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Phytochemical insights into green tea and its therapeutic potential

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ABSTRACT

Green tea (*Camellia sinensis*), one of the most widely consumed beverages globally, has gained remarkable attention for its rich phytochemical profile and diverse health-promoting properties. Traditionally consumed in countries such as China, Japan, Korea, and North Africa, green tea is increasingly becoming popular worldwide owing to its bioactive compounds, including polyphenols, catechins, tannins, gallic acid, and an array of vitamins and minerals. These constituents exert powerful antioxidant, anti-inflammatory, and antimicrobial activities that contribute to their therapeutic potential. The increasing scientific evidence suggests that green tea plays a pivotal role in the prevention and management of various chronic diseases, particularly by suppressing tumor progression, modulating metabolic disorders, enhancing wound healing, and improving cardiovascular and neurological health. The ability of green tea to mitigate oxidative stress and regulate cellular signaling pathways underscores its role in maintaining overall well-being. This review aims to comprehensively explore the phytochemistry of green tea, highlighting its major bioactive components and their mechanistic actions on human health. Special emphasis is placed on the therapeutic potential of catechins, particularly epigallocatechin gallate (EGCG), which has been extensively studied for its anticancer, cardioprotective, and neuroprotective effects. By integrating phytochemical insights with recent advancements in biomedical research, this review underscores green tea as a natural, functional beverage with profound implications for disease prevention and health promotion.

Keywords: *Camellia sinensis*, Green tea, Antioxidants, Catechins, Epigallocatechin, Gallate.

INTRODUCTION

Green tea, made from the leaves and buds of *Camellia sinensis*, is one of the oldest drinks in the world, which differs from black tea in the fact that it does not undergo the same withering and oxidation process as involved in the preparation of black tea [1, 2]. As per the available literature, tea was first consumed by the Chinese population around 2737 BC [3]. Every year, approximately 600,000 tons of green tea is consumed by humans all across the globe- China, England, Japan, Morocco, Kuwait, Turkey, Qatar, India and Kenya are the major tea producing countries [4, 5]. In the Asian folk medicine, tea has been used as an effective medicine in treating different diseases [6]. It is regarded as a functional food due to its potential to impart many physiological benefits to the consumer [7]. Tea is accessible in three forms- Black tea, in which the leaves are fermented through oxidation by the action of enzyme polyphenoloxidase; oolong tea, in which the leaves are allowed to undergo partial fermentation and the third tea is green tea, in which the process of fermentation is avoided by the inactivation of polyphenoloxidase enzyme by giving a slight thermal treatment [8]. The green tea leaf extract contains many polyphenols, that are known to have higher antioxidant activity as compared to vitamin E and vitamin C [9]. Green tea can be consumed in a variety of forms, from traditional drinking method to supplemental tablets [10]. The biological significance of green tea phytochemicals has been demonstrated across multiple systems. EGCG and related catechins act as powerful free radical scavengers and modulators of signaling pathways, influencing processes such as mitochondrial function, nuclear factor erythroid 2–related factor (Nrf2)-mediated antioxidant defense, and NF-κB-driven inflammatory cascades [11]. These properties underpin green tea's protective role in conditions ranging from kidney injury to cardiovascular and metabolic disorders. Beyond antioxidation, emerging evidence highlights direct immunomodulatory effects of EGCG, particularly in balancing Th/Treg cell differentiation, offering promise in autoimmune diseases such as rheumatoid arthritis, multiple sclerosis, and ulcerative colitis [12]. Green tea is used for its neuroprotective effects [13], treatment of cardiovascular disorders [14], obesity [15] and so forth. It also has anti-carcinogenic property and helps to control proliferation, apoptosis and angiogenesis in tumor cells [16-19]. This review aims to consolidate current insights into the phytochemistry of green tea and explore how its bioactive constituents contribute to therapeutic potential across diverse pathological contexts.

