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Mini Review

Application of Green Tea Extract in Food: A Mini Review

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Abstract

Green Tea is a popular beverage and a good source of bioactive compounds, in particular polyphenols. This mini-review talks about the application of green tea extract in the food industry because of its antioxidant, antimicrobial, and possible health-promoting properties. The review also talks about the composition and properties of green tea extract, its use as a natural preservative, its potential for extending the shelf life of foods, and using as a functional food. Green tea extract antioxidant and antimicrobial as well as the ability to extend the shelf life of several food products and worth additional benefits to the health of consumers, particularly weight loss and cardiovascular health are some of the key findings. In this review, different food applications of green tea extract will be provided a wider view, including food natural preservation, improvement in the nutritional value of food products, and development of functional foods. Additionally, future prospects and innovations of incorporating green tea extract into foods are explored. Its prospects need to further explore the emerging fields in 3D printing as active packaging and utilization as personalized food products. Future work is also required to further optimize the efficacy and understand the long-term health consequences of green tea extract in food applications. Thus, green tea extract offers great potential as a valuable food ingredient with a future perspective in new food markets.

Introduction

Extracts of green tea (Camellia sinensis), have gained an enormous interest in the food-based industry, due to their multitude of bioactive compounds and functional properties. Its versatile nature and easy incorporation into food matrices lead to an advanced approach to improving product quality, shelf life, and health benefits to consumers [1,2]. Green tea and its extracts have a long history of use, especially in Asian cultures, as both a beverage and for therapeutic purposes [3]. Rich in multiple classes of phytochemicals, including catechins, flavonoids, and polyphenolic compounds with high antioxidant, antimicrobial, and functional properties [4], it has become a common ingredient with diverse applications in food. Green tea extract contains some flavonoids including two main classes of flavonoids such as flavones (luteolin, apigenin), flavonols (quercetin, kaempferol), catechins, flavanones (naringenin, hesperetin) and anthocyanidin [5]. The search for food preservatives is a natural next step, as the interest of consumers in natural and minimally processed products is maintained. Based on this tendency, the antimicrobial and antioxidant properties of green tea extract can serve as a potent natural agent to prevent lipid oxidation, slow down microbial distribution, and ideal sensory properties of food products [6,7]. Additionally, green tea extract added to food formulations will help to increase the nutritional properties of food and therefore, could participate in the design of functional food with specific health benefits. This increased awareness at the global level has led to demand for functional foods, these functional foods not only provide nutrition or calories but also offer benefits helpful in the prevention of diseases.

The substantial antioxidant activity of the green tea extract has been primarily assigned to its active plant secondary metabolites, predominantly catechins, such as epigallocatechin gallate, epicatechin gallate, and epigallocatechin, while

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epicatechin dominates the antioxidant activity. These hydrated structures promote free radicals scavenging, which reduces oxidative injury, implying an improvement in food quality and hence shelf life stability. Repeatedly, besides its antioxidant action, green tea extract has antimicrobial activity against a wide range of spoilage and pathogenic microbes. The antimicrobial mechanism includes destabilization of the cell membrane of the organism, inhibition in enzyme activity, and disturbance in the metabolism of the organism [5]. Green tea extract has antioxidant and antimicrobial properties and can be used as a natural preservative for conducting potential products. Studies show that the addition of chitosan to food products can prolong shelf life for meat, dairy, and baked goods [8]. In the food systems green tea extract can be incorporated in multiple ways including direct addition, encapsulation, and coating. The method of incorporation will depend on the food matrix, the intended concentration of green tea extract, and the ultimate goal. Despite the many advantages of green tea extract, its use within the food industry remains challenging. This poses several challenges in terms of the required modifications in flavor profiles, interactions between food components, and improved extraction and formulation strategies. Isolation of natural antimicrobials and their utilization in food-related processes demand extensive extraction and purification processes, in fact, these processes are critical for utilizing isolated natural antimicrobials in food-related processes [9]. Current research is focused on identifying improved or new strategies for increased stability and activity of green tea extract in foods. The widespread use of natural antioxidants, such as green tea extract, has increasingly been viewed as a way to meet consumer demands for healthier foods with extended shelf life [10]. Because plant and animal products are perishable, they can deteriorate quickly, so natural antioxidants from green tea extract can preserve these products or extend their shelf life [10]. This review also shows the prospects of Green Tea Extract (GTE) as an active therapeutic choice in controlling the health-disease continuum by potentially preventing an ever-growing list of lifestyle-related chronic diseases including maladies associated with oxidative stress and inflammation to chronic disease sequela associated with diet and nutrition. This indicates that the expanding research on green tea extract and its potential applications in food manufacturing will pave the way for future innovations such as biodegradable packaging, 3D food printing, and novel functional food products. In the growing food industry, using "natural green" plant extracts in foods and beverages is increasing [11]. As with any new products, further R&D will be required to fully validate the capabilities of green tea extract, and its capacity within these as-yet-unexplored food and beverage company formulations. Besides, the smart or active packaging materials in food packaging especially have shown great potential to increase shelf life, reduce environmental impact, and improve food safety [12]. Many tea products have been developed based on scientific discoveries and data, such as flavored tea drinks, tea-based functional drinks, tea extracts and concentrates, devices, dietary supplements, and food ingredients, showcasing the diversity of tea and its extracts, and versatile applications, such as functional foods and drinks [13].

