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The Impact of Matcha Green Tea on Human Health – Mechanisms of Action, Clinical Evidence, and Health Effects

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ABSTRACT

Matcha green tea, a powdered whole-leaf preparation from shade-grown *Camellia sinensis*, exhibits a unique biochemical profile rich in catechins (particularly EGCG), L-theanine, caffeine, and chlorophyll, distinguishing it from conventional green teas. This narrative review synthesizes evidence on matcha's composition, mechanisms of action, and health effects. Mechanistically, EGCG activates the Nrf2/Keap1 antioxidant pathway, suppresses inflammatory signaling, and synergizes with L-theanine/caffeine to enhance cognitive function, while modulating gut microbiota toward beneficial taxa like *Coprococcus*.

Clinical and preclinical studies demonstrate cardiometabolic benefits including improved glycemic control, lipid profiles, and hepatic protection against NAFLD, alongside cognitive

enhancements and reduced exercise-induced fatigue. Preliminary data suggest anti-cancer potential via apoptosis induction and metabolic inhibition in tumor cells. Despite promising mechanistic insights, human trials remain limited by small samples, short durations, and heterogeneous preparations.

Matcha emerges as a functional food with multifaceted health potential, warranting large-scale randomized controlled trials to establish optimal dosing, long-term efficacy, and safety for evidence-based recommendations.

Keywords: Matcha green tea, EGCG, catechins, L-theanine, Nrf2/Keap1 pathway, antioxidant activity, anti-inflammatory effects, gut microbiota, cardiometabolic health, cognitive function, NAFLD, anti-cancer properties

1. Introduction

Matcha, a finely grounded powder derived from shade-grown *Camellia sinensis* leaves, is a specific type of Japanese green tea traditionally prepared from tencha and consumed as a suspended whole-leaf powder rather than a filtered infusion [1]. Originating from Japan, where it has long been used in the tea ceremony, matcha is characterized by high levels of polyphenols, amino acids, caffeine and chlorophyll, which together give it a distinctive biochemical profile and sensory properties in comparison to other green teas [2]. In recent years, matcha has attracted growing scientific and commercial interest and nowadays is often used not only as a beverage but also as an ingredient in foods and functional drinks, including cakes, noodles, ice creams and various beverages[1].

A growing body of evidence from both animal and human studies suggests that regular consumption of matcha may affect many aspects of health, including cardiovascular and metabolic health, cognitive function, antioxidant defense mechanisms, and gut microbiota composition[3]. These potential benefits are primarily attributed to the exceptionally high concentration of bioactive polyphenols in matcha, particularly catechins such as epigallocatechin-3 gallate (EGCG), as well as other compounds including L-theanine, caffeine, and chlorophyll [4]. However, despite growing consumer interest and increasing experimental evidence, comprehensive clinical studies in humans remain limited, and the mechanisms underlying the health effects of matcha require further clarification[5].

This narrative review synthesizes current scientific literature to evaluate the chemical composition of matcha, the biological mechanisms of action of its major bioactive components, the existing clinical evidence for health effects.

2. Composition and Biochemistry of Matcha

2.1 Catechins and Polyphenolic Content

Catechins, the main polyphenols found in green tea, account for 80–90% of flavonoids and about 40% of water-soluble solids. The four main types are (-)-epicatechin (EC), (-)-epigallocatechin (EGC), (-)-epicatechin-3-gallate (ECG), and (-)-epigallocatechin-3-gallate (EGCG). EGCG is present in the highest amount (~60%), followed by EGC (~20%), ECG (~14%) and EC (~6%), which makes it the subject of most health-related research [6]. Green tea contains more catechins than other teas due to minimal processing without fermentation. Commercial analyses confirm green teas have higher catechin levels (up to 7.44 mg/g) than black teas (0-3.47 mg/g) [7]. Matcha, as powdered green tea from shade-grown leaves, shows elevated polyphenol levels with flavonoids at 99–139 mg RE/g and phenolics at 169–273 mg GAE/g (methanol extracts). Chlorogenic acid dominates phenolic profiles, enhancing matcha's antioxidant capacity beyond regular green tea [8].