Phytochemistry

Till date, various researchers have attempted to investigate the phytoconstituents in green tea and different type of componentshave been reported (Figure 1). Green tea is a reservoir of polyphenols like flavan-3-ols, flavandiols, flavonoids, thearubigins, tannins, rutin and phenolic acid like gallic acid. Catechins are the standard flavonoids present in it which include-epigallocatechin-3-gallate (EGCG), epicatechin-3-gallate (ECG), epigallocatechin (EGC) and epicatechin (EC) [20]. It also contains proteins which include amino acids such as L-theanine, tyrosine, tryptophan, threonine, 5-N-ethylglutamine, glutamic acid, serine, glycine, valine, leucine, aspartic acid, lysine and arginine [21]. Various carbohydrates such as glucose, cellulose, cellulosic fiber, sucrose [22] and glycosides like galactose, rhamnose, rutin and p-coumaric moiety are also present [23]. Moreover, a number of trace elements such as magnesium, chromium, manganese, calcium, copper, zinc, iron, selenium, sodium cobalt and nickel are present and enhance its properties [24-27]. Presence of vitamin C, B2, B3, K and some traces of Vitamin E and β-carotene, α-, β-, γ-, δ-tocopherols, riboflavin have a huge impact on the qualities of green tea [28,29]. It is noteworthy that green tea is extremely rich in macro-elements and a source of fluorine, iodine and phosphorus [21]. Additionally, green tea also contains xanthine bases, including theophylline and caffeine as well as pigments such as carotenoids and chlorophyll [22]. A phytochemical known as Quercetin is also present in green tea in the form of kaempferol-3-O-(glucose-(1, 3-rhamnose-1,6-glucose) and quercetin-3-O-(glucose-(1,3-rhamnose-1,6-galactose) [23,30,31]. Experimental work on methanolic green tea extracts confirms these findings. Gas chromatography–mass spectrometry (GC–MS) has identified more than 70 phytochemicals, including polyphenols, flavonoids, tannins, and other bioactive metabolites. Quantitative assays showed significant amounts of total phenolics (128.8 mg GAE/g), flavonoids (83.74 mg QE/g), and tannins (11.66 mg TAE/g), which correlate with its antioxidant and therapeutic potential [32].

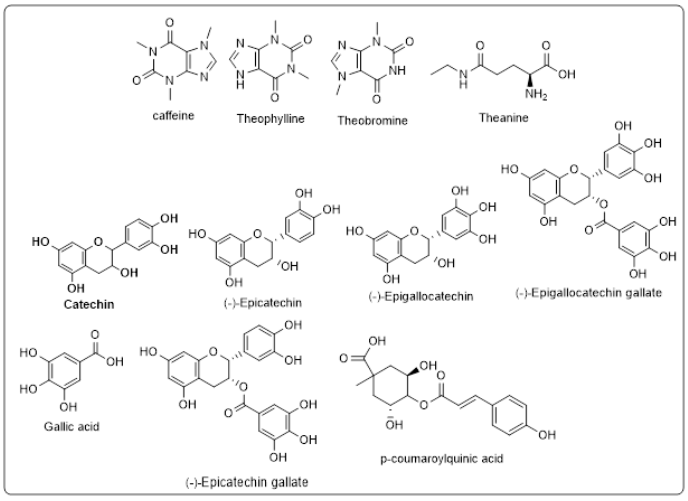

Figure 1: Major constituents of Green Tea including- catechin and their derivatives

Nutritional value of green tea

GT typically contains more significant amounts of polyphenols, mostly the catechins [33,34], caffeine [35,33,36], minerals [37,36,38,5] trace amounts of vitamins [35,36], amino acids [36,37], non-protein amino acid L-theanine [39].

The chemical composition of green tea is complex: proteins (15-20% dry weight), whose enzymes constitute an important fraction; amino acids (1-4% dry weight) such as theanine or 5-N-ethylglutamine, glutamic acid, tryptophan, glycine, serine, aspartic acid, tyrosine, valine, leucine, threonine, arginine, and lysine are also present. Carbohydrates (5-7% dry weight) such as cellulose, pectins, glucose, fructose, and sucrose; minerals and trace elements (5% dry weight) such as calcium, magnesium, chromium, manganese, iron, copper, zinc, molybdenum, selenium, sodium, phosphorus, cobalt, strontium, nickel, potassium, fluorine, and aluminum. Trace amounts of lipids (linoleic and α-linolenic acids), sterols (stigmasterol), vitamins (B, C, E), xanthic bases (caffeine, theophylline), pigments (chlorophyll, carotenoids), and volatile compounds (aldehydes, alcohols, esters, lactones, hydrocarbons) are also present. Due to the great importance of the mineral presence in tea, many studies have determined their tea leaves and their infusions [40]. Fresh leaves contain, an average, 3-4% of alkaloids known as methylxanthines, such as caffeine, theobromine, and theophylline [41].

THERAPEUTIC BENEFITS:

Green tea has been widely recognized for its diverse therapeutic benefits (Figure 2), which make it an ideal choice for regular consumption as a health-promoting beverage. Its bioactive constituents, particularly polyphenols and catechins, are responsible for a broad spectrum of physiological effects that extend beyond basic nutrition [42]. These benefits include a significant reduction in the risk of cancer and cardiovascular diseases through their antioxidant and anti-proliferative actions, as well as the inhibition of viral and bacterial infections owing to their antimicrobial properties. Moreover, green tea consumption has been linked to reduced fat absorption and improved lipid metabolism, thereby contributing to weight management and the prevention of obesity-related complications. It also exhibits anti-ageing properties by mitigating oxidative stress and cellular damage, while its anti-inflammatory effects aid in alleviating chronic inflammatory conditions. In addition, studies have highlighted its anti-viral, anti-microbial, and neuroprotective activities, suggesting a potential role in the prevention of neurodegenerative disorders such as Alzheimer's and Parkinson's disease [43]. In light of these diverse biological activities, it becomes evident that green tea holds remarkable therapeutic potential. In the following sections, we will comprehensively discuss its health-promoting effects, with particular emphasis on its role in reducing the risk of chronic diseases, modulating metabolic processes, enhancing immune function, and protecting against oxidative and inflammatory damage.

