Advances in Pharmacology and Therapeutics Journal

Shahid Sadoughi University of Medical Sciences, Yazd, Iran

SHAHID SADOUGHI UNIVERSITY OF MEDICAL SCIENCES

Review Article

Major Antioxidant Compounds in Green Tea and Their Properties: Evidence in Human and Preclinical Phases, A Narrative Review

Running Title: Antioxidant Compounds in Green Tea Studies

Roghayeh Pourbagher[1], **Ali Nosrati Andevari**[2*]

[1] Cellular and Molecular Biology Research Center, Health Research Institute, Babol University of Medical Sciences, Babol, Iran.

[2] Department of Clinical Biochemistry, Afzalipour Faculty of Medicine, Kerman University of Medical Sciences, Kerman, Iran.

ARTICLEINFO

Received: 12/13/2025
Accepted: 06/10/2026

***Corresponding author**
Department of Clinical Biochemistry, Afzalipour Faculty of Medicine, Kerman University of Medical Sciences, Kerman, Iran.
Tel: +98-9362090578

E-mail
nosrati.ali70@gmail.com

ORCID ID
0000-0002-8699-4688

Abstract

An imbalance between reactive oxygen species (ROS) and antioxidants in the body is characterized as oxidative stress. These unstable molecules, known as ROS, can damage cellular components, including DNA, lipids, and proteins. Reactive species are neutralized by antioxidants, thereby safeguarding cells against oxidative damage. Oxidative stress occurs when ROS are produced in such quantities that the body is unable to remove or neutralize them. This condition can result in cell lesions and is implicated in various disorders, including aging, cancer, cardiovascular diseases, neurological disorders, and inflammatory conditions (1-3). Phytochemicals found in various natural compounds exhibit high therapeutic indices. One notable compound that contains antioxidants is green tea, which helps to debarment various diseases. Green tea comprises bioactive compounds with substantial antioxidant characteristics. These compounds assist in neutralizing hazardous free radicals, suppress lipid peroxidation, mitigate DNA damage induced by oxidative stress, modulate redox-sensitive transcription factors, and upregulate antioxidant enzymes (3-5).

Main Points: The compounds in green tea make it a beneficial beverage for preventing oxidative stress and inflammation, along with their associated complications such as aging, cancer, cardiovascular disease, neurological disorders, and inflammatory diseases.

Keywords: ROS, Antioxidant, Green tea, Catechin, Flavonoid, Vitamin C.

Citation: Pourbagher R, Nosrati Andevari A. Major Antioxidant Compounds in Green Tea and Their Properties: Evidence in Human and Preclinical Phases, A Narrative Review. Adv Pharmacol Ther J. 2025;5(4): 218-228.

Introduction

An imbalance between reactive oxygen species (ROS) and antioxidants in the body is characterized as oxidative stress. These unstable molecules, known as ROS, can damage cellular components, including DNA, lipids, and proteins. Reactive species are neutralized by antioxidants, thereby safeguarding cells against oxidative damage. Oxidative stress occurs when ROS are produced in such quantities that the body is unable to remove or neutralize them. This condition can result in cell lesion and is implicated in various disorders, including aging, cancer, cardiovascular diseases, neurological disorders, and inflammatory conditions (1-3). Phytochemicals found in various natural compounds exhibit high therapeutic indices. One notable compound that contains antioxidants is green tea, which helps to debarment various diseases. Green tea comprises bioactive compounds with substantial antioxidant characteristics. These compounds assist in neutralizing hazardous free radicals, suppress lipid peroxidation, mitigate DNA damage induced by oxidative stress, modulate redox-sensitive transcription factors, and upregulate antioxidant enzymes (3-5).

This study aimed to determine the major antioxidant compounds in green tea, their properties, and to review the evidence related to the antioxidant function of green tea.

Methods

This article is a narrative review. The databases PubMed, Scopus, and Google Scholar were utilized to conduct this study. Most of the studies were published between 2015 and 2025. Considering the important antioxidant compounds in green tea and the factors related to oxidative stress, which have been studied in relation to the antioxidant compounds present in green tea, appropriate keywords were selected. The keywords included green tea, ROS, oxidative stress, antioxidants, catechins, flavonoids, and vitamin C, Nrf2, PPAR, Sirt-1, GPx, RCT, GSH, SOD, CAT, and MDA. Approximately 90 articles were evaluated, and similar articles have been deleted; 79 articles were selected for the final analysis.

Results and Discussions

Green tea: Green tea, an ancient beverage, originates from the Camellia sinensis plant and offers numerous health benefits. After harvest, green tea is quickly steamed or pan-fried, which allows it to retain its green color and delicate flavor. Unlike black tea, it is not fermented. In many cultures, green tea holds dual significance, functioning not only as a revitalizing beverage but also as a cultural icon, especially in East Asia (6, 7). However, green tea is a widely consumed beverage favored by a significant portion of the global population (6).

Antioxidant compounds in green tea: Green tea contains various antioxidants, including catechins, flavonoids, and vitamin C.

