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Nutraceuticals of Tea (*Camellia sinensis*) for Human Health

Kula Kamal Senapati

Abstract

This book chapter describes about the phytochemicals in tea which are significantly useful in preparing nutraceutical products. The polyphenols along with other bioactive compounds present in tea have many pharmacological properties which attribute to the development of various food products where tea constitutes as an active ingredient. This chapter also discusses the potential uses of tea and their bioactive constituents in treatment and prevention of diseases in human which infer the potentiality of developing and popularizing nutraceuticals of tea.

Keywords: nutraceuticals, phytochemicals, catechins, polyphenols, antioxidant, therapeutic properties

1. Introduction

Nutraceuticals are promising class of natural products that encompasses the combined terms “nutrition” and pharmaceuticals” which incorporates the characteristics of both nutritional and pharmaceutical and thus exhibit several health benefits. The food or food products having nutraceuticals properties can be used as medicine in addition to nutritional values and have been used to support proper functioning of the body, treat and prevention of diseases, and increase the life expectancy of human beings [1–4]. Currently nutraceuticals have been explored in several diseases in prevention and cure such cancer, diabetics, cardiovascular, diseases etc.

Tea (*Camellia sinensis* L.) is one of the most popular and widely consumed beverage world-wide. Commercially tea is mostly available in three varieties viz. black (red tea), green and oolong (yellow tea) tea which differ in their physical and chemical characteristics arising from their different manufacturing process. Black tea consumption is highest in western countries which accounts for around 78% of worldwide consumption. The green tea is mostly consumed in Japan and China and accounts for 20% whereas oolong tea is consumed 2% only. Black tea is widely consumed in India and India is one of the largest tea producers in the world and it occupies about 70% of domestic consumption of the total tea production in the country.

The black tea is fully fermented and known for its characteristic brown liquor whereas green tea is unfermented and known for its light greenish yellow liquor. The oolong is semi-fermented and liquor characteristic lies in between the black and green tea. All the three types differ in their taste and flavor and accordingly their chemical profiling also varies.

Tea contains a variety of bioactive compounds such as polyphenols, polysaccharides, vitamins, amino acids etc. having medicinal properties which can be used as food additives in preparation of nutraceuticals [5–8]. Tea is mainly chemically

characterized by their polyphenolic compounds and their polymerized products along other bioactive compounds in minor quantities.

The polyphenols which are produced by the plant as secondary metabolites are the major constituents in tea. Other secondary metabolites present in tea are phenolic acids, purine alkaloids, tannins, flavonols and their glycosides. The polyphenols in tea are catechins (C) and their conjugated products viz. epigallocatechingallate (EGCG), epigallocatechins (EGC), epicatechingallate (ECG) and epicatechins (EC) and present in higher quantities in green tea. The other two class of polyphenols found in black tea are theaflavins (TFs) and thearubigins (TRs) which are present in significant quantities in black tea and less quantity in oolong tea. The catechin polyphenols in tea are health-promising due to their antioxidant properties and are very useful in preparation of nutraceuticals from tea [9–14].

In addition, tea contains other beneficiary substances to our health such as fluoride, caffeine, minerals, trace elements e.g. manganese, chromium etc. which also added nutraceutical value of tea and its food additive which also add nutraceutical value of tea or its food additives [15]. Looking to the therapeutic properties of these phytochemicals in tea, different food products have been prepared with tea or its extract which are rich in these active ingredients. These products include ready to drink beverages, instant tea, confections, cereal bars, pet foods, candy etc. So, there is a huge possibility of using bioactive constituents in tea as food additive which provide medical or health benefit in prevention and treatment of disease and thus tea can be potentially used for the development of nutraceuticals.

In this chapter, various bioactive compounds in tea (green, black, oolong and white teas) and their properties which can be employed as nutraceuticals in the form of food or part of food products has been discussed. Further, we have addressed the role of these tea nutraceuticals and their application in prevention and treatment of various diseases.