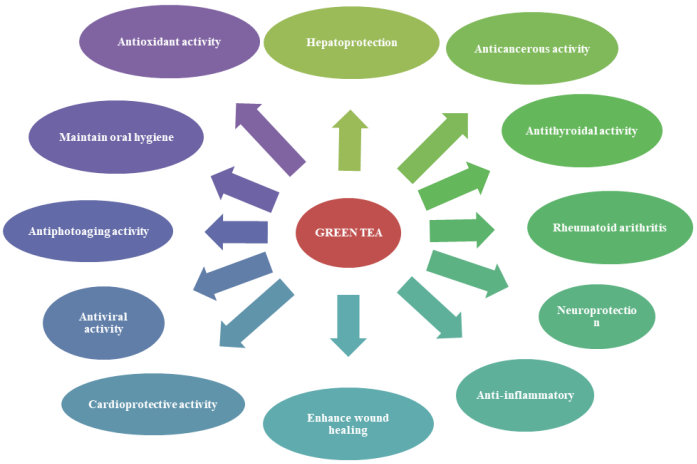

Figure 2: Multi-dimensional benefits of green tea consumption

Cardioprotective Effect

Cardiovascular diseases are one of the major causes of mortality worldwide contributing to 7 million deaths yearly [44, 45]. Hypertension is the most relevant reason behind such diseases [46]. Many researchershave observed that green tea catechins help to lower the blood pressure [47]. In an observational study, uptake of one cup of green tea each day was directly related with marginally lower hazard of death from cardiovascular causes [48]. *In vitro* studies depict that green tea catechins employ a cardioprotective effect through number of mechanisms that include the prevention of oxidation, vascular inflammation, and thrombogenesis and by improving the endothelial dysfunction [49,50]. Supplementation ofgreen tea is found to ease the

complications of the inflammatory process that emerges after the utilization of cardiopulmonarybypass for major cardiovascular medical procedure [51,52]. Studies have demonstrated that EGCG supplementation reduces systolic and diastolic blood pressure in both animal models and humans, with effects linked to suppression of renin and angiotensin-converting enzyme activity, as well as modulation of key signaling pathways such as PI3K/Akt/eNOS [53,54]. It also provides cardioprotection during ischemic and reperfusion injuries by attenuating oxidative stress, apoptosis, and inflammatory responses in cardiac tissues [55]. EGCG also modulates lipid profiles by lowering low-density lipoprotein cholesterol and triglycerides, while increasing high-density lipoprotein cholesterol, which is essential for maintaining cardiovascular health [56]. These multifaceted actions indicate that regular consumption of green tea could be beneficial as an adjunct dietary approach for the prevention and management of cardiovascular diseases.

Antioxidant Property

Green tea is known to have an effective antioxidant activity, which is proven by a number of researches and studies. The antioxidant properties of green teaaredue to its ability to lessen the levels of free radicals by binding to Reactive Oxygen Species (ROS), and by enhancing the activity of antioxidant enzymes [24,57].The catechins present in green tea, have a high antioxidant activity and are effective against oxidative stress by effectively scavenging the reactive oxygen species (ROS) [58]. When the Total Antioxidant Capacity (TAC) of green tea was compared to vegetables like spinach, garlic and Brussel sprouts according to the Oxygen Radical Absorbance Capacity (ORAC) method, it was found that the TAC of green tea was significantly higher than that of other vegetables [59].

