Hop and Medicinal Plants, Year XXXII, No. 1-2, 2024
ISSN 2360 – 0179 print, ISSN 2360 – 0187 electronic

Camellia sinensis L. (Green Tea): Bioactive Compounds and Pharmacological Properties – A Comprehensive Review

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Abstract: Medicinal plants have become increasingly preferred over drugs due to the sense of well-being they promote, thanks to their rich content in bioactive compounds with many health benefits, as well as their lack of adverse effects compared to pharmaceuticals. At the same time, they can relieve the symptoms of some conditions and also contribute to the prevention of various chronic diseases, including obesity, diabetes, and cancer. *Camellia sinensis* L., known as the plant from which green, black, and oolong teas are obtained, as well as other varieties, is one of the most famous medicinal plants, bringing a multitude of benefits to the human body, mainly through the compounds in its leaves, the largest proportion being represented by catechins, a type of polyphenol recognized for their strong antioxidant properties. EGCG (epigallocatechin gallate), the most important and abundant catechin, is known for its ability to neutralize free radicals and reduce oxidative stress.Although less studied, the flowers of this plant are also rich in bioactive compounds found in the leaves, along with unique compounds but also others with multiple therapeutic properties. Research indicates that the regular consumption of green tea (*Camellia sinensis* L.) significantly enhances life quality and promotes longevity by lowering the risk of cardiovascular diseases and certain types of cancer, including colorectal and gastric cancers.

Keywords: *Camellia sinensis* L., green tea, pharmacology, phytochemistry

Introduction

Originating in ancient China, tea has spread globally and is now a staple beverage for over 3 billion people (Wang, 2019). Natural products, such as tea, have been central to traditional remedies for centuries, providing effective and affordable alternatives to synthetic pharmaceuticals while generally producing fewer adverse effects. These products often act on multiple systems within the body, offering a therapeutic profile with a lower risk of side effects compared to synthetic drugs (Aboulwafa et al., 2019; Balazi et al., 2019; De Amorim et al., 2018; Talukdar et al., 2022; Xu et al., 2018; Yoneda et al., 2019).

The tea plant, *Camellia sinensis* L., from the Theaceae family, is processed into various types, including green, black, yellow, white, and oolong tea. People primarily harvest tea from *Camellia sinensis* var. sinensis or *Camellia sinensis* var. assamica, pruning the plant to waist height to make harvesting easier. They typically prefer younger leaves due to their changing chemical profile with age.Green tea is especially popular in Asia, where it holds a long-standing role in traditional Chinese medicine as a cooling, diuretic, and anti-inflammatory remedy (Hayat et al. 2015; Long et al., 2022).

Kombucha fermentation, a drink renowned for its antioxidant, anti-diabetic, and anticancer properties, also widely uses green tea leaves (Khadrawy et al., 2017; Xu et al., 2022). Green tea, the earliest recorded form, is unfermented, preserving a higher concentration of natural compounds, including polyphenols, caffeine, theanine, and tea polysaccharides. These bioactive compounds have many health benefits, such as lowering blood sugar, preventing cancer, and acting as an antioxidant (Balazi et al., 2019; De Amorim et al., 2018; Talukdar et al., 2022; Xu et al., 2018; Yoneda et al., 2019; Zhao et al., 2022). This makes green tea a great choice for people with high blood pressure, heart disease, coronary artery disease, and diabetes (Balazi et al., 2019; De Amorim et al., 2018; Zhao et al., 2022).

Epigallocatechin gallate (EGCG), a key compound in green tea, has demonstrated cholesterol-lowering, anti-angiogenic, and anti-mutagenic properties. Additional research has suggested benefits of green tea consumption for blood sugar control and energy expenditure. Beyond these, green tea exhibits anti-obesity, anti-inflammatory, and potential longevity-promoting effects (Chakravorty et al., 2019; Chaudhary et al., 2023; Hayat et al., 2015; Miranda et al., 2022; Yang et al., 2014).

Bioactive compounds

The tea plant, *Camellia sinensis* L., is a notable source of bioactive compounds (Figure 1), especially polyphenols, that contribute to its use as a functional beverage with numerous health benefits (Chen et al., 2020; Nibir et al., 2017; Shang et al., 2021; Zhang et al., 2019). Among its various forms, green tea is unique for preserving the plant's natural composition due to minimal processing.This results in a high polyphenol content, reaching up to 50–70% of the extractable material, which is primarily composed of catechins such as epigallocatechin-3-gallate (EGCG), epicatechin (EC), and epicatechin gallate (ECG) (Aboulwafa et al., 2019; Cosme et al., 2020). These catechins constitute around 30–40% of the tea leaf's dry weight, with EGCG being the most abundant. Collectively, they are associated with antioxidant, anti-inflammatory, and anti-cancer properties, making green tea a natural candidate for health-promoting applications (Brimson et al., 2022; Cosme et al., 2020; Xu et al., 2021; Zhang et al., 2021; Zhao et al., 2022).