Catechins: A flavonoid called catechin is classified as a member of the flavan-3-ols subclass. Catechins are found in various foods, particularly tea, chocolate, and some fruits, and are recognized for their antioxidant properties (8). Camellia sinensis leaves contain 25-35% catechins by dry weight (9). Green

  DOI: https://doi.org/10.18502/aptj.v5i4.21771

tea contains the most catechins, ranging from 100 to 300 mg per cup (approximately 240 ml) (10). They are the most important antioxidants found in green tea. Therefore, the antioxidant activity of the tea is enhanced by its catechin content. Black tea contains fewer catechins than green tea because catechins are converted to theaflavins during the fermentation process. Moreover, catechins with catechol groups have less antioxidant effect than those with pyrogallol groups. This is because, in the pyrogallol group, the presence of three hydroxyl (–OH) groups allows catechins to react more effectively with and neutralize free radicals. In fact, catechins with a pyrogallol group are generally more stable against oxidation (11). The antioxidant properties of catechins are influenced not only by their chemical composition but also by the surrounding environment. Catechins are highly resistant to degradation in acidic aqueous solutions with pH levels below 4, whereas they are less stable in more alkaline solutions with a pH above 6 (12). Li et al. demonstrated that catechins are more stable at a pH of around 4 and have high concentrations (13). In addition, catechins are highly dependent on temperature for their stability. Catechins degrade as the temperature increases. Xu et al. reported that the lowest degradation rate for a specific type of catechin occurred at pH 3 and 25°C, while the highest degradation rate was observed at pH 8 and 135°C (14). In addition, the concentration of oxygen plays a notable role in determining the stability and antioxidant properties of catechins. A higher oxygen content increases catechin oxidation, which lowers its stability (12).

Also, the processes of cultivation, harvesting, withering, steaming, rolling, drying, and packaging affect the catechin content in green tea (15-17).

In general, the effectiveness of catechins in inhibiting toxicity, metabolic syndrome, cardiovascular diseases, malignancies, neurodegenerative disorders, autoimmune diseases, respiratory issues, microbial infections, and digestive disorders has been confirmed (18).

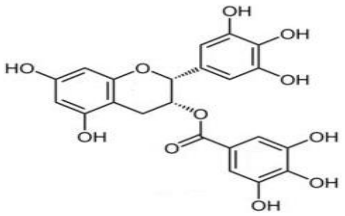
Catechins (**Figure 1**) include the following compounds: Epigallocatechin-3-gallate (EGCG) is a notable polyphenol predominantly found in green tea, recognized for its antioxidant properties and potential health benefits (19). It has a structured backbone consisting of a flavan-3-ol unit, which includes a benzopyran ring (a benzene ring fused to a pyran ring) and eight hydroxyl (–OH) groups. Specifically, EGCG contains a gallate group attached to the epigallocatechin structure. The hydroxyl groups impart hydrophilicity to EGCG, while the aromatic rings exhibit lipophilic properties, enabling interaction with various biological membranes and compounds (20). EGCG remains stable in the body under low oxygen conditions; as a result, it exhibits antioxidant and anti-inflammatory characteristics in both physiological and pathological conditions. Furthermore, EGCG has a significant impact on cardiovascular health. It is linked to improving cholesterol levels, lowering blood pressure, and enhancing the function of blood vessels (20, 21). Inhibiting the growth of cancer cells, EGCG may decrease the likelihood of developing breast and prostate cancer (22). Also, it raises fat oxidation and improves metabolic rates, helping with weight loss (23). Its neuroprotective properties and capacity to

cross the blood-brain barrier enable it to have a positive influence on brain health (24). Moreover, EGCG is beneficial in reducing vascular complications by lowering blood sugar levels (25). Furthermore, EGCG may help prevent premature aging and skin diseases (26). It improves wound healing by stimulating cell growth and movement (27). Also, EGCG influences the expression of growth factors involved in tissue repair, making it useful for treating skin injuries (28). The EGCG content in green tea typically ranges from 50 mg to 200 mg per cup (29).

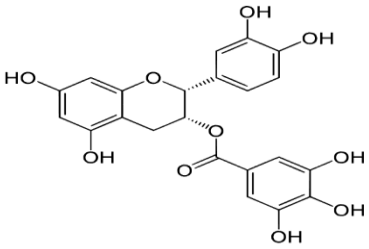
Epicatechin-3-gallate (ECG): Like EGCG, ECG is a flavonoid family compound with polyphenolic properties and is mainly present in green tea (19). ECG contains a gallate group attached to the epicatechin structure. It has two hydroxyl groups on the benzene ring (whereas EGCG has three). This makes ECG less reactive and reduces its antioxidant capacity compared to EGCG (30). ECG plays similar roles for health as EGCG, but fewer studies have been conducted on its beneficial properties. It appears to have less anti-inflammatory potential than EGCG due to its structural differences (31).

Epigallocatechin (EGC): EGC is a type of catechin that contains three hydroxyl groups and is part of the flavonoid group. Unlike EGCG, EGC does not contain a gallate group; instead, EGCG is an ester of EGC and gallic acid. Generally, EGC and ECG have four hydroxyl groups (32). But EGC is present in lower amounts in green tea than EGCG. Although ECG shares similar beneficial properties with EGCG, it exhibits fewer anti-inflammatory, antioxidant, and other health benefits compared to EGCG (33).

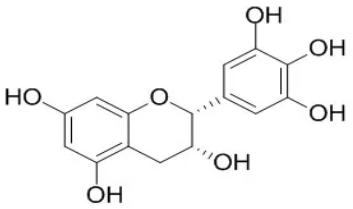
Epicatechin (EC): EC is a flavanol whose structure includes two benzene rings, a three-carbon chain connecting the rings, and three hydroxyl (OH) groups located on the benzene rings. Like other catechins, EC has fewer beneficial effects than EGCG (34).



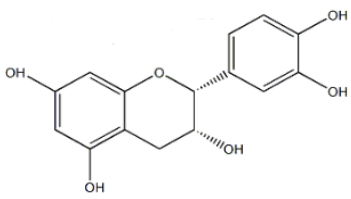
EGCG



ECG



EGC



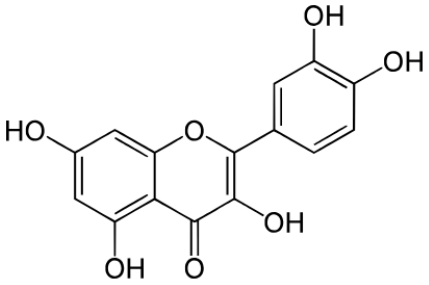
EC

Figure 1. Different types of catechins. EGCG: Epigallocatechin-3-gallate, ECG: Epicatechin-3-gallate, EGC: Epigallocatechin, EC: Epicatechin.