2.2 L-Theanine and Caffeine

In addition to catechins, matcha contains substantial quantities of L-theanine, an amino acid unique among tea beverages for its concentration and bioactivity. The presence of L-theanine modulates caffeine's effects through synergistic interactions affecting neurotransmitter synthesis and psychophysiological responses [9]. In native matcha samples, caffeine concentrations ranged from 14.1–16.1 mg/g, L-theanine from 4.22–9.85 mg/g, and theobromine from 0.14–0.27 mg/g. In the undigested residue after in vitro digestion, only caffeine (3.66–5.26 mg/g) and trace L-theanine (0.09–0.15 mg/g) were detected. The digestion process releases most of these compounds, with caffeine and L-theanine as the primary alkaloids available in matcha [10].

2.3 Other Bioactive Compounds

Matcha contains complex non-volatile metabolite profiles comprising 1383 compounds, with 263 flavonoids, 232 phenolic acids, and 197 amino acids and derivatives being predominant. Chlorophyll and phenolic acids (primarily chlorogenic acid) contribute to color and antioxidant

capacity. Volatile aroma compounds number approximately 97 key molecules, with aldehydes dominating the characteristic seaweed-like profile [11].

3. Mechanisms of Biological Action

3.1 Antioxidant Mechanisms and the Nrf2/Keap1 Pathway

Matcha green tea contains polyphenols that directly bind to and disrupt the interaction between Keap1 and Nrf2 proteins. The main active compound, epigallocatechin-3-gallate (EGCG), has the strongest binding to Keap1's Kelch domain, forming 11 hydrogen bonds that prevent Nrf2 degradation. When Nrf2 is released from Keap1, it moves to the cell nucleus where it activates antioxidant defense genes including detoxification enzymes (NQO1, UGT1A6, GCLC), antioxidant enzymes (SOD, CAT, GSH-Px), and cellular transporters (p-gp, MRP2). Other matcha catechins (ECG, EGC, EC, C) work together with EGCG to enhance this antioxidant pathway[12]. Studies have shown that EGCG (100 μM) pretreatment reduced H_2O_2-induced aging in human stem cells from 75% to 30% senescent cells. EGCG increased nuclear Nrf2 levels 2.5-fold and decreased aging markers (acetyl-p53 and p21). When Nrf2 was knocked down with siRNA, EGCG lost its protective effect, proving Nrf2 is essential for EGCG's antioxidant protection [13]. These findings demonstrate that matcha's antioxidant effects are mediated primarily through Nrf2/Keap1 pathway activation, enhancing cellular antioxidant defense across diverse models.

3.2 Anti-inflammatory Signaling

Matcha green tea effectively reduces inflammation through multiple pathways. Matcha significantly attenuated gamma radiation-induced acute kidney injury (AKI) in female rats, outperforming etoricoxib by reducing serum creatinine/urea, oxidative stress markers and inflammatory cytokines[14]. Green tea extract reduced airway hyperresponsiveness, inflammatory cells, Th2 cytokines in asthmatic mice. Extract inhibited oxidative stress, mitogen-activated protein kinases (MAPKs) phosphorylation, and metalloproteinase-9 (MMP-9) activity, preventing mucus hypersecretion and airway inflammation comparable to dexamethasone [15].

3.4 Neurocognitive Mechanisms: L-Theanine and Caffeine Synergy

L-theanine, present in matcha, reduces stress-induced cortisol and enhances alpha-wave brain activity through inhibition of glutamine transport and modulation of GABA, serotonin, and

dopamine signaling. Matcha intake significantly improved attention and executive function under mild acute psychological stress in middle-aged and older adults compared to caffeine alone, demonstrating the synergistic benefits of L-theanine and caffeine. Continuous matcha consumption increased work performance in attention-demanding tasks, whereas single caffeine doses only enhanced reaction time [16].