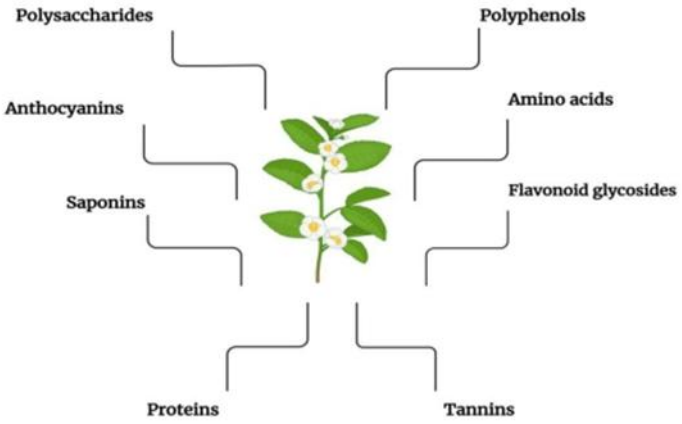

Figure 1. Bioactive compounds of *Camellia sinensis* L.

In addition to polyphenols, tea leaves contain a variety of amino acids, particularly theanine, which contributes to tea's unique umami flavor and accounts for 1–2% of the dry weight (Chang et al., 2023; Custodio-Mendoza et al., 2024; Deb et al., 2019). Researchers recognize the effects of this amino acid, along with others such as glutamic acid, aspartic acid, and serine, on relaxation, neuroprotection, and blood pressure regulation. Tea leaves also contain flavonoid glycosides such as quercetin and myricetin, which

enhance its antioxidant profile (Xiang et al., 2023; Yao et al., 2019). Furthermore, the presence of tannins, responsible for the beverage's astringency, plays a role in its distinct taste and bioactivity (Ricci et al., 2017; Xie et al., 2020).

The tea flowers, which share some of the bioactive compounds of the leaves but in different concentrations, provide additional health benefits. These include proteins, saponins, and polysaccharides that offer antioxidative, gastroprotective, and hypoglycemic effects (Chen et al., 2018; Zhang et al., 2023). Additionally, anthocyanins and unique pigments found in tea flowers contribute to both their color and antioxidant properties, enhancing their value beyond that of the leaves alone (Chen et al., 2020).

Overall, the combined effects of catechins, amino acids, caffeine, and other active components found in *Camellia sinensis* L. offer a spectrum of health-promoting benefits. These range from supporting metabolic and cardiovascular health to neuroprotective effects, all of which highlight tea's potential as a natural health aid (Brimson et al., 2022; Jiang et al., 2021; Talukdar et al., 2022; Zhang et al., 2019; Zhang et al., 2020; Zhao et al., 2022). Ongoing research continues to reveal how this complex phytochemical profile contributes to tea's role in both wellness and disease prevention.

Antidiabetic Mechanisms

Research highlights green tea as a valuable aid in managing Type 2 Diabetes Mellitus (T2DM), which is commonly associated with obesity and high blood pressure. Green tea, renowned for its antioxidative and anti-inflammatory properties, has demonstrated the ability to lower serum lipid levels and boost antioxidant enzymes like reduced glutathione and glutathione peroxidase, thereby enhancing the body's antioxidant defenses (Wang et al., 2020; Zhang et al., 2019). However, randomized controlled trials have substantiated green tea's antihyperglycemic effect, while studies on general tea consumption and insulin resistance remain inconclusive due to the diversity in dietary and lifestyle factors (Zhong et al., 2022).

Green tea's effects on insulin resistance and glucose regulation largely contribute to its anti-diabetic benefits. There is evidence that compounds in green tea, especially polyphenols, can make fat cells take in more glucose by improving the binding of

insulin receptors and turning on the GLUT-4 glucose transporter (El-Sherif et al., 2018; Suliburshka et al., 2016). These compounds also impact the expression of genes involved in lipid and glucose metabolism, such as PPAR, which lead to lowered blood glucose levels and improved insulin sensitivity in animal studies (Zhao et al., 2022; Zhou et al., 2021). Additionally, green tea's hypoglycemic properties in diabetic models have been found to be comparable to those of metformin, a common antidiabetic drug.

