Journal of Medicinal Plants Research Vol. 5(11), pp. 2110-2124, 4 June, 2011
Available online at http://www.academicjournals.org/JMPR
ISSN 1996-0875 ©2011 Academic Journals

Review

The aroma, taste, color and bioactive constituents of tea

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Accepted 7 March, 2011

The genus *Camellia sinensis* belongs to the family of Theaceae of the flowering plants. The leaves and leaf buds of *C. sinensis* are used to produce tea. The chemical composition of tea leaves has been thoroughly studied and the main constituents belong to the polyphenol group accounting for 25 to 35% on a dry weight basis. *C. sinensis* also contains various chemical constituents including methylxanthines, amino acids, chlorophyll, carotenoids, lipids, carbohydrates, vitamins, and more than 600 volatile compounds. Literature reports indicated that consumption of tea protects from various physiological and pharmacological effects which could be because of the presence of crucial therapeutic compounds which are more bio-stable and direct acting than those present in other medicinal plants. The activities of the compounds from tea are so pervading that they are virtually broad spectrum in their actions. This article provides a critical review of different phytochemicals isolated from tea and their associated medicinal properties as well as the chemical constituents responsible for aroma, taste and color.

Key words: Tea, *Camellia sinensis*, chemical constituents, biological activity, aroma, taste, color.

INTRODUCTION

The tea plant *Camellia sinensis* is a native to Southeast Asia but is currently cultivated in > 30 countries around the world. *C. sinensis* is the species of plant whose leaves and leaf buds are used to produce tea. It is of the genus *Camellia*, a genus of flowering plants in the family Theaceae. Tea is consumed worldwide, although in greatly different amounts; it is generally accepted that, next to water, tea is the most consumed beverage in the world, with per capita consumption of <120 mL/d (Katiyar et al., 1996). The fresh tea leaves are usually used for tea manufacturing and are harvested by hand plucking or mechanical plucking. Compared to mechanical plucking, hand plucking is more labor intensive and time consuming and less efficient, but with higher uniformity. The well known high quality green teas are mostly produced from hand-plucking fresh tea leaves from China. According to the different ways of processing, especially the extent of fermentation, tea is usually divided into three basic types: green tea (non-fermented), oolong tea (semi-fermented) and black tea (fully fermented). Alternatively, with the combination of the ways of processing and the characteristic quality of manufactured tea, tea is classified into six types: green tea, yellow tea, dark tea (containing brick tea and pu-erh tea), white tea, oolong tea and black tea. The so called fermentation in tea processing is not the anaerobic breakdown of energy-rich compound (as a carbohydrate to carbon dioxide and alcohol or to an organic acid), but in essence is mainly the oxidative polymerization and condensation of catechins catalyzed by endogenous polyphenol oxidase and peroxidase.

The oxidation products such as theaflvins and therubigins contribute to tea color and taste of the black tea. Moreover, tea quality is also determined by the processing techniques employed. The three basic types of tea; green, oolong and black have different quality characteristics, including aroma, taste and color, and appearance. Of the total amount of tea produced and consumed in the world, 78% is black, 20% is green, and < 2% is oolong tea. Black tea is consumed primarily in Western countries and in some Asian countries, whereas green tea is consumed primarily in China, Japan, India, and a few countries in North Africa and the Middle East. Oolong tea production and consumption are confined to southeastern China and Taiwan (Katiyar et al., 1996). Kukicha (twig tea) is also harvested from *C. sinensis*, but

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uses twigs and stems rather than leaves. Tea currently is the hot topic in both nutritional and therapeutic research worldwide. This is not so because tea is the most preferred drink after water, but because of the presence of crucial therapeutic compounds in tea which are more bio-stable and direct acting than those found in other plants. The activities of these compounds are so all pervading that they are virtually broad spectrum in their actions. Besides, the natural integration of aromatic and therapeutic compounds in tea is a rather unique attribute.

CHEMICAL CONSTITUENTS OF TEA

The chemical composition of tea leaves has been thoroughly studied. The main constituents of tea leaves belong to the polyphenol group accounting for 25 to 35% on a dry weight basis (Balentine, 1997; Hara et al., 1995d). The polyphenols (Mukhtar et al., 2000) in tea mainly include the following six groups of compounds: flavanols, hydroxyl-4-flavanols, anthocyanins, flavones, flavonols and phenolic acids. Important and characteristic tea polyphenols are the flavanols of which catechins (flavan-3-ols) are pre- dominant and the major ones are: (-)-epicatechin (EC), (-)-epicatechin gallate (ECG), (-)-epigallocatechin (EGC), (-)-epigallocatechin gallate (EGCG), (+)-catechin (C), and (+)-gallocatechin (GC) (Hara et al., 1995a; Liang et al., 2003). These compounds contribute to the bitterness, astringency and sweet aftertaste of tea beverages (Hara et al., 1995b). Tea contains also favonols, mainly quercetin, kaempferol, myrecetin, and their glycosides. In black tea, the oxidation of polyphenols during processing leads to the formation of catechins and gallic acid complexes such as theaflavins, theaflavinic acids, thearubigins or theasinensis, and of proanthocyanidin polymers (Balentine et al., 1997; Hara et al., 1995c; Lee et al., 2008). Methylxanthines are present with 2 to 4% as caffeine and a small amount of theophylline and of theobromine (Hara et al., 1995a). Tea contains many amino acids, but theanine, specific to the tea plant, is the most abundant, accounting for 50% of the total amino acids. Amino acid degradation is involved in the biogenesis of the tea aroma (Balentine et al., 1997). Chlorophyll, carotenoids, lipids and volatile compounds are not major constituents in a tea brew but they also play an important role in the development of the aroma (Hara et al., 1995d).

Volatile fractions of tea leaves have been studied in detail and more than 600 different molecules have been isolated (Hara et al., 1995c, e; Shimoda et al., 1995). These include terpenoids and degradation products of amino acids, carotenoids and linoleic acid (Hara et al., 1995a). Tea also contains carbohydrates, vitamins E, K, A, low levels of B vitamins and vitamin C (in green tea only). Tea also provides useful amounts of potassium, manganese and fluoride ions to the diet (Hara et al., 1995d).

This brief overview of the complex composition of tea leaves helps to understand the constituents of tea in particular those that may promote health. A compilation of the major chemical constituents from Tea found from various reports in literature are given as follows along with chemical structures for selected compounds.

Polyphenols

(-) Epicatechin (EC), (-) epicatechin gallate (ECG), (-) epigallocatechin (EGC), (-) epigallocatechin gallate (EGCG), (+) catechin (C), (+) gallocatechin (GC), theflavin, theflavin-3-O-gallate, theflavin-3'-O-gallate, theflavin-3,3'-di-O-gallate, isotheflavin, theflavin isomer, theflavic acid, epitheflavic acid, epitheflavic acid-3;-O-gallate, etc (Table 1)(Figure 1)

Minerals

Mineral constitutes about 4 to 9% of the inorganic matter of tea (fluorine, potassium, aluminum, iodine, selenium, nickel, and manganese.

AROMA, TASTE AND COLOR OF TEA

A cup of infusion of made tea is completely different from the infusion of fresh tea flushes in color, taste and aroma. These characteristics are developed during the manufacturing process after the harvesting of tea flushes. Tea flush is generally a reference to young shoots of tea that consists of terminal bud and two adjacent leaves. In fresh tea flush there exists a wide variety of non-volatile compounds; polyphenols, flavonols and flavonol glycosides, flavones, phenolic acids and depsides, amino acids, chlorophyll and other pigments, carbohydrates, organic acids, caffeine and other alkaloids, minerals, vitamins and enzymes. The total phenols in tea flush ranges from 20 to 35% (Table 2). A series of changes occur in the process of manufacturing tea (made tea). The three basic types of manufacturing tea are green, semi-fermented and black tea. They differ mainly in the degree of fermentation. Green tea undergoes little or no fermentation, and black tea is produced as a result of full fermentation. Semi-fermented (oolong tea) is a product of partial fermented tea. The difference in color, taste and aroma of various teas are caused by the manufacturing process.

Aroma of made tea

Aroma is one of the critical aspects of tea quality which can determine acceptance or rejection of a tea before it is tasted. Early research on tea aroma can be traced back over 170 years (Mulder, 1838), but progress on a more scientific basis has been achieved by the application of modern analytical techniques since 1960's, when gas

Table 1. Approximate % by Weight of Selected Tea Polyphenols (Catechins) (Zhen 2002a)

Polyphenols in Tea	Abbreviations of Selected Catechins	Approximate % by Weight of Catechins
(+)-Catechin	(+)-C	3
(-)-Epicatechin	(-)-EC	14
(-)-EGC-3-O-*p*-coumarate		
(-)-EC-3-O-cinnamte		
(-)-Epigallocatechin	(-)-EGC	44
(+)-Gallocatechin	(+)-GC	6
(-)-EC-3-O-p-hydroxy benzoate		
(-)-Epiafzelechin		
(-)-Epicatechin gallate	(-)-ECG	9
(-)-Epigallocatechin gallate	(-)-EGCG	23
(-)-EGC-3,3-di-O-gallate		
(-)-EGC-3,4-di-O-gallate		
(-)-EC-3,5-di-O-gallate		
(-)-EGC-3,5-di-O-gallate		
(-)-Epiafzelechin 3-O-gallate		
(-)-EC-3-O-(3''-O-methyl)gallate		
(-)-EC-3-O-(4''-O-methyl)gallate		
(-)-EGC-3-O-(3''-O-methyl)gallate		

chromatography was widely used, especially when capillary column techniques are available. Tremendous advances in gas chromatography and combined gas chromatography-mass spectrometry have greatly increased our knowledge of tea aroma. All the data reported so far shows that more than 630 compounds have been reported responsible in tea aroma. One of the primary goals in aroma research is to identify constituents which are responsible for the characteristic aroma of tea. Many attempts have been made to look for the key compounds for the aroma of tea (Takei et al., 1976; Yamaguchi et al., 1981; Yamanishi, 1978) but no single compound or group of compounds have been identified as responsible for the full tea aroma. It is generally believed that the characteristics of various kinds of tea consist of a balance of very complicated mixtures of aroma compounds in tea. Tables 3 and 4 showed the list of compounds that are arranged into chemical categories to demonstrate their distribution. Eleven selected classes were considered (Yamanishi, 1995). Research on tea aroma has been well reviewed in a series of papers (Screier, 1988; Yamanishi, 1995, 1996; Takeo, 1996; Kawakami, 1997).

