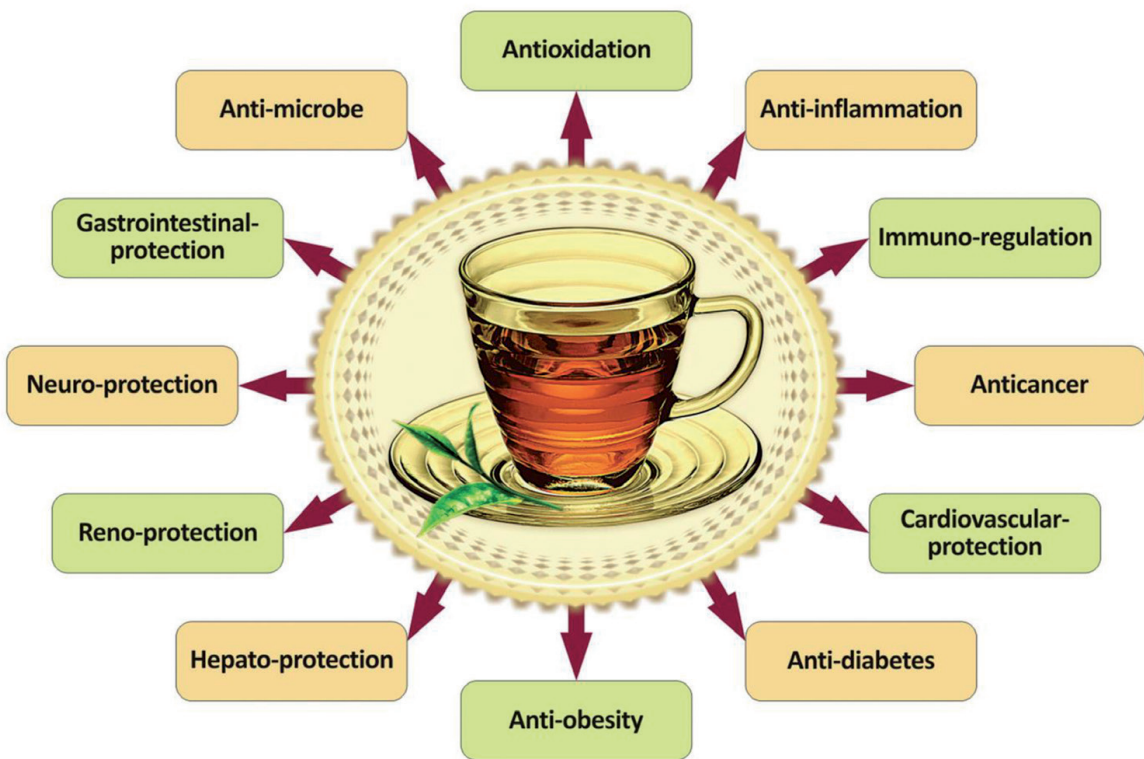
Caffeine content of tea is lower than that of coffee. Tea may lower your chances of having a heart attack or having a stroke. It may aid in weight loss and beneficial to your bones. Tea may help you keep your grin bright. It helps to enhance the immune system and aid in the fight against cancer. Herbal tea may be beneficial to the digestive system. The benefits of tea are depicted in **Figure 5** and explained in detail below.

### 5.1 Antioxidant properties of tea polyphenols

Antioxidant activity is defined as a molecule's or ion's ability to avoid oxidative reactions with other molecules. Phenolic compounds found in green tea leaves have antioxidant potential through a variety of mechanisms, providing additional protection against oxidants as well as additional protection against oxidative reactions and reactive species [44]. The oxidative series of events proposed by Miguel et al. [39] provides an overview of the major antioxidant effects (preventive and primary antioxidants), which may also be presented by polyphenol-rich green tea extracts. Preventive antioxidants can protect against oxidative reactions by lowering local oxygen concentrations, preventing the initiation of chain reactions by scavenging radicals (e.g., HO•, O2•-), preventing radical generation, and breaking down lipid peroxides to peroxy and alkoxy radicals.