Neuroprotective Effect

Increased level of Reactive oxygen species (ROS) inside the brain can have serious health effects such as mitochondrial dysfunction and apoptosis that could lead to neurodegenerative diseases like Alzheimer's and Parkinson's disease [60]. In a rat model specified for the study of Alzheimer's disease, green tea was found to reduce memory impairments and prevent oxidative damage in the hippocampus of the model mouse, this effect could be attributed to the increased levels of ECGC present in the green tea [61]. Transgenic mice model, that expressed amyloid precursor proteins were orally administered 50mg/kg of ECGC for a period of 4 months, which resulted in a significant reduction in the levels of Amyloid β (Aβ), thereby preventing its accumulation [62]. Polyphenolic content of green tea when administered orally, to the monkeys with Parkinson' disease showed reduced motor impairments and attenuated dopamine depletion, which overall improved the motor functions of the brain [63]. In transgenic nematode strains, extracts of green tea were found to delay the Amyloid β induced paralysis [64]. This can be owed to the fact that EGCG can remodel amyloid-β and α-synuclein aggregates into non-toxic forms, promote autophagic and proteasomal clearance of misfolded proteins, and modulate enzymes involved in amyloid precursor protein processing [65]. Beyond this, green tea catechins act as natural metal chelators, reducing copper, zinc, and iron-induced neurotoxicity and aggregation [66,67]. Epidemiological and clinical studies support these findings, showing associations between regular green tea consumption and lower risks of cognitive decline, dementia, and Parkinson's disease [68,66,69]. Intervention trials demonstrate improvements in memory, attention, and executive function, with benefits linked to reduced oxidative stress and inflammatory markers. Animal and cellular models further reveal mitochondrial protection, enhanced neuronal survival, and even promotion of neurogenesis, particularly in the hippocampus [67]. Taken together, these findings suggest that green tea polyphenols, due to their safety and accessibility, hold significant promise as preventive agents in combating neurodegenerative disorders.

Anti-Inflammatory Action

Epigallocatechin-3-gallate (EGCG), a chemical constituent of green tea, is a strong and a highly effective anti-inflammatory substance that has the potential to inhibit production and proliferation of several immune system molecules which cause severe inflammation [70]. Cells derived from the peripheral blood of healthy individuals were cultured in a blend of 30 μM Epigallocatechin-3-gallate, 3 μM epigallocatechin, 2 μM epicatechin-3-gallate, and 1.4 μM epicatechin, and also separately with all four catechins. It was observed that in both the cases, catechins were capable of reducing the expression of inflammatory factors nucleic factor-κ B (NFκB) and toll like receptor-4. They also retarded the migration and production of reactive oxygen species (ROS), nitric oxide, and peroxynitrite [71]. EGCG has a defensive impact on the inflammation induced by lipopolysaccharide (LPS). It has been found in a study conducted by Liu and colleagues that EGCG inhibited the LPS-mediated induction of proinflammatory cytokines (TNF-α, IL-1β and IL-6). Along with this, EGCG also prevented the LPS-initiated creation of ROS in neurons [72]. The anti-inflammatory effects of green tea are largely mediated through the suppression of nuclear factor-kappa B (NF-κB) signaling, downregulation of pro-inflammatory enzymes such as cyclooxygenase-2 (COX-2), and inhibition of inflammasome activation. In the context of kidney injury, green tea extract (GTE) has been shown to reduce gentamicin-induced nephrotoxicity by directly blocking inflammatory cascades, reducing the expression of NF-κB, COX-2, IL-1β, and MCP-1, while simultaneously enhancing the production of anti-inflammatory cytokines like IL-6 and IL-10 [11].

These findings align with other recent works demonstrating that green tea polyphenols can ameliorate inflammation in various pathological conditions. For example, clinical studies have shown that green tea supplementation improves renal function and inflammatory status in patients with diabetic nephropathy [73] These studies collectively reinforce the therapeutic potential of green tea as a natural anti-inflammatory agent.

Antimicrobial Properties

A significant amount of research has explored the antimicrobial properties of green tea catechins. These studies have found that green tea catechins can inhibit a wide variety of microorganisms i.e. Gram-positive and Gram-negative aerobic bacteria, anaerobic bacteria, viruses and fungi (Table. 1). Green tea catechins not only directly affect microorganisms but also help prevent infections. Studies on mice and ferrets showed that drinking green tea could stop the spread of bacteria and viruses. In humans, drinking green tea led to fewer fevers, fewer colds or flu symptoms, and fewer infections with Influenza A or B [74].

(a) Antibacterial Activity:

Among the antimicrobial mechanisms attributed to green tea are: damage to the bacterial cell membrane, inhibition of bacterial fatty acid synthesis, inhibition of other enzymes (e.g., protein tyrosine kinase, cysteine proteinases, DNA gyrase, ATP synthase), and inhibition of efflux pump activity [73]. The bacteria affected by green tea extract are listed in Table 2.

