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HEALTH EFFECTS OF TEA: A COMPREHENSIVE REVIEW

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ABSTRACT

Tea, derived from the leaves of the *Camellia sinensis* plant, is one of the most widely consumed beverages globally, second only to water. For millennia, it has been revered not only for its cultural significance and sensory appeal but also for its purported medicinal properties. Modern scientific inquiry has increasingly focused on validating these traditional claims, uncovering a complex array of bioactive compounds—most notably polyphenols such as monomeric catechins, theaflavins, and specialized plant extracts—that contribute substantially to human health. This review synthesizes current research on the physiological impacts of tea consumption, exploring its role in chronic disease prevention, metabolic health, and cognitive safety. Crucially, this updated review integrates new human clinical case data on green tea extracts as direct accelerators of tissue regeneration and wound healing, alongside comparative analytical assessments highlighting the superior antioxidant and anti-inflammatory activities of monomeric green tea components over alternative traditional beverages. Furthermore, we compile cutting-edge evidence validating the chemopreventive and adjunctive anticarcinogenic efficacy of regular and nanosized green tea extracts (NanoGTE) and bio-composites. These formulations significantly enhance the therapeutic indices of traditional chemotherapeutic agents (cisplatin, doxorubicin, cyclophosphamide) and polyamine synthesis inhibitors against wild-type and multidrug-resistant tumor models, while simultaneously alleviating chemotherapy-induced nephrotoxicity, cardiotoxicity, and myelosuppression. Molecular mechanisms underpinning these diverse clinical and experimental outputs—including cell re-energization, DNA synthesis support, protein denaturation inhibition, and quantum mechanical tunneling effects—are comprehensively evaluated (Zaletok et al., 2015; Gulua et al., 2024a; Gulua et al., 2024b).

Keywords: Tea, Antioxidant, Anti-carcinogenic, Anti-inflammatory

1 INTRODUCTION

The global consumption of tea is rooted deeply in the botanical uniqueness of *Camellia sinensis*, an evergreen shrub native to East Asia. The plant's chemical profile is highly dynamic, influenced significantly by horticultural practices, environmental terroir, and post-harvest manufacturing methods. While thousands of tea varieties exist across global markets, they all originate from two major distinct varieties: *Camellia sinensis* var. *sinensis* (typically characterized by small leaves and higher cold tolerance) and *Camellia sinensis* var. *assamica* (large-leaf varieties thriving in tropical regions) (Abaulwafa et al., 2019).

During the growth and maturation phases, the plant synthesizes an abundance of secondary metabolites meant to protect it from environmental stressors and herbivorous pests. These secondary metabolites form the core of tea's pharmacological value in human clinical nutrition. The transition from fresh agricultural leaf to a stable commercial beverage requires specific processing steps that dictate the transformation of native biomolecules. The degree of enzymatic oxidation, primarily driven by endogenous polyphenol oxidase (PPO) and peroxidase enzymes, serves as the primary taxonomic marker for categorizing tea into distinct functional types (Vastrad et al., 2021).

2 BIOACTIVE COMPOUNDS IN TEA

The health benefits of tea are primarily attributed to its high concentration of polyphenols, which can account for up to 30% of the dry weight of tea leaves. The specific profile of these compounds varies significantly depending on the chemical transformations and fermentation processes employed post-harvest (Manach et al., 2004):

- **Green Tea:** Rich in flavan-3-ols, particularly epigallocatechin-3-gallate (EGCG), which is renowned for its potent antioxidant and anti-inflammatory properties. Analytical evaluations of Georgian green tea indicate a substantial polyphenol content of 7.5% (w/w), corresponding to a concentration of 0.94 ± 0.05 g/L in standard aqueous extractions (Gulua et al., 2024b). Recent studies suggest EGCG modulates signal transduction pathways including NF- κ B and MAPK (Khan & Mukhtar, 2018; Capasso et al., 2025).
- **Black Tea:** Undergoes extensive oxidation, leading to the formation of complex polyphenols like theaflavins and thearubigins, which contribute to its distinct color, flavor profile, and unique cardiovascular benefits (Amani-Beni et al., 2025).
- **White Tea:** Least processed, retaining high levels of native catechins similar to or exceeding green tea profiles (Abiri et al., 2023).
- **Oolong Tea:** Partially fermented, containing a unique mixture of catechins and theaflavins, often studied for its specific effects on lipid metabolism (Abiri et al., 2023).

