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TEA POLYPHENOLS – THEIR ANTIOXIDANT PROPERTIES AND BIOLOGICAL ACTIVITY – A REVIEW

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Tea is the most widely consumed beverage in the world. Tea leaves are a source of polyphenols, especially catechins, a decisive group for their antioxidative activity. This paper reviews what is known of green tea species, its leaves processing and changes occurring in tea components. The main green tea polyphenols are catechins: (±)-catechin C, (-)-epicatechin EC, (+)-gallocatechin GC, (-)-epigallocatechin EGC, (-)-epicatechin gallate ECG, and (-)-epigallocatechin gallate EGCG. Antioxidant and antimicrobial activity of these compounds and crude extracts of teas are described. The review highlights also the potentials of green tea, its health benefits in terms of antimutagenic and anticarcinogenic properties as well as protective agents against cardiovascular diseases.

INTRODUCTION

Chemical compounds that are naturally occurring dietary components and their influence on human body are more and more interesting for scientists. Polyphenols, biologically active compounds of plant origin, are classified as non–nutrients. An average daily intake of polyphenols with the diet is approximatively 1 gram, which can be important in fighting free radicals activity in human body [Scalbert & Williamson, 2000]. Recent research have shown the antioxidant potential of food constituents. Numerous epidemiological studies have indicated that food and beverages rich in polyphenols are an important factor in preventing diseases, decreasing mortality from cardiovascular and meoplastic diseases, and slowing down the aging processes [Di Carlo *et al.*, 1999]. Green tea contains relatively large amounts of polyphenols, mainly catechins and their derivatives, considered to exert a protective effect against cancer and cardiovascular diseases. As tea is one of the most popular beverages, it could be a tremendously important source of polyphenolic constituents.

TEA'S PROFILE

Tea is an evergreen shrub or tree from Theaceae family, species *Camelia*. Its leaves are dark green and shiny, opposite and round, flowers are large, white, pink or red and fruits small and brown. Two basic botanical varieties include: Chinese tea's shrub (*Camelia sinensis*) as well as Indian tea tree (*Camelia assamica*) [Balentine *et al.*, 1997; Chu & Juneja, 1997]. Tea is grown in a number of countries, however mainly in China, India, Japan and on Ceylon [Fernandez *et al.*, 2002]. Harvesting lasts throughout the year yet its time influences the quality of tea leaves. The best teas are from the spring collection as then they are delicate and the most aromatic, top grade teas, however, are gained from undeveloped leaves and young leaflets of top twigs, which, further prepared, show suitable gustatory features and special aroma [Chu & Juneja, 1997]. According to Chinese mythology, a tea plant was discovered thousands years ago in South-East Asia. Initially tea leave infusion has been considered for medicine, later on it became the most popular beverage all over the world. Tea market is very rich. Over three hundred tea species are produced. The basic classification includes three categories of teas: green, oolong and black [Harbowy & Balentine, 1997]. According to *The Tea Council*, the world production of tea in 1998 was 2.96×10^6 tones, and US Food and Drug Administration claims that in 1999 it was 2.87×10^6 tones. In the annual output about 20% is constituted by green tea, and over 70% – by black tea. According to Mukhtar and Ahmad [1999], at present the average tea consumption reaches about 120 mL/day/person. The preferences in tea consumption are different in various regions of the world. Most Americans and Europeans prefer black tea; the Japanese and Northern China inhabitants prefer green tea. Oolong tea is mainly consumed in Taiwan and Southern China.

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TECHNOLOGICAL PROCESSING OF TEA LEAVES – THE TEA TYPES

Processed tea leaves were classified into three types, in respect of different fermentation degree: non-fermented (green), semi-fermented (oolong) as well as entirely fermented (black) [Chu & Juneja, 1997]. The process of tea production depending on its kind consists of four basic stages. Collected shrub or tree tea leaves undergo partial withering. Then the leaves are roasted to inactivate oxidative enzymes, rolled up, dried and sorted. The colour of the final product tea is green, its taste is gentle and constringent. In China, the taste of green tea is improved by the addition of jasmine flowers. The process of black tea production is more complicated. The leaves are also subjected to withering during which the first fermentation processes occur. Next, they are rolled up and undergo fermentation. Fermented leaves are roasted, until the dark-brown or black colour, thereafter a suitable aroma appears. Blocking the activity of enzymes (polyphenol oxidase and glycosidase) as well as stopping the fermentation is the aim of roasting [Chu & Juneja, 1997; Lin *et al.*, 1998a]. Semi fermented tea – oolong – is partially fermented tea with considerably shorter fermentation time than the black one [Balentine *et al.*, 1997].

TEA POLYPHENOLS

Tea leaves are, apart from wine, fruit and vegetables, a very good source of polyphenolic compounds [Ho *et al.*, 1997]. Green tea leaves consist of flavonoids as well as phenolic acids which can make up to 30% of fresh leaves dry weight and only 10% of dry weight of black tea [Wang *et al.*, 2000]. Those constituents are referred to as bioflavonoids or vitamin P, as they show a wide spectrum of biological effects in living organisms [Dreosti, 1996]. The most important polyphenol groups tea leaves are substances whose nomenclature is still a divergence. These compounds are offen referred to as flavan-3-ols or catechins [Balentine, 1997]. Tea leaves have been reported to be the only food product containing epigallocatechin gallate (EGCG) [Chu & Juneja, 1997].