Various components within green tea—like catechins, polysaccharides, and saponins—contribute uniquely to these antidiabetic effects. For instance, although catechins alone may not directly reduce blood glucose, they enhance insulin secretion when paired with insulinotropic agents (Zhong et al., 2022). Meanwhile, green tea polysaccharides demonstrate notable hypoglycemic activity, influenced by their structure and molecular properties (Chen et al., 2020). Tea flower-derived saponins, such as floratheasaponins A, B, and C, also demonstrate a strong ability to lower blood glucose in rats loaded with sucrose (Zhang et al., 2014).

Additional research underscores the protective role of green tea in mitigating complications associated with diabetes. Polyphenols, especially EGCG, protect pancreatic β-cells by stopping oxidative stress and inflammatory responses. These are two main things that cause β-cells to break down in diabetes (Chaudhary et al., 2023; Meng et al., 2019). EGCG has also shown promise in renoprotection and in reducing diabetic retinopathy risk by impeding pathological blood vessel growth (Aboulwafa et al., 2019; Asbaghi et al., 2019; Peixoto et al., 2015).

Meta-analyses further support green tea's role in diabetes management. In one meta-analysis of 17 randomized controlled trials, green tea was associated with reduced fasting blood glucose, HbA1c, and fasting insulin levels among subjects with metabolic disorders (Brimson et al., 2022). Researchers linked a 20% lower risk of T2DM to drinking four or more cups daily. Long-term consumption has also shown benefits on body weight, BMI, and lipid levels by reducing triglycerides and total cholesterol, especially in individuals with T2DM (Qi et al., 2014). Additionally, green tea intake may elevate adiponectin levels, which play a critical role in modulating the link between fat accumulation, insulin sensitivity, and inflammation, thereby reducing diabetes risk (Asbaghi et al., 2020; Rydén et al., 2016; Silva et al., 2014).

Obesity management

Research highlights the potential of tea-derived compounds in weight management, particularly their anti-obesity effects. For example, methanol extracts from tea flower buds demonstrate the ability to reduce both body weight gain and visceral fat in mice on a high-fat diet. The main compound in the n-butanol-soluble fraction, chakasaponins II, is largely responsible for this effect. It inhibits food intake, slows down gastric emptying, and suppresses the hypothalamic appetite signal neuropeptide Y at the mRNA level (Chen et al., 2020; Zheng et al., 2015). Beyond flower buds, green tea extracts—especially through saponins—show promise in obesity management by reducing fat digestion via inhibition of gastric and pancreatic lipases, which subsequently disrupts lipid emulsification processes (Aboulwafa et al., 2019; Pervin et al., 2016). Additional contributions come from EGCG and caffeine, which stimulate thermogenesis, fat oxidation, and energy expenditure without significantly affecting cholesterol or blood pressure (Rothenberg et al., 2018). The combination of green tea catechins and caffeine has also been associated with improved body weight control by enhancing sustained energy use, fat oxidation, and the preservation of lean body mass (Janssens et al., 2016).

Furthermore, studies have linked EGCG to increased lipolysis and anti-adipogenic effects, targeting fatty acid synthase, positioning it as a promising therapeutic agent for appetite and weight control (Lee et al., 2024; Wu et al., 2017). Research indicates that various types of tea exhibit anti-obesity effects, with black tea's theaflavins and green tea's polysaccharides demonstrating significant benefits; the combination of polysaccharides and polyphenols appears particularly effective (Brimson et al., 2022; Takemoto and Takemoto, 2018; Xu et al., 2015). Tea polyphenols, such as EGCG, stop pancreatic lipase from working, which lowers the rate at which fat is absorbed and stops weight gain by lowering the amount of sugar and fat that is eaten (Brimson et al., 2022; Zhao et al., 2018).

Cardioprotective properties

The flavonoids in green tea, which contribute to lowering cardiovascular risks, are largely responsible for its cardioprotective effects. Researchers have linked a daily consumption of approximately 338 mg of flavonoids, found in a typical cup of green tea, to a lower

risk of cardiovascular events (Brimson et al., 2022; Chung et al., 2020). Additionally, studies have shown that the polyphenols in green tea, particularly catechins, reduce both systolic and diastolic blood pressure, with average reductions of 1.94–2.08 mmHg for systolic measurements and 1.71–1.94 mmHg for diastolic measurements (Brimson et al., 2022; Chieng and Kistler, 2021). Regular tea drinking has been linked to lower risks of heart disease and death from any cause. For every extra cup of tea a person drinks every day, there is a 4% drop in the risk of dying from heart disease, a 2% drop in the risk of cardiovascular events, a 4% drop in the risk of stroke, and a 1.5% drop in the risk of death overall (Brimson et al., 2022; Zhang et al., 2015).