2. Phytochemicals in tea

There are a variety of chemicals in tea which are therapeutically important and they also vary in different types of commercially available teas viz. green, black and oolong tea. The chemical characteristics of tea are also varying with variation of plant species, geographic locations, climatic condition, horticultural practices as well as plucking parameters of the tea leaves [16, 17]. Polyphenols comprises of a large group of phytochemicals, the major polyphenolic constituents in tea which account for maximum 30% total dry weight of tea leaves are the flavanols, also known as catechins. Of these polyphenolic catechins, eight catechins are appeared in significant quantities which include (+)-catechin, (-)-epicatechin, (-)-gallocatechin, (-)-epigallocatechin, (-)-catechin gallate, (-)-epicatechin gallate, (-)-gallocatechin gallate, (-)-epigallocatechin gallate.

Tea beverage is chemically characterized mainly by polyphenolic constituents (mostly flavonoids) and their polymerized compounds. Four polyphenolic catechins which are in large quantities in green tea are (-)-epigallocatechin-3-gallate (EGCG), (-)-epigallocatechin (EGC), (-)-epicatechin-3-gallate (ECG), and (-)-epicatechin (EC) (**Table 1**). These catechins are highest in green tea (30-40% in dry weight) and least in black tea (10% in dry weight) in which catechins undergo condensation and polymerization into other phenolic compounds theaflavins and thearubigins during enzymatic oxidation of catechins during fermentation process of black tea manufacturing [18, 19]. The oolong tea has substantial amount of catechins with other oligomeric polyphenols [20].

Apart from polyphenols, there are a number of phytochemicals which are significantly important in medicinal use. These phytochemicals are oxyaromatic acids (gallic, caffeic, quinic, chlorogenic and *n*-coumaric acids, flavonols (Quercetin, kaempferol, myricetin), pigments (carotenoids, chlorophyll), alkaloids (caffeine, theophylline, theobromine), amino acids, lipids, polysaccharides, vitamins, lignans and saponins which also attribute to the widely explored medicinal value of tea [21–23].

The major polyphenolic compounds in different types of tea which differ due to their manufacturing processes are highlighted in **Table 2**. The white tea is least processed of all the tea types and thus it intakes maximum polyphenols whereas the black tea is fully fermented through enzyme mediated oxidation of polyphenols into oligomeric and polymeric flavanols (theaflavins, thearubigins and other oligomers) with characteristics flavor and color. In black tea processing, tea leaves (standard plucking two and a bud) are crushed to undergo enzymatic oxidation (polyphenol oxidase) and subsequent condensation of tea catechins in to the formation of theaflavins (TFs) (oligomeric) and thearubigins (TRs) (polymeric) products. This fermentation process is being limited in case of oolong tea. In green tea this enzymatic oxidation is prevented by steaming (or pan-frying) of fresh tea leaves. Therefore, the green tea infusion contains major quantities of polyphenol catechins (30-40% dry weight of four major catechins viz. (–)-Epigallocatechin-3-gallate (EGCG), (–)-epigallocatechin (EGC), (–)-epicatechin-3-gallate (ECG), and (–)-epicatechin (EC)). Since all major polyphenols are oxidized in black tea, it contains less amount of catechins (3-10%) along with theaflavins (2-6%), thearubigins (>20%) and gallic acids in significant quantities. The oolong contains green tea catechins and less amount of black tea theaflavins and thearubigins due to its partial fermentation process.

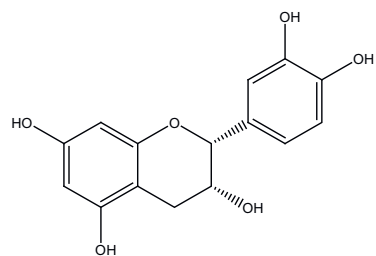
In water extract, all types of tea also contain caffeine in quantity of 2-5%.