In tea leaves three basic polyphenol groups can be distinguished: catechin, theaflavins and thearubigenes [Yanishlieva-Maslarowa & Heinonen, 2001]. Both green and black tea contains a similar quantity of flavonoids, differing in respect of their chemical structures. Green tea is characterised by a higher content of simple flavonoids – catechins which become transformed to more complex compounds (theaflavins and thearubigens) during the fermentation of tea leaves [Balentine *et al.*, 1997]. Other products of polyphenol oxidation are tannins. Tannins were divided into two groups: hydrolysable, water-soluble, including simple phenolic acids, gallic acid esterified into the polyols, and nonhydrolysable tannins (condensed), the polymers of elementary flavonoids particles [Chung *et al.*, 1998].

Catechins are flavan derivatives and in a group of flavonoids they are distinguished by the highest oxidation degree of heterocyclic ring and by good solubility in water. In tea leaves, they appear mainly in the form of gallic acid esters. The main catechins of green tea are: (+)-catechin (C), (-)-epicatechin (EC), (-)-gallocatechin (GC), (-)-epicatechin gallate (ECG), (-)-epigallocatechin (EGC), (-)-epigallocatechin gallate (EGCG) [Ninomiya *et al.*, 1997]. The structural formula of catechin was introduced in Figure 1.

The presence of methylated catechins was reported by Saijo *et al.* [1982] and Sano *et al.* [1999]. According to mass spectrometry and nuclear magnetic resonance two catechins derivatives were identified as (-)-epigallocatechin–3-(3-*O*--methylgallate) and as (-)-epigallocatechin-3-(4-*O*-methylgallate) [Amarowicz & Shahidi, 2003]. TLC separation of methylated EGCG was reported by Amarowicz *et al.* [2005a].

The content of proanthocyanidins in green tea is at least 10 times lower than catechins [Hashimoto *et al.,* 1992]. Four dimeric proanthocyanidin gallates (prodelphidin B-2 3'-*O*--gallate, procyanidins B-2 3,3'-di-*O*-gallate, B-2 3'-*O*-gallate, and B-4 3'-*O*-gallate) and two dimeric flavan-3-ol gallates in which two flavanol units are linked at the B-ring have been reported by Nonaka *et al*. [1984]. At least 12 proanthocyanidins were identified in green tea samples by means of HPLC-MS and HPLC-DAD [Kiehne *et al.*, 1997]. Among them EGC-EGCG, EC-EC-EC, EC-EGC, EGC--EGC, EGCG-EGCG, EC-ECG, EGCG-ECG, ECG--EGCG, ECG-ECG were present.

EGCG is an extremely active compound with eight -OH groups determining its high antioxidant activity. Investigations have shown that green tea contains a larger quantity of catechins than the black one [Khokhar & Magnusdottir, 2002]. In contrast, black teas contain a larger quantity of gallic acid, which is likely to be released during fermentation from catechin gallates [Halder *et al.*, 1998]. The content of catechins in tea leaves is also a result of multiple factors, leaf age, because tea produced from young leaves contains considerably larger quantities of these compounds. The content of EC, EGC, EGCG, and ECG in eight commercial green teas determined by Price and Spitzer [1993] reached 0.87–2.0%, 2.75–5.44%, 2.19–3.95%, 0.56–0.91%, respectively (results in % w/w). Mukhtar and Ahmad [1999] studied the polyphenolic composition of tea leaves infusion. They showed that the cup of green tea infusion contained about 400 mg of polyphenolic antioxidants, of which 200 mg was EGCG. On the contrary, while Graham [1992] reported, that a cup of green tea infusion might contain about 90 mg of EGCG. On the grounds of the above-mentioned data it is possible to believe that many factors influence the composition of tea leaves polyphenols as well as prepared infusion.

It was observed that the content of catechins in tea leaves is closely correlated with the quality of infusion. The highest content of catechins was noted in teas produced from young tea leaves [Thanaraj & Seshardi, 1990].

CHANGES OF TEA POLYPHENOLS DURING PROCESSING

During the fermentation of tea leaves the monomeric catechins are subject to the action of polyphenol oxidase [Halder *et al.*, 1998]. The activity of this enzyme causes oxidation of catechins to quinones which further undergo poly-