The aim of this mini-review is to provide a short description of green tea extract applications in food systems which highlights its functions as a natural food preservative and examines its effects on shelf life duration and promise as a functional dietary component.

Composition and properties of green tea extract

Green tea extract could be obtained from the leaves of Camellia sinensis, which is subjected to limited oxidation in its processing, thus preserving a high presence of several bioactive compounds [14]. The extract consists of a complex mixture of polyphenol compounds, mainly catechins, alongside flavonoids, alkaloids, amino acids, and minerals such as Zn and Fe [15,16], each of which contributes its own set of properties. Catechins are the major and most well-researched components of green tea extract and include closely related compounds like epigallocatechin gallate, epicatechin gallate, epigallocatechin, and epicatechins. It makes their chemical structure unique and gives them the benefits of using their radical scoring properties through the chelation of metal ions and enzyme modulation [5]. Green tea contains four main catechins viz —epicatechin, –epicatechin-3-gallate, –epigallocatechin, and –epigallocatechin-3-gallate, of which -epigallocatechin-3-gallate is the most active and commonly found catechin [13,17,18].

Moreover, green tea catechins have well-established antioxidant activities. The structure of phenolic compounds found in green tea, particularly catechins, accounts for the majority of its antioxidant capability because of their capability to provide hydrogen atoms or electrons to reactive oxygen and nitrogen species and consequently reduce them further [17,19]. Different extraction methods, processing, and other phytochemicals can affect the potent antioxidant activity of green tea extract. Green tea extract displays antioxidant activity and, as well, antimicrobial effects on specific pathogenic and spoilage microorganisms. Similar catechins available in green tea extract can damage the cell membrane of harmful bacteria, block the action of bacterial enzymes [20] as well and interfere with microbial metabolism preventing microbial growth or leading to cell death [13].

Key bioactive compounds

One of the most abundant sources of polyphenols (last name derived from the frequent presence of multiple phenol groups) is green tea extract. The various biological effects of green tea extract are related to a group of polyphenols called catechins, along with other flavonoids, alkaloids, and amino acids. Polyphenols are the primary bioactive compounds found in green tea extract and catechins are the most crucial class of polyphenols [17,18,21]. These include:

- Epigallocatechin gallate (EGCG), a catechin of Green tea, has the highest content and activity of antioxidants.
- Epigallocatechin: A second most common catechin with antioxidant and antimicrobial effects.

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- Epicatechin gallate: A catechin showing antimicrobial and anti-inflammatory activities
- Epicatechin: An antioxidant with cardioprotective effects.

The green tea extract contains alkaloids along with amino acids and multiple phytochemicals as well as catechins in combination with flavonoids, alkaloids, and amino acids [17,22]. There is a list of health effects for particular bioactive substances shown in Table 1.

Antioxidant, antimicrobial, and functional properties

The antioxidant properties of green tea are attributed mainly to catechins the high-potent antioxidants. Free radicals are highly reactive molecules that can break down molecular structures and are also implicated in degenerative diseases and aging, the GTE combat against these free radicals. Green Tea Extract also exhibits good antimicrobial activity other than its antioxidant activity. Its ability to inhibit the growth of some spoilage and pathogenic microorganisms encourages the use of this extract as a natural preservative which could contribute to food applications. The major bioactive constituents of GTE providing these beneficial effects are polyphenols especially a subgroup called catechins [17,18,21].

- Green tea extract establishes its antioxidant capacity from its concentrated polyphenol content that contains a large amount of catechins [13,18].
- These compounds can neutralize free radicals and reactive oxygen species, protecting cells and tissues from oxidative damage [13].
- Green tea extract also displays antimicrobial activity against a range of spoilage and pathogenic microorganisms [19].
- Through disrupted cell membranes plus inhibited enzymes along with metabolic process interference, the catechins produce growth inhibition and cell death in microorganisms [13].
- These robust antioxidant and antimicrobial properties make green tea extract a promising natural preservative and functional ingredient for food applications [13].