Primary antioxidants play a role in subsequent events by causing peroxides to decompose into nonradical products and inhibiting hydrogen removal from oxidable by intermediate radicals such as peroxy and alkoxy radicals. These radicals are reactive oxygen species that cause oxidative damage to biological and food systems. The major effects are related to lipid and protein oxidation, membrane damage, mutagenesis, and carcinogenesis, and it is critical to assess how natural extracts impact and mitigate these effects.

Many studies have found a strong and positive correlation ( $p > 0.05$ ) between the phenolic compounds and their antioxidant potential in several plant species [52, 53]. This



**Figure 5.**  
*Health benefits of tea.*

antioxidant mechanism found in plants plays an important role in reducing lipid oxidation in (plant and animal) tissues, because when it is included in the human diet, it not only preserves the food's quality, but it also lowers the risk of developing certain diseases.

The correlation between phenolic content and antioxidant activity as measured by multiple methods is an important finding in studies on phenolic compounds in green tea extracts. Green tea's structural differences among phenolic compounds also play an important role in antioxidant activity. Individual flavanol content of green tea was found to be inversely related to radical content of green tea leaves in a study conducted by Socha et al. [54]. The correlation coefficient for epigallocatechin gallate was higher than that of the other tested flavanols. This result was linked to the presence of hydroxyl groups in the aromatic rings of gallyl and galloyl substituents, because flavanols lacking this substituent had lower antioxidant activity.

Induction of antioxidant enzymes by EGCG with detailed molecular mechanism have been studied [9]. EGCG has been studied for antiradical activity which was proved to have stronger activity than the antioxidants such as vitamin E and vitamin C [55]. By binding to different molecules, catechins in particular EGCG modulate the compounds' activity and in turn regulates the cell-signalling pathway [56].

## **5.2 Cardiovascular disease**

Cardiovascular diseases are one of the leading causes of death, accounting for nearly one-third of all deaths globally. Sano et al. [57] investigated the relationship between green tea consumption and the incidence of cardiovascular disease and discovered that patients without cardiovascular disease consumed more green tea than those with cardiovascular disease (5.9 and 3.5 cups, respectively). Green tea consumption was linked to a lower risk of coronary artery disease in Chinese patients, according to Wang et al. [58]. In this study, the risk was found to be inversely related to green tea consumption, with a dose-dependent effect as the frequency, period, and amount of green tea consumed increased. Fung et al. [59] reported that chronic green tea consumption results in a different pattern of behaviour. Plasma levels of selected catechin derivatives were measured after 1 and 2 hours of green tea consumption, as well as after 7 days of daily consumption. After 1 hour of tea consumption, the plasma level of epigallocatechin gallate was the highest among the catechin derivatives tested, followed by epigallocatechin and epicatechin gallate, which remained elevated even after 2 hours of green tea consumption. An unexpected result was observed in the chronic consumption evaluation because only epicatechin gallate had a higher level in plasma.

The effectiveness of tea polyphenols against CVD by regulating lipid metabolism, cell proliferation, platelet aggregation and antithrombotic activity has been studied by reduction of total cholesterol, LDL and triglycerides which are helpful in development of atherosclerosis [60]. The study on EGCG has been shown effective in reduction of lipid metabolising enzyme activities in the serum and cardiac tissue thereby resulting into less lipidemic pathologies [61]. In an in vivo study on mice, 40 mg/kg/day of EGCG was administered which resulted in decrease of LDL and the size of atherosclerotic plaques in the aortas, and increase in HDL [62].

## **5.3 Anti-cancer properties**

Increased levels of reactive oxygen species (ROS) and oxidative stress modulation have an important role in the activation of carcinogenesis, and polyphenols act against these mechanisms by preventing or controlling the tumorigenesis [63]. Tea polyphenols



have been effective in inhibiting enzymes related to cell proliferation and tumour progression [34]. Theaflavins in tea can act as anti-cancerous compounds by controlling the DNA damage which is the main cause of induction of cancer. They act by scavenging the free radicals which inhibits the mutagenicity and cleavage of single strand DNA [41].