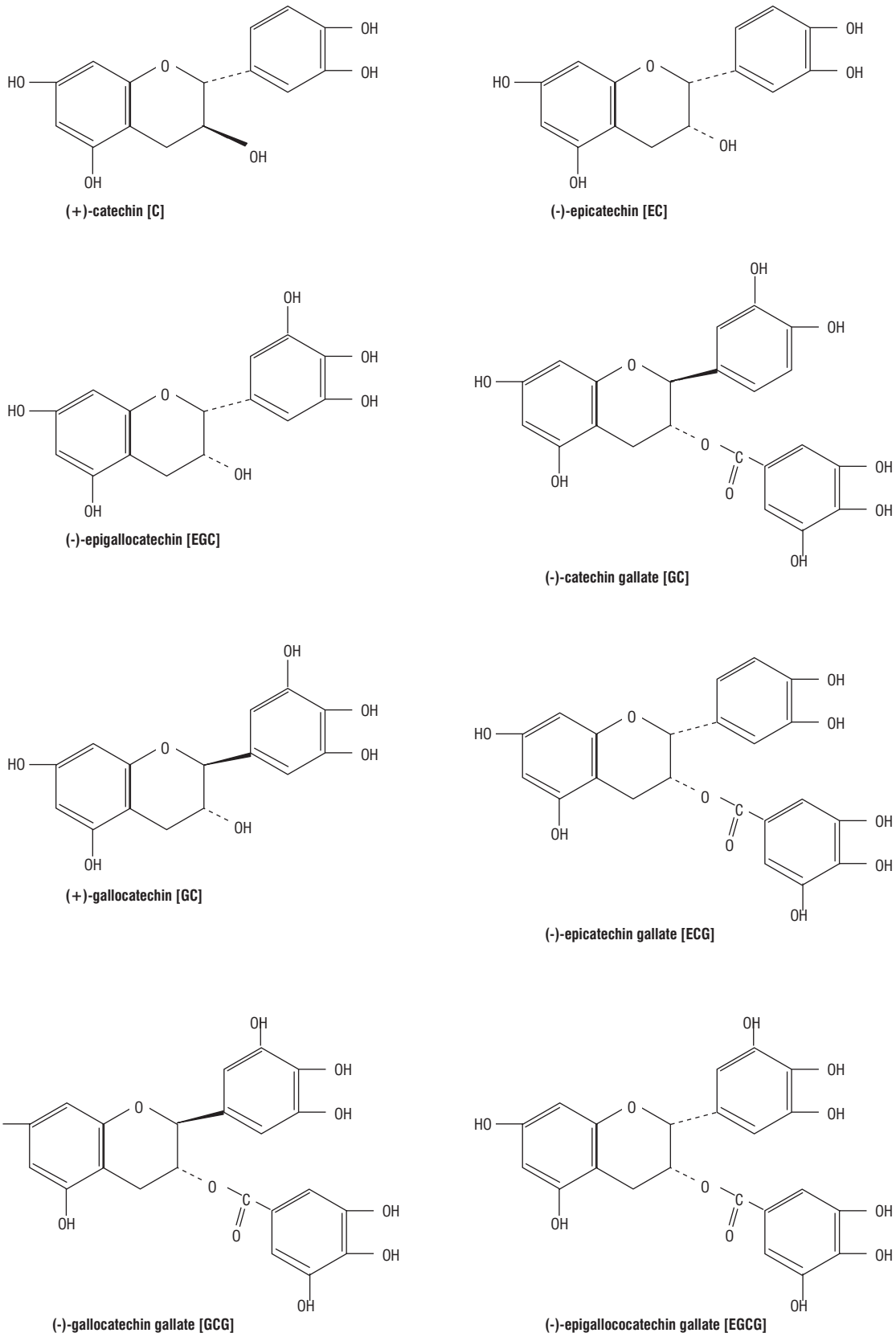

FIGURE 1. Chemical structure of green tea catechin.

merization to bisflavans and to more complex structures of theaflavins, thearubigens and higher molecular mass compounds [Lin *et al.*, 1998a; Bailey & Nursten, 1993]. Theaflavins and their gallates, appear in black tea due to oxidative condensation between (-)-epicatechin and (-)-epigallocatechin [Tanaka *et al.*, 2002]. Gradual lowering of flavanol content is another consequence of tea leaves fermentation process [Sava *et al.*, 2001]. Different investigations

have indicated that the process of fermentation influences the level of catechins in tea leaves, however the content of alkaloids becomes altered to a small extent [Schulz *et al.*, 1999]. The degree of tea fermentation was assumed as 0 to 85% (0% – green, 85% – black). On the grounds of the conducted analyses it was found that a catechin level (EGCG, EGC, ECG, EC, C and GCG) lowers gradually during fermentation, however, the level of gallic acid grows. The levels of theaflavins and thearubigens also decrease gradually, while the level of caffeine increases in the process of 85% fermentation from 8.69 to 16.03 mg/100 mg of leaf dry weight [Lin *et al.*, 1998a]. Transformations of polyphenols can be due to physical and chemical factors (temperature, oxygenation) or they can be the result of specific hydrolyzing enzymes affecting the phenolic compounds (β-glycosidase) and oxidizing these compounds (polyphenol oxidase) [Halder *et al.*, 1998]. In fermented leaves of tea, the activity of oxidative enzymes leads to the transformation of tannins and catechins to brown-black products. Some of these products show affinity to melanin [Sava *et al.*, 2001]. After obtaining suitable qualitative features tea leaves are dried to inhibit further oxygenation reactions. The inactivation of enzymes is the indispensable factor for product's stability during storage [Dougan *et al.*, 1979; Temple *et al.*, 2001].