Taste of made tea

Taste of food is mainly composed of five basic sensations; that is, sweetness, astringency, sourness, bitterness and umami (Tamura et al., 1969). A delicious cup of tea infusion is an ingenious balance of various taste sensations. Astringency is a drying, puckering sensation in the mouth that affects the whole of the tongue more or less uniformly (Lea et al., 1978). Bitterness is usually unpleasant, but sometimes desirable in moderate amounts, and is perceived predominantly at the back of, and sometimes along side of, the tongue (Moncrieff, 1967). The umami is a Japanese term, it is similar to the “meaty” taste (Shallenberger, 1993) or “brothy” taste. Strong astringency and bitterness, median umami and sweetness, as well as slight sourness characterize green tea. Nakagawa et al. (1970) suggested the relative importance of these five taste sensations in green tea as follows: astringency 4.17, bitterness 3.44, umami 1.42, sweetness 0.53, saltiness and sourness <0.3. Nakagawa (1975) studied the correlation between the chemical composition and organoleptic properties of various grades of green tea. His results indicated that the astringency and bitterness of green tea infusion was mainly determined by the contents of catechins and other phenolic compounds. Besides catechins and caffeine, some amino acids (such as arginine, alanine, etc) also contribute to the bitterness of green tea infusion. The umami taste of green tea infusion was shown to be due to some amino acids such as theanine, serine, etc(Figure 1-11) and the sweetness to sugars. A cup of good quality black tea infusion is characterized by the bright reddish brown color, brisk, strong taste and rich flavor. Astringency in black tea is divided into two types: tangy and non-tangy, by Sanderson et al. (1976). The tangy astringency with a sharp and puckering action and little after taste effect, and the non-tangy astringency which is tasteless, mouth drying and mouth-coating, with a lingering (more than 60 s) after taste effect. Caffeine together with black tea

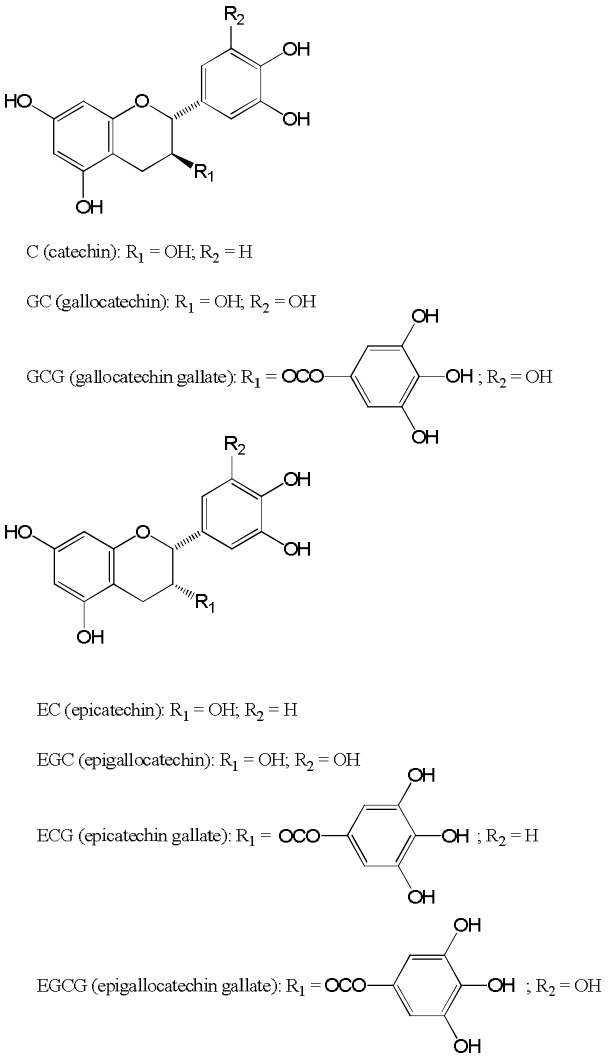


Figure 1. Polyphenols; (-) Epicatechin (EC), (-) epicatechin gallate (ECG), (-) epigallocatechin (EGC), (-) epigallocatechin gallate (EGCG), (+) catechin (C), (+) gallocatechin (GC), theflavin, theflavin-3-O-gallate, theflavin-3'-O-gallate, theflavin-3,3'-di-O-gallate, isotheflavin, theflavin isomer, theflavic acid, epitheflavic acid, epitheflavic acid-3;-O-gallate, etc (Table 1) (Figure 1).

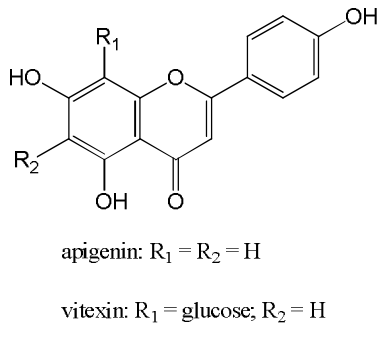


Figure 2. Apigenin, vitexin, isovitexin

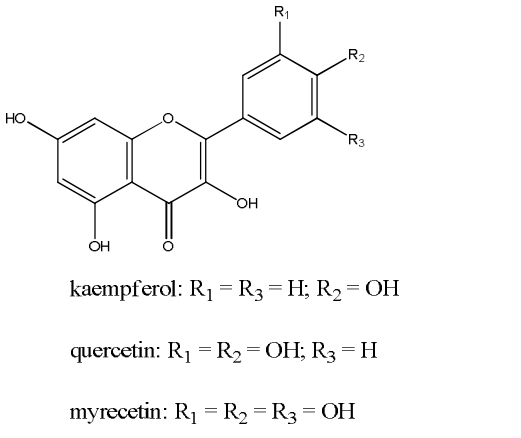


Figure 3. Kaempferol, quercetin, myrecetin

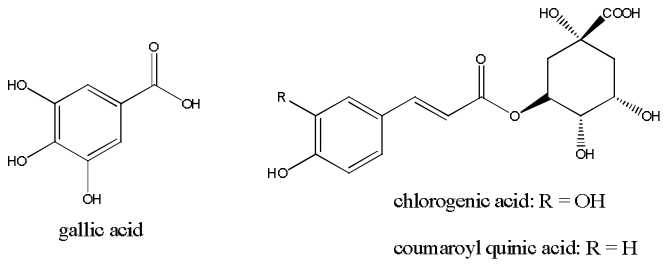


Figure 4. Gallic acid, chlorogenic acid, coumaroyl quinic acid

polyphenols was necessary for the expression of reasonable amounts of tangy astringency. Decaffeination may change the nature of astringency from tangy to non-tangy type (Sanderson et al., 1976). The gallated tea flavonols are related to astringency and also to the bitterness taste; the non-gallated tea flavonols are related to bitterness, however, are not related to or only slightly related to the astringent taste of black tea infusion. Among theoflavins (TFs), theoflavin is less astringent. The contribution of TF-digallate and mono-gallate to astringency is 6.4 and 2.2 times to that of theaflavin. There were inconclusive conclusions on the individual chemical components which have been evaluated as contributing to the total quality of black tea. Mellowness and sweet taste as well as its special aroma characterizes a cup of good quality oolong tea infusion. The taste of oolong tea infusion is quite unusual and depends on the various fermentation degrees. The content of TFs was very low or absent in light fermented oolong tea. Even in heavy-fermented oolnag tea, TFs content was only one tenth of that in black tea due to low cell breakage rate (around 30%). However thearubigins (TRs) contents formed via oxidation of EGC and its gallate (Takayangi et al., 1984).