3. Nutraceutical properties of tea phytochemicals

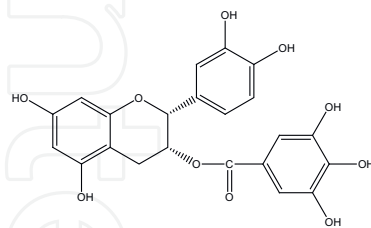
The therapeutic properties of tea extract are associated with the polyphenolic contents which have the highest antioxidant capacity amongst other bio-active compounds. The green tea extract has higher antioxidant capacity than that of black tea or oolong tea due the higher quantities of catechin polyphenols viz. EGCG, EGC, ECG, EC [24]. The EGCG has the highest anti-oxidant activity followed by ECG and EC whereas EGC has the lowest activity [25]. The EGCG can inhibit the production of hydrogen peroxide and superoxide radicals by tumor promoter-activated neutrophils in our body. Among the three major types of tea (green, black, oolong), green tea has the highest antioxidant activity and black tea has the lowest one. The antioxidant activity of green tea and its polyphenols have been studied in a number of *in vitro* and *in vivo* experiments and in most of these researches EGCG (major constituent in green tea) is well documented and significantly important. These nonnutritive phytochemicals are potential nutraceuticals and their easy bioavailability makes their useful consumption in prevention of diseases. The higher antioxidant properties of black tea are associated with minor quantities of catechins and other oligomeric polyphenols. In addition to different types of tea which differ in chemical contents, the health-promising factors of tea also varies with cultivars to cultivars and their geographic locations. Therefore, it is very important to determine the bioactivity of tea of different varieties in obtaining nutraceutical values.

Recent researches have gained attention in therapeutic use of tea polyphenols of green and black tea in diseases associated to metabolic syndromes. Green tea

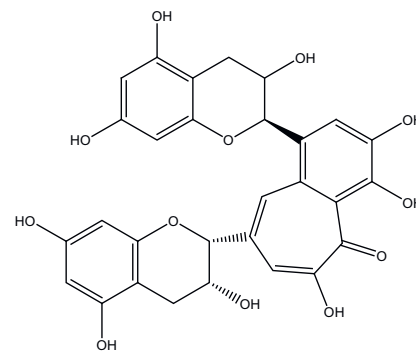
Tea polyphenols in green and black tea



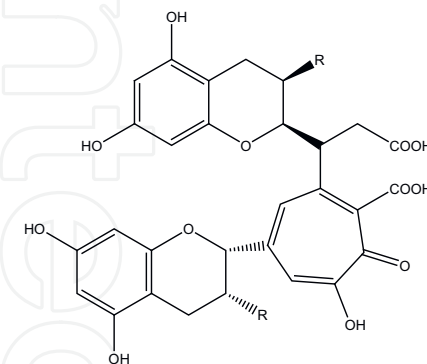
(-)-Epicatechin



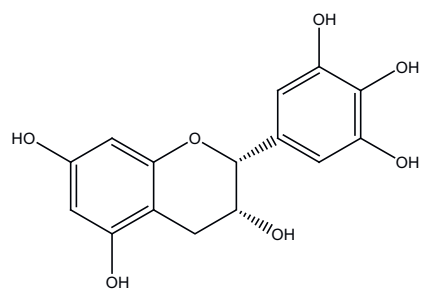
(-)-Epicatechin-3-gallate



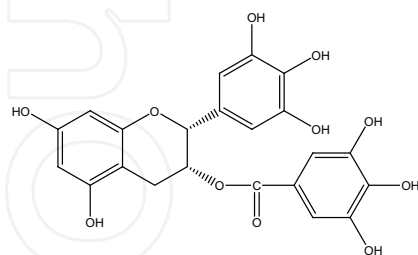
Theaflavin



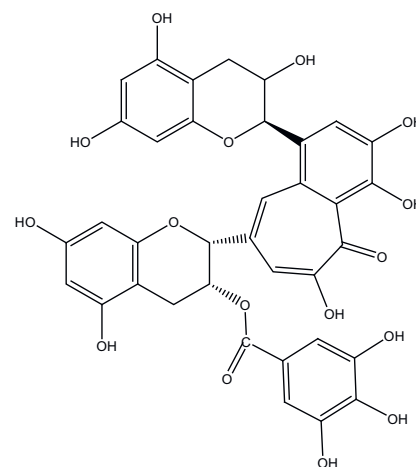
**Thearubigins
(R= Gallate or other group)**