FACTORS INFLUENCING CATECHIN CONTENTS IN TEA LEAVES EXTRACTS

Chen *et al.* [1996a] studied the influence of temperature and time of extraction on the content of polyphenols in oolong tea. They stated that the rise of catechin content was proportional to an increase in temperature and time. The highest quantity of catechins was extracted at a temperature of 77–80°C [Khokhar & Magnusdottir, 2002]. In other investigations it was found that high temperature of steam and tea leaves infusion (120°C, 30 min) causes epimerization of C, EGCG, ECG, EGC and EC which undergo conversion to suitable epimers: (-)-gallocatechin gallate (GCG), (-)- catechin gallate (CG), (-)-gallocatechin (GC) as well as (-)-catechin [Chen *et al.*, 2001]. During the investigations on catechin migration to infusion it was noticed that the smaller flavanols molecules: EC and EGC were extracted more quickly than EGCG and ECG. The efficiency of a hot aqueous extraction for catechins from green tea was not dissimilar to that for major flavour and colour components from black tea [Price & Spitzer, 1994]. The results of investigations show that with an increase in the pH of tea leaves infusion, its chemical composition changes considerably. A high decrease in theaflavins content was noted (from 30.7% in pH 4.9 to undetectable at pH 9.45). Secondly, the EGCG, ECG and EGC were reduced by about 97; 45.5 and 3.0%, respectively. However, the content of caffeine, gallic acid and epicatechin was observed to increase. The increase in epicatechin content may result from disintegration or separation from ECG and EGCG. The rise in caffeine content is linked with disintegration of the caffeine-theaflavins aggregate, as the theaflavins are degraded in alkaline medium [Spiro *et al.*, 1987; Liang & Xu, 2001]. Chen *et al.* [1998, 2001] analysed the influence of pH on the quantity of catechins in green tea infusion. The results suggest that the rise in medium pH causes the increase in catechins degradation. In alkaline medium catechins were unstable and almost totally disintegrated in several minutes, while at pH<4 they showed large stability [Zhu *et al.*, 1997; Friedman & Jurgens, 2000]. Their results are consistent with investigations of catechin stability in canned tea drinks. Moreover, ascorbic acid was shown to display better protective proprieties than citric acid. This is possibly due to the reducing properties of ascorbic acid protecting catechins and also lowering the concentration of dissolved oxygen in a solution, which can contribute to the rate of catechins decrease by the oxygenation process. It is believed that green tea catechins undergo degradation during the production and storage of drinks. Heating these drinks at a temperature of 98°C for 15 min, caused a decrease in catechin content by about 1–15%, the subsequent 6 h of heating caused a 5% decrease. Heating at 120°C for 20 min caused 23% degradation of catechins. Catechin content was also studied in the tea leaves infusions prepared several times. It decreased with every next infusion of tea leaves. Flavonols, however, were considerably more slowly released from tea leaves and their content decrease was lower [Wang *et al.*, 2000].

ANTIOXIDANT ACTIVITY OF TEA POLYPHENOLS

Results of numerous investigations have confirmed that flavanols isolated from green, black and red tea leaves possess very strong antioxidant proprieties (Table 1). Vastag [1998] found that a cup of tea leaves infusion is "the injection of antioxidants" showing a higher capability for scavenging free radicals than vitamin C and E.

Results of the early Japanese investigations on the antioxidant activity of catechins in oil systems were often contradictory. Matsuzaki and Hara [1985] have shown that EGCG demonstrated the strongest activity, whereas Tanizawa *et al.* [1983] reported that EC showed the strongest antioxidative activity among catechins. According to Kajimoto [1963], EGC was the strongest natural antioxidant of green tea.

In a β-carotene-linoleate model system ECG possessed the strongest antioxidative activity and EGC showed the weakest effect [Amarowicz & Shahidi, 1995]. The antioxidant activity of a reconstituted catechin mixture in the proportions present in the crude extract was lower than that of the crude mixture itself. Roedig-Penman and Gordon [1997] reported that the green tea water extract was highly effective as a natural antioxidant for an oil-in-water emulsion storage (pH 5.5, 40 days at 30°C).

The DPPH radical scavenging ability of catechins was EGCG>ECG>EGC>EC and that of theaflavins was TF_2>TF_1>TF [Chen & Ho, 1995]. The authors reported also that EGCG, ECG, EGC showed higher lipid oxidation-inhibition activity, as measured by the Rancimat assay, compared to BHT and theaflavins. The green and black teas had much higher antioxidant activities against peroxyl radicals than 22 common vegetables [Cao *et al.*, 1996]. In experiments of Gadov *et al.* [1997], the tea extracts (of rooibos, green, oolong, black teas) were strong inhibitors of β-carotene bleaching and active scavengers of DPPH radical.

TABLE 1. Antioxidant activity of green tea polyphenols.