In addition some of the secondary polyphenolic compounds such as oolonghomobisflavane, to the theasinensin, and oolongotheanine were formed related

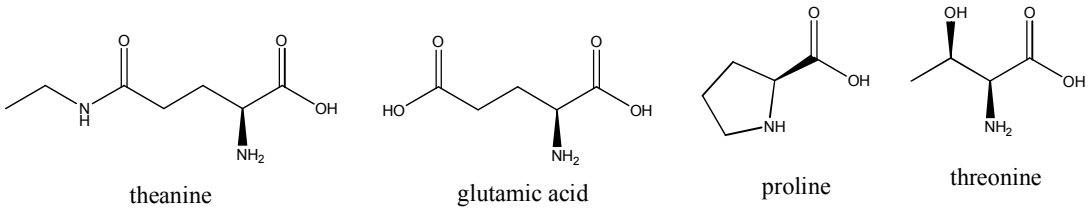


Figure 5. Theanine, glutamic acid, proline, threonine

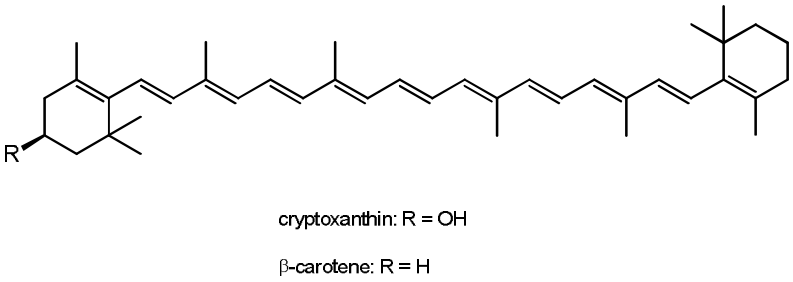


Figure 6. Cryptoxanthin, β-carotene

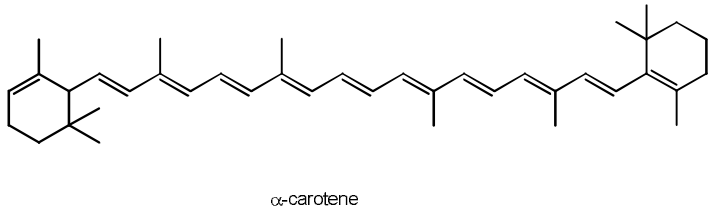


Figure 7. α-Carotene

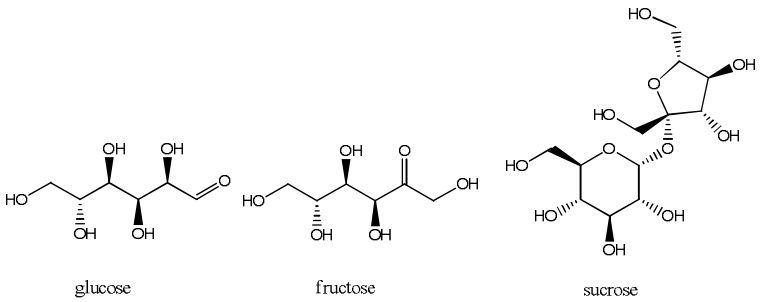


Figure 8. Glucose, fructose, sucrose

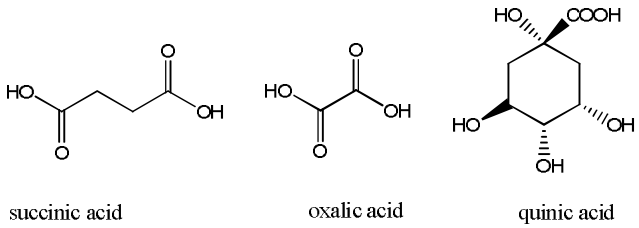
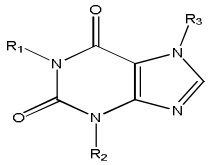


Figure 9. Succinic acid, oxalic acid, quinic acid



caffeine: $R_1 = R_2 = R_3 = CH_3$

theophylline: $R_1 = R_2 = CH_3$; $R_3 = H$

theobromine: $R_2 = R_3 = CH_3$; $R_1 = H$

xanthine: $R_1 = R_2 = R_3 = H$

Figure 10. Caffeine, theobromine, theophylline, xanthine

infusion taste (Nonaka et al., 1983; Nagabayashi et al., 1992).

Thus the mellowness and sweetness of oolong tea infusion are the integrated taste of non-oxidized catechins, TRs, some secondary polyphenolic compounds, caffeine, free amino acids and related sugars. The astringency of oolong tea is lower and the sweetness taste is stronger than those of green tea. The compounds responsible are still in need of clarification (Table 5).

Color of made tea

Shade of color in made from tea and the infusion color are two attributes besides aroma and taste in the evaluation of various kinds of tea. Green tea infusion contains no highly colored products formed by the oxidation of polyphenolic compounds, and the desired color is greenish or yellowish green without any trace of red or brown color. The green color is the main shade of color in the infused leaf and the infusion of green tea. It is mainly determined by the chlorophyll content and the ratio of chlorophyll A which is dark green and chlorophyll B which is yellowish-green in color.

The TFs and the flavonols as their glycosides are the contributors for yellow color. The degradative products of chlorophyll (pheophytin and pheophorbide) may cause the made tea color to become darker. The degradation is activated by the chlorophyllase enzyme, high temperature and high humidity. Infact the green infusion color is not produced by the soluble amounts of chlorophyll. It is because the chlorophyll is not soluble in water.

The yellow color in green tea infusion is mainly determined by the water soluble flavonols (1.3 to 1.5% of the tea leaves dry weight), which include kaempferol, quercetine, isoquercetin, myricetin, myricitrin, rutin, kaempferitrin, etc and flavones (0.02% of the tea leaves in dry weight) which include apigenin, isovitexin, vitexin, saponarin, vicenin-2, etc as well as their glycosides; besides the water soluble anthocyanins. The red color is the main shade of color in black tea. TFs are generally yellow in color and TRs are generally red in color. The colored TFs and TRs are produced by the enzymatic oxidation and condensation of catechins in green leaf during fermentation process.

The different ratios of TFs and TRs constitute the different shade of black tea. It is produced by the decomposed products of chlorophyll, protein, pectin, sugar and phenolic compounds which form in the manufacturing process of black tea and accumulate on the surface of made tea. Liu et al. (1990) pointed out that the pheophytins/TR ration value could be used to reflect the color of black tea. The higher the ratio vale, the more black bloom the made tea has. On the other hand, unexpected color may possibly be a sign of poor-quality tea.

A grayish appearance may possibly be due to poor processing or even an indication of spoilage or adulteration. The infusion color of oolong tea is generally reddish-brown in moderate to heavy fermented oolong and dark greenish color in light fermented oolong. The color determining compounds in light-fermented tea are composed of the flavonols and flavones in green tea and small amounts of TFs and TRs in black tea. In the moderate and heavy-fermented oolong tea, the major color-determining compounds are the TRs and their oxidized polymers. The amount of TFs in heavy-fermented oolong tea is only one-tenth of the TFs in black tea (Nagabayashi et al., 1992). In addition, some homobisflavin compounds such as oolonghomobisflavin A, B (Nagabayashi et al., 1992), theasinensin D, E, F, G (Nonaka et al., 1983) and oolongthenin (Nagabayashi et al., 1992) are related to the color of oolong tea infusion (Table 6).

BIOLOGICAL ACTIVITY OF TEA CHEMICAL CONSTITUENTS

Tea polyphenols and antioxidant activity

Antioxidants protect the body against the damaging effects of free radicals produced naturally within the body. But over production of these free radicals due to environmental pollution, smoking or physiological disorders may disrupt the body's own antioxidant system and resulting in the production of free radicals far in excess of what is good for health. An imbalance between free radical production and natural antioxidants could cause damage to proteins and DNA, the genetic material within the cells. A compound that prevents oxidative damages, therefore, an antioxidant. A plethora of evidence suggests strong antioxidant potentials of tea flavonoids in containing or suppressing the production of excess free radicals (Weisburger et al., 2000). Though most of the studies involved were laboratory-based and animal model-based (that mimic human system), they are nevertheless unequivocal that tea flavonoids can inhibit the actions of specified free radicals in human systems. A

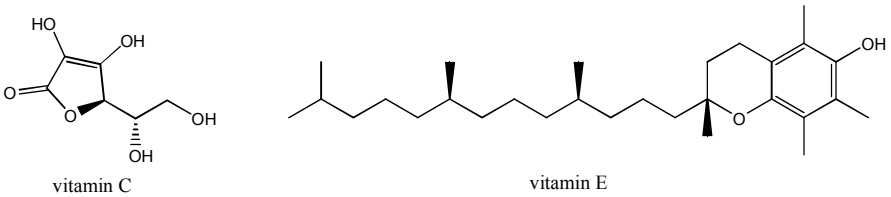


Figure 11. Vitamins C and E

Table 2. Composition of fresh tea flush (% dry weight) (Zhen, 2002b).

Class of Component	Name of Each Component	% Dry Weight of Each Component
Acids		
	Amino acids	2-4
	Organic acids	0.5-2
Minerals		
	Insoluble minerals	1.5-3
	Soluble minerals	2-4
Saccharides		
	Carbohydrates	3-5
	Cellulose	6-8
	Polysaccharides	4-10
Polyphenols/Flavonoids		
	(-)-EC	1-3
	(-)-ECG	2-4
	(-)-EGC	4-7
	(-)-EGCG	9-14
	(-)-GC	1-2
	(+)-C	0.5-1
	Flavonol glucosides	3-4
	Minor Catechins	0.4-1
	Proanthocyanindins	2-3
Other Compounds		
	Caffeine	3-4
	Pigments, Insoluble pigments	0.5-0.8, 0.5
	Lignin	4-6
	Lipids	2-4
	Saponins	0.04-0.07
	Vitamins	0.6-1
	Volatiles	0.01-0.02

Table 3. Aroma constituents of tea (Yamanishi, 1995; Zhen 2002c).

Compound Class	Compound Type	Number of Compounds of each Type
I Aliphatic		
	Hydrocarbons	14
	Alcohols	51
	Aldehydes	45
	Ketones	30
	Acids	63
	Esters	52
II Alicyclic		

Table 3 Contnd.