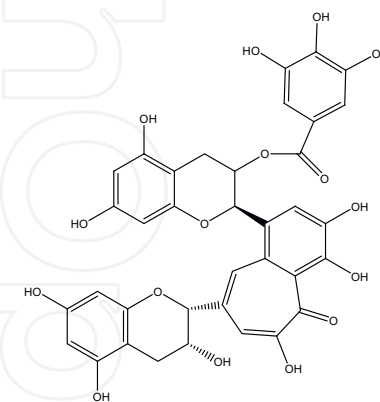
(-)-Epigallocatechin



(-)-Epigallocatechin-3-gallate

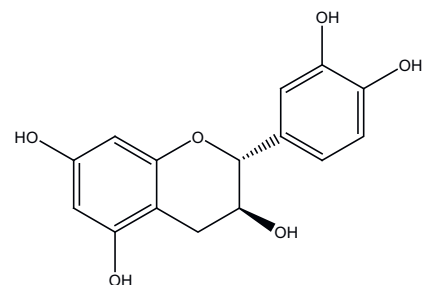


Theaflavin-3-gallate

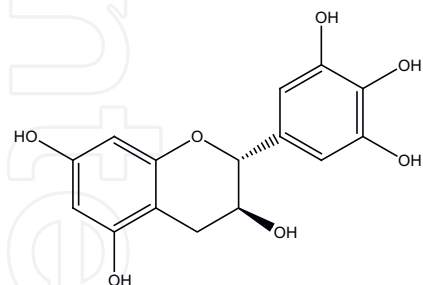


Theaflavin-3'-gallate

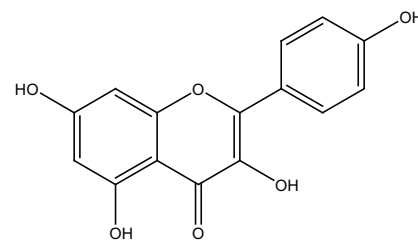
Tea polyphenols in green and black tea



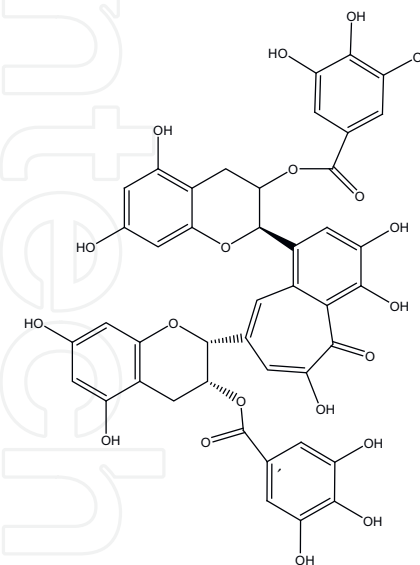
(+)-Catechin



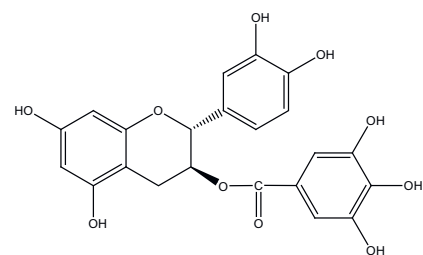
(+)-Gallocatechin



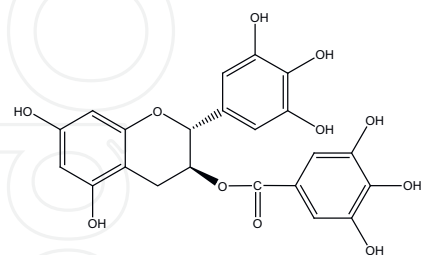
Kaempferol



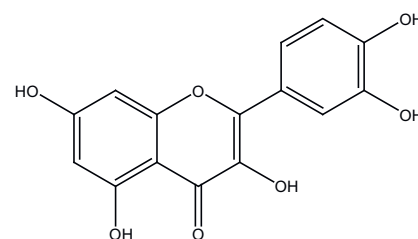
Theaflavin-3, 3'-gallate



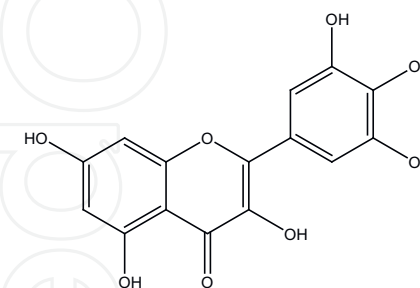
(+)-Catechin-3-gallate



(+)-Gallocatechin-3-gallate



Quercetin



Myricetin

Table 1.
 Chemical structures of major polyphenols (flavonoids: flavanols and flavonols) in Green tea and Black tea.

Type of tea	Processing technique	Physio-chemical changes	Major polyphenols
Green	Withering, steaming (Japan) or roasting (China), rolling and drying	Deactivation of enzymes to prevent fermentation (oxidation of polyphenol)	Catechins (Flavan-3-ols)
Black (red tea)	Withering, crushing, rolling, drying	Fermented (in presence of enzymes (polyphenol oxidase and peroxidase enzymes)	Catechins, theaflavins, thearubigins
Oolong	Withering, rolling, drying	Partially fermented (partial oxidation)	Catechins, theaflavins, procyanidins
White	Withering, drying	Unfermented	Catechins

Table 2.
Major polyphenols and processing conditions of different varieties of tea.