(b) Anti-viral Activity:

Green tea (*Camellia sinensis*) is one of the richest natural sources of polyphenols, especially catechins such as epigallocatechin-3-gallate (EGCG), which have attracted attention for their strong antiviral properties. According to Burkard et al. (2025), polyphenols including EGCG can interfere with nearly every stage of viral infection, from viral attachment and entry to replication, transcription, and release of new viral particles [90]. EGCG is found to restrict the Hepatitis C infection (HCV), by getting affixed to the objective cell and averting the spread of the contamination to various other cells within the body [91]. In the case of hepatitis B virus (HBV), EGCG significantly

reduces viral RNA levels and suppresses the expression of viral core proteins. It acts partly by reducing internalization through the

Table 1: Microorganisms impacted by green tea [75-78]

Bacteria	Viruses	Fungi	Parasites
Acinetobacter baumannii	*Epstein-Barr virus*	*Actinomyces spp.*	*Trypanosoma cruzi*
Bacillus cereus	*Hepatitis B*	*Aspergillus niger*	
Escherichia coli (intestinal)	*Hepatitis C*	*Candida albicans*	
Escherichia coli (uropathogenic)	HIV-1		
Enterococcus faecalis	HSV-1		
Helicobacter pylori	Influenza A H1N1		
Listeria monocytogenes	Influenza A H3N2		
Porphyromonas gingivalis	Influenza A H5N2		
Prevotella intermedia	Influenza B		
Proteus mirabilis	Coronavirus		
Pseudomonas aeruginosa	Enterovirus 71		
Salmonella typhi	Bovine coronavirus		
Salmonella typhimurium	Chikungunya virus		
Staphylococcus aureus	Zika virus		
Staphylococcus epidermidis	DENV-2		
Methicillin-resistant *Staphylococcus aureus*			
Staphylococcus epidermidis			
Stenotrophomonas maltophilia			
Streptococcus mutans			
Streptococcus pyogenes			
Vibrio cholerae			
Yersinia enterocolitica			

Table 2: Antibacterial effects of green tea

Source	Organisms studied	References
Water extraction	*P.aeruginosa* *S.aureus*	[79]
Water extraction	MRSA MDR *P.aeruginosa*	[80]
Pure EGCG	*Acinetobacter baumannii*	[81]
Methanol extraction	*S. mutans*	[82]
Water extraction	*L. monocytogenes*	[83]
Ethanol extract	*E. coli* *P.aeruginosa* *S.aureus*	[84]
Pure EGCG	*Listeria monocytogenes*	[85]
Pure EGCG	*Proteus mirabilis* *Streptococcus pyogenes*	[86]
Water extraction	*Proteus mirabilis* *Streptococcus pyogenes*	[86]
Catechin mixture	*P.gingivalis*	[87]
Pure EGCG	*Stenotrophomonas maltophilia*	[88]
Water extraction	*E. coli*	[89]

sodium/taurocholate cotransporter polypeptide (NTCP), a receptor crucial for HBV entry into hepatocytes. Additionally, EGCG has been shown to inhibit the activation of farnesoid-X receptor (FXR), thereby limiting viral gene transcription [90]. In research, EGCG was found to suppress the chikungunya infection and also lower the severity in the post phases of viral disease [92]. The antiviral and the immunomodulatory impact of green tea may lessen the illnesses caused due to viruses, including that witnessed in COVID-19 [93,94]. Also, during the COVID-19 pandemic immunity of body was highly affected by novel corona virus therefore researcher used several immune-booster agents like green tea, Black pepper, Ginger, Swaras, Kwath, Kalka, Hima etc. and it was concluded that polyphenols & other compounds have shown significant effect to boost immunity during viral infection [95,96].Importantly, green tea catechins are not only direct antivirals but also modulators of the host immune response. EGCG and related compounds can regulate NF-κB pathways, enhance interferon responses, and reduce virus-induced oxidative stress. These multifaceted actions make green tea

polyphenols promising candidates for developing supportive antiviral therapies [90].

Wound Healing

Wound healing is a multifaceted and an intertwined process that involves the replacement of the damaged and the missing cellular and tissue layers [97]. Various studies have been performed to fathom the effect of green tea in the wound healing process. In a study to find out the effect of green tea on wound healing, 36 healthy Wistar rats, each weighing between 200-250g were chosen and were divided into 3 groups- A, B and C. The back skin of the rats was disinfected using Betadine 10%, and a 4 cm long incision was made on each ratusing calipers. The incision was deep enough to go down through the dermis and hypodermis. This was followed by making 4 stiches at 1 cm intervals by using a 3.0 nylon string. The rats in the group A, B and C, were then treated with Vaseline and 0.6% green tea extract, Vaseline and normal saline respectively for a period of 21 days. On the 7th day of this experiment the stitches were removed. The length of the wounds was measured on 2nd day, and since 7th day it was measured each day. The final measurement was taken on the 21st day. The mean healing time was calculated and it was found that the group A had a comparatively lower healing time in the first two weeks than the remaining two groups, the microscopic analysis revealed the difference in the wound healing process between group A and the rest of the two groups [98]. The skin-wounding effects of green tea involve modulation of several cellular and molecular mechanisms. EGCG exerts strong antioxidant and anti-inflammatory properties, which help minimize oxidative stress and inflammation at wound sites. This action reduces lipid peroxidation, limits neutrophil infiltration, and promotes fibroblast proliferation, all crucial steps for wound healing [99].