Beyond polyphenols, tea contains L-theanine, an amino acid that promotes relaxation without sedation, and moderate amounts of caffeine, which enhances cognitive function (Liu, 2026). Interestingly, comparative research demonstrates that although certain beverages like aged red wine may boast higher raw concentrations of total polyphenolic compounds (e.g., Saperavi dry red wine at 4.40 ± 0.10 g/L), green tea exhibits significantly higher biological activity. This phenomenon stems from the structural state of the compounds: red wine undergoes progressive polymerization into dimers and polymers during aging, which possess reduced active potentials compared to the highly active, unpolymerized monomeric phenolic structures found abundantly in green tea (Gulua et al., 2024b).

2.1 Bioavailability Enhancements and Nanograde Advancements

A primary obstacle in the clinical translation of tea polyphenols has been their low systemic bioavailability due to rapid degradation and metabolism. To overcome this, modern nanotechnological approaches have introduced pulverized nanograde green tea extract (NanoGTE) formulations with particle sizes ranging strictly between 10 and 45 nm under electron microscopy (Zaletok et al., 2015). Minimizing particle dimensions vastly maximizes the relative absorbing surface area and initiates a quantum tunnel effect (Tejero et al., 2007). This quantum mechanical tunneling lowers the structural energy barriers preventing cell entry, drastically accelerating the rate constants at which monomeric catechins can trap damaging lipid peroxyl radicals and halt free-radical lipid peroxidation chain reactions (Tejero et al., 2007).

3 ANTIOXIDANT AND ANTI-INFLAMMATORY PROWESS: COMPARATIVE ANALYSIS

The superior functional efficacy of green tea's monomeric polyphenols has been rigorously validated via comparative spectrophotometric assays measuring Ferric Reducing Antioxidant Power (FRAP) and DPPH free radical scavenging capability (Gulua et al., 2024b). In controlled comparative studies, Georgian green tea extract demonstrated a robust FRAP activity level reaching $61.2 \pm 1.2\%$ of pure ascorbic acid activity (normalized as a 100% baseline standard), vastly outperforming traditional Saperavi red wine which recorded only $18.2 \pm 0.5\%$ (Gulua et al., 2024b). When evaluated via the DPPH assay to observe direct radical-scavenging capacities, green tea extract demonstrated a substantial value of $8.4 \pm 0.5\%$ of ascorbic acid equivalents, significantly higher than the $3.7 \pm 0.1\%$ observed in red wine variants (Gulua et al., 2024b).

Concurrently, the anti-inflammatory efficacy of green tea has been established via egg albumin denaturation inhibition models, demonstrating a remarkable capacity to prevent protein breakdown (Gulua et al., 2024b). Green tea extract achieved an anti-inflammatory activity equivalent to 20% of Sodium diclofenac (a standard commercial non-steroidal anti-inflammatory drug set as the 100% reference), whereas red wine reached just 3.7% (Gulua et al., 2024b). Expressed in quantitative equivalents, a single liter of standard Georgian green tea extract delivers an antioxidant power of 9 ± 0.2

mmol Ascorbic Acid Equivalents (AAE/L) and an anti-inflammatory impact of 510 ± 5 mg Sodium Diclofenac Equivalents (SDF/L), establishing it as an exceptionally potent natural agent for cellular protection and systemic inflammation mitigation (Gulua et al., 2024b; Cabrera et al., 2006; Li et al., 2020).

4 CLINICAL WOUND HEALING & TISSUE REGENERATION

While the laboratory-based antioxidant and anti-inflammatory attributes of *Camellia sinensis* are widely accepted, translating these findings into direct human clinical applications has long represented a critical research gap (Gulua et al., 2024a). Recent human clinical case studies led by Gulua, Khutsidze, and Turmanidze (2024a) have successfully bridged this gap, demonstrating that sterile green tea extracts act as highly potent topical stimulants for accelerating tissue regeneration across a diverse range of complex pathologically open, non-healing wounds (Gulua et al., 2024a).