3.5 Modulation of the Gut Microbiota

Matcha modulates the composition of the gut microbiota by reversing dysbiosis caused by a high-fat diet, in particular by increasing the number of obesity-alleviating bacteria (*Alloprevotella*, *Ileibacterium*, *Rikenella*) and reducing the number of obesity-promoting bacteria (*Romboutsia*). Matcha also affects key intestinal metabolites, including formononetin, vitamin C, and short-chain fatty acid precursors [17]. A randomized study showed that consuming matcha green tea significantly altered the diversity of the microbial composition. Matcha consumption significantly increased the abundance of *Coprococcus*, which produces short-chain fatty acids (SCFA) associated with butyrate synthesis and improved metabolic health, while reducing the number of potentially pathogenic *Fusobacterium* bacteria. These changes in the microflora provided potential health benefits by modulating bacterial metabolites and inhibiting harmful bacteria[18].

4. Health Effects and Clinical Evidence

4.1 Cardiometabolic Health: Weight, Glucose Metabolism, and Lipid Profiles

A prospective, non-randomized open-label comparative study in overweight and obese individuals following a low-calorie diet found that adding matcha tea once daily led to a potential decrease in fasting blood glucose and insulin, a potential improvement in HDL-C, and a potential decrease in leptin levels, although between-group differences in anthropometric and lipid outcomes were not statistically significant. Matcha intake was also associated with a potential increase in superoxide dismutase activity, a potential decrease in glutathione peroxidase activity, a significant increase in the anti-inflammatory cytokine IL-10, and a trend toward lower IL-6, suggesting possible antioxidant and anti-inflammatory effects [19]. In another study, supplementation with matcha green tea powder significantly reduced weight gain, visceral fat accumulation, and fatty liver in mice fed a high-fat diet for 8 weeks. Serum glucose, total cholesterol, triglycerides, and LDL/HDL ratios were significantly reduced, along

with a decrease in ALT/AST markers of liver damage. These cardiometabolic improvements resulted from upregulation of farnesoid X receptor (FXR) expression in the liver and inhibition of lipogenic genes, demonstrating the efficacy of matcha in restoring metabolic homeostasis through modulation of the gut-liver axis [20]. In the context of non-alcoholic fatty liver disease (NAFLD) matcha significantly reduced body weight, visceral fat, serum glucose, cholesterol, triglycerides, and liver damage markers (ALT/AST) in high-fat diet-fed obese mice. Liver histology showed decreased fat accumulation and inflammation, while molecular analysis demonstrated improved lipid metabolism and reduced liver inflammation. These findings confirm matcha's hepatoprotective effects against NAFLD through enhanced fat metabolism and anti-inflammatory mechanisms [21].

4.2 Cognitive and Psychological Effects

A randomized controlled trial examining the effects of matcha consumption on cognitive functions and sleep quality in older adults with mild cognitive decline found that regular matcha consumption could improve emotional perception and sleep quality. Additionally, the study suggested potential improvement in general cognition, though the difference between groups did not reach statistical significance [22]. Matcha extract significantly improved memory and learning deficits in high-fat diet-fed mice, as shown by better performance in Y-maze, passive avoidance, and Morris water maze tests. These memory improvements were accompanied by enhanced brain antioxidant defenses, restored cholinergic system, and reduced neuroinflammation. Matcha protected against metabolic disorder-induced cognitive decline through multiple neuroprotective mechanisms acting on brain oxidative stress and neurotransmitter systems [23].