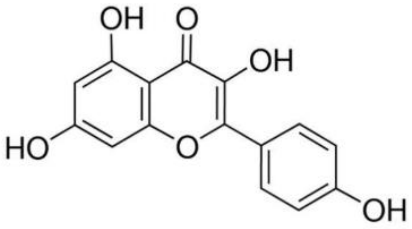
  DOI: https://doi.org/10.18502/aptj.v5i4.21771

Other flavonoids

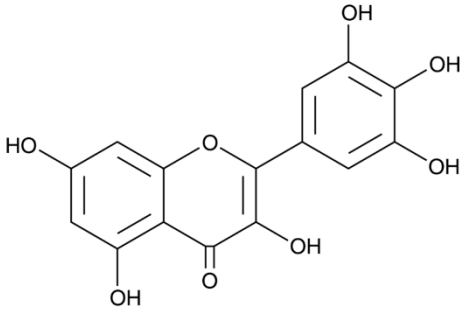
Flavonols: Flavonols are a group of polyphenolic compounds that belong to the flavonoid class found in various plants. They are widely recognized for their antioxidant properties and play significant roles in plant physiology and human health. The fundamental framework of flavonols comprises two phenolic rings linked to a heterocyclic C ring (36). Quercetin, kaempferol, and myricetin are common flavonols that exhibit variations in the quantity and placement of hydroxyl groups and other substituents on their molecular rings (37). Flavonols serve multiple crucial roles in plant life and human biology. One significant activity of flavonols is their antioxidant properties. In plants, flavonols also serve as protective compounds against ultraviolet radiation, pathogens, and herbivores. The pigmentation of flowers and fruits is linked to these entities, facilitating their attraction of pollinators and seed dispersers (38, 39). The health effects of flavonols are similar to those of catechins. The estimated concentration of quercetin in Camellia sinensis is between 2 and 2.5 g/kg (40). Quercetin can help alleviate allergy symptoms by preventing the release of histamine from mast cells and thereby maintaining their stability (41). Kaempferol may exhibit phytoestrogenic activity and potentially affect hormonal balance (42). Kaempferol strengthens the immune system, has protective effects on the liver, and is useful in preventing diabetes, cancers, and cardiovascular diseases (43, 44). According to the figure below, myricetin has a higher number of OH groups than quercetin and kaempferol. As a result, Myricetin has greater antioxidant properties in neutralizing free radicals than the other two.



Quercetin



Kaempferol



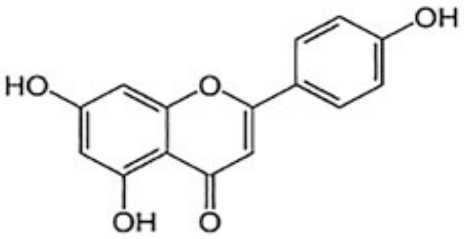
Myricetin

(45)

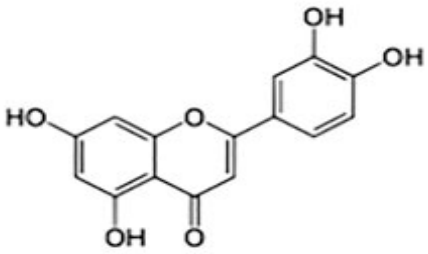
Figure 2. Different types of flavonols. Quercetin, kaempferol, and myricetin.

Flavones: Flavones are compounds found in green tea that are structurally and functionally similar to flavonols. Flavones consist of three aromatic rings, a carbon skeleton, and various substituents. These compounds are notable for their antioxidant properties and are particularly significant in the process of plant pigmentation, UV protection, and attracting pollinators. These compounds include

apigenin and luteolin (46-48). Apigenin and luteolin are present in numerous types of fruits and vegetables, particularly in parsley, celery, chamomile, and green pepper (49, 50). Their concentration in green tea is relatively low compared to the aforementioned sources (51, 52). The chemical structures of different types of flavones are shown in **Figure 3**.



Apigenin



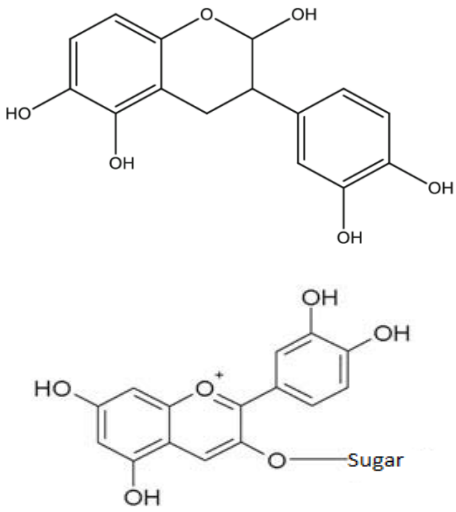
Luteolin

(45, 53)

Figure 3. Different types of flavones. Apigenin and luteolin.

Proanthocyanidins **(PAs):** PAs, or condensed tannins, are groups of compounds discovered in numerous plants, different types of fruits, and several vegetables. They are polymers of flavan-3-ols that include two types. A-type has a unique bond structure between its monomeric units, providing distinct biochemical properties. B-type is the more common form, characterized by a basic structure of catechin and epicatechin units. Both types have antioxidant effects and other catechin-like properties. Green tea mainly contains B-type (54, 55). The content of PAs in green tea is relatively low compared to other sources, such as certain berries and red wine, where A-type proanthocyanidins can also be found (56, 57).