Nonfermented Chinese green tea, which has a lot of catechins, lowers the risk of coronary heart disease by slowing the development of atherosclerosis. This is because it stops LDL from oxidizing and stops foam cells from forming in the arteries (Aboulwafa et al., 2019; Li et al., 2022). By inhibiting the formation of advanced glycation end products (AGEs) in collagen, green tea consumption further enhances heart health (Aboulwafa et al., 2019; Chung et al., 2022). Studies show that drinking four or more cups daily can lower the risk of myocardial infarction by improving antioxidant enzyme levels, stimulating glucose pathways, and boosting mitochondrial function, while also reducing cardiac hypertrophy and enhancing both systolic and diastolic heart performance (Aboulwafa et al., 2019; Lustosa et al., 2016; Pang et al., 2016; Wei et al., 2020).

Green tea also aids in managing key cardiovascular disease risk factors by reducing total cholesterol, lowering LDL cholesterol, and decreasing blood pressure. In addition, it supports microvascular function and increases oxygen levels in the skin across age groups (Aboulwafa et al., 2019; Wasilewski et al., 2016; Yousaf et al., 2014; Zhang et al., 2023). It lowers high cholesterol in several ways, such as by helping the liver get rid of cholesterol and stopping the intestines from absorbing it. This causes more bile acid and cholesterol to be released into the feces and lowers plasma cholesterol levels (Aboulwafa et al., 2019; Egert et al., 2020; Xu et al., 2020). Furthermore, green tea enhances cardiovascular protection by boosting cellular antioxidant capacity and inhibiting oxidizing enzymes in the arterial wall, thereby inhibiting LDL oxidation (Aboulwafa et al., 2019; Afzalpour et al., 2017).

Anticancer activity

Over the past two decades, extensive research has examined the potential anticancer effects of tea, particularly green tea, focusing on its impact on various cancer types, including colorectal cancer. Although epidemiological studies have yielded mixed results due to factors like sample size limitations and lifestyle factors that can obscure findings, several studies indicate promising outcomes. For instance, a cohort study showed that among nonsmokers, increased green tea consumption was associated with a reduced risk of colorectal cancer, regardless of gender (Chang et al., 2019). The small intestine only partially absorbs catechins from tea, but they can reach the colon and rectum in active forms, where they inhibit carcinogenic compounds like nitrosamines and heterocyclic amines. Further studies in China and Japan have confirmed that regular green tea intake (around 250g/month or five or more cups per day) may help lower the risks of colorectal and gastric cancers (Zhang et al., 2019).

Polyphenols, particularly EGCG and EGC, which are unique to *Camellia sinensis* and absent in other *Camellia* species, are responsible for the primary antitumor activity of green tea (Chen et al., 2020). EGCG is particularly effective against cancer, inhibiting cell cycle progression and promoting apoptosis. These polyphenols also stop fatty acid synthase, manage protease activity during endothelial morphogenesis, and stop vascular endothelial growth factor, which is an important part of tumor growth and angiogenesis (Mo et al., 2022; Mokra et al., 2023; Morbidelli, 2016; Singh et al., 2021). Green tea has powerful anticancer effects on many types of cancer. It has been shown to decrease the growth of tumors in the stomach, duodenum, large intestine, and colon. It has also stopped gastric cancer cells from spreading to other parts of the body and greatly slowed the growth of hepatocellular carcinoma cells (Arcone et al., 2016; James et al., 2023; Talukdar et al., 2022). Additionally, studies have shown that green tea consumption decreases DNA damage and reduces the recurrence of colorectal adenomas in patients who have previously undergone complete removal of these lesions (Aboulwafa et al., 2019).

Moreover, green tea catechins, particularly ECG and EGCG, exhibit strong antioxidant effects that help neutralize reactive oxygen species (ROS), which play a role in cancer progression. Although ROS are crucial for cellular signaling, excessive levels can stimulate tumor development. Green tea polyphenols promote apoptosis in cancer cells by generating ROS, effectively limiting tumor growth (Chaudhary et

al., 2023). Green tea catechins can also fight leukemia. Compounds such as (+)-gallocatechin, EGC, EC, EGCG, and ECG can slow down erythroblastic leukemia cells in a way that depends on the dose. EGCG stops the growth of human leukemic cell lines but not healthy cells. It does this by causing apoptosis in B- and T-cell chronic lymphocytic leukemia cells (Aboulwafa et al., 2019).