catechins have been explored to antioxidant, anticarcinogenic, anti-inflammatory, probiotic, anti-inflammatory, thermogenic, and antimicrobial activities. These have been found to inhibit carcinogenesis of the skin, lung, esophagus, stomach, liver, small intestine, colon, bladder, prostate, and mammary gland in animal studies [26]. Black and green tea can protect oxidative damage of red blood cells [27].

Looking in to the various health benefits of tea phytochemicals, tea extracts in liquid or powder form can be effectively used in food products such as sweets, biscuits, bread, cake, candies, ready-to-drink beverages as well as other polyphenol rich food supplements. The tea nutraceuticals are also available in various form of tablets, capsules and health drinks. In addition, tea also contains other nutritional substances such as dietary fiber and proteins after polyphenols extraction in tea for use in nutraceuticals which also give health benefits [28]. Consumption of tea with lemon juice (ascorbic acid) has manifold benefits in making more accessible of tea antioxidants (catechins) to get absorbed as well as enhance the iron absorption in our body [15]. Further, compounds in tea can inhibit iron absorption from foods; drinking green tea with lemon reduces that effect. The combination of honey with green tea has been used since very past as they are very effective in healing wounds. The health-promoting activities of tea also vary cultivar to cultivar and thus it is important to identify the cultivars having specific bioactivity so as to use the nutraceutical properties properly. The phytochemicals in tea and their nutraceutical properties are depicted in **Figure 1**.

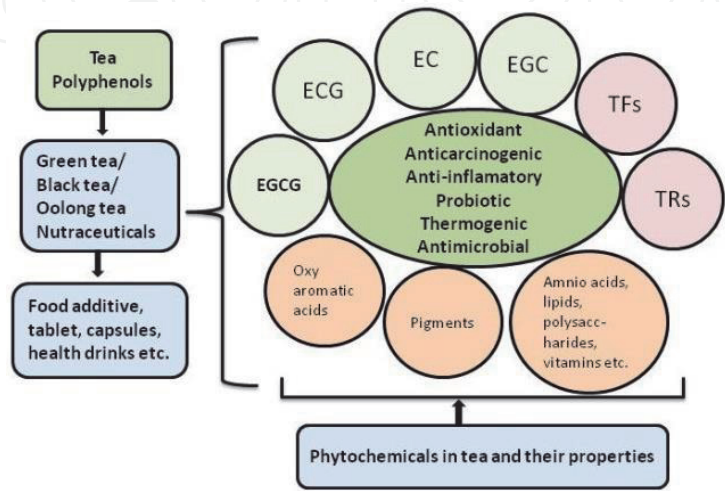


Figure 1.
Role and mechanism of nutraceutical properties of tea phytochemicals.