Anthocyanins: These pigments are mainly found in plants and are soluble in water. They are associated with the red, purple, and blue colors of many fruits, vegetables, and flowers (58). Anthocyanins are glycosides derived from anthocyanidins, with a sugar molecule bound to the anthocyanidin backbone. The basic structure comprises an aromatic ring, a carbonyl group, and typically hydroxyl groups (59). Anthocyanins are less common in green tea, where they are found in small amounts. Like other flavonoids, anthocyanins exhibit antioxidant and anti-inflammatory effects (60). **Figure 4** shows the chemical structures of proanthocyanidin and anthocyanidin.



(61, 62)

Figure 4. Proanthocyanidin and Anthocyanin

Vitamin C: Although the antioxidant and anti-inflammatory characteristics of green tea are primarily attributed to its polyphenols and catechins,

  DOI: https://doi.org/10.18502/aptj.v5i4.21771

some of these effects also result from the presence of vitamin C. However, vitamin C is found in lower amounts in green tea compared to other sources, such as citrus fruits and vegetables (63). **Figure 5** provides an overview of the major antioxidant compounds present in green tea.

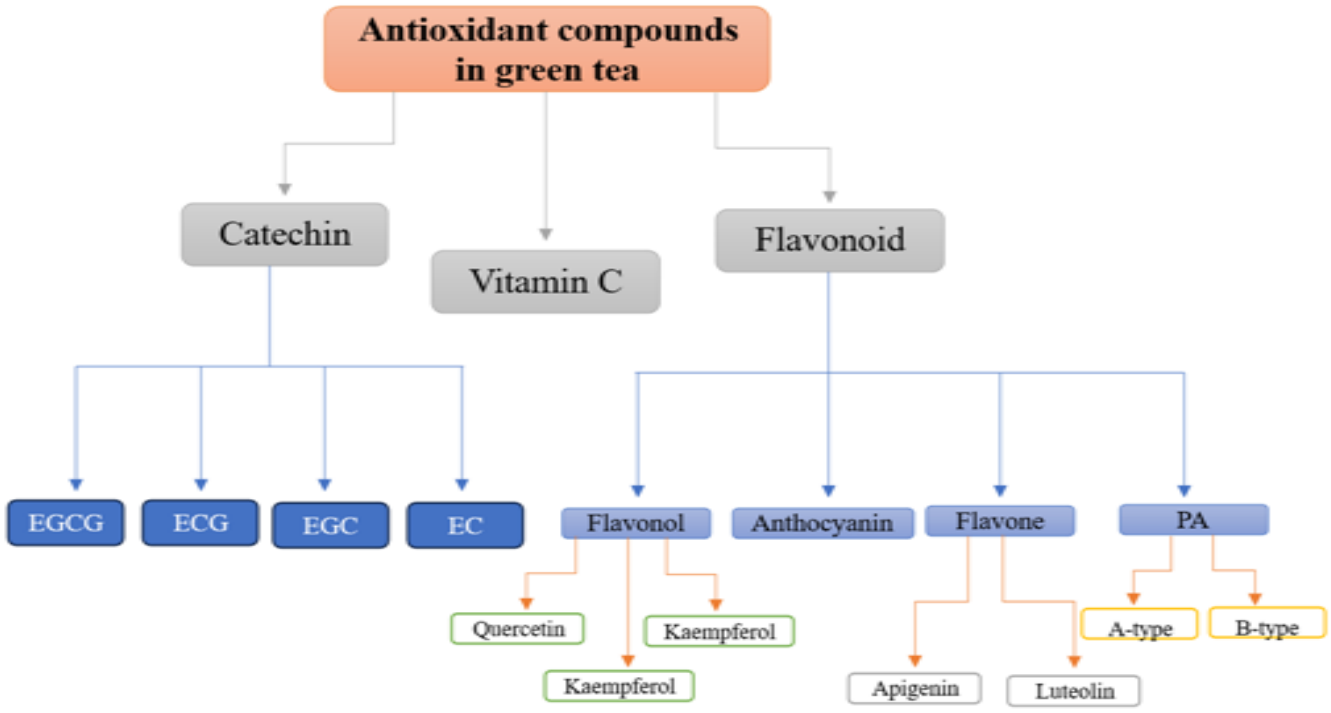


Figure 5. Antioxidant compounds in green tea. Catechins, other flavonoids, and vitamin C. Catechins include EGCG, EGC, ECG, and EC. Other flavonoids include flavonols, flavones, anthocyanins, and PAs. EGCG: Epigallocatechin-3-gallate, EGC: Epicatechin-3-gallate, ECG: Epigallocatechin, EC: Epicatechin. PAs: Proanthocyanidins

Evidence of the antioxidant properties of green tea and its various constituents

Nuclear factor erythroid 2-related factor 2, known as Nrf2, is a vital transcription factor in cellular protection against oxidative stress. This factor triggers an increase in antioxidant proteins and detoxifying enzymes, thereby safeguarding cells against harm inflicted by multiple stressors. When the cell is not experiencing stress conditions, Nrf2 remains inactive in the cytoplasm by interacting with its inhibitor. Kelch-like ECH-associated protein 1 (Keap1) acts as an inhibitor for Nrf2 and is involved in its tagging for degradation via the proteasome and ubiquitination. The function of Nrf2 relies on its interaction with the antioxidant response element (ARE) in the nucleus (64).