4.3 Effects on Athletic Performance and Fatigue

Matcha green tea consumption during resistance training reduces salivary cortisol, decreases exercise-induced fatigue, and increases skeletal muscle mass and strength compared to placebo. Changes in gut microbiota composition, particularly increases in *Ruminococcus*, *Butyricimonas*, and *Oscillospira*, positively correlated with greater muscle strength gains. Bioactive compounds in matcha (EGCG, L-theanine, and lutein) reduce oxidative stress and modulate stress-response hormones, supporting muscle recovery and adaptation [24].

4.4 Potential Anti-Cancer Properties

In vitro studies demonstrate matcha green tea's cytotoxic effects against multiple cancer cell lines, including tongue squamous cell carcinoma (TSCC). Matcha treatment significantly increased apoptosis rates, upregulated pro-apoptotic p53 protein expression, and downregulated anti-apoptotic Bcl-2 compared to controls. These findings highlight matcha's promising anticancer potential [25]. Matcha green tea selectively inhibited breast cancer stem cell propagation by 50% while minimally affecting bulk tumor cells. It suppressed both mitochondrial respiration and glycolysis, reducing cancer cell energy production [26]. In HER2/neu mice, green tea polyphenols synergistically with broccoli sprouts reduced mammary tumor incidence/volume via tumor suppressor upregulation and oncogenic downregulation, inducing cell cycle arrest and apoptosis [27]. These findings underscore matcha's anticancer potential through metabolic reprogramming.

5. Conclusion

Matcha green tea represents a bioactive-rich functional beverage with a multifaceted health potential supported by growing clinical evidence. Its unique composition, characterized by exceptionally high levels of catechins (particularly EGCG), L-theanine, caffeine, and chlorophyll, distinguishes matcha from other green teas. Experimental studies demonstrate that matcha activates key cellular pathways regulating oxidative stress and inflammation, most notably through Nrf2/Keap1 pathway modulation and suppression of MAPK-driven pro-inflammatory cascades. These molecular mechanisms translate into measurable physiological benefits, including improved antioxidant defense, reduced oxidative damage, and modulation of immune and metabolic responses. Evidence from human and animal studies suggests beneficial effects of matcha consumption on cardiometabolic health, cognitive performance, and gut microbiota composition. Matcha appears to support glycemic control, lipid metabolism, and hepatic protection in metabolic disorders, likely through regulation of the gut–liver axis and lipid homeostasis genes. Synergistic interactions between L-theanine and caffeine contribute to enhanced attention, cognitive flexibility, and stress reduction. Emerging data also indicate potential anti-cancer properties of matcha, related to the ability of its polyphenols to induce apoptosis, inhibit tumor cell proliferation, and suppress cancer cell metabolism.

Despite the encouraging body of evidence summarized in this review, significant research gaps remain that limit the translation of preclinical findings into clinical recommendations. Currently, the number of well-designed, large-scale randomized controlled trials investigating the health effects of matcha in humans is insufficient. Many existing studies are limited by small sample sizes, short intervention periods, lack of blinding, or absence of standardized matcha preparations, which hinders direct comparisons and reproducibility of results. Furthermore, most evidence for anti-cancer, neuroprotective, and hepatoprotective effects derives from in vitro or animal models, with limited validation in human populations.

In conclusion, matcha can be regarded as a promising functional food with diverse biological effects arising from a well-characterized network of bioactive compounds and cellular targets. Its regular consumption may contribute to improved metabolic, cognitive, and overall health status.

DISCLOSURE

Author's contribution

Conceptualization: B.Wróbel; methodology: B.Wróbel; check: F.Basta; formal analysis: L.Wójcik; investigation: M.Filipski; resources: M.Filipski; data curation: F.Basta; writing - rough preparation: K.Ptaszkiewicz; writing - review and editing: K.Ptaszkiewicz; visualization: L.Wójcik; supervision: M.Filipski; project administration: K.Ptaszkiewicz; receiving funding- no specific funding.

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In preparing this work, the authors used Perplexity for the purpose of checking language accuracy. After using this tool, the authors have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication.

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