4. Tea phytochemicals as Nutraceuticals in different diseases

Tea is beneficial in protection and prevention of numerous critical diseases such as different cancers, diabetes, neurodegenerative and cardiovascular diseases [29–31]. The polyphenols, the major phytochemicals present in tea are known for their antioxidant properties due to their abilities to scavenge free radical species such as hydroxyl radical (OH), hydrogen peroxide (H₂O₂) and superoxide anion (O₂^{·-}) and thus their consumption confer them as potential cancer chemopreventive agents as well as other free radical induced diseases. The polyphenol extract of tea has been effectively used in cancer prevention, protection cardiovascular diseases, reduce weight-loss, anti-allergic, prebiotics, osteoarthritis protection etc. [32, 33]. Green tea extract comprises of nearly 40% of polyphenols of which nearly 25% accounts for different catechins and their gallates of which EGCG is the highest in quantity (about 11%), the most studied polyphenols in therapeutic properties. Black tea polyphenols theaflavins, theaflavin gallates (which are dimers of two different catechins and their gallates) and thearubigins with 2-6% in quantity in addition to 3-10% of catechins gain attention in different diseases [34].

Herein, we wish to discuss the health benefits of tea in common and major diseases such as diabetes, cardiovascular diseases, obesity, cancers, as well as others minor diseases related to microbial and inflammatory types. The role of major phtochemicals of tea in different diseases is outlined in **Table 3**.

4.1 Tea phytochemicals in diabetics

Diabetes mellitus, a highly alarming disease worldwide is associated with high levels of blood glucose other than normal which is associated with insufficient insulin production or its ineffectiveness.

Polyphenols in green and black tea are very effective in reducing hyperglycemia and insulin resistance which can manage the blood glucose in diabetes [31, 35, 36].

Thus, tea polyphenols present potential nutraceuticals for various facets of type 2 diabetes mellitus. In type 2 diabetes, insulin tolerance is developed following major metabolic disorder which led to numerous health complications reducing the quality of life and increasing the mortality rate [37]. It has become evident from various *in vivo* experiments that polyphenol phytochemicals and their additive food products modulate metabolism of carbohydrates and lipids, reduce hyperglycemia, insulin resistance, and improve many other metabolic process related to prevention and suppression of diabetics [35]. Consumption of black or green tea on daily can suppress the diabetic cataract and lower the glucose level in blood [36]. Similarly

Phytochemicals of tea	Health benefits
Polyphenol extract of green tea	Cancer prevention, protection cardiovascular diseases, reduce weight-loss, anti-allergic, prebiotics, osteoarthritis protection etc.
Epigallocatechin-3-Gallate (EGCG), Epigallocatechin (EGC), epicatechingallate (ECG)	Anticancer, cardioprotection, Neuroprotection, Obesity management, osteoprotection, Anti-inflammation, Diabetes control and renal protection, Antimicrobial and skin care etc.
Theaflavins, Thearubigins, bisflavonols	Antioxidative, antithrombogenic, and anti-inflammatory, anti-carcinogenic, anti-mutagenic, neuroprotective etc.

Table 3.
Role of major phytochemicals of tea in different diseases.

oolong tea has profound effect in treatment of type 2 diabetes [35]. However, further clinical study is required to develop nutraceutical products to apply in diabetic patients for prevention and cure. It was reported in an investigation in Japan that daily intake of about 6 cups of tea could reduce the diabetes affected people [38]. Recently, significant contribution of black tea polyphenol viz. theaflavins and thearubigins were found very effective in oxidative stress related diseases such as diabetes [31]. Therefore, tea nutraceuticals are very much promising in control and treatment of diabetes.

It has been reported that polyphenols have the hypoglycemic effects which are associated in reducing intestinal absorption of dietary carbohydrates affecting glucose metabolism, improvement of β -cell function and insulin action, inducing insulin secretion, and anti-inflammatory and anti-oxidative activity [39].