Anti-photoaging Activity

Skin is the integral part of the innate immune system that acts as an external barrier and is aptly refereed as the first line of defense as it shields the internal organs of the body and maintains the homeostasis through a variety of processes [100]. Aging of skin is a compound process brought about by the intrinsic process of senescence, and extrinsic damage caused by various external factors like chronic exposure to UV irradiation, a process more commonly known as photoaging [101,33]. UV radiations cause skin damage mainly due to increased production of ROS [102]. Green tea is a potential candidate that is used in anti-photoaging therapies, mainly due to the high content of polyphenols [33]. In an investigational study, UV irradiated mice which had undergone photoaging process were fed tea polyphenols. Increased hydroxyproline content was observed in them along with enhanced catalase activity, which is known to effectively scavenge the UV induced ROS, thereby lowering the ill effects of photoaging [103]. In another such study, mice fed with green tea extracts showed reduced signs of UV induced photoaging like wrinkles [104]. In order to deduce the effect of green tea in humans, green tea extract was applied to the wrinkles that are formed in the outer corner of the eye more commonly known as crow's feet of 42 Korean females for a period of 8 days. The result of this study displayed low wrinkles indicating towards the antiwrinkle property of green tea [105]. Mechanistic studies show that EGCG activates antioxidant pathways such as Nrf2, suppresses pro-inflammatory signaling like NF-κB and MAPK, and enhances collagen synthesis through modulation of the TGF-β/Smad pathway. These actions help maintain the extracellular matrix, prevent wrinkle formation, and improve skin elasticity, making green tea a promising natural agent for photoaging prevention and long-term skin health [106].

Anti-cancerous Activity

The mechanism of the anti-cancerous activity of green tea is due the presence of EGCG, which is involved the activation of the proapoptotic factor, BAX and the release of cytochrome c from the mitochondria to the cytosol [107]. The EGCG, also acts by inhibiting the cyclin-dependent kinases (CDKs), which are extremely essential in the cell cycle progression, apart from this, EGCG is capable of inducing the expression of p27 and p21 [108]. In a study conducted in Japan, a group of women intaking green tea was found to have a decreased risk of total cancer mortality [109]. In case of oral and pharyngeal cancer, women consuming more than five cups of green tea a day had a lower risk of acquiring cancer, in comparison, to women drinking less than one cup daily [110]. In a study, breast cancer has been found to be less frequent in Asian women with a high intake of green tea and soybean. This result is indicative that the phytoconstituents of soybean may enhance the inhibitory effect of green tea on the progression of breast cancer [111]. Roychoudhury and team, used five different doses of green tea extract to treat pig ovarian granulosa cells and measured the hormone secreted by granulosa cells using EIA. The apoptotic markers caspase-3 and p53 were shown to rise in granulosa cells at the highest dose (200 g/mL). Therefore, they proposed that activation of caspase-3 and p53 might eventually cause ovarian cells to undergo apoptosis [112]. Molecular investigations have shown that EGCG induces programmed cell death by activating caspase-dependent apoptosis, disrupting mitochondrial function, and increasing pro-apoptotic proteins such as Bax while reducing anti-apoptotic proteins like Bcl-2. It also suppresses tumor cell proliferation by inhibiting cyclin-dependent kinases and reducing cyclin D1, while enhancing cell cycle inhibitors such as p21 and p27. Beyond growth control, EGCG modulates key signaling pathways including MAPK, NF-κB, PI3K/Akt, and JAK/STAT, leading to reduced inflammation, oxidative stress, and immune evasion. For example, in lung cancer cells (A549 and Lu99), EGCG reduced PD-L1 expression via JAK2/STAT1 inhibition, while in breast cancer models, it blocked glycolytic enzymes, induced autophagy, and promoted apoptosis [113,114].

Green tea also impacts the tumor microenvironment by reducing angiogenesis through VEGF suppression and limiting invasion by downregulating matrix metalloproteinases (MMPs). In cervical and colorectal cancers, EGCG interferes with key oncogenic drivers such as HPV E6/E7, AKT/PI3K/mTOR, and ERK1/2, while enhancing tumor suppressor pathways like p53 and TGF-β/Smad, ultimately inhibiting epithelial-to-mesenchymal transition and metastasis. Importantly, formulation approaches such as nano-EGCG and phospholipid complexes improve its stability and bioavailability, increasing its therapeutic potential [115,113]. Together, these findings position green tea catechins as promising multi-targeted agents for cancer prevention and therapy, complementing conventional treatments and warranting further clinical validation.