	Ketones	10
	Esters	3
II Aromatic		
	Hydrocarbons	25
	Alcohols	5
	Aldehydes	18
	Ketones	16
	Acids	3
	Esters	19
IV Miscellaneous		
	Terpenoid Hydrocarbons	33
	Terpenoid Alcohols	33
	Terpenoid Aldehydes	5
	Terpenoid Ketones	3
	Terpenoid Acids	3
	Terpenoid Esters	8
	Ionone derivatives	21
	Lactones	25
	Phenolic Compounds	22
	Pyrroles	12
	Pyridines	17
	Pyrazines	24
	Furanoid	17
	Sulfur compounds	14
	Others	47

few human studies are however emphatic that tea consumption reduces the oxidative damages to DNA in the human cells. Moreover, pilot studies using biomarkers established that green tea consumtion for seven days could appreciably reduce DNA damage among both smokers and non-smokers (Lee et al., 1997). A balance of evidence indicates tea confers a mild beneficial effect of cardiovascular health, and even decreases the risk of heart diseases. A tea is major source of flavonoids in tea drinking populations, it can provide a certain amount of health benefits as well (Banerjee, 1992). The antioxidant activity of tea polyphenols (TP) and the cooperative antioxidant activity of TP and other natural antioxidants were detected by using ferric reducing/antioxidant power assay (FRAP) and the results showed that it showed the highest antioxidant activity when the concentration of EGCG in tea catechins was 40% approximately 50% (Wang et al., 2010). The antioxidant activity and total phenolics content (TPC) of freshly prepared green tea extract (GTE) as affected by time, temperature and stirring were determined using the FRAP and Folin-Ciocalteu assays (Molan et al., 2009) and was concluded that brewing conditions such as extraction temperature, period of extraction, ratio of tea leaves to extracting with water, and stirring are important factors for determining the FRAP values and TPC in GTE. These factors should be taken into consideration during preparation for nutritional benefits during usual consumption of this beverage. Buzzini et al. (2009) reported that green tea polyphenols in particular catechins represent a reservoir of molecules characterized by antioxidant activity. Major chemical compounds in different extracts from tea flowers (*C. sinensis*) were analyzed (Yang et al., 2007) and the results showed that ethyl acetate fraction of ethanol-extract of tea flower (EEA) exhibited the highest quenching activity to hydroxyl radicals (SC50 11.6 µg/mL), followed by ethanol-extract (EE) of tea flower (SC50 19.7 µg/mL). Further it was found that the contents of flavones, polyphenols and catechins in EE and EEA fractions were higher than those in other fractions.

Tea polyphenols and the risk of cancer

Abundant experimental and epidemiologic evidence accumulated mainly in the past decade from several centers worldwide provides a convincing argument that polyphenolic antioxidants present in green and black tea can reduce cancer risk in a variety of animal tumor bioassay systems (Katiyar et al., 1996; Dreosti et al., 1997; Kohlmeier et al., 1997). Most of the studies

Table 4. Biochemical compounds responsible for aroma(flavor) (Scrieer, 1988; Yamanishi, 19951996; Takeo, 1996; Kawakami, 1997).

Compounds	Aroma (flavor)
Linalool, Linalool oxide	Sweet
Geraniol, Phenylacetaldehyde	Floral
Nerolidol, Benzaldehyde, Methyl salicylate, Phenyl ethanol	Fruity
Trans-2-Hexenal, *n*-Hexanal, *Cis*-3-Hexenol, Grassy, β-Ionone	Fresh flavor

Table 5. Biochemical compounds responsible for taste (Yamanishi, 1995).

Compounds	Taste
Polyphenol	Astringent
Amino acids	Brothy
Caffeine	Bitter
Theaflavins	Astringent
Thearubigin	Ashy and slight astringent

Table 6. Biochemical compounds responsible for color (Nakagawa et al., 1970, 1975; Liu et al., 1990).

Compounds	Color
Theaflavins	Yellowish brown
Thearubigins	Reddish brown
Flavonol glycosides	Light yellow
Pheophorbide	Brownish
Pheophytin	Blackish
Carotene	Yellow

showing the preventive effects of tea were conducted with green tea; only a few studies assessed the usefulness of black tea (Katiyar et al., 1996). These studies showed that the consumption of tea and its polyphenolic constituents affords protection against chemical carcinogen or ultraviolet radiation induced skin cancer in the mouse model. Tea consumption also affords protection against cancers induced by chemical carcinogens that involve the lung, forestomach, esophagus, duodenum, pancreas, liver, breast, colon, and skin in mice, rats, and hamsters. A review on this area of research (Katiyar et al., 1996) and the bioavailability of the polyphenols from tea has been established by others (Hollman et al., 1997). The relevance of the extensive laboratory information for human health can be assessed only through epidemiologic observations, however, especially in a population with high cancer risk. Much of the cancer-preventive effects of green tea are mediated by EGCG, the major polyphenolic constituent of green tea (Katiyar et al., 1996). One cup (240 mL) of brewed green tea contains up to 200 mg EGCG. Many consumer products, including shampoos, creams, drinks, cosmetics, lollipops, and ice creams, have been supplemented with green tea extracts and are available in grocery stores and pharmacies.

The use of biochemical modulators in cancer chemotherapy has been studied extensively (Sadzuka et al., 1998). The adverse effects of modulating drugs can be life threatening, and their use increases the patient's medication burden as well. Thus, the substances used in diet and beverages should be studied for their potential as biochemical modulators that could increase the efficacy of therapy. In this regard, Sadzuka et al. (1998) showed that the oral administration of green tea enhanced the tumor-inhibitory effects of doxorubicin on Ehrlich ascites carcinomas implanted in CDF1 and BDF1 mice. The study showed that green tea treatment increases the concentration of doxorubicin in tumor but not in normal tissue. If these observations can be verified in human populations, they may have relevance to cancer chemotherapy. Recently, Yang et al. (2010) reported that the extracts of green tea and green tea polyphenols have exhibited inhibitory effects against the formation and development of tumors at different organ sites in animals. These include animal models for skin, lung, oral cavity, esophagus, stomach, intestine, colon, liver, pancreas, bladder, mammary gland, and prostate cancers. Lambert et al. (2010) reported that green tea and EGCG can inhibit tumorigenesis during the initiation, promotion and progression stages in animal models of carcinogenesis. Several review articles have been reported the importance of tea and its polyphenols towards the treatment of cancer (Zaveri, 2006; Ju et al., 2007; Lambert et al., 2007; Yang et al., 2007).

Tea polyphenols and the risk coronary heart disease

Coronary heart disease is most prevalent in the Western world, probably as a result of the lifestyle in this part of the world, which includes a diet high in saturated fats and low physical activity, and the large proportion of the population who smoke cigarettes and have high blood pressure. A variety of epidemiologic studies showed the preventive effect of green tea consumption against atherosclerosis and coronary heart disease (Weisberger et al., 1996; Thelle et al., 1995). Tea consumption has also been shown to reduce the risk of high blood cholesterol concentrations and high blood pressure (Stensvold et al., 1992). In addition, studies in experimental animals showed the preventive effect of green tea against atherosclerosis (Tijburg et al., 1997). He et al. (2006) reported that the tea polyphenols (TP) possess many beneficial properties, such as reducing the risk of cancer and heart diseases, and acting as natural antioxidants for the food industry. A review article by Dubick et al. (2001) indicated that Wine, and tea polyphenols, have biological activities that may modify certain risk factors associated with atherogenesis and

cardiovascular diseases. Research conducted in recent years revealed that both black and green tea has very similar beneficial attributes in lowering the risk of many human diseases, including several types of cancer and heart diseases (Gupta et al., 2008).

Antibacterial and antiviral effects of tea

Green tea catechins have demonstrated antibacterial activity against both “gram-positive” and “gram-negative” bacteria which can be harmful to humans. Tea extracts inhibit enteric pathogens such as *Staphylococcus aureus*, *S. epidermis*, *Plesiomonas shigelloides* (Toda et al., 1989), *Salmonella typhi*, *S. tiphimurium*, *S. enteritidis*, *Shigella flexneri*, *S. disenteriae* and *Vibrio cholerae*, *V. parahaemolyticus* (Mitscher et al., 1997; Toda et al., 1989; Toda et al., 1991), *Campylobacter jejuni* and *C. coli* (Diker et al., 1991) but are not effective against *Escherichia coli*, *Pseudomonas aeruginosa* or *Aeromonas hydrophila* (Toda et al., 1989). Black and green tea extracts can also kill *Helicobacter pylori* associated with gastric, peptic and duodenal ulcer diseases (Diker et al., 1994). However, the tea concentration used in these studies exceeded normal human consumption levels. Tea polyphenols can selectively inhibit the growth of clostridia and promote the growth of bifidobacteria in human large intestine. The bacterial balance in intestinal microflora may be important for the prevention of colon cancer (Okubo et al., 1997). Antimicrobial activity against cariogenic and periodontal bacteria has been reported. Tea polyphenols inhibit Streptococcus mutans (Sakanaka et al., 1989), S. sobrinus (Sakanaka et al., 1990) and Porphyromonas gingivalis, bacteria responsible for tooth decay (Kakuda et al., 1994; Sakanaka et al., 1996). They hinder the synthesis of insoluble glucans by glucosyltransferases, and the sucrose-dependant bacteria cell adherence to tooth and epithelium, by reducing collagenase activity (Mitscher et al., 1997; Sakanaka et al., 1990, 1996).