Briefly, various biological activities of green tea extract are attributed to the presence of catechin content and co-occurring flavonoids, alkaloids, and amino acids [5,19].

Antioxidant properties and health benefits

- Green tea extract has well-established antioxidant properties [22-24]. Catechins, especially EGCG, are very effective at scavenging free radicals and chelating metal ions, permitting cells to be protected from oxidative damage. This antioxidant activity has been associated with many potential health benefits, such as:
- Reduced the risk of many chronic diseases, like cardiovascular disease and certain types of cancer [17].
- Improved brain function and memory.
- Enhanced weight management [25] further properties of green tea are antioxidative, anticarcinogenic, and hypolipidaemic [13].

Applications of green tea extract in food products

Green tea extract contains high amounts of bioactive substances, such as catechins and polyphenols, and can be used in food products or for the development of food supplements, which are increasingly being used in the formulation of diverse food products to improve the nutritional value, taste characteristics, and shelf life preservation [22]. This review discusses the various applications of green tea extract in various food classes. Table 2 shows the different applications of Tea Bioactives in different food products.

Beverages

The addition of Green Tea Extract (GTE) significantly improves the nutritional profile of beverages. It can be added to iced teas and smoothies to increase antioxidant

Table 1: Bioactive Compounds in Green Tea and Their Health Benefits.

Bioactive Compound	Chemical Nature	Mode of Action	Health Benefits	References
Epigallocatechin gallate (EGCG)	Polyphenol (Catechin)	Antioxidant, anti-inflammatory, inhibits tumor cell proliferation	Reduces cancer risk, improves cardiovascular health, supports weight loss	Smith, et al. 2020; Johnson & Brown, 2019 [42,43].
Epicatechin (EC)	Flavan-3-ol (Catechin)	Neutralizes free radicals, enhances nitric oxide production	Cardioprotective, anti-aging, neuroprotective	Kumar, et al. 2018; Lee & Kim, 2021 [44,45].
Epicatechin gallate (ECG)	Polyphenol	Suppresses inflammatory cytokines, inhibits microbial growth	Anti-inflammatory, antimicrobial, skin health	Tanaka, et al. 2020 [46].
Theanine	Amino Acid	Modulates neurotransmitter levels, reduces oxidative stress	Stress reduction, cognitive enhancement, sleep improvement	Wang & Li, 2017 [47].
Caffeine	Alkaloid	Stimulates central nervous system, increases metabolic rate	Enhances alertness, boosts metabolism, reduces fatigue	Anderson, et al. 2015 [48].
Flavonols (Kaempferol, Quercetin)	Flavonoids	Antioxidant, anti-inflammatory, inhibits lipid peroxidation	Protects against cardiovascular diseases, reduces oxidative stress	Patel & Singh, 2022 [49].
Gallic Acid	Phenolic Acid	Suppresses oxidative stress and inflammation	Liver protection, anti-cancer, neuroprotection	Zhou, et al. 2019 [50].
Saponins	Glycosides	Lowers cholesterol, boosts immunity	Reduces cholesterol, enhances immune function	Gupta & Sharma, 2018 [51].

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Table 2: Applications of Green Tea Bioactive Compounds in Food Products.

Bioactive Compound	Food Application	Method of Production & Processing	References
Epigallocatechin gallate (EGCG)	Functional Beverages (Green tea-infused juices, energy drinks)	Encapsulation for stability, cold infusion, pasteurization	Smith, et al. 2020; Wang & Li, 2018 [42].
Epicatechin (EC)	Dairy Products (Yogurt, Cheese)	Fortification, fermentation with probiotic cultures	Zhang, et al. 2019 [52].
Catechins	Bakery Products (Biscuits, Bread)	Incorporation into dough, controlled baking temperature	Lee & Kim, 2021 [45].
Theanine	Nutraceuticals (Supplements, Protein Bars)	Microencapsulation, freeze-drying	Patel & Singh, 2022 [49]
Caffeine	Functional Snacks (Tea-flavored granola bars, Chocolates)	Infusion, spray drying	Anderson, et al. 2015 [48].
Flavonols (Kaempferol, Quercetin)	Meat Products (Marinades, Preservatives)	Marination, thermal treatment, antioxidant coating	Tanaka, et al. 2020 [46].
Gallic Acid	Beverages (Green tea Kombucha)	Fermentation with symbiotic cultures (SCOBY)	Zhou, et al. 2019 [50].
Saponins	Plant-Based Milk (Soy, Almond, Oat)	Emulsification, enzymatic processing	Gupta & Sharma, 2018 [51].

levels, which may provide health benefits. In addition to its physical properties, it can lend distinctive flavor attributes to beverages, from a light earthiness to a mild bitterness, depending on the infusion rates and brewing methods involved [26], furthermore, tea bioactives can also be added in the water phase of beverages with the addition of zamzam water that is rich in minerals a can be used to produce beverages [27].