EGCG at a dose of 50 mg/kg was discovered by Ye et al. to stimulate the expression of Nrf2, peroxisome proliferator-activated receptor gamma (PPAR-γ), and sirtuin-1 (SIRT-1) in mice with crescentic glomerulonephritis (GN) (65). PPAR-γ has a vital function in mitigating oxidative stress through multiple mechanisms, including the upregulation of direct transcription of antioxidant genes, modulation of inflammatory pathways, and protection against cellular damage (66). SIRT-1 is an NAD^+-dependent

deacetylase known for its significant antioxidant activity. It boosts the activity and expression of antioxidant proteins and enzymes (67). Xie et al. demonstrated that EGCG reduced ROS concentrations and upregulated Nrf2 and its associated targets, including the antioxidant proteins solute carrier family 7 member 11 (Slc7A11), heme oxygenase-1 (HO-1), and glutathione peroxidase-4 (GPx-4), in intestinal mucosal injury in C57 BL/6 J mice (68).

SLC7A11 is known as the cystine/glutamate transporter (system X-), and it contributes to cellular antioxidant defense by transporting cystine into the cell. Inside the cell, cystine is reduced to cysteine, which is an essential component for glutathione synthesis (69). HO-1 is an enzyme whose antioxidant role is due to its function in the breakdown of heme to biliverdin. Excess free heme can generate ROS, which can result in oxidative stress and damage to cells. Biliverdin is rapidly converted to bilirubin, which is a potent antioxidant (70).

In a randomized controlled trial (RCT) published by Venkatakrishnan et al., the intake of 780.6 mg of green tea catechin over 12 weeks in subjects with moderate hypercholesterolemia resulted in significant improvements in glutathione (GSH) levels and the antioxidant enzymes superoxide dismutase (SOD), glutathione reductase (GR), catalase (CAT), and GPx (71). Hu et al. stated that treatment with green tea extract (GTE) for three days elevated the expression of SOD1 and SOD2 in rats with cardiac arrest (72).

Malondialdehyde (MDA) is a highly reactive aldehyde recognized as a biomarker for oxidative stress measurement. It is produced as a final product of lipid peroxidation (73, 74). Suraphad et al. demonstrated that serum MDA levels significantly decreased two hours following the ingestion of 400 mL of green tea in healthy individuals (75).

Other factors involved in oxidative stress include cyclooxygenase-2 (COX-2), inducible nitric oxide synthase (iNOS), and myeloperoxidase (MPO). Lee et al. stated that treatment with green tea extract (GTE) for two weeks downregulated COX-2, iNOS, and MPO in mice with colitis (76, 77). Furthermore, Mostafa et al. showed that GTE intake for 8 weeks reduced MDA and MPO in rats with lung toxicity (78). Also, Chung et al. reported that COX-2 activity in a high-fat diet was notably declined by treatment with green tea extract (1–2%) (79).

Conclusion

Green tea contains antioxidant compounds including catechins, flavonols, flavones, proanthocyanidins, anthocyanins, and vitamin C, which make it a beneficial beverage for preventing oxidative stress and inflammation, along with associated complications such as aging, cancer, cardiovascular diseases, neurological disorders, and inflammatory diseases. Preclinical and human studies have shown the potential antioxidant properties of green tea. Future studies should design randomized controlled trials that use different doses of green tea extract or components, inflammatory and anti-inflammatory variables in different patients.

Acknowledgments: I would like to thank Dr. Durdi Qujeq for his guidance.

Conflict of interests: There is no conflict of interest.

  DOI: https://doi.org/10.18502/aptj.v5i4.21771

Author Contributions: AN contributed to the design of the article and **figures**.

Funding: No financial or other support from any specific organization or individual was provided for the details of this article.