Nerolidol in the volatile fraction of green tea, and fluoride also present in green tea, contribute to the antibacterial action of tea extracts against *Streptococcus mutants* (Antony et al., 1997). Horiba et al. (1991), Terada et al. (1993) and Young et al. (1994) reported that tea consumption provides protection against bacterial infection. Nakayama et al. (1990) and Tao (1992) found that tea provides protection against-viral infection. Horiuchi et al. (1992) reported that tea prevents human influenza. Polyphenols and sesquiterpenes of tea have a synergistic effect on the antibacterial activity and the anticariogenic properties of tea (Kakuda et al., 1994). Cariogenic bacteria release lactic acid that destroys tooth enamel, but tea can increase the acid resistance of teeth to these injuries (Gutman et al., 1996). Protection against caries by tea polyphenols has been demonstrated with rats (Antony et al., 1997). Some results indicate that tea catechins are potentially antiviral and antiprotozoiac agents (Gutman et al., 1996). EGCG agglutinates and inhibits influenza A and B viruses in animal cell culture (Mitscher et al., 1997). An antiviral activity has been found against HIV virus enzymes and against rotaviruses and anteroviruses in monkey cell culture when previously treated with EGCG (Mitscher et al., 1997).

A significant part of scientific interest of academy or industry is focused on discovering novel natural antimicrobial drugs and the occurrence of secondary metabolites in some plants exhibiting a more or less pronounced antimicrobial activity is a well-known phenomenon. Among them, green tea polyphenols represent a reservoir of molecules characterized by antioxidant, antiradical and antimicrobial activity. In particular, catechins have proven to be effective towards both prokaryotic, eukaryotic microorganisms (Buzzini et al., 2009) and *Candida albicans* (Evensen et al., 2009). Tea polyphenols were evaluated for their ability to inhibit enterovirus 71 (EV71) replication in Vero cell culture. Among the polyphenolic compounds tested, epigallocatechin gallate (EGCG) potently inhibited replication of EV71. EGCG also reduced the titer of infectious progeny virus by 95%.

Quant. RT-PCR analysis also revealed that EGCG suppressed replication of genomic RNA. It was accompanied by an increased cytoprotective effect. EGCG caused 5-fold increase in the viability of EV71-infected cells. The viral inhibitory effect correlated well with the antioxidant capacity of polyphenol. Mechanistically, EV71 infection led to increased oxidative stress, as shown by increased dichlorofluorescein and MitoSOX Red fluorescence. Upon EGCG treatment, reactive oxygen species (ROS) generation was significantly reduced. Consistent with this, EV71 replication was enhanced in glucose-6-phosphate dehydrogenase deficient cells, and such enhancement was largely reversed by EGCG.

These findings suggest that EGCG may suppress viral replication via modulation of cellular redox milieu (Ho et al., 2009). Wang et al. (2007) reported that the natural extract of tea having the primary active ingredient of tea polyphenols comprises EGCG (epigallocatechin gallate) can be used for inhibiting hepatitis B virus.

Anti-inflammatory effects of tea

In several studies from our laboratory and elsewhere, the polyphenolic fraction from green tea was shown to protect against inflammation caused by certain chemicals, such as 12-*O*tetradecanoylphorbol- 13-acetate, a principal irritant in croton oil (Katiyar et al., 1992, 1993, 1996), or by ultraviolet radiation B (290 to 320 nm) (Agarwal et al., 1993). Green tea has also been shown to be effective against the immunosuppression caused by ultraviolet radiation B (Katiyar et al., 1995a, 1996). In addition, green tea polyphenols have shown protection against cytokines induced by tumors (Katiyar

et al., 1995b).

Extracts of green tea and polyphenols present therein have been shown to inhibit the inflammatory responses in vitro in different cell types and the development of arthritis in animal model studies. There is considerable evidence that (-)-epigallocatechin-3-gallate (EGCG), the predominant green tea polyphenol which mimic its effects, inhibits enzyme activities and signal transduction pathways that play important roles in inflammation and joint destruction in arthritis (Singh et al., 2010). Cao et al. (2008) reported that green tea and cinnamon polyphenols improve glucose, insulin, lipids and related variables, and are anti-inflammatory; function as antioxidants and decrease neurodegeneration.

Diabetes and renal failure effects of tea

Diabetes is associated with high blood glucose content. Green and black tea extracts can decrease significantly the blood glucose level of aged rats by reducing the glucose absorption and uptake in different ways (Zeyuan et al., 1998).

It is reported that tea polyphenolics inhibit alpha-amylase activity in saliva, reduce the intestinal amylase activity which in turn lowers the hydrolysis of starch to glucose and reduces glucose assimilation (Hara et al., 1995f). It was also found that tea reduces the glucose mucosal uptake because polysaccharides inhibit the glucose absorption and the diphenylamine of tea promotes its metabolism (Zeyuan et al., 1998). Polyphenols can also decrease digestive enzyme activity and reduce glucose absorption (Zeyuan et al., 1998). They decrease uremic toxin levels and the methylguanidine of hemodialysis patients (Sakanaka et al., 1997).

Polyphenols also protect against oxidative stress associated with late complications in diabetes pathology and are useful to maintain a balance between pro- and anti-oxidants in the organism (Zeyuan et al., 1998).

Tea consumption is associated with an increase in urine volume and electrolyte elimination, notably sodium, along with a blood pressure decrease (systolic and diastolic values) in hypertensive adenine-induced rats (Yokogoshi et al., 1995). Green tea catechins can suppress the progression of renal failure induced in rats or in renal cell culture, relieve the related mesangial proliferation and glomerular sclerotic lesions and reduce levels of uremic toxins in the blood (Yokozawa et al., 1996; Yokozawa et al., 1997; Yokozawa et al., 1998). Recent reports indicated that an aqueous solution of green tea polyphenols (GTP) was found to inhibit lipid peroxidation (LP), scavenge hydroxyl and superoxide radicals *in vitro*. Concentration needed for 50% inhibition of superoxide, hydroxyl and LP radicals were 10, 52.5 and 136 µg/mL, respectively. Administration of GTP (500 mg/kg body weight) to normal rats increased glucose tolerance significantly ($P<0.005$) at 60 min. GTP was also found to reduce serum glucose level in alloxan diabetic rats significantly at a dose level of 100 mg/kg body weight (Sabu et al., 2002).

The polymeric polyphenol extracted (9000 to 18,000 average molecular weight) obtained from a fermented tea (oolong, red tea, etc.), comprising a partial structure wherein there are contained a procyanidin structure resulting from polymerization of a catechin and/or a gallic ester thereof as well as a structure resulting from bonding of B-rings of catechins and/or gallic esters thereof exhibits a mitochondria activating potency, a hyperglycemia inhibiting potency, a body weight gain inhibiting potency (Numata et al., 2006).

Functionalities of tea and tea polyphenols in animal models

Administration of green or black tea to animal models of oxidative stress and oxidative stress-associated pathologies (for example, cancer, inflammation and atherosclerosis), elicits a range of responses that are consistent with the proposal that tea flavonoids or their metabolites are not only bioavailable, but are also active in affecting cellular processes *in vivo*, by mechanisms that may be related to their antioxidant functionalities (Table 7).

Effects of tea polyphenols against other diseases

Many studies have shown that the consumption of tea or its polyphenols can afford protection against diseases other than cancer and coronary heart disease. A few of these studies are as follows: Weisburger (1996) showed that tea is protective against stroke; Fujita (1994) and Kao et al. (1995) reported that tea consumption lowers the risk of osteoporosis; Imai et al (1995) reported protection against liver disease; Ishigami et al. (1993) reported the inhibition of dental caries by tea. Tea polyphenols are perhaps the most abundant and efficient antioxidants and are the star players in the immune system, regulating a delicate balance between the immune cell functions by modulating their secretion of specific cytokines. Green tea (-)-epigallocatechin gallate and tea ext. have shown immunostimulatory effects in mice, impairing the migration of macrophages/monocytes and neutrophils to the inflammatory lesions by regulating the secretion of interleukin-10 (IL-10), interferon-γ (IFN-γ), tumor necrosis factor α (TNF-α) and IL-12. Tea polyphenols play interesting roles in the development and activation of immune cells, thereby modulating their Th1/Th2 balance. Ethylamine, a degradation product of L-theanine, has shown remarkable effects in priming human Vδ2Vγ2 T cells and further enhancing their memory to abrogate microbial infections. These and other aspects of tea constituents are opening up newer frontiers in their development as therapeutics and nutraceuticals without having any adverse health effects

Table 7. Importance of Various Polyphenols Present in Tea in Various Animal Models (Cadenas et al., 2002)