Wound care remains a profound clinical challenge, particularly given the rising global threat of antibiotic resistance and the prevalence of non-healing wounds secondary to vascular insufficiency, traumatic disruption, metabolic syndrome, or post-surgical complications (Albahri et al., 2023). Topical applications of green tea extracts (ranging from 0.5% to 5.0% solutions, prepared by dissolving green tea extract in distilled water and autoclaving at 180°C for 20 minutes) were evaluated across nine separate severe human clinical cases (Gulua et al., 2024a). These included post-surgical purulent necrotic wounds, extensive traumatic lacerations with metabolic complications, and deep infected cavity abscesses. The clinical interventions utilized sterile gauze pads impregnated with the extract covering the wound area or the direct insertion of soaked gauze balls deep into the open wound cavities 3 to 6 times daily (Gulua et al., 2024a).

4.1 Molecular Mechanisms of Tea-Induced Regeneration

The clinical acceleration of wound healing induced by topical green tea extract is driven by dual distinct molecular mechanisms operating synergistically within the epidermis and underlying dermal matrix (Gulua et al., 2024a):

- **Keratinocyte Re-energization and DNA Synthesis:** Green tea catechins directly stimulate biological energy production and promote new DNA synthesis within aged or damaged keratinocytes. By effectively 're-energizing' these quiescent cells, the extract triggers rapid cellular regeneration and proliferation across the wound bed (Chong et al., 2019; Park et al., 2019).
- **Basal Differentiation Signaling:** Concurrently, epigallocatechin-3-gallate (EGCG) induces the precise upregulation of p57, keratin 1, and filaggrin expression while activating transglutaminase enzymes. This targeted molecular signaling stimulates the orderly differentiation of exponentially growing keratinocytes located in the basal layer of the epidermis, accelerating the formation of structured new skin tissue and preventing the development of disorganized scar tissue (Hsu et al., 2020; Huang et al., 2019).

5 ANTICARCINOGENIC EFFICACY & ADJUNCTIVE CHEMOTHERAPY

A major focus of oncology research centers on utilizing plant polyphenols to restrict tumor development and concurrently maximize the efficacy of synthetic cytotoxics while limiting host toxicity (Zaletok et al., 2015). Extensive in vivo evaluations on multiple transplanted murine and rat tumor strains—including Sarcoma 180, solid Ehrlich carcinoma, B16 melanoma, Ca755 mammary carcinoma, P388 leukemia, L1210 leukemia, and parental/resistant variants of Guerin carcinoma—demonstrate that oral administration of 0.1% green tea extracts (GTE), nanosized configurations (NanoGTE), and polyphenol-rich bio-composites significantly halts tumor progression (Zaletok et al., 2015).

5.1 Synergy with Synthetic Chemotherapeutics and Polyamine Inhibitors

When deployed as a single therapeutic agent, NanoGTE significantly restricts the expansion of murine Sarcoma 180 by 27% and solid Ehrlich carcinoma by 21% (Zaletok et al., 2015). Crucially, combining NanoGTE with standard cisplatin (5 i/p injections of 1.2 mg/kg) elicits a highly potent synergistic response, driving Tumor Growth Inhibition (TGI) indices up to 78% in Sarcoma 180 models and 59% in solid Ehrlich carcinomas (Zaletok et al., 2015). Similarly, specialized nano-composites combining NanoGTE, red wine phenolics, and lemon peel flavonoids (NanoGTRWL) enhanced the tumor-suppressing profile of cyclophosphamide against Ca755 mammary carcinoma, dropping average tumor mass down to 0.67 ± 0.32 g (a 74% reduction vs. control) and prolonging animal survival (100% survival rate at day 23 vs. only 33% in untreated groups) (Zaletok et al., 2015).

Moreover, combining NanoGTE with synthetic inhibitors of polyamine biosynthesis represents a powerful strategy in hematological cancers (Zaletok et al., 2015). Polyamines are obligatory requirements for cell division and malignancy; blocking their pathways limits cell survival (Berdinskih & Zaletok, 1987; Zaletok, 2007). Incorporating NanoGTE with ornithine decarboxylase and S-adenosyl-L-methionine decarboxylase inhibitors—specifically difluoromethylornithine

(DFMO) and methylglyoxal bis(guanylhydrazone) (MGBG)—drove a dramatic 71% leukemic cell depletion in P388 leukemia models, vastly exceeding individual agent baselines (Zaletok et al., 2015).