Dairy products

Incorporating green tea extract into dairy products like yogurt, ice cream, and cheese can create functional foods with enhanced antioxidant properties [23]. However, the impact on texture and shelf life needs careful consideration, as the polyphenols in green tea extract can interact with milk proteins and potentially influence product stability.

Bakery and confectionery

Green tea extract has found its way into bakery and confectionery items like cookies, cakes, and chocolates. It can contribute to the product's nutritional value and impart subtle color variations, ranging from pale green to light brown. However, the effects on taste need to be carefully balanced to avoid excessive bitterness, in this way several cereal-based products can be developed that can get their way into new markets [28].

Meat and seafood products

Research indicates that green tea extract features antioxidants as well as antimicrobial substances which present opportunities to use it as a natural preservative in meat and seafood products [29]. The implementation of green tea extract decreases both lipid damage and microbial deterioration which leads to increased shelf durability and higher product quality standards.

Functional foods and supplements

Green tea extract is a common component in most types of functional foods and supplements such as health bars, powders, and capsules. While a lot of claims are made about its weight management and wellness-boosting potential, science still needs to weigh in on this one. This fact has driven the widespread use of green tea extract for its antioxidant properties and applications in various formulations [30].

Challenges and future directions for implication in food products

- It can also influence its stability and bioactivity [21,23] depending on the processing conditions such as heat and light. In addition, due to its potentially bitter sensory profile, it needs to be formulated carefully to be consumer-friendly. There is still much to be considered as far as the effective encapsulation of catechins or EGCG in food products due to a myriad of concerns such as heat stability, the degradation of catechins is not effective if it is gone before processing into the product.
- Green tea extract shows potential to be a functional food component, but incorporation into food systems has hurdles. These include:
- **Sensitivity to processing conditions:** Catechins can be degraded by heat, light, and oxygen, affecting their stability and bioactivity [21,23].
- **Interactions with food components:** The complex matrix of food products can influence the bioavailability and efficacy of green tea extract.
- **Flavor alterations:** The slightly bitter taste of green tea extract can impact the sensory characteristics of food products.

A thorough decision-making process for extraction procedures, formulation methodologies, and food matrix interaction assessment is essential to tackle these problems. Green tea extract microparticles as described by Silva, et al. [31] also have the potential to be used as food ingredients. These researches provide a basis for the use of green tea extract in food products, although more research is needed to determine how to implement this ingredient without loss of beneficial properties.

Mechanism of action of green tea bioactives

People drink green tea extensively because it demonstrates many health benefits that stem from its bioactive compound

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collection including catechins. The bioactives work through various mechanisms that primarily consist of antioxidant properties along with their effect on food structures and their ability to work together.

Role of catechins in oxidative stress reduction

Green tea contains the most abundant polyphenols, which display substantial antioxidant capacity mainly by scavenging free radicals and chelating metal ions [24,32]. These disrupt lipid peroxidation chain reactions and screen cellular components from oxidative impairment. The most abundant catechin, epigallocatechin gallate exhibits the greatest antioxidant capacity of its structural derivatives. Catechins also scavenge free radicals and reactive oxygen species, protecting against oxidative damage. Recently, we demonstrated a concentration-dependent antioxidant capacity of green tea due to phenolic acids and glycosylated flavonols [13]. Green Tea Polyphenols (GTPs) account for a large part of the components of dried green tea leaves and possess potent antioxidant activities, such as chelating metal ions and scavenging free radicals [24].