4.2 Tea photochemicals in cardiovascular diseases

The cardiovascular diseases such as hypertension (high blood pressure), coronary heart diseases (heart attack), cerebrovascular disease (stroke), heart failure, peripheral vascular diseases, etc. have been increasing day by day. The major causes of these are foods habits, chemicals used in food and food products, chemicals used in cultivation as well as lack of awareness.

Green tea consumption has been found to be effective in reduction of cardiovascular related disorders through decreased serum cholesterol and triglyceride. It has been reported in a study carried out in Japan that regular green tea consumption (≥ 500 mL) reduced the mortality rate in women in cardio vascular diseases by 31% as compared to those who consume non-regularly [40].

The green consumption has the effect of reducing the risk of coronary heart diseases by lowering the hyperlipidemia and total body cholesterol in body [41]. Moreover, EGCG the major catechin in green tea has been shown its usefulness in cardioprotective effects (inhibiting the formation of cardiac hypertrophy), antithrombotic and antiplatelet activities which are associated with cardiovascular diseases [42]. The theaflavin and thearubigins in black tea functional drinks are valuable against lipid and glucose related abnormalities especially high cholesterol and LDL levels [31].

4.3 Tea phytochemicals in obesity

Obesity has been considered as a serious concern globally effecting large number of peoples. It is associated with accumulation of excess body fats which stimulate various disorders in body such as hypertension, osteoarthritis, hyperlipidemia, heart attack, etc. [43] It is identified as a major factor in many metabolic syndrome such as stroke, heart failure, hypertension, diabetics, arthritis, etc.. The oolong tea food products also were also found to be very effective in decrease of in weight of obese people [44]. The green tea catechin, EGCG has been found to be beneficial on obesity [45]. Catechins in tea helps in weight management and consumption of green tea catechins results significant reduction in body weight in human [46].

4.4 Tea phytochemicals in oral diseases

Tea phytochemicals are useful in treatment and prevention of various types oral diseases which include tooth decay and oral cancers [47, 48], dental plaque and dental caries [49]. The tea extract and fluoride in tea can prevent the carcinogenic activity of oral bacteria such as *Escherichia coli*, *Streptococcus salivarius*, and *Streptococcus mutans* [50].

4.5 Tea phytochemicals in cancers

Tea nutraceutical acts as powerful antioxidants are very much promising in prevention of cancers. Experimental studies have demonstrated the use of tea bioactive compounds in prevention of cancers in different organs [51]. The tea catechins has been found to act as anticarcinogenic and chemopreventive agents. Several animal model studies in mice showed the inhibiting of chemical induced 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK) tumorigenesis, tumor cell proliferation, progression of adenoma to carcinoma, as well as lung carcinogenesis. [52]. It has been conferred from several experimental evidences that tea can be effectively used in inhibition of carcinogenesis in different parts of our body such as skin, lung, stomach, esophagus, liver, small intestine, pancreas, colon, bladder, etc. [53]. In these experimental studies it was found that polyphenols in green tea acted on cell apoptosis, cell proliferation, cell cycle in tumour growth and migration. All these activities resulted in reduced the risk of certain types cancers such as skin, colorectal, prostate, breast etc. through their activity in cell apoptosis, cell proliferation, cell cycle in tumour growth and cell migration. Among four major catechins in green tea, EGCG has been extensively studied and found to be most effective polyphenols [54]. Theaflavins in black tea inhibit the DNA damage which is a major cause of induction of cancer [55] The anti-carcinogenic activity of tea polyphenols is associated with their capacity to bind with carcinogens and thereby enabled the metabolism. Cancer preventive activity of black tea is known from the report of induction of apoptosis in human leukemia cells by black tea and its polyphenols [56]. Black tea is also effective in protecting immunocytes from tumor-induced apoptosis [57].