Suppression of elevated cytochrome P450 1A1 (CYP1A1) in cells is inhibited by theaflavins which in turn prevents the cellular DNA damage, carcinogen related DNA damage and oxidative stress induced cytotoxicity [59]. EGCG has been investigated for proliferation of epidermal cell line A431 in humans. *In vitro* inhibition of protein tyrosine kinase activities of EGF-R, PDGF-R and FGF-R are strongly inhibited the DNA synthesis of A431 cells [64]. Tea polyphenols have been shown inhibition for PKC, MAPK, and AP-1 activities in NIH 3 T3 cells [65]. In mouse epidermal JB6 C1 41 cells inhibition of UVB-induced phosphatidylinositol-3-kinase (PI3K) activation was studied for tea polyphenols [66]. Some tea catechins of green and black tea have been potent inhibitor of Bcl-2 antiapoptotic family proteins, which shows a strong link of tea polyphenols and their anticancerous properties [34].

Given the growing interest in the relationship between dietary flavonoids and cancer initiation and progression, this important field is likely to see increased effort and attract and stimulate additional vigorous research [67]. In liver carcinoma cells, effect of tea catechins have studied and showed that due to the activity of EGCG, H2P2 mediated cytotoxicity was suppressed with increase in cellular glutathione levels [63]. The effect of catechin, epicatechin, ECG, EGC and EGCG in A549 cells have been studied for apoptosis and cell proliferation [68]. Tea polyphenols have been shown for inhibition activity for the enzymes involved in oestrogen biosynthesis, which might play role in the development of breast cancer [69].

## **5.4 Obesity and lipogenesis**

Tea catechins have been proved to be very effective for obesity by the acting on the adipose tissue. These tea catechins have been effective for suppression of enzymes involved in fatty acid, triacylglycerols and cholesterol metabolism [70]. Rocha et al. [71] showed in rat model study that daily consumption of green tea extract decreased adipose tissue, adiposity index, cholesterol, triacylglycerols and reduction in hypertrophy of adipocytes. Green tea catechins were showed for inhibition of enzymes metabolising noradrenaline, this mechanism have been effective in lipid metabolism [72]. A study conducted in the United States on men and women for consumption of black, oolong and green tea was showed inverse association for body mass index and metabolic syndrome markers [73].

## **5.5 Other health beneficial effects**

Significant *in vitro* and animal model research support the beneficial effects of polyphenols in a variety of gastrointestinal diseases [74]. Recent human studies suggest that green tea may help to promote oral health as well as other physiological functions like anti-hypertensive effect, body weight control, anti-inflammatory, anti-antibacterial, and antiviral activity, solar ultraviolet protection, bone mineral density increase, anti-fibrotic properties, and neuroprotective power [20, 75]. Tea catechins have been studied for beneficial activity on bone, wherein the cell lines and animal model studies revealed that they are effective for osteoporosis [76]. Green tea catechins have been investigated as dietary polyphenols for their neurodegenerative diseases due to their anti-amyloidogenic properties [77]. Also EGCG has been studied for neuroprotective properties by evaluation of its brain accessibility [78]. Tea

catechins also have been shown effective against hyperglycemia and its related type 2 diabetes mellitus complications [79]. Green tea consumption has increased bone formation and improved bone strength; however, it decreased the process for deterioration of bone microstructure which was studied in postmenopausal women [80].

Manach et al. [81] estimated the daily intake of catechin and proanthocyanidin dimers and trimers to be 18–50 mg/d. In Caco-2 cells, efflux transport was greatest in the following order: EC > EGC > ECG = EGCG [82]. Pgp, MRP1 and MRP2 efflux transporters have also been found to play roles in the absorption and excretion of green tea catechins [83]. Recent research has shown that green tea catechins undergo methylation, glucuronidation, and sulfation in in vitro, animal, and human systems [81, 83, 84].