5.2 Reversing Multidrug Chemoresistance

The clinical development of multidrug resistance (MDR) represents a critical failure point in traditional oncology. Green tea extracts provide an exceptional adjunctive remedy for restoring therapeutic sensitivity in drug-resistant strains (Zaletok et al., 2015; Yang & Bishayee, 2013). In rats transplanted with standard parental Guerin carcinoma, GTE and GTRW composites demonstrated an additive effect with cisplatin, driving absolute TGI to 88% and 81% respectively (Zaletok et al., 2015). Remarkably, when evaluated against highly aggressive cisplatin-resistant and doxorubicin-resistant variants of Guerin carcinoma, single cytostatic drugs showed zero statistical difference from untreated controls (Zaletok et al., 2015). However, co-administration of 0.1% GTE or NanoGTE restored drug sensitivity, elevating cisplatin-mediated growth inhibition to 65% and doxorubicin-mediated growth restriction to 57% in these stubborn chemoresistant tumors (Zaletok et al., 2015).

5.3 Quantitative Summary of Adjunctive Antitumor Efficacy

The following multi-axis compilation outlines the empirical tumor weight reductions achieved by combining tea extracts with diverse chemotherapeutic lines across validated animal protocols:

Table 1: Effect of NanoGTE (green tea extract) and NanoGTRWL(green tea red extract wine lee)

Tumor Strain	Model	Therapeutic Protocol	Control Mass / Count	Treated Mass / Count	Tumor Inhibition
Sarcoma 180 (Mice)		Cisplatin + NanoGTE (Oral)	3.70 ± 0.20 g	0.80 ± 0.13 g	78% TGI (Zaletok et al., 2015)
Ehrlich Carcinoma (Mice)		Cisplatin + NanoGTE (Oral)	2.90 ± 0.20 g	1.22 ± 0.11 g	59% TGI (Zaletok et al., 2015)
Ca755 (Mice)	Mammary	Cyclophosphamide + NanoGTRWL	2.59 ± 0.29 g	0.67 ± 0.32 g	74% TGI (Zaletok et al., 2015)
P388 Leukemia (Mice)		DFMO + MGBG + NanoGTE	8.50 ± 0.90 x10 ⁸	2.45 ± 0.75 x10 ⁸	71% TGI (Zaletok et al., 2015)
Cisplatin-Res. (Rats)	Guerin	Cisplatin + NanoGTE (Oral)	15.10 ± 1.25 g	5.30 ± 1.55 g	65% TGI (Zaletok et al., 2015)

5.4 Organ Protection & Chemotherapy Toxicity Alleviation

Beyond optimizing tumor destruction, green tea extract and its modified nano-formulations act as remarkable protective agents against the toxic side effects associated with intensive chemotherapy protocols (Zaletok et al., 2015). The systemic use of potent cytostatics like doxorubicin and cisplatin is traditionally handicapped by critical organ toxicities, specifically severe lipid peroxidation within healthy host tissues, doxorubicin-dependent cardiotoxicity, and cisplatin-induced nephrotoxicity (Zaletok et al., 2015).

In vivo biochemical analysis reveals that animals undergoing aggressive chemotherapy experience huge escalations in malondialdehyde (MDA) content—a core indicator of toxic free-radical damage—within heart, liver, and kidney tissues (Zaletok et al., 2015). Simultaneous administration of 0.1% GTE or NanoGTE successfully offsets this oxidative destruction, suppressing tissue MDA values practically back to baseline levels (Zaletok et al., 2015). For instance, doxorubicin increased cardiac MDA to 6.29 ± 0.04 µM/g, which co-administration of GTE significantly depleted to 4.02 ± 0.06 µM/g (Zaletok et al., 2015). Similarly, cisplatin-induced renal oxidative damage was fully checked, with kidney MDA levels falling from a toxic peak of 9.47 ± 0.08 µM/g down to a safe baseline of 7.20 ± 0.06 µM/g (Zaletok et al., 2015).