Material tested	Aim/Models/Methods	References
Aqueous extracts of rooibos, green, oolong and black teas	DPPH$^{\bullet}$ scavenging and α-carotene bleaching	Gadov *et al.* [1997]
123 batches of tea (most of them were green tea)	Principal component regression (PCR) was used to model the relation between the total antioxidant capacity and the NIR spectra of green tea	Zhang *et al.* [2004]
Catechins	The antioxidative mechanisms of catechins were studied by investigation products generated by AAPH-induced radical oxidation	Kondo *et al.* [1998]
Catechins and their epimerided, acylated, and glucosylated derivatives	DPPH$^{\bullet}$ scavenging by EPR spectrometry	Nanjo *et al.* [1996]
Green tea extracts, EGCG, ECG	Model food emulsion; PV, conjugated dienes	Roeding-Penman & Gordon [1997]
Green tea catechins	Stabilization of seal blubber and menhaden oils; PV, conjugated dienes	Wanasundara & Shahidi [1996] Wanasundara & Shahidi [1998]
Green tea catechins	Inhibition of peroxynitrite formation by 3-morpholinosydnonimine and scavenging of peroxynitrite itself	Chung *et al.* [1998b]
ECG, EC, C	Antiradical activity against alkyl peroxyl radical	Nakao *et al.* [1998]
Green tea extract, individual catechins, reconstituted catechin mixture	β-Carotene bleaching	Amarowicz & Shahidi [1995]
Green tea catechins and theaflavins	DPPH$^{\bullet}$ and superoxide scavenging, Rancimat method	Chen & Ho [1995]
Various tea extracts	DPPH$^{\bullet}$ scavenging, reduction power, scavenging of superoxide, hydroxyl radical scavenging activity by EPR spectrometry	Yen & Chen [1995]
Tea catechins and their epimers	Structure-antioxidant activity; EPR spectrometry	Guo *et al.* [1999]
Catechin	Effect of enzymatic and chemical oxidation on the antioxidant capacity of catechin; DPPH$^{\bullet}$ scavenging	Nicoli *et al.* [2000]
Green and black tea extracts	Different brewing conditions; TEAC, LDL oxidation	Liebert *et al.* [1999]
Ethanol extracts of black, dark-green and ginseng teas	Canola oil; oxygen consumption	Chen *et al.* [1996b]
Tea theaflavins and methylated catechins	Canola oil; oxygen consumption	Su *et al.* [2004]
Green tea catechins	Meat model system; TBARS, hexanal and pentanal content	Shahidi & Alexander [1998]
Green tea extract	Raw minced red meat, poultry and fish muscle; TBARS	Tang *et al.* [2001]
Green tea extracts	Meat model system; TBARS	Amarowicz *et al.* [2005]
Green tea catechins	NMR analytical approach to clarify the antioxidative molecular mechanism of catechins using DPPH$^{\bullet}$	Sawai & Sakata [1998]
Green tea catechins	Formation of radicals and chemiluminescence during the autoxidation of tea catechins	Yoshioka *et al.* [1991]
Green tea catechins	Relative antioxidative activities of catechins against radicals generated in the aqueous phase and against propagating lipid peroxyl radicals	Salah *et al.* [1995]
EC and ECG	Protective effect of EC and ECG on lipid peroxidation in phospholipid bilayers	Terao *et al.* [1994]
Green and black tea extracts	Antioxidant activities against peroxyl and hydroxyl radicals	Cao *et al.* [1996]
Tea catechin oxypolymers	Antioxidant and pro-oxidant effects tested using a deoxyribose assay, a photoreduction of NBT assay, a lipoxygenase assay, PV assay, and animal test	Li & Xie [2000]
C and EGCG	Recovery of growth arrest of *Escherichia coli* under oxidative conditions	Inoue *et al.* [1996]
Green tea extract	Degradation and oxidation products of stigmasterol in TAG of sunflower oil	Rudzińska *et al.* [2004]
Green and black tea extracts	DPPH$^{\bullet}$ and ABTS$^{+\bullet}$ scavenging	Gramza *et al.* [2005]

The antiradical activity of green and black tea ethanol and water extracts was measured with the use of two different methods of scavenging: the stable free radicals $ABTS^{+\bullet}$ and $DPPH^{\bullet}$ [Gramza *et al.*, 2005]. The extracts examined showed different antiradical activity. The best activity in scavenging $ABTS^{+\bullet}$ expressed as TAA (total antioxidant activity) was reported for black tea aqueous and ethanol extracts. Green tea extracts were four times less effective. Aqueous extracts showed 50% lower activity than equivalent ethanol extracts. Research proved that the antiradical activity of plant extracts is dependent on the mechanisms of oxidative activity of free radicals used and the chemical structure of antioxidants.

In the study by Rudzińska *et al.* [2004], a green tea ethanol extract inhibited, to some extent, degradation of stigmasterol in a model system containing TAG of sunflower oil and sterol standard over 9 days of incubation at 60°C.

In a meat model system at a concentration of 200 mg/kg, the antioxidant activity of individual catechins evaluated by TBA values was EGCG≈ECG>EGC>EC. The results of hexanal and pentanal contents in the headspace volatiles of meat treated with catechins showed the same order of catechins as antioxidants [Shahidi & Alexander, 1998]. In an experiment with raw minced red meat, poultry and fish muscle, the antioxidant potential of green tea catechins (40% of EGCG, 24% of EGC, 12% of ECG, and 10% of EC) was two to fourfold greater than that of α-tocopherol at the same concetration [Tang *et al.*, 2001]. The percent inhibition of TBARS development by several crude green tea extracts using a meat model system varied from 27.9 to 55.7% (*i.e.* based on extract addition of 25 ppm), 62.8 to 88.7% (*i.e.* 50 ppm), 78.7 to 100% (*i.e.* 100 ppm), and 94.3 to 100% (*i.e.* 200 ppm). Proanthocyanidin fraction was less active compared to the crude extract from which it was derived [Amarowicz *et al.*, 2005b].

The results of research by Nanjo *et al.* [1996] with acelated and glucosylated catechin derivatives suggested that the gallolyl moiety attached to flavan-3-ol at 3 position has a strong capability for scavenging the DPPH radical as well as the *o*-trihydroxyl group in the B ring, which elevates the radical scavenging effect above that of the *o*-dihydroxyl group. In the aqueous phase, the order of the effectiveness of catechins as radical ($ABTS^{\bullet+}$) scavengers was ECG> > EGCG>EGC>EC≈C. Against propagating lipid peroxyl radical species, EC and C were as effective as ECG and EGCG; the activity of EGC was the lowest [Salah *et al.*, 1995]. In experiments of Terao *et al.* [1994], EC and ECG retarded the accumulation of yolk phosphatidylcholine hydroperoxides when the suspension was exposed to water–soluble radical initiator (AAPH). The antiradical activity of catechins against peroxyl radicals in a liposomal and aqueous system, except for EGC, was observed by Kondo *et al.* [1999]. Using LC/MS and spectroscopy studies these authors found that EC can be gently converted to an anthocyanin-like compound by radical oxidtion.