## **6. Effect of tea phenolic on iron absorption**

Iron is stored in the body as ferritin and hemosiderin, which are found throughout the body, with a largest amount typically found in the liver, spleen, and bone marrow. Tea flavonoids are responsible for tea's inhibitory action on non-heme iron absorption [85]. Tea flavonoids are polyphenols with two aromatic rings and two or more hydroxyl groups as a functional group [86]. The development of a complex compound of tea flavonoids with iron is the process through which tea inhibits iron absorption. Iron is selectively bound by the galloyl group primarily present in these phenolic compounds [87]. Merhav et al. [88] revealed the iron status of Israeli infants in their investigation. They discovered an overall frequency of anaemia of 48.4% and a tenfold greater incidence of microcytic anaemia in tea-drinking neonates compared to the non-tea-drinking control group. Razagui et al. [89] investigated the iron status of 15 mentally challenged menstruation women, a population with limited food intake. They examined the link between tea drinking and iron status. It was discovered that participants with depleted iron levels consumed much more tea during meals (563 ml/meal/d) than ladies with adequate iron reserves (184 ml/meal/d). According to Zijp et al. [90], simultaneous consumption of tea reduces iron absorption from a test meal by 60 to 70 percent.

## **7. Application of tea phenolics in textile and allied sectors**

Polyphenols can be grafted onto fibres and fabrics using both enzyme-mediated and non-enzyme-mediated techniques, and their bioactivities vary depending on the type of phenolic compound used. In the development of environmentally friendly coloration and functionalization of textiles, polyphenol grafting onto textile fibres is a promising alternative to conventional synthetic dyestuffs [91]. Cheng et al. [92] reported in the literature on the use of tea as a natural dye and flame retardant finish on silk. They discovered that the oxidative polymerisation of polyphenols during alkaline extraction resulted in the formation of macromolecular polyphenols, which could give silk flame retardancy. Postmordanting with metal salts clearly improved the poor fastness characteristics. Because sufficient tea stem extract was used, dyed silk demonstrated good flame retardant, antibacterial, and antioxidant properties. According to Bonet-Aracil et al. [93], tea extracts behave differently depending on the type of tea used (green, red, or black). Green tea has the highest total antioxidant content when it comes to antioxidant effect. While dyeing, red tea had the highest colour strength value, whereas green tea had the lowest UPF value and red and black had higher values.



## 8. Conclusion

Tea, which is consumed all over the world, is thought to be not only a popular beverage but also can be an antioxidative agent that is readily available in everyday life. Polyphenols such as theaflavins and thearubigins, as well as catechins, which are major constituents of tea, are thought to be primarily responsible for several beneficial effects. Tea's antioxidant properties include its ability to inhibit free radical generation, scavenge free radicals, and chelate transition metal ions. It is clear that, despite extensive research, the composition of tea is still unknown. Only 20% of the approximately 2.5 million metric tonnes of dried tea produced is green tea, and less than 2% is oolong tea. Green tea is primarily consumed in China, Japan, and a few North African and Middle Eastern countries. Fresh tea leaf is unusually high in catechins, a flavanol group of polyphenols that can account for up to 30% of the dry leaf weight. Other polyphenols include flavonols and their glycosides, as well as depsides like chlorogenic acid, coumarylquinic acid, and theogallin, which is unique to tea (3-galloylquinic acid). Caffeine is present in an average concentration of 3%, with very small amounts of the other common methylxanthines, theobromine and theophylline also present. Teas used in pharmacological studies should be classified according to their type, source, and method of production. It would be preferable to include analytical information such as caffeine and catechin content. Methods of preparation should be specified when using tea extracts or fractions. Tea polyphenols can also reduce the risk of certain types of cancer by inducing phase I and phase II metabolic enzymes that increase the formation and excretion of carcinogen-detoxified metabolites. The research interest in tea components may provide a method to reduce the incidence and mortality from a variety of diseases. In general, tea is a more affordable natural beverage than modern beverages such as soft drinks.

### Author details

Jyoti V. Vastrad<sup>1\*</sup>, Pratikhya Badanayak<sup>1</sup> and Giridhar Goudar<sup>2</sup>

<sup>1</sup> Department of Textile and Apparel Designing, College of Rural Home Science, University of Agricultural Sciences, Dharwad, Karnataka, India

<sup>2</sup> Biochem Research and Testing Laboratory, Dharwad, Karnataka, India

\*Address all correspondence to: [vastradjv@uasd.in](mailto:vastradjv@uasd.in)

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