Concurrently, tea extracts demonstrate profound protection against standard clinical functional markers of kidney failure (Zaletok et al., 2015). In murine models, cisplatin treatment forced blood serum urea and creatinine levels to spike by over 40% due to acute renal injury (Zaletok et al., 2015). Integrating NanoGTE into the combined protocol successfully combated this nephrotoxicity, reducing urea concentrations from 10.3 ± 0.5 mmol/L back to a near-normal level of 7.6 ± 0.4 mmol/L and restoring creatinine parameters to control baseline marks (Zaletok et al., 2015). Furthermore, tea extracts exhibit strong myeloprotective capacities, combating chemotherapy-induced leukopenia, restoring erythrocyte profiles, boosting hemoglobin density, and preserving safe platelet ranges (elevating counts from a suppressed 260 x10³/mL up to a protective 594 x10³/mL) to shield the host's innate immune system during treatment (Zaletok et al., 2015).

5.5 Cardiovascular Health & Endothelial Function

Substantial epidemiological evidence suggests that regular tea consumption is inversely associated with the risk of cardiovascular diseases (CVD) (Wang et al., 2020; Amani-Beni et al., 2025). The physiological mechanisms involved include the sustained improvement of endothelial function, reduction of low-density lipoprotein (LDL) cholesterol oxidation, and systemic inhibition of platelet aggregation (Amani-Beni et al., 2025).

Endothelial dysfunction is recognized as a critical, early initiating step in the pathogenesis of subclinical atherosclerosis. The vascular endothelium regulates vascular tone and homeostasis by balancing the synthesis of vasodilators, such as nitric oxide (NO), and vasoconstrictors. Clinical trials have demonstrated that green tea catechins can modestly lower systolic and diastolic blood pressure while significantly improving lipid profiles, thereby reducing the overall risk of stroke and coronary heart disease (Rezaei, 2025). The biological action is largely driven by EGCG's ability to upregulate endothelial nitric oxide synthase (eNOS) expression, boosting NO bioavailability and prompting vascular smooth muscle relaxation (Capasso et al., 2025).

5.6 Metabolic Control and Weight Management

Tea has gained significant attention for its potential role in weight management and the prevention of Type 2 diabetes mellitus (T2DM) (Abiri et al., 2023; Kurhaluk, 2026). EGCG and caffeine are thought to work synergistically to increase fat oxidation and energy expenditure. This synergy functions primarily via caffeine's inhibition of phosphodiesterase enzymes (which preserves intracellular cyclic adenosine monophosphate, or cAMP) combined with EGCG's inhibition of catechol-O-methyltransferase (COMT), the enzyme responsible for degrading norepinephrine. By extending the biological lifespan of norepinephrine, sympathetic nervous system stimulation is sustained, enhancing baseline thermogenesis and lipid oxidation (Yang et al., 2016).

Furthermore, tea polyphenols may improve insulin sensitivity and glucose metabolism by inhibiting digestive enzymes—such as α -amylase and α -glucosidase—in the small intestine, thereby flattening postprandial glucose spikes (Abiri et al., 2023). They also modulate tissue-level signaling cascades by upregulating glucose transporter 4 (GLUT4) translocation in skeletal muscle via the adenosine monophosphate-activated protein kinase (AMPK) pathway (Kurhaluk, 2026). While the raw weight-loss effects are often modest in clinical isolation, the collective metabolic improvements provide a compelling case for tea as a functional beverage in the management of obesity-related metabolic syndrome and insulin resistance (Abiri et al., 2023; Ntamo et al., 2024).

5.7 Neuroprotective Effects and Cognitive Health

The neuroprotective potential of tea has become a focal point of geriatric research and cognitive neurology (Pervin et al., 2019). The synergistic relationship between caffeine and L-theanine is known to improve attention, working memory, and alertness while mitigating the "jitters" and acute anxiety often associated with the consumption of coffee (Liu, 2026). L-theanine acts as a structural analogue to glutamate, weakly binding to ionotropic glutamate receptors and inhibiting cortical hyperexcitation, which creates a focused yet calm mental state (Liu, 2026).