Immunomodulatory Effects

EGCG and EGC, which are common in green tea, can influence the immune system by affecting the growth of T lymphocytes and the production of cytokines. Research shows that green tea extract can boost lymphoblast growth, leading to more lymphocytes. EGCG can also increase the production of IL-1α, IL-1β, monocytes, and lymphocytes [116]. Additionally, green tea extract has been found to help immunocompromised patients with Candida albicans infections by boosting IL-8, IL-17A, and human β-defensin expression [117].

A study found that green tea has an immune-boosting effect in a murine model with cyclophosphamide-induced immunosuppression, likely by stimulating both cellular and humoral immune functions, which leads to higher total leukocyte counts [118]. These findings suggest that green tea could be a potential immunomodulator that helps maintain immune balance during illness. In another murine model, green tea extract was shown to reduce antigen-specific IgE production by increasing the number of CD4+ CD25+ regulatory T (TR) lymphocytes in the spleen, indicating that green tea extract may help regulate allergic responses [119].

Green tea extract and EGCG have been found to improve arthritis symptoms, such as pathological arthritic features and serum CII-specific IgG2a antibody levels in animal models. Additionally, EGCG

treatment significantly reduced the production of inflammation-related cytokines, including IL-6, IFN-γ, and TNF-α, while increasing the production of IL-10 [120].

Calgarotto *et al*. (2021) reported a significant decrease in ROS in BM CD34+ cells after a 30-day treatment, supporting the idea that green tea can protect cells and tissues from oxidative damage by scavenging oxygen-free radicals. Green tea also seemed to reduce the number of TR immunosuppressive cells and the level of CXCR4 expression in TR cells, possibly reversing the suppressive nature of the bone marrow microenvironment [121]. Another study (Wu, 2016) found that green tea can help reduce the symptoms and pathology of autoimmune diseases in animal models [122]. A recent study reported that supplementation with green tea catechins led to reduced serum levels of pro-inflammatory markers such as TNF-α and IL-6, while simultaneously enhancing anti-inflammatory mediators like IL-10. Importantly, these changes were correlated with improvements in immune balance and a reduction in chronic inflammation, supporting the therapeutic role of green tea in immune-mediated conditions. This case demonstrates how dietary intake of green tea, even as a simple beverage or in extract form, can positively influence immune pathways in real-world clinical settings, making it a valuable adjunct in both prevention and management of inflammatory and autoimmune diseases [12].

OTHER BENEFITS:

Hepatoprotective Effect

Liver has a vital role in the processes of metabolism and detoxification in the body any disorder associated with this organ can prove to be a major health issue [123]. Studies have shown that green tea is highly capable of reducing the development of obesity and Non-alcoholic liver disease (NAFLD), both of which are serious public health problems. The protective effects of green tea are largely attributed to its polyphenolic compounds, particularly epigallocatechin-3-gallate (EGCG), which exert antioxidant, anti-inflammatory, and lipid-lowering activities. Evidence suggests that green tea consumption improves hepatic lipid metabolism, decreases oxidative stress, and reduces insulin resistance, thereby mitigating the progression of NAFLD [124,125].

In treatment of Rheumatoid arthritis

Rheumatoid Arthritis (RA), an autoimmune disease that majorly attacks the joints present in the body, is caused due to proinflammatory cytokines such as TNF-α, IL-1β, and IL-17. Therefore, clamping down of the production of these cytokines is considered to be a potential strategy to treat RA [126]. EGCG, a potent compound found in green tea is known to suppress the expression of these proinflammatory cytokines, therefore, green tea could be used in order to prevent or hamper the progression of RA towards severity [127]. Animal models of RA demonstrate that green tea supplementation alleviates joint swelling, improves mobility, and delays cartilage destruction, highlighting its disease-modifying potential. Recent studies suggest that regular intake of green tea or EGCG-based formulations may complement conventional disease-modifying antirheumatic drugs (DMARDs), potentially enhancing their efficacy while minimizing adverse effects [128]. Collectively, these findings support the use of green tea as a functional dietary intervention for RA management, though further clinical studies are warranted to establish optimal dosage and long-term safety.

Oral hygiene

Green tea possesses anticaries property and is effective against dental caries, this property is attributed to its fluoride content [129]. A study performed by Naderi and colleagues clearly indicated that green tea shows and inhibitory effect on *Streptococcus mutans*, which is a bacteria involved in the cariogenic process [82]. It is stated that gargling with green tea extract inhibits infection by influenza virus and the application of the green tea extract to the oral and nasal cavities inhibited growth of various pathogens [130]. Green tea has become a potent ingredient of mouthwashes to boost up the oral hygiene [129]. Green tea strengthens oral defense mechanisms by reducing oxidative stress in gingival tissues and upregulating endogenous antioxidant enzymes, thus limiting tissue damage during chronic inflammation. The anti-inflammatory capacity of catechins, through pathways such as NF-κB suppression, contributes not only to healthier periodontal tissues but also to enhanced wound healing after dental interventions [131]. Taken together, these findings suggest that green tea can be integrated into modern oral hygiene strategies as a sustainable and patient-friendly alternative, either complementing or partly replacing conventional treatments.