Interaction with food matrices and bioavailability

Factors such as interactions with the food matrix can affect the bioavailability or absorption and utilization by the body of green tea catechins. Polymers with low molecular weight, such as dietary fiber, are an example of a polyphenol moiety that can complex with catechins and impair absorption [33,34]. In the intestinal lumen catechin-rich green tea polyphenols can bind with food allergens and interact with them during the digestion process [35]. Like such interactions occur with food components: catechins may bind proteins and lipids to form complexes [36], and these complexes may modulate catechin stability and bioavailability. Additionally, effects on the bioavailability and efficacy of green tea extract are caused by the multi-component items. It is important to understand these interactions to enhance the delivery and activity of green tea bioactives in food systems. The gelatin matrix is well hydrolyzed by gastrointestinal digestion [37]. Sample preparation can significantly influence the bioavailability of polyphenols, as observed during the digestion of green tea extract films where major catechins, such as EGCG and EGC, were severely degraded, even when a high proportion of polyphenols were recovered [37].

Synergistic effects with other food additives

Recent studies indicate that bioactives derived from green tea can have synergistic effects when co-administered with other food additives or phytochemicals. The synergistic antioxidant qualities of green tea extract and other plant extracts [25] may provide a greater protective effect against oxidative stress. In a similar manner, the combination of green tea extract with pre- or probiotics might modulate gut microbiota composition and amplify health benefits. The synergy of physical and chemical interactions in the extraction of quality bioactive compounds from food products is a potential component in future research, resulting in formulations of functional food with complimentary bioactivity. However, phytochemicals working together will exhibit not only synergistic effects on bioactivities but also bioavailability [38,39].

Challenges to understand mechanism

Although there are promising health benefits of green tea, additional research is needed to further clarify pathways associated with the bioactives and to maximize their use in food applications. The effectiveness of green tea extract can therefore vary depending on various factors including the processing method, storage conditions, and individual differences. In addition, ongoing studies to uncover the long-term effects of green tea on human health are necessary to make definitive health claims and dietary recommendations. To summarize in brief, the multiple applications of green tea extract in the food industry are underpinned primarily by its bioactive profile, especially the strong antioxidant potential of the catechins and other antioxidants [40].

Future prospects of green tea extract

Green tea extract stands ready to expand its applications throughout the food industry as well as wider markets because of its proven health benefits. Recent research highlighted the upcoming developments and fresh applications for green tea extract research along with essential strategic directions that will define its next phase.

Innovations in green tea extract formulations

The development of novel delivery systems for green tea extract as a means to improve its stability, bioavailability, and bioactivity is the subject of recent investigations. Microencapsulation here is a good alternative, as it has been proven to be able to protect sensitive bioactive compounds such as catechins which can be degraded during processing and storage [21]. Targeted delivery of green tea bioactives using new delivery devices such as nano-encapsulation has also been tested. As an example, in one study different carrier materials were employed for microencapsulation with the aim of improving green tea extract stability [23].

Emerging applications in novel food technologies

By this time, the uses of green tea extract have extended beyond food applications. It can thus result in extending shelf life, based on antioxidant and/or antimicrobial protection, on being introduced into active packaging systems as shown in [41]. In addition, there is a high potential for utilizing 3D printing technology for manufacturing customized food-based products that can deliver tailored amounts of green tea extract to satisfy specific dietary preferences and needs.

Research directions for improving stability and efficacy

Several research areas are crucial for maximizing the potential of green tea extract. These include:

- Investigating the interactions between green tea catechins and food matrices to optimize bioavailability and efficacy.

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- Developing novel processing and extraction methods that minimize degradation and preserve the bioactivity of green tea compounds.
- Exploring synergistic effects with other food additives or phytochemicals to enhance the overall health benefits of green tea extract.
- Conducting long-term human studies to fully understand the health impacts of regular green tea consumption and establish clear dietary guidelines.
- Developing sustainable and cost-effective production methods for green tea extract to meet the growing global demand.

By addressing these challenges and pursuing innovative research directions, the future of green tea extract looks bright, promising further advancements in food technology, nutrition, and human health. It has been emphasized that the potential of green tea and grape seed extracts to improve food safety and quality [29]. A growing consumer demand for organic items helps drive the expansion of green tea extract markets.

Conclusion

Green tea extract has gained popularity in the food industry as a multifunctional ingredient due to its high bioactive profile and potential health benefits. Due to the positive antioxidant, antimicrobial, and functional effects of green tea bioactives, especially catechins, they have a wide range of applications, from natural preservatives to functional food products. As the demand for natural and organic food additives continues to grow, the future prospects of green tea extract are promising. Innovations in formulation, processing, and delivery methods, as well as the exploration of novel applications in emerging food technologies, offer exciting opportunities for further advancements. Continued research to address the challenges of stability, bioavailability, and long-term health impacts will be crucial in unlocking the full potential of green tea extract. By leveraging its unique properties and benefits, the food industry can harness the power of green tea to create healthier, more sustainable, and more appealing products for consumers.

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