Name of the Compound	Type of Cell Used in Animal Model	Function of Each Compound	Reference
Catechin	Human imblical vein endothelial cells	Protection against linoleic hydroperoxide-induced toxicity by α-tocopherol	Kaneko et al 1990
EGCG	a) Rat peritoneal exudates cells	a) Inhibition of A23187, or 48/80-induced histamine and leukotriene B_4 release, antiallergy	a) Matsuo et al 1996
	b) W138 and SV40-transformed W138 cells, Caco-2 cell line	b) Preferential growth inhibition, apoptosis induction, and C-foslc-myc expression of transformed cells	b) Chen et al 1998
	c) Peritoneal macrophages	c) Blocks LPS-induced NO synthase expression and protein levels through down regulation NF-*κ*B transcription	c) Lin et al 1997
EGC, ECG	Rat peritoneal exudates cells	Inhibition of A23187, or 48/80-induced histamine and leukotriene B_4 release, antiallergy	Matsuo et al 1996
Tannin fraction, EGCG, CG, EGC, EC	Smooth muscle cells	Inhibition of cell proliferation	Yozokowa et al 1995
Green tea catechin extract, EGCG	Human stomach cancer, KATO III cell line	Growth inhibition and stimulation of apoptosis	Hibasami et al 1998
Green tea extract/ECG	Ehrlich ascites tumor cell line	Decrease cell thiol status and cell viability by SH groups	Kennedy et al 1999
Catechins, gallates, theflavins	Various	Review on various antimutagenic and carcinogenic properties, by a multitude of mechanisms	Kuroda et al 1999
EC, myricetin, quercetin	MCF-7 breast cancer cell line	Differential effects on proliferation, morphology, and detoxification enzyme activity, alter metabolic activation of carcinogens	Rodgers et al 1998
Flavonols	Human (diabetic) lymphocytes	Ex vivo protection against H_2O_2-induced DNA damage, independent of plasma antioxidant status	Lean et al 1999
Quercetin	a) Human endolethial cells	a) Inhibition PMA and TNF-α induced ICAM-1 expression by AP-1 and JNK, anti-inflammatory	a) Kobuchi et al 1999
	b) HepG2 cell line	b) Inhibition H_2O_2-induced NF- *κ*B binding activity, 8-oxodG and DNA strand breaks	b) Musonda et al 1998
	c) LPS-activated RAW 264.7 macrophage cell line	c) Inhibition LPS-activated NO production possibly by iNOS enzyme expression	c) Kim et al 1999
	d) MCF-7 breast cancer cell line	d) Inhibition estrogen and TGF-induced growth stimulation by antiestrogen action	d) Miodini et al 1999
	e) Rat hepatic stellate and Kupfer cells	e) Suppression of growth factor/LPS-induced responses (e.g., cell proliferation, α-actin expression, MAP-kinase activation, TNF-α excretion, NO production)	e) Kawada et al 1998
		f) Cell cycle arrest, blocking of IP3 signaling, synergy with genestein	f) Shen et al 1997
	f) OVCAR-5 cell line	g) Hypoxanthine-xanthine oxidase, H2O2, 1-chloro-2,4-dinitrobenzene, aminotriazole-induced cell damage by lipid peroxidation, not direct ROS scavenging	g) Kuhlamann et al 1998
	g) Renal tubular epithelial LLC-PK1 cell line		

(Singh et al., 2006). Afaq et al. (2004) indicated that tea consumption promotes healthy changes in obesity, longevity, osteoporosis, neural function, and fecal odor. The health benefits associated with green tea

consumption have also been corroborated in animal studies of cancer chemoprevention, hypercholesterolemia, atherosclerosis, Parkinson's disease, Alzheimer's disease, and other aging-related disorders (Zaveri et al., 2006).

CONCLUSIONS

Dietary habits influence the risk of developing a variety of diseases, especially cancer and heart disease. The use of dietary substances is receiving increasing attention as a practical approach for reducing the risk of developing these diseases. Tea may play an active role in the prevention of certain kinds of disorders, especially chronic diseases in humans. The utilization of tea and tea products for prevention is promising. Epidemiologic observations and laboratory studies have indicated that tea consumption may have beneficial effects in reducing certain types of cancer in some populations. Although a considerable body of information provides evidence supporting the preventive potential of tea against cancer, a proper understanding of the mechanisms by which tea polyphenols reduce the risk of diseases is necessary to devise strategies for better health. Catechins are more and more recognized as responsible for the strong antioxidant activity, and the anti-cancer, anti-atherosclerosis, anti-inflammatory, and anti-diabetes properties of tea extracts. Black tea is the major form of tea consumed, but its chemistry, biological activities, and chemopreventive properties, especially of the polyphenols that are present, are not well defined. Because the epidemiologic studies and research findings in laboratory animals have shown the chemopreventive potential of tea polyphenols in cancer, the usefulness of tea polyphenols for humans should be evaluated in clinical trials. Because information on the bioavailability of tea polyphenols after tea consumption is limited in humans, studies on absorption, distribution, and metabolism of green and black tea polyphenols in animals and humans are needed. After careful evaluation of the available data and additional studies, specific recommendations may be made for consumption of tea by humans. The usefulness of tea polyphenols may be extended by combining them with other consumer products, such as food items and vitamin supplements. This “designer-item” approach may be useful for the human population. What needs to be further investigated includes the determination of the active constituent, elucidation of the basic mechanism of action, and the evaluation of clinical effectiveness. Modern medical research has provided a wide range of evidence that tea may be effective in therapy. For example, tea and its polyphenol components display cytotoxicity to cancer cells and show therapeutic efficacy against tumor growth in experimental animals. Another example is that due to its antimicrobial activity tea seems to be useful for treating certain kinds of infections. Moreover, tea may be used as biochemical modulator to enhance the therapeutic effectiveness of other drugs. It is still premature to say tea indeed is a panacea and that all problems relating to its medicinal values have been resolved. But it is correct to say that great progress has been made and more in store. The progress made so far rests on the salient work as described above, and a sense of strategic policy is needed to fully explore the untapped potentials of tea. For the purpose of therapeutic application, it is essential to identify and isolate the active constituent, to evaluate the therapeutic efficacy with relevant models, and to detect the possible toxic effects before entering clinical trials.

REFERENCES

Afaq F, Adhami VM, Ahmad N, Mukhtar H (2004). Health benefits of tea consumption. (eds): Wilson T, Temple NJ, Jacobs DR, Jr. Beverages in Nutr. Health, pp. 143-156.

Agarwal R, Katiyar SK, Khan SG, Mukhtar H (1993). Protection against ultraviolet B radiation-induced effects in the skin of SKH-1 hairless mice by a polyphenolic fraction isolated from green tea. Photochem. Photobiol., 58: 695-700.

Antony JIX, Shankaranaryana ML (1997). Polyphenols of green tea. Int. Food Ingred., 5: 47-50.

Balentine DA (1997). Introduction: tea and health. Crit. Rev. Food Sci. Nutr., 8: 691-669.

Banerjee B (1992). Tea as a health drink. Co-ordination Committee of Planets Association, Kolkata.

Buzzini P, Vignolini P, Goretti M, Turchetti B, Branda E, Marchegiani E, Pinelli P, Romani A (2009). Green tea catechins: a class of molecules with antimicrobial activity. Handbook of Green Tea and Health Research. Publisher: Nova Science Publishers, Inc. Hauppauge, NY, pp. 23-43.

Cao H, Qin B, Panickar KS, Anderson RA (2008). Tea and cinnamon polyphenols improve the metabolic syndrome. Agro. Food Ind. Hi Tech., 19: 14-17.

Cadenas E, Packer L (2002). Handbook of Antioxidants (eds). Taylor and Francis, pp. 381-382.

Chen ZP, Schell JB, Ho CT, Chen KY (1998). Green tea epigallocatechin gallate shows a pronounced growth inhibitory effect on cancerous cells not on their normal counterparts. Cancer Lett., 129: 173-179.

Diker KS, Akan M, Hascelik G, Yurdako KM (1991). The bactericidal activity of tea against *Campylobacter jejuni* and *Campylobacter coli*. Lett. Appl. Microbiol., 12: 34-35.

Diker KS, Hascelik G (1994). The bactericidal activity of tea against Helicobacter pylori. Lett. Appl. Microbiol., 19: 299-300.

Dreaosti IE, Wargovich MJ, Yang CS (1997). Inhibition of carcinogenesis by tea: the evidence from experimental studies. Crit. Rev. Food Sci. Nutr., 37: 761-770.

Dubick MA, Omaye ST (2001). Modification of atherogenesis and heart disease by grape wine and tea polyphenols. Handbook of Nutraceuticals and Functional Foods. (eds) Wildman REC, CRC Press, pp. 235-260.

Evensen NA, Braun PC (2009). The effects of tea polyphenols on *Candida albicans*: Inhibition of biofilm formation and proteasome inactivation. Can. J. Microbiol., 55: 1033-1039.

Fujita T (1994). Osteoporosis in Japan: factors contributing to the low incidence of hip fracture. Adv. Nutr. Res., 9: 89-99.

Gutman RL, Ryu BH (1996). Rediscovering tea. An exploration of the scientific literature. HerbalGram, 37: 33-48.

Gupta J, Siddique YH, Beg T, Ara G, Afzal M (2008). A review on the beneficial effects of tea polyphenols on human health. Int. J. Pharmacol., 4: 314-338.

Hara Y, Luo SJ, Wickremashinghe RL, Yamanishi T (1995a). Botany (of tea). Food Rev. Int., 11: 371-374.

Hara Y, Luo SJ, Wickremashinghe RL, Yamanishi T (1995b). IV. Processing tea. Food Rev. Int., 11: 409-434.

Hara Y, Luo SJ, Wickremashinghe RL, Yamanishi T (1995c). V.