References

1. Andevari AN, Moein S, Qujeq D, Moazezi Z, Tilaki KH. The effect of atorvastatin on the concentrations of methylglyoxal, glyoxalase 1, and aldo–keto reductase family 1 member B10 in patients with type 2 diabetes mellitus and prediabetes. Int. J. Diabetes Dev. Ctries. 2024;44(2):400-8.
2. Engwa GA, Nweke FN, Nkeh-Chungag BN. Free radicals, oxidative stress-related diseases and antioxidant supplementation. Alternative Therapies in Health & Medicine. 2022;28(1).
3. Naghdi N. Folklore medicinal plants used in liver disease: a review. International Journal of Green Pharmacy (IJGP). 2018;12(03).
4. Prasanth MI, Sivamaruthi BS, Chaiyasut C, Tencomnao T. A review of the role of green tea (Camellia sinensis) in antiphotoaging, stress resistance, neuroprotection, and autophagy. Nutrients. 2019;11(2):474.
5. Lotfy DM, Mostafa DM, Taha EF, Ibrahim SI. Matcha Green Tea (Camellia sinensis) Inhibits Gamma Radiation-Induced Genotoxic Damage and Oxidative Stress Via Modulating P38 MAPK Pathway and ROS Generation in Murine Bone Marrow. Pharmaceutical Chemistry Journal. 2024:1-9.
6. Pan S-Y, Nie Q, Tai H-C, Song X-L, Tong Y-F, Zhang L-J-F, et al. Tea and tea drinking: China's outstanding contributions to the mankind. Chinese medicine. 2022;17(1):27.
7. Wang Z-M, Zhao D, Wang H, Wang Q-M, Zhou B, Wang L-S. Green tea consumption and the risk of coronary heart disease: A systematic review and meta-analysis of cohort studies. Nutrition, Metabolism and Cardiovascular Diseases. 2023;33(4):715-23.
8. Mita SR, Husni P, Putriana NA, Maharani R, Hendrawan RP, Dewi DA. A recent update on the potential use of catechins in cosmeceuticals. Cosmetics. 2024;11(1):23.
9. Capasso L, De Masi L, Sirignano C, Maresca V, Basile A, Nebbioso A, et al. Epigallocatechin Gallate (EGCG): Pharmacological Properties, Biological Activities and Therapeutic Potential. Molecules. 2025;30(3):654.
10. Additives EPoF, Food NSat, Younes M, Aggett P, Aguilar F, Crebelli R, et al. Scientific opinion on the safety of green tea catechins. EFSA journal. 2018;16(4):e05239.
11. Musial C, Kuban-Jankowska A, Gorska-Ponikowska M. Beneficial properties of green tea catechins. International journal of molecular sciences. 2020;21(5):1744.
12. Ananingsih VK, Sharma A, Zhou W. Green tea catechins during food processing and storage: A review on stability and detection. Food research international. 2013;50(2):469-79.
13. Li N, Taylor LS, Ferruzzi MG, Mauer LJ. Kinetic study of catechin stability: Effects of pH, concentration, and temperature. Journal of agricultural and food chemistry. 2012;60(51):12531-9.
14. Xu Y-Q, Yu P, Zhou W. Combined effect of pH and temperature on the stability and antioxidant capacity of epigallocatechin gallate (EGCG) in aqueous system. Journal of Food Engineering. 2019;250:46-54.
15. Kaewkeeree W. Study effect of the tea processing on the charactristic of coffee leaf tea. 2012.
16. Baldi A, Abramovič H, Poklar Ulrih N, Daglia M. Tea catechins. Handbook of dietary phytochemicals. 2019:1-46.
17. Cherotich M. Characterization of Bacterial and Fungal Contaminants Of Black Cut, Tear & Curl and Green Teas (Camellia Sinensis) From Selected Factories in Kenya: UOK; 2024.
18. Talebi M, Talebi M, Farkhondeh T, Mishra G, Ilgün S, Samarghandian S. New insights into the role of the Nrf2 signaling pathway in green tea catechin applications. Phytotherapy Research. 2021;35(6):3078-112.
19. Mokra D, Joskova M, Mokry J. Therapeutic effects of green tea polyphenol (–)-Epigallocatechin-3-Gallate (EGCG) in relation to molecular pathways controlling inflammation, oxidative stress, and apoptosis. International journal of molecular sciences. 2022;24(1):340.
20. Mereles D, Hunstein W. Epigallocatechin-3-gallate (EGCG) for clinical trials: more pitfalls than promises? International journal of molecular sciences. 2011;12(9):5592-603.
21. Eng QY, Thanikachalam PV, Ramamurthy S. Molecular understanding of Epigallocatechin gallate (EGCG) in cardiovascular and metabolic diseases. Journal of ethnopharmacology. 2018;210:296-310.
22. Wang P, Wang B, Chung S, Wu Y, Henning SM, Vadgama JV. Increased chemopreventive effect by combining arctigenin, green tea polyphenol and curcumin in prostate and breast cancer cells. RSC advances. 2014;4(66):35242-50.
23. Kapoor MP, Sugita M, Fukuzawa Y, Okubo T. Physiological effects of epigallocatechin-3-gallate (EGCG) on energy expenditure for prospective fat oxidation in humans: A systematic review and meta-analysis. The Journal of nutritional biochemistry. 2017;43:1-10.
24. Unno K, Pervin M, Nakagawa A, Iguchi K, Hara A, Takagaki A, et al. Blood–brain barrier permeability of green tea catechin metabolites and their neuritogenic activity in human neuroblastoma SH-SY5Y cells. Molecular nutrition & food research. 2017;61(12):1700294.
25. Hadi S, Alipour M, Aghamohammadi V, Shahemi S, Ghafouri-Taleghani F, Pourjavidi N, et al. Improvement in fasting blood sugar, anthropometric measurement and hs-CRP after consumption of epigallocatechin-3-gallate