Under Schaal oven test condition at 65°C over a 144-h period seal blubber and menhaden oils treated with tea catechins showed excellent oxidative stability as compared to samples with the addition of commonly used antioxidants (BHA, BHT, TBHQ, α-tocopherol). The potency of catechins in prevention of marine oils oxidation was in the order of ECG>EGCG>EGC>EC. EGC was slightly more affective than TBHQ in the system used [Wanasundara & Shahidi, 1996]. Under the same experimental conditions, a green tea dechlorophylized extract at 200, 500, and 500 ppm exhibited in marine oils the higher efficacy than that of BHA, BHT, and α-tocopherol [Wanasundara & Shahidi, 1998]. The ethanol extracts of green tea strongly inhibited the oxidation of canola oil compared to BHT. Oolong tea examined exhibited only moderate antioxidant activity [Chen *et al.*, 1996b]. Catechins were much more effective than theaflavins (TF_1, TF_2A, TF_2B, TF_3) against the lipid oxidation of canola oil. Oxidation was conducted at 95°C by monitoring oxygen consumption and decreases in the linoleic and α-linolenic acids of canola oil. Among theaflavins, TF_3 was found to be the most effective [Su *et al.*, 2004].

ANTIMUTAGENIC AND ANTICANCEROGENIC PROPERTIES OF TEA POLYPHENOLICS

The intracellular bio-antimutagenesis of tea polyphenols is generated by the modulation of metabolism of promutagens, blocking or suppression, and modulation of DNA [Kuroda & Hara, 1999]. Green tea polyphenolics can interact directly with some promutagens or inhibit them on the way of the cytochrome P-450-dependent bioactivation. The competitive inhibition of the NADPH-cytochrome c reductase by catechins was reported by Steele *et al.* [1985]. In experiments of Kada *et al.* [1985], green tea polyphenols gave a high bio-antimutagenic effect against spontaneous mutations resulting from altered DNA-polymerase III in the strain of *Bacillus subtilis*. Individual catechins have also been reported to reduced mutation induction by UV in *Escherichia coli* [Shimoi *et al.*, 1986].

Anticancerogenic properties of green tea are related to the presence of many flavonoids from the group of catechins, especially of EGCG [Ahmad *et al.*, 1997; Katiyar & Mukhtar, 1997; Mukhtar & Ahmad, 1999; Osawa *et al.*, 1995]. It was stated that about 1/3 of cancer incidence is caused by incorrect nutritional habits, and therefore suitable diet manipulation may be an important tool in cancer prevention [Weisburger, 1996; Jankun *et al.*, 1997]. Table 2 compiles some results dealing with the anticancerogenic properties of green tea polyphenolics obtained in animal models.

Kim and Masuda [1997] claimed that it is highly likely that green tea shows a beneficial effect to reduce cancer risk. To elucidate the inhibitory effects of catechins on carcinogenesis the authors listed such mechanisms as: antioxidation activities of green tea polyphenols; traping of carcinogens; inhibition of nitrosation reactions; inhibition of the growth of intestinal clostridia; inhibition of biochemical signals of tumor initiation; and inhibition of biochemical signals of tumor promotion.

According to Kuroda and Hara [1999], tea polyphenols demonstrate their antimutagenic and anticarcinogenic activity due to such various mechanisms as: inhibition of mutagens and carcinogens acting extracellularly (desmuta-

TABLE 2. Green tea polyphenols as anticarcinogenic compounds in animal models.

Compound tested	Organ/chemicals used for tumorgenesis/animals	References
Green tea infusion (2% oral administration)	Esophageal; N–nitrosomethylbenzylamine (NMBzA); rats	Han & Xu [1990]
Green tea infusion (1.2% oral administration)	Forestomach; benzo(a)pyrene (BP); mice	Wang *et al.* [1992]
EGCG (0.05% solution)	Glandular stomach; N-methyl-N'-nitro-nitrosoguanidine (MNNG); rats	Yamane *et al.* [1995]
EGCG (0.05% solution)	Duodenum; MNNG; mice	Fujita *et al.* [1989]
EGCG (topic application)	Skin; 7,12-dimethyl benzanthracene (DMBA) and benzopyrenediolo-xide (BPDE); mice	Khan *et al.* [1988]
EGCG (topic applition)	Skin; ultraviolet radiation; mice	Katiyar & Mukhtar [2001]
EGCG (oral application)	Spontaneous skin tumor; mice	Paul *et al.* [2005]
Tea infusion (0.65% or 1.25%)	Lung; 4-methylnitrosoamino-3-pyridyl-1-butanone (NNK); mice	Xu *et al.* [1992]
Green tea solution (0.1, 0.2, 0.4, 0.6%)	Lung; 4-methylnitrosoamino-3-pyridyl-1-butanone (NNK), mice	Liao *et al.* [2004]
Green tea leaves (2.5% in diet)	Liver; NDEA; rats	Li [1991]
Green tea polyphenols (500 mg/kg/day)	Pancreas; N-nitroso-bis-(2-oxopropyl)amine (BOP); Syrian golden hamsters	Harada [1991]
Green tea polyphenols	Colon; azoxymethane; rats	Yamane *et al.* [1991]
Polyphenolic fraction of green tea (oral infu-sion)	Prostate; the autochthonous transgenic adenocarcinoma of the mouse prostate model	Gupta *et al.* [2001]

genesis) or intracellularly (bio-antimutagenesis); inhibition by acting on initiated or meoplastic cells; inhibition of invasion and metastasis; and induction of apoptosis.