4.6 Other applications of tea phytochemicals

Consumption of tea has other several promising-health benefits such as it decrease the risk of hypertension [58], lowers the risk of osteoporosis, protects

Green tea supplements	Observed effects	In vivo study
Polyphenol extract	Increase in hydroxyproline content and catalase activity, Decrease in protein carbonyl content, Inhibit protein oxidation induced by UV radiations.	Mice
Aqueous extracts	Increase the level of collagen and elastin fibers. Reduced expression of MMP-3 enzymes.	Mice
Green tea extract	Reduce muscle atrophy and mediate insulin resistance, Reduce fat accumulation and lipid droplets.	Mice, C. elegans
Epigallocatechin gallate (EGCG)	Reduce the number of cells affected by sunburn, Maintain equilibrium during redox reaction.	
EGCG	Extend lifespan.	Drosophila, C. elegans
Cholinergic acid	Delay age-related decline in body movements	C. elegans
Theanine	Stress resistance and lifespan extension.	C. elegans
Crude green tea extract	Reduction in total body iron.	Fruit flies

Table 4.
Effect of green tea on photoaging, stress resistance, neuroprotection and associated health complications: in vivo studies [67].

Green tea supplements	Observed effects	Clinical study (human)
Polyphenol extract	Conjugate metabolites in plasma, blister fluid, and skin biopsy samples	Consume capsules of green tea polyphenols
Green tea extract	Reduction in the level of cells with sunburn; Lesser DNA damage when compared to vehicle control; Reduced the prevalence of Alzheimer's disease and cognitive impairment; Free radical scavenging and anti-wrinkle effects	Topical application
EGCG, EC, and EGC	Decreased sunburn cells (Lesser activity when compared to the crude extracts).	Topical application
Polyphenol extract	Improvement in facial skin and in controlling erythema	Oral supplements of green tea polyphenols

Table 5.
Effect of green tea on photoaging, stress resistance, neuroprotection and associated health complications: Clinical trials [67].

against the risk of hip fractures [59, 60], improves the metabolic activity of the bacteria in intestinal tract [61].

The bioactive compounds in oolong tea such as polyphenol, caffeine have the antistress and antioxidant activities which can prevent the diseases related to stress [62]. The green tea catechin, EGCG is useful in inhibition of HIV infection and HIV-1 replication and multi-drug resistant *Staphylococcus aureus* infections [63]. Tea also shows antifungal activity which is higher in black tea followed by green tea and white tea [64]. Black is also effective in asthma disease which is ascribed by the antihistaminic and anti-inflammatory activities of the flavonol glycosides contained in black tea [65]. Tea extract also shows antiallergic activity by suppressing histamine activity controlling the allergic response including inflammation, urticaria, mastocytosis, asthma, and dermatitis [66].

Some other beneficial effects of the constituents are antiaging, stress control, ant-bacterial, anti-viral, and useful in Parkinson's disease, Alzheimer's disease etc. Recently, Tencomnao et al. [67] discussed the results of some *in vivo* studies on the effects of green tea supplements on various health benefits such photoaging, stress resistance, neuroprotection, and associated health complications and some of these are outlined in **Table 4**. Some of the major clinical trials on these various health benefits are depicted in **Table 5**.

5. Conclusions

This chapter discusses the nutraceutical properties of bioactive compounds in tea in particular polyphenols and their role in health benefits. The catechins in tea viz. EGCG, EGC, ECG and EC have therapeutic properties such as antioxidant, anti-diabetic, anti-microbial, anti-inflammatory as well as anti-cancer properties. The black tea polyphenols the flavins and thearubigins also show many profound therapeutic values. In addition, oolong tea and white tea are also pharmacologically important. Therefore, consumption of tea in its various form viz. green tea, black tea, oolong tea and other food products with tea as active ingredient have been increased now a days. There are many more food products with tea and or its extracted components as additive have been developed which includes instant tea beverage, confections, cereal bars, pet foods etc. Considering the growing interest

in nutraceuticals due to their several health values, the aim of the present chapter is to outline the nutraceutical potential of phytochemicals of tea with their known therapeutic properties. Due to their ready bioavailability, the possibilities of using nutraceuticals from tea as natural healers in treatment and prevention of diseases have been explored.

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