Antioxidant activity

Researchers have extensively studied green tea, particularly its extract, for its ability to counteract lipid peroxidation, a key factor in many diseases. As early as 1997, research showed that green tea extract, containing tea polyphenols, theanine, and caffeine, was effective at inhibiting copper-catalyzed low-density lipoprotein oxidation. Among these compounds, polyphenols exhibited the strongest antioxidant activity, followed by theanine and caffeine. One of the proposed mechanisms for green tea's antioxidant effect is its ability to bind with metal ions like copper, preventing oxidation (Zhao et al., 2022).

Green tea's polyphenolic compounds, such as catechins, flavonol glycosides, and polysaccharides, found in both the tea leaves and flowers, primarily contribute to its antioxidant potential. These compounds, particularly epigallocatechin gallate and epicatechin gallate, are known to be potent free radical scavengers, providing protection against oxidative stress. Research has highlighted the significant role of these compounds in neutralizing free radicals, which can otherwise cause cellular damage and contribute to various diseases. Studies have also shown that the antioxidant properties of green tea flowers come from a similar set of compounds, offering another source of these health benefits (Chen et al., 2022).

Green tea's reputation in traditional medicine as a powerful antioxidant stems from its polyphenolic content, particularly flavanols that easily react with free radicals. These compounds work by either donating or accepting hydrogen atoms to neutralize reactive oxygen species, which can cause cellular damage. The presence of specific structural features, such as hydroxyl groups, in green tea's polyphenols enhances their effectiveness in scavenging radicals. Compounds like epicatechin and epicatechin gallate not only act as antioxidants themselves but also support the body's natural antioxidant systems,

like vitamin E, improving overall protection against oxidative damage (Aboulwafa et al., 2019).

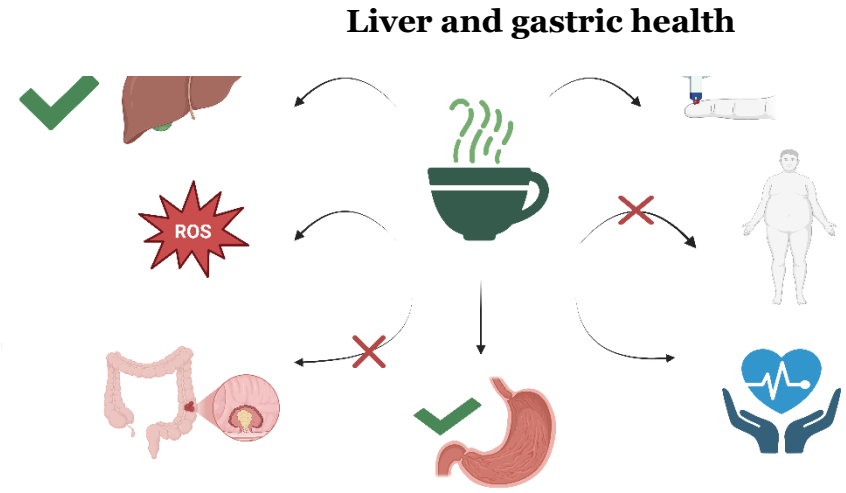

Figure 2. Health benefits of *Camellia sinensis L.*

Green tea exhibits hepatoprotective properties in addition to its gastric benefits.Studies have indicated that green tea can prevent liver damage by enhancing antioxidant activity and reducing oxidative stress. Researchers have found that it lowers the levels of serum liver enzymes, such as ALT and AST, which are markers of liver injury, and prevents the accumulation of harmful substances in the liver.Key compounds such as epigallocatechin gallate contribute to these protective effects, suppressing cell damage and improving liver function, especially in cases of induced toxicity. Furthermore, green tea's high polyphenol content helps to regulate liver metabolism, counteracting the negative effects of oxidative stress and inflammation (Aboulwafa et al., 2019).

Conclusion

In conclusion, recent research confirms the essential role of Camellia sinensis L. for good health and well-being, thanks to its bioactive compounds, especially polyphenols such as epigallocatechin gallate, catechins, and flavonoids, which contribute to its therapeutic benefits. These include antioxidant, anti-inflammatory, anti-diabetic, anti-obesity, and anti-cancer effects, supporting the prevention and

management of chronic conditions such as type 2 diabetes, cardiovascular diseases, obesity, and certain cancers. Also, studies suggest that green tea offers hepatoprotective and gastroprotective benefits, indicating its potential in preventing liver and digestive disorders. Existing evidence supports the use of green tea as an effective natural alternative in improving health and preventing chronic diseases, making it promising in complementary treatments. Ongoing research will improve our understanding of how its components contribute to preventing lifestyle-related diseases.

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