The results of epidemiological investigations on germicidal proprieties of tea catechins suggest their essential role in the digestive tract [Hara, 1997]. In spite of their germicidal proprieties, allowing to lower levels of many pathogens (*Escherichia coli*), catechins do not influence the development of lactic acid bacteria *Lactobacillus* and *Bifidobacterium* [Sakanaka *et al.*, 1989; Okubo & Juneja, 1997]. Oguni *et al.* [1988] demonstrated the existence of a strong relationship between the quantity of tea leaves infusion consumed and the incidence of stomach cancer. The results of investigations by Kinlen *et al.* [1988] did not confirm the above-mentioned conclusions; these authors found a positive correlation between the quantity of tea leaves infusion consumed and the incidence of stomach cancer.

Knowledge of anticancerogenic properties of tea polyphenols could be essential in strategy against tumor [Fujiki *et al.*, 1998]. Unfortunately, a clear anticancerogenic mechanism has not been explained yet. One of the basic shortcomings of investigations on polyphenolic properties is that it is not possible to separate the influence of phenolic components from the lifestyle of people taking part in the investigations [Schwarz *et al.*, 1994]. The undeniable fact of beneficial proprieties of tea polyphenols are the results indicating the longevity of women who were practicing traditional tea leaves brewing method, Chan-you, consisting in the consumption of infusion prepared from powder rubbed tea leaves, flooded with small portions of hot water and beaten to the consistency of a cream [Sadakata *et al.*, 1992].

Jankun *et al.* [1997] and Swiercz *et al.* [1997] claimed that a tea component EGCG showed strong inhibitory properies in angiostatic urokinase activity. Urokinase facilitates angiogenesis – the formation of blood vessels around tumors and the spreading of cancer cells throughout the entire body. In other investigations it was shown that the same tea component strongly inhibited cancer cells growth and their DNA replication causing their apoptosis [Smith & Dou, 2001]. Epicatechins act as anticancerogens due to the activation of the second phase detoxication enzymes which accelerate the removal of activated chemical cancerogenes from cells [Lin *et al.*, 1998b]. Observations conducted in Japan suggest that the consumption of more than three cups of tea leaves infusion daily is possibly a protective factor against the growth of breast tumor in its early stage [Inoue *et al.*, 2001].

Many cancer therapeutic agents exert their effect through initiation of apoptosis. The programmed cell death process is a basic biological phenomenon that occurs when a genetically encoded cell death-signaling program is activated [Korsmeyer, 1995]. A number of phytochemicals with an antioxidant activity can mediate apoptosis [Lopaczyński & Zeisel, 2001]. Many studies have identified tea polyphenols as the apoptotic agents. Table 3 summarised some results of experiments showing the apoptoic effect of green tea polyphenols.

TEA POLYPHENOLS AND CARDIOVASCULAR DISEASES

Tea may display a protective role against cardiovascular diseases *via* a number of different mechanisms, one of which are its antioxidative properties. As a result of LDL cholestereol oxidation, monocytes are recruited to the arterial wall and monocyte-derived macrophages accumulate the excessive amount of oxidised LDL and become lipid-laden foam cell [Tijburg *et al.*, 1997]. Several epidemiological studies have demonstrated a significant and substantial reduction in cardiovascular heart disease risk in tea drinkers [Keli *et al.*, 1996; Stensvold *et al.*, 1992; Hertog *et al.*, 1993;

TABLE 3. Apoptotic effect of tea polyphenols.

Compound tested	Information about experiment and results	References
Tea polyphenols	Lung; benzo(a)pyrene (BP); mice; increase of apoptotic cells.	Banerjee *et al.* [2005]
Tea polyphenols	Ehrlich's ascites carcinoma (EAC); initiation of mitochondrial death cascade in EAC cells.	Bhattacharyya *et al.* [2005]
Tea polyphenols	Human lung cells; the change of intracellular Ca^{2+} concentration, phosphatase and tensin homolog (PTEN) protein and cyclin D_1 protein expression.	Xi *et al.* [2005]
Tea polyphenols	Human leukemia cells; expression of apoptosis-releated genes.	Kundu *et al.* [2005]
EGCG	Oral carcinoma cell line; cDNA microarray; induction of the cyclin-dependent kinase inhibitor $pWAF_1$.	Hsu *et al.* [2005]
Acetylated synthetic analogs of catechins	Human leukemic, prostate, breast cancer cells; induction of apoptosis.	Kuhn *et al.* [2005]
EGCG	Prostate cancer LnCaP cells; induction of apoptosis.	Hastak *et al.* [2005]
EGCG	Human pancreatic cancer cells; caspase-3 activation, poly-ADP ribose polymerase cleavage; EGCG-invoked Bax oligomerization and depolarization of mitochondrial membranes to facilitate cytochrome c release into cytosol.	Quanung *et al.* [2005]
EGCG	Two human melanoma cell lines; upregulation of proapoptic Bax and activation caspase-7, and -9.	Nihal *et al.* [2005]
EGCG (oral administration)	Spontaneous skin tumor; mice; selective induction of apoptosis.	Paul *et al.* [2005]
Catechins	Colon cancer cells; ECG is the strongest NAG-1 (non-steroid anti-inflamantory drug activated gene) inducer among the catechins tested.	Baek *et al.* [2004]
Tea leaves (oral administration)	Lung carcinogenesis; the apoptosis index was significantly higher in lung adenomas from 0.6% tea-treated mice.	Liao *et al.* [2004]
EGCG	Human cancerous lines (cervix carcinoma, chronic myelogenous leukemia, multiple myeloma); a combined treatment of radiation and EGCG resulted in a significant enhancement of apoptosis.	Baatout *et al.* [2004]
Black tea	Ehrlich's ascites carcinoma (EAC); mice; Bcl-2/Bax ratio was increased and the immunocytes were protected from tumor-induced apoptosis.	Bhattacharyya *et al.* [2004]
Theaflavins (TF-1, TF-2A, TF-2B, TF-3) and EGCG	Murine myeloid leukemia cells; the four tested theaflavins and EGCG were found to be potent in inducing apoptosis.	Lung *et al.* [2004]
EGCG	Human endocervical cells (HEN); DNA ladder assay; induction of apoptosis.	Yokoyama *et al.* [2004]
EGCG	Hep-2 laryngeal, LoVo colon , HeLa cervical carcinoma cells; induction of apoptosis in cells of the examined neoplastic line in a dose-related manner.	Borska *et al.* [2003]