Chemical composition of tea. Food Rev. Int., 11: 435-456.
Hara Y, Luo SJ, Wickremashinghe RL, Yamanishi T (1995d). VI. Biochemistry of processing black tea. Food Rev. Int., 11: 457-471.
Hara Y, Luo SJ, Wickremashinghe RL, Yamanishi T (1995e) VIII. Flavor of tea. Food Rev. Int., 11: 477-525.
Hara Y, Luo SJ, Wickremashinghe RL, Yamanishi T (1995f). IX. Uses and benefits of tea. Food Rev. Int., 11(11): 527-542.
He Q, Lu Y, Yao K (2006). Effects of tea polyphenols on the activities of α-amylase, pepsin, trypsin and lipase. Food Chem., 101: 1178-1182.
Hibasami H, KomiyaT, Achiwa Y, Ohnishi K, Kojima T, Nakanishi K, Akashi K, Hara Y (1998). Induction of apoptosis in human stomach cancer cells by green tea catechins. Oncol. Rep., 5: 527-529.
Ho HY, Cheng ML, Weng SF, Leu YLC, Tsun YD (2009). Antiviral Effect of Epigallocatechin Gallate on Enterovirus 71. J. Agric. Food Chem., 57: 6140-6147.
Hollman PC, Tijburg LB, Yang CS (1997). Bioavailability of flavonoids from tea. Crit. Rev. Food Sci. Nutr., 37: 719-38.
Horiba N, Maekawa Y, Ito M, Matsumoto T, Nakamura H (1991). A pilot study of Japanese green tea as a medicament: Antibacterial and bactericidal effects. J. Endod., 17: 122-124.
Horiuchi Y, Toda M, Okubo S (1992). Protective activity of tea and catechins against Bordetella pertusis, Kansenshogaku Zasshi, 66: 599-605.
Ju J, Lu G, Lambert JD, Yang CS (2007). Inhibition of carcinogenesis by tea constituents. Semin. Cancer Biol., 17: 395-402.
Imai K, Nakachi K (1995). Cross sectional study of effects of drinking green tea on cardiovascular and liver diseases. Br. Med. J. Clin. Res., 310: 693-696.
Ishigami T, Hara Y (1993). Proc. Intern. Tea Sci. Tea Sci., Human Health, Calcutta, India, 125.
Kakuda T, Takihara T, Sakane I, Mortelmans K (1994). Antimicrobial activity of tea extracts against peridontopathic bacteria. Nippon Nogeikagaku Kaishi, 68: 241-243.
Kaneko T, Matsuo M, Baba N (1990). Inhibition of linoleic acid hydroperoxide-induced toxicity in cultured human umbilical vein endothelial cells by catechins. Chem. Biol. Interact., 114: 109-119.
Kao PC, P'eng FK (1995). How to reduce the risk factors of osteoporosis in Asia. Zhonghua Yi Xue Za Zhi (Taipei), 55: 209-213.
Katiyar SK, Agarwal R, Wood GS, Mukhtar H (1992). Inhibition of 12-*O*-tetradecanoylphorbol- 13-acetate-caused tumor promotion in 7,12-dimethylbenz[*a*]anthracene-initiated SENCAR mouse skin by a polyphenolic fraction isolated from green tea. Cancer Res., 52: 6890-6897.
Katiyar SK, Agarwal R, Ekker S (1993). Protection against 12-*O*tetradecanoylphorbol-13-acetate-caused inflammation in SENCAR mouse ear skin by polyphenolic fraction isolated from green tea. Carcinog., 14: 361-365.
Katiyar SK, Elmets CA, Agarwal R, Mukhtar H (1995). Protection against ultraviolet-B radiation-induced local and systemic suppression of contact hypersensitivity and edema responses in C3H/HeN mice by green tea polyphenols. Photochem. Photobiol., 62: 855–861.
Katiyar SK, Rupp CO, Korman NJ, Agarwal R, Mukhtar H (1995). Inhibition of 12-*O*-tetradecanoylphorbol-13-acetate and other skin tumorpromoter-caused induction of epidermal interleukin-1 alpha mRNA and protein expression in SENCAR mice by green tea polyphenols. J. Invest. Dermatol., 105: 394-398.
Katiyar SK, Mukhtar H (1996). Tea in chemoprevention of cancer: epidemiologic and experimental studies. Int. J. Oncol., 8: 221-238.
Kawada N, Seki S, Inoue M, Kuroki T (1998). Effects of antioxidants, resveratrol, quercetin, and N-acetylcysteine on the functions of cultured rat hepatic stellatw cells and Kupffer cells. Hepatology, 27: 1265-1274.
Kawakami M (1997). Comparison of extraction techniques for characterizing tea aroma and analysis of tea by GC-FTIR-MS. In: Plant volatile analysis Linskens, HF and Jackson JF. (eds) Springer, Saladruck, Berlin, pp. 211-229.
Kennedy DO, Matsumoto M, Kojima A, Matsui YI (1999). Cellular thiol status and cell death in the effect of green tea polyphenols in Ehlrich ascites tumor cells. Chem. Biol. Interact., 122: 59-71.
Kim HK, Cheon BS, Kin YH, Kim SY, Kim SP (1999). Effects of naturally occurring flavonoids on nitric oxide production in the macrophage cell line RAW 264.7 and their structure-activity relationships. Biochem. Pharmacol., 58: 759-765.
Kobuchi H, Roy S, Sen CK, Nguyen HG, Packer L (1999). Quercetin inhibits inducible ICAM-1 expression in human endolethial cells through the JNK pathway. Am. J. Physiol. Cell Physiol., 46: C403-C411.
Kohlmeier L, Weterings KGC, Steck S, Kok FJ (1997). Tea and cancer prevention: An evaluation of the epidemiologic literature. Nutr. Cancer, 27: 1-13.
Kuhlmann MK, Burkhardt G, Horsch E, Wagner M, Kohler H (1998). Inhibition of oxidant-induced lipid peroxidation in cultures renal tubular epilethial cells (LLC-PK1) by quercetin. Free Radic. Res., 29: 451-460.
Kuroda Y, Hara Y (1999). Antimutagenic and anticarcenogenic activity of tea polyphenols. Mutat. Res., 436: 69-97.
Lambert JD, Elias RJ (2010). The antioxidant and pro-oxidant activities of green tea polyphenols: A role in cancer prevention. Arch. Biochem. Biophys., 501: 65-72.
Lea AGH, Arnold GM (1978). The phenolics of cider: bitterness and astringency. J. Sci. Food Agric., 20: 478-448.
Lean MEJ, Noroozi M, Kelly I, Burns J, Talwar D, Sattar N, Crozier A (1999). Dietary flavonols protect diabetic human lymphocytes against oxidative damage to DNA. Diabetes, 48: 176-181.
Lee I, KimYH, Kang MH (1997). Chemopreventive effects of green tea against cigarette smoke induced mutations in humans. J. Cell. Biochem., 27: 168.
Lee VSY, Chen CR, Lio YW, Tzen JTC, Chang CI (2008). Structural determination and DPHH radical scavenging activity of two acylated tetraglycosides in Oolong Tea. Chem. Pharm. Bull., 56: 851-853.
Liang Y, Lu J, Zhang L, Wu S, Wu Y (2003). Estimation of black tea quality by analysis of chemical composition and colour difference of tea infusions Food Chem., 80: 283-290.
Lin YL, Lin JK (1997). (-) Epigallocatechin-3-gallate blocks the induction of nitric oxide synthase by downregulating lipopolysaccharide induced activity of transcription factor nuclear factor-kappa B. Mol. Pharmacol., 52: 465-472.
Liu ZH, Huang XY, Shi ZP (1990). Relationship between pigments and the colors of black tea and oolong tea (Chines) (Cha Ye Ke Xue). J. Tea Sci., 9: 141-158.
Matsuo N, Yamada K, Yamashita K, Shoji K, Mori M, Sugano M (1996). Inhibitory effect of tea polyphenols on histamine and leukotriene B-4 release from rat peritoneal exudates cells. *In vitro* Cell Dev. Biol., 32: 340-344.
Miodini P, Fioravanti L, Di FG, Cappelletti V (1999). The two phytoestrogens genestein and quercetin exert different effects on oestrogen receptor function. Br. J. Cancer, 80: 1150-1155.
Mitscher LA, Jung M, Shankel D, Dou JH, Steele L, Pillai S (1997). Chemoprotection: a review of the potential therapeutic antioxidant properties of green tea (*Camellia sinensis*) and certain of its constituents. Med. Res. Rev., 17: 327-365.
Molan AL, De S, Meagher L (2009). Antioxidant activity and polyphenol content of green tea flavan-3-ols and oligomeric proanthocyanidins. Int. J. Food Sci. Nutr., 60: 497-506.
Moncrieff RW (1967). The chemical senses, 3rd Ed., Leonard Hill Press, London, pp. 58-59.
Mukhtar H, Ahmad N (2000). Tea Polyphenols: prevention of cancer and optimizing health. Am. J. Clin. Nutr., 71 (suppl): 1698S-1702S.
Mulder GJ (1838). Chemische untersuchung des chinesischenund javanischen Thees. Ann. Phys. Chemie Leipzig XII, (161): 161-180.
Musonda CA, Chipman JK (1998). Quercetin inhibits hydrogen peroxide induced NF-kappa B DNA binding activity and DNA damage in HepG2 cells. Carcinog., 19: 1583-1589.
Nagabayashi T (1992). Chemistry and function of green tea, black tea and oolong tea. Hong-Xie Publisher, Japan.
Nakagawa M (1970). Constituents in tea leaf and their contribution to the taste of green tea liquors. Jpn. Agric. Res. Q., 5: 43-47.
Nakagawa M (1975). Chemical components and taste of green tea. Jpn. Agr. Res. Q., 9: 156-160.
Nakayama M, Toda M, Okubo S, Shimamura T (1990). Inhibition of influenza virus infection by tea. Lett. Appl. Microbiol., 11: 38–40.
Nonaka G, Kawahara O, Nishioka I (1983). Tannins and related compounds.XV. A new class of dimeric flavan-3-ol gallates,