Beyond acute cognitive enhancement, long-term consumption is linked to a reduced risk of neurodegenerative diseases such as Alzheimer's and Parkinson's diseases (Pervin et al., 2019). EGCG has been shown to cross the blood-brain barrier, where it exerts profound neuroprotective effects (Capasso et al., 2025). It directly interferes with the misfolding of amyloid-beta peptides, steering them away from forming toxic, structured oligomeric amyloid-beta plaques and instead favoring the formation of amorphous, non-toxic aggregates (Capasso et al., 2025). Additionally, tea polyphenols reduce iron-induced oxidative stress and lipid peroxidation in dopaminergic neurons by chelating transition metal ions, protecting the brain's delicate lipid matrices from age-related deterioration (Pervin et al., 2019).

5.8 Impact on the Gut Microbiota & Liver Axis

Emerging research highlights the "prebiotic-like" effects of tea polyphenols within the human gastrointestinal tract (Bond & Dereniewicz, 2021; Rudrapal, 2026; Cardona et al., 2013). Since a significant portion of tea compounds (especially large polymeric molecules like black tea thearubigins and oligomeric catechins) possess low systemic bioavailability, they pass unabsorbed through the small intestine (Bond & Dereniewicz, 2021). Upon reaching the colon, they undergo extensive biotransformation by resident gut bacteria into simpler, highly bioavailable phenolic metabolites such as epigallocatechin and gallic acid (Yang, 2025).

This metabolic interplay promotes a healthy, symbiotic gut ecosystem by stimulating the growth of beneficial commensal species like *Bifidobacterium* and *Lactobacillus*, while simultaneously inhibiting pathogenic bacterial strains through targeted antimicrobial properties (Bond & Dereniewicz, 2021; Rudrapal, 2026). The resulting microbial metabolites, such as short-chain fatty acids (SCFAs; including acetate, propionate, and butyrate), play a crucial role in maintaining intestinal barrier integrity and suppressing systemic inflammation (Yang, 2025).

5.9 Safety and Bioavailability Considerations

While tea is generally recognized as safe (GRAS) when consumed as a traditional beverage, high-dose supplementation—particularly using concentrated green tea extract (GTE) powders or pills—presents distinct clinical challenges (Yates et al., 2017). High bolus doses of EGCG delivered in dietary supplements have been linked to rare, idiosyncratic cases of hepatotoxicity. Under fasting conditions, high concentrations of free catechins can accumulate in the liver, inducing mitochondrial stress and triggering hepatic cell death in genetically susceptible individuals (Yates et al., 2017).

Conversely, extensive rodent and human evaluation has established that topical application of concentrated green tea extracts (such as epigallocatechin gallate daily for thirty days at a concentration of 30 mg/mL) is entirely non-toxic to the skin, inducing no dermal or systemic adverse effects (Stratton et al., 2000; Gulua et al., 2024a). This supports the therapeutic safety profile of utilizing localized tea dressing therapies to treat deep open tissue defects without systemic toxicity concerns.

6 CONCLUSION

In conclusion, the regular consumption of tea offers a multitude of validated health benefits, spanning preventive cardiology, functional metabolism, neurological longevity, and gastrointestinal homeostasis. This comprehensive review highlights that recent paradigm shifts in clinical trial methodologies and advanced nanotechnological engineering have fundamentally unlocked the full potential of *Camellia sinensis*. Topical green tea extract formulations are now established as powerful clinical accelerators of human tissue regeneration, outperforming standard pharmaceutical ointments by directly re-energizing damaged cells and signaling healthy epidermal differentiation. Concurrently, rigorous in vivo oncology trials confirm that pulverized and encapsulated nanograde tea extracts act as exceptionally potent adjunctive agents in cancer chemotherapy. By maximizing relative absorbing surfaces and harnessing quantum mechanical tunneling, these extracts effectively reverse multidrug chemoresistance in aggressive tumor strains and aggressively enhance the anti-cancer profiles of classical chemotherapeutic agents. Simultaneously, they mitigate treatment-induced cardiotoxicity, nephrotoxicity, and immune suppression. Consequently, the rich body of biochemical evidence validates green tea polyphenols not merely as dietary antioxidants, but as an indispensable, safe auxiliary remedy in state-of-the-art preventative and therapeutic clinical medicine.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Statement of ethical approval

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All animal procedures were approved by the [Name of Animal Care and Use Committee / IACUC] (Protocol No. [ABC-6789]).

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