Anti-thyroidal activity

Catechin present in green tea has the anti-thyroidal as well as goitrogenic potential, which is proven by a study in which green tea extract (GTE) when fed to rats at relatively high doses caused hyperthyroidism in them by altering morphological and functional status of thyroid [132,133].

Future Prospects of Green tea

Green tea has gained global attention not only as a traditional beverage but also as a functional food with remarkable therapeutic promise (Figure 3). Its diverse phytochemicals, especially catechins such as epigallocatechin-3-gallate, continue to be the focus of research exploring their role in human health.

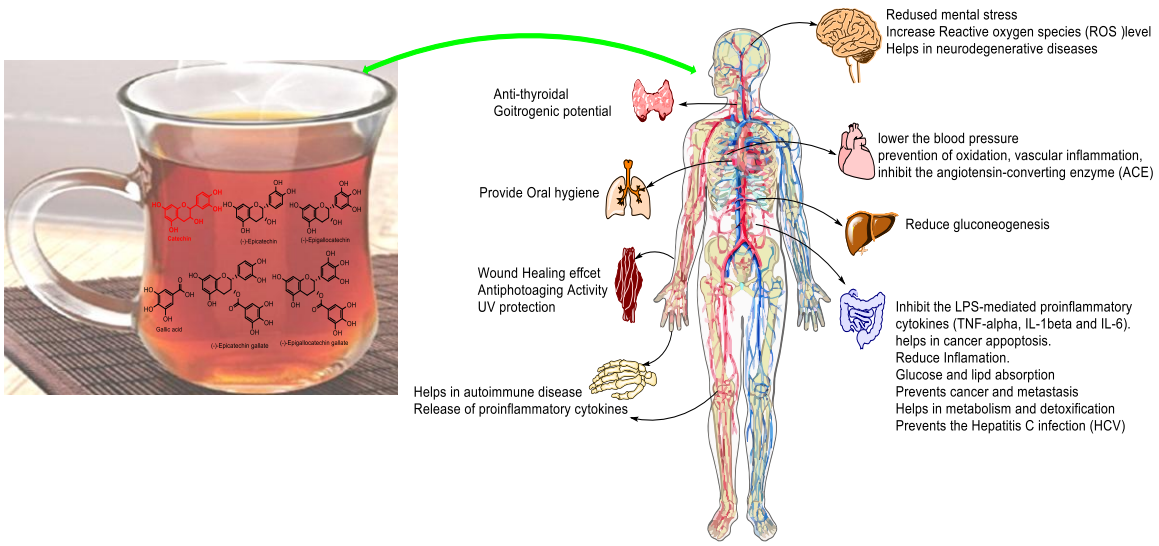

Figure 3: Benefits of green tea in human health

A key future direction lies in addressing the challenge of poor bioavailability of green tea catechins. Advances in nanotechnology and encapsulation strategies are being investigated to enhance stability, absorption, and therapeutic efficacy, thereby bridging the gap between promising laboratory findings and clinical translation. Also, the rising consumer demand for natural health-promoting products has positioned green tea at the forefront of nutraceutical and functional food markets. Its incorporation into dietary supplements, skincare, oral health products, and fortified foods highlights its growing commercial and clinical relevance. Overall, the future prospects of green tea rest on continued clinical validation, mechanistic studies, and innovative delivery systems. As research advances, green tea may evolve from being a traditional health beverage into a scientifically established, multi-target therapeutic agent capable of contributing to modern preventive and therapeutic strategies.

CONCLUSION

Demand of green tea has been increased globally in the last few years, Green tea is highly beneficial for obese patients, cardiovascular problems, and low immunity, etc. A wide range of benefits of green tea have been discussed in this piece of literature. The presence of vital bioactive compounds, keeps green tea in the good books of the medicinal literature. On the basis of sufficient numbers of research work done on green tea,it can be suggested to use green tea, parallelly with a balanced diet in order to procure best of its benefits. This review therefore concludes that green tea consumption may be considered beneficial for human health.

Conflict of interest

The authors declared no conflict of interest.

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Abbreviations Used

Reactive oxygen species (ROS), epigallocatechin-3-gallate (EGCG), Green tea extract (GTE) and Total Antioxidant Capacity (TAC).

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