(EGCG) in patients with type 2 diabetes mellitus. Nutrition & Food Science. 2020;50(2):348-59.
26. Wang L, Lee W, Cui YR, Ahn G, Jeon Y-J. Protective effect of green tea catechin against urban fine dust particle-induced skin aging by regulation of NF-κB, AP-1, and MAPKs signaling pathways. Environmental Pollution. 2019;252:1318-24.
27. Li M, Xu J, Shi T, Yu H, Bi J, Chen G. Epigallocatechin-3-gallate augments therapeutic effects of mesenchymal stem cells in skin wound healing. Clinical and Experimental Pharmacology and Physiology. 2016;43(11):1115-24.
28. Sinha S, Pant K, Mishra A, Anand J. Curative potential of EGCG based nanoforms in wound infection and wound healing. International Journal of Polymeric Materials and Polymeric Biomaterials. 2024:1-18.
29. Chen PC, Wheeler DS, Malhotra V, Odoms K, Denenberg AG, Wong HR. A green tea-derived polyphenol, epigallocatechin-3-gallate, inhibits IκB kinase activation and IL-8 gene expression in respiratory epithelium. Inflammation. 2002;26:233-41.
30. Wang S, Jiang C, Jing H, Du X, Zhu S, Wang H, et al. Synthesis of ECG ((−)-epicatechin gallate) acylated derivatives as new inhibitors of α-amylase and their mechanism on delaying starch digestion. Food Bioscience. 2023;52:102466.
31. Li Z, Feng C, Dong H, Jin W, Zhang W, Zhan J, et al. Health promoting activities and corresponding mechanism of (–)-epicatechin-3-gallate. Food Science and Human Wellness. 2022;11(3):568-78.
32. Botten D, Fugallo G, Fraternali F, Molteni C. Structural properties of green tea catechins. The Journal of Physical Chemistry B. 2015;119(40):12860-7.
33. Peter B, Bosze S, Horvath R. Biophysical characteristics of proteins and living cells exposed to the green tea polyphenol epigallocatechin-3-gallate (EGCg): review of recent advances from molecular mechanisms to nanomedicine and clinical trials. European Biophysics Journal. 2017;46:1-24.
34. Qu Z, Liu A, Li P, Liu C, Xiao W, Huang J, et al. Advances in physiological functions and mechanisms of (−)-epicatechin. Critical reviews in food science and nutrition. 2021;61(2):211-33.
35. Bigelow R, Cardelli J. The green tea catechins,(−)-Epigallocatechin-3-gallate (EGCG) and (−)-Epicatechin-3-gallate (ECG), inhibit HGF/Met signaling in immortalized and tumorigenic breast epithelial cells. Oncogene. 2006;25(13):1922-30.
36. Russo D. Flavonoids and the structure-antioxidant activity relationship. J Pharmacogn Nat Prod. 2018;4(1).
37. Felice MR, Maugeri A, De Sarro G, Navarra M, Barreca D. Molecular pathways involved in the anti-cancer activity of flavonols: a focus on myricetin and kaempferol. International Journal of Molecular Sciences. 2022;23(8):4411.
38. Dwivedi A, Mishra VK, Pandey S, Jain PA. Secondary metabolites shielding plant against confluence of environmental factors. Agrica. 2018;7(2):121-30.
39. Xing A, Wang X, Nazir MF, Zhang X, Wang X, Yang R, et al. Transcriptomic and metabolomic profiling of flavonoid biosynthesis provides novel insights into petals coloration in Asian cotton (Gossypium arboreum L.). BMC Plant Biology. 2022;22(1):416.
40. Savic IM, Nikolic VD, Savic IM, Nikolic LB, Stankovic MZ. Development and validation of a new RP-HPLC method for determination of quercetin in green tea. Journal of analytical chemistry. 2013;68:906-11.
41. Mlcek J, Jurikova T, Skrovankova S, Sochor J. Quercetin and its anti-allergic immune response. Molecules. 2016;21(5):623.
42. Kim S-H, Choi K-C. Anti-cancer effect and underlying mechanism (s) of kaempferol, a phytoestrogen, on the regulation of apoptosis in diverse cancer cell models. Toxicological research. 2013;29:229-34.
43. Ren J, Lu Y, Qian Y, Chen B, Wu T, Ji G. Recent progress regarding kaempferol for the treatment of various diseases. Experimental and therapeutic medicine. 2019;18(4):2759-76.
44. Jia Z, Chen A, Wang C, He M, Xu J, Fu H, et al. Amelioration effects of Kaempferol on immune response following chronic intermittent cold-stress. Research in veterinary science. 2019;125:390-6.
45. Hasnat H, Shompa SA, Islam MM, Alam S, Richi FT, Emon NU, et al. Flavonoids: A treasure house of prospective pharmacological potentials. Heliyon. 2024;10(6).
46. Ishizaki A, Miura A, Kataoka H. Determination of Luteolin and Apigenin in Herbal Teas by Online In-Tube Solid-Phase Microextraction Coupled with LC–MS/MS. Foods. 2024;13(11):1687.
47. Albert NW, Lafferty DJ, Moss SM, Davies KM. Flavonoids–flowers, fruit, forage and the future. Journal of the Royal Society of New Zealand. 2023;53(3):304-31.
48. Martens S, Mithöfer A. Flavones and flavone synthases. Phytochemistry. 2005;66(20):2399-407.
49. Salehi B, Venditti A, Sharifi-Rad M, Kręgiel D, Sharifi-Rad J, Durazzo A, et al. The therapeutic potential of apigenin. International journal of molecular sciences. 2019;20(6):1305.
50. Taban K, İlhan M, Süntar I. Luteolin: Advances on resources, biosynthesis pathway, bioavailability, bioactivity, and pharmacology. Handbook of dietary flavonoids: Springer; 2023. p. 1-37.
51. Karaźniewicz-Łada M, Wójtowski JA, Główka F, Danków R, Pikul J, Gryszczyńska A, et al. Application of UPLC-MS/MS method for analysis of apigenin, apigenin 7-glucoside and chlorogenic acid in goat serum. Chromatographia. 2023;86(5):401-11.
52. Dramou P, Itatahine A, Fizir M, Ait Mehdi Y, Kutoka PT, He H. Preparation of novel molecularly imprinted magnetic graphene oxide and their application for quercetin determination. Journal of Chromatography B. 2019;1124:273-83.
53. De Stefano A, Caporali S, Di Daniele N, Rovella V, Cardillo C, Schinzari F, et al. Anti-inflammatory and