theasinensins A and B, and proanthocyanin gallates from green tea leaf. (I). Chem. Pharm. Bull., 31: 3906.
Numata O, Fujiwara T, Hosoda K, Ozawa T (2006). Polymeric polyphenol extracted from fermented tea, therapeutic agent for mitochondrial disease, preventive/therapeutic agent for diabetes mellitus, and food or beverage. PCT Int. Appl. WO 2006049258, 32 p.
Okubo T, Juneja R (1997). Effects of green tea polyphenols on human intestinal microflora. In T. Yamamoto, L. R. Juneja, D.-C. Chu, M. Kim, Chemistry and Applications of Green Tea. Salem: CRC Press LLC, pp. 109-122
Rodgers EH, Grant MH (1998). The effect of the flavonoids, quercetin, myricetin, and epicatechin on the growth and enzyme activity of MCF7 human breast cancer cells. Chem. Biol. Interact., 116: 213-228.
Sabu MC, Smitha K, Ramadasan K (2002). Anti-diabetic activity of green tea polyphenols and their role in reducing oxidative stress in experimental diabetes. J. Ethnopharmacol., 83: 109-116.
Sanderson GW, Kanadive AS, Eisenburg LS (1976). Contribution of polyphenolic compounds to the taste of green tea. In Charala, M. and Katz, I., (eds), Phenolic, Sulfur and Nitrogen compounds in Food Flavour, ACS Symposium Series, No 26, American Chemical Society, Washington, pp. 14-46.
Sadzuka Y, Sugiyama T, Hirota S (1998). Modulation of cancer chemotherapy by green tea. Clin. Cancer Res., 4: 153-156.
Sakanaka S, Kim M, Taniguchi M, Yamamoto T (1989). Antibacterial substances in Japanese green tea extract against Streptococcus mutants, a carcinogenic bacterium. Agric. Biol. Chem., 53: 2307-2311.
Sakanaka S, Kim M, Taniguchi M, Yamamoto T (1990). Inhibitory effects of green tea polyphenols on glucan synthesis and cellular adherence of cariogenic Streptococci. Agric. Biol. Chem., 54: 2925-2929.
Sakanaka S, Aizawa M, Kim M, Yamamoto T (1996). Inhibitory effects of green tea polyphenols on growth and cellular adherence of an oral bacterium, *Porphyromonas gingivalis*. Biosci. Biotechnol. Biochem., 60: 745-749.
Sakanaka S, Kim M (1997). Suppressive effect of uremic toxin formation by tea polyphenols. In T. Yamamoto, L. R. Juneja, D.-C. Chu, and M. Kim, Chemistry and applications of green tea, Salem: CRC Press LLC, pp. 75-86.
Schreier P (1988). Analysis of black tea volatiles. In: Linskens H.F. and Jackson J.F. (eds) Analysis of Nonalcoholic Beverages, Springer, Saladruck, Berlin, pp. 296-320.
Shallenberger RS (1993). Taste Chemistry, Chapman and Hall, London, UK, pp. 5-20.
Shen F, Weber G (1997). Synergistic action of quercetin and genestein in human ovarian carcinoma cells. Oncol. Res., 9: 597-602.
Shimoda M, Shiratsuchi H, Osajima Y (1995). Comparison of the odor concentrates by SDE and adsorptive column method from green tea infusion. J. Agric. Food Chem., 43: 1616-1620.
Singh J, Qazi GN (2006). Immunomodulatory activity of tea. Editor(s): Jain, Narender K.; Siddiqi, Maqsood; Weisburger, John. Protective Effects of Tea on Human Health. Publisher: CAB International, Wallingford, UK CODEN: 69KBMY Conference; General Review written in English, pp. 34-44.
Singh R, Akhtar N, Haqqi TM (2010). Green tea polyphenol epigallocatechin-3-gallate: Inflammation and arthritis. Life Sci., 86: 907-918.
Stensvold I, Tverdal A, Solvoll K, Foss OP (1992). Tea consumption: relationship to cholesterol, blood pressure, and coronary and total mortality. Prev. Med., 21: 546-553.
Tamura S, Ishima N, Saito E (1969). Proceedings of Japanese Symposium on taste and smell, 3: 3-5.
Takayangi H, Anan T, Ikegaya K (1984). Chemical composition of oolong tea and pouching tea, Tea Res. J., 60: 54-68.
Takeo T (1996). The relation between clonal characteristic and tea aroma. FFI J., 168: 35-45.
Takei Y, Ishiwata K, Yamanishi T (1976). Aroma components characteristic of spring green tea. Agric. Biol. Chem., 40: 2151-2157.
Tao P (1992). The inhibitory effects of catechin derivatives on the activities of human immunodeficiency virus reverse transcriptase and DNA polymerases. Zhongguo Yi Xue Ke Xue Yuan Xue Bao, 14: 334-338.
Terada A, Hara H, Nakajyo S (1993). Effect of supplements of tea polyphenols on the caecal flora and caecal metabolites of chicks. Microb. Ecol. Health Dis., 6: 3-9.
Thelle DS (1995). Coffee, tea and coronary heart disease. Curr. Opin. Lipidol., 6: 25-27.
Tijburg LBM, Wiseman SA, Meijer GW, Weststrate JA (1997). Effects of green tea, black tea and dietary lipophilic antioxidants on LDL oxidizability and atherosclerosis in hypercholesterolaemic rabbits. Atheroscler., 135: 37–48.
Toda M, Okubo S, Hiyoshi R, Tadakatsu S (1989). The bactericidal activity of tea and coffee. Lett. Appl. Microbiol., 8: 123-125.
Toda M, Okubo S, Ikigai H, Suzuki T, Suzuki Y, Shimamura T (1991). The protective activity of tea against infection by Vibrio cholerae. J. Appl. Bacteriol., 70: 109-112.
Wang H, Xu J, Deng F, Hu Z (2007). Natural extract of green tea for inhibiting hepatitis B virus and its primary active ingredient. Faming Zhuanli Shenqing Gongkai Shuomingshu, CN 101028382, 9pp.
Wang Y, Xu P, Li L, Zhang X, Shou Z, Yang X (2010). Research on total antioxidant activity of tea polyphenols and other natural antioxidants. Chaye Kexue, 30: 109-114.
Weisburger JH (1996). Tea antioxidants and health. In: Cadenas E, Packer L, eds. Handbook of antioxidants. New York: Marcel Dekker, pp. 469–486.
Weisburger JH (2000). Tea. In: The Cambridge World History of Food. Eds: K. Kipple and K. C. Orneals). Cambridge Univ. Press. Cambridge, pp. 712-720.
Yamaguchi K, Shibamoto T (1981). Volatile constituents of green tea Gyokuro (Camellia sinensis L. Var. Yubikita). J. Agric. Food Chem., 29: 366-370.
Yamanishi T (1978). Flavour of green tea. Japan Agric. Res. Q., 12: 205-210.
Yamanishi T (1995). Flavor of tea. Food Rev. Int., 11: 477-525.
Yamanishi T (1996). Tea aroma. FFI J., 168: 23-34.
Yang Z, Xu Y, Jie G, He P, Tu Y (2007). Study on the antioxidant activity of tea flowers (Camellia sinensis). Asia Pac. J. Clin. Nutr., 16(Suppl. 1): 148-152.
Yang CS, Wang X (2010). Green Tea and Cancer Prevention. Nutr. Cancer, 62: 931-937.
Yokogoshi H, Kato Y, Sagesaka MY, Takihara MT, Kakuda T, Takeuchi N (1995). Reduction effect of theanine on blood pressure and brain 5-hydroxyindoles in spontaneously hypertensive rats. Biosci. Biotechnol. Biochem., 59: 615-618.
Yokozawa T, Oura H, Nakagawa H, Sakanaka S, Kim M (1995). Effects of a component of green tea on the proliferation of vascular smooth muscle cells. Biosci. Biotechnol. Biochem., 59: 2134-2136.
Yokozawa T, Chung H, Young H, Li Q, Oura H (1996). Effectiveness of green tea tannin on rats with chronic renal failure. Biosci. Biotechnol. Biochem., 60: 1000-1005.
Yokozawa T, Dong E, Chung HY, Oura H, Nakagawa H (1997). Inhibitory effect of green tea on injury to a cultured renal epithelium cell line, LLC-PK. Biosci. Biotechnol. Biochem., 61: 204-206.
Yokozawa T, Dong E, Nakagawa T, Kashiwagi H, Nakagawa H, Takeuchi S, Chung HY (1998). In vitro and in vivo studies on the radical-scavenging activity of tea. J. Agric. Food Chem., 46: 2143-2150.
Young SK, Mu JK, Jeong OK, Jong HL (1994). The effect of hot water extract and flavor compounds of mugwort on microbial growth. J. Korean Soc. Food Nutr., 23: 994-1000.
Zeyuan D, Bingying T, Xiaolin L, Jinming H, Yifeng C (1998). Effect of green tea and black tea on the blood glucose, the blood triglycerides, and antioxidation in aged rats. J. Agric. Food Chem., 46: 875-878.
Zaveri NT (2006). Green tea and its polyphenolic catechins: Medicinal uses in cancer and noncancer applications. Life Sci., 78: 2073-2080.
Zhen Y (2002a). Tea-Bioactivity and Therapeutic Potential (ed). Taylor and Francis, NY, p. 60.
Zhen Y (2002b). Tea-Bioactivity and Therapeutic Potential (ed). Taylor and Francis, NY, p. 58.
Zhen Y (2002c). Tea-Bioactivity and Therapeutic Potential (ed). Taylor and Francis, NY. P. 89