  DOI: https://doi.org/10.18502/aptj.v5i4.21771

proliferative properties of luteolin-7-O-glucoside. International journal of molecular sciences. 2021;22(3):1321.
54. Nawrot-Hadzik I, Matkowski A, Hadzik J, Dobrowolska-Czopor B, Olchowy C, Dominiak M, et al. Proanthocyanidins and flavan-3-ols in the prevention and treatment of periodontitis—Antibacterial effects. Nutrients. 2021;13(1):165.
55. Jin AL, Ozga JA, Kennedy JA, Koerner-Smith JL, Botar G, Reinecke DM. Developmental profile of anthocyanin, flavonol, and proanthocyanidin type, content, and localization in saskatoon fruits (Amelanchier alnifolia Nutt.). Journal of Agricultural and Food Chemistry. 2015;63(5):1601-14.
56. Tanaka T, Matsuo Y, Kouno I. Chemistry of secondary polyphenols produced during processing of tea and selected foods. International journal of molecular sciences. 2009;11(1):14-40.
57. Zeng Y, Zhao L, Wang K, Renard CM, Le Bourvellec C, Hu Z, et al. A-type proanthocyanidins: Sources, structure, bioactivity, processing, nutrition, and potential applications. Comprehensive reviews in food science and food safety. 2024;23(3):e13352.
58. Khoo HE, Azlan A, Tang ST, Lim SM. Anthocyanidins and anthocyanins: Colored pigments as food, pharmaceutical ingredients, and the potential health benefits. Food & nutrition research. 2017;61(1):1361779.
59. Li B, Wang L, Bai W, Chen W, Chen F, Shu C. Anthocyanins. Scope and progress on anthocyanins: Springer; 2021. p. 2-17.
60. Ma Z, Du B, Li J, Yang Y, Zhu F. An insight into anti-inflammatory activities and inflammation related diseases of anthocyanins: A review of both in vivo and in vitro investigations. International Journal of Molecular Sciences. 2021;22(20):11076.
61. Nandakumar V, Singh T, Katiyar SK. Multi-targeted prevention and therapy of cancer by proanthocyanidins. Cancer letters. 2008;269(2):378-87.
62. Li W, Zhang J, Zhang L. Assessment of the formation of A-type proanthocyanidin by model reaction to blueberry extract and epicatechin. Lwt. 2020;134:110169.
63. Jakubczyk K, Melkis K, Maciejewska-Markiewicz D, Muzykiewicz-Szymańska A, Nowak A, Skonieczna-Żydecka K. Innovative approaches to enhancing kombucha through flavour additives: a phytochemical and antioxidant analysis. Food & Function. 2025.
64. Liu S, Pi J, Zhang Q. Signal amplification in the KEAP1-NRF2-ARE antioxidant response pathway. Redox biology. 2022;54:102389.
65. Ye T, Zhen J, Du Y, Zhou JK, Peng A, Vaziri ND, et al. Green tea polyphenol (−)-epigallocatechin-3-gallate restores Nrf2 activity and ameliorates crescentic glomerulonephritis. PloS one. 2015;10(3):e0119543.
66. Ciavarella C, Motta I, Valente S, Pasquinelli G. Pharmacological (or synthetic) and nutritional agonists of PPAR-γ as candidates for cytokine storm modulation in COVID-19 disease. Molecules. 2020;25(9):2076.
67. Yang Y, Liu Y, Wang Y, Chao Y, Zhang J, Jia Y, et al. Regulation of SIRT1 and its roles in inflammation. Frontiers in immunology. 2022;13:831168.
68. Xie L-W, Cai S, Zhao T-S, Li M, Tian Y. Green tea derivative (−)-epigallocatechin-3-gallate (EGCG) confers protection against ionizing radiation-induced intestinal epithelial cell death both in vitro and in vivo. Free Radical Biology and Medicine. 2020;161:175-86.
69. Zhang W, Feng J, Ni Y, Li G, Wang Y, Cao Y, et al. The role of SLC7A11 in diabetic wound healing: novel insights and new therapeutic strategies. Frontiers in Immunology. 2024;15:1467531.
70. Mancuso C. Biliverdin as a disease-modifying agent: An integrated viewpoint. Free Radical Biology and Medicine. 2023;207:133-43.
71. Venkatakrishnan K, Chiu H-F, Cheng J-C, Chang Y-H, Lu Y-Y, Han Y-C, et al. Comparative studies on the hypolipidemic, antioxidant and hepatoprotective activities of catechin-enriched green and oolong tea in a double-blind clinical trial. Food & function. 2018;9(2):1205-13.
72. Hu W, Wang H, Shu Q, Chen M, Xie L. Green tea polyphenols modulated cerebral SOD expression and endoplasmic reticulum stress in cardiac arrest/cardiopulmonary resuscitation rats. BioMed Research International. 2020;2020(1):5080832.
73. Anbari K, Hasanvand A, Andevari AN, Abbaszadeh S. Concise overview: A review on natural antioxidants and important herbal plants on gastrointestinal System. Research Journal of Pharmacy and Technology. 2019;12(2):841-7.
74. Abbaszadeh S, Andevari A, Koohpayeh A, Naghdi N, Alizadeh M, Beyranvand F, et al. Folklore medicinal plants used in liver disease: A review. International Journal of Green Pharmacy. 2018;12(3):S463-S72.
75. Suraphad P, Suklaew PO, Ngamukote S, Adisakwattana S, Mäkynen K. The effect of isomaltulose together with green tea on glycemic response and antioxidant capacity: A single-blind, crossover study in healthy subjects. Nutrients. 2017;9(5):464.
76. Lee M-S, Lee J, Kim Y. Green tea extract containing piper retrofractum fruit ameliorates DSS-induced colitis via modulating MicroRNA-21 expression and NF-κB activity. Nutrients. 2022;14(13):2684.
77.Andevari AN, Qujeq D. Anti-inflammatory Mechanisms Beyond Cholesterol-Lowering Capabilities of Statins: Evidence from in vitro and in vivo Studies. Advances in Pharmacology and Therapeutics Journal. 2025.
78. Mostafa HE-S, Allithy ANA, Abdellatif NA, Anani M, Fareed SA, El-Shafei DA, et al. Amelioration of pulmonary aflatoxicosis by green tea extract: An in vivo study. Toxicon. 2021;189:48-55.
79. Chung M-Y, Mah E, Masterjohn C, Noh SK, Park HJ, Clark RM, et al. Green tea lowers hepatic COX-2 and prostaglandin E2 in rats with dietary fat-induced nonalcoholic steatohepatitis. Journal of medicinal food. 2015;18(6):648-55.