Sesso *et al.*, 1999; Geleijnse *et al.*, 1999; Davies *et al.*, 2003]. On the grounds of the results obtained Imai and Nakachi [1995] suggested that subjects consuming more than 10 cups of green tea infusion daily, were characterized by a decreased cholesterol level of blood. Other investigations indicated that after consumption of 300 and 450 mL of green tea infusion, the antioxidant activity of blood serum increased [Sung *et al.*, 2000]. Five servings of tea per day over a 3-week treatment reduced total cholesterol (6.5%), LDL cholesterol (11.1%), apolipoprotein B (5%), and lipoprotein(a) (16.4%) in mildly hyper-cholesterolemic adults, compared with the placebo with added caffeine [Davies *et al.*, 2003]. There were significant differences in plasma LDL and adiponectin levels, and plasma LDL particle size of the patients with the coronary artery disease before and after 1-month intake of oolong tea [Shimada *et al.*, 2004]. Kuhn *et al.* [2005] reported that LDL receptor expression was increased dramatically in HepG2 and HeLa cells treated with (-)-EGCG. This identified molecular mechanism may be related to the previously reported cholesterol-lowering and heart disease-preventative effects of green tea. The theaflavin-enriched green tea extract was studied as an effective adjunct to a low-saturated-fat diet to reduce LDL-C in hypercholesterolemic adults (a total of 240 men and women aged 18 years or older [Maron *et al.*, 2003].

Tea flavonoids protect low density lipoproteins LDL fraction against oxidation by activating synthesis of the prostaglandins and possess antiplatelet and metal chelating proprieties [Acker *et al.*, 1998]. A comparative analysis of the antioxidant activities of green and black tea water extracts showed the same rate of oxidation inhibition in blood serum lipoproteins and protection of blood vessels from blocking [Hodgson *et al.*, 1999, 2002]. Green tea cate-

chins can regenerate α-tocopherol, the main antioxidant protecting the LDL fraction against oxidation [Kono *et al.*, 1992; Vinson & Dabbagh, 1998; Zhu *et al.*, 1999].

Investigations conducted on rats fed green tea catechins showed a decrease in cholesterol and triacyloglycerol levels in blood and their non-toxicity in relation to liver and kidneys. Additional interesting aspect of the research was that in spite of the same quantity of diet consumed, a decrease of about 10–18% body weight was observed in relation to the control group non-feed with tea catechins [Lin *et al.*, 1998b].

On the basis of the experiments of Kuo *et al.* [2005], it seemed that the fully fermented pu-erh and black tea leaves and partially fermented oolong tea leaves were more effective on their growth suppressive and hypolipidemic effects as compared to the non-fermented green tea leaves. Pu-erh tea leaves administered orally (4% of diet) to male Sprague--Dawley rats for 30 weeks could increase the level of HDL--C and decrease the level of LDL-C. The results of experiments with mice suggest that daily intraperitoneal injections of EGCG (10 mg/kg) reduces evolving atherosclerotic lesions to a different extent [Chyu *et al.*, 2004]. There were concentration-dependent decreases in the total cholesterol content in cultured rat mesangial cells when treated with 40 ng/L to 40 mg/L of tea polyphenolics [Zhang & Gan, 2003]. EGCG treatment in the apolipoprotein E-null mice resulted in an increase in the antioxidant capacity in local vascular tissue and systemic circulation and reduced vascular smooth muscle cell proliferation and redox-sensitive gene activation *in vitro*. EGCG reduced cuff-induced evolving atherosclerotic plaque size [Chyu *et al.*, 2004].

The effect of purified catechins on micellar solubility of cholesterol was examined in an *in vitro* study by Ikeda *et al.* [2003]. The addition of gallate esters of catechins reduced micellar solubility of cholesterol by precipitating cholesterol from bile salt micelles. (-)-Catechin gallate and (-)-gallocatechin gallate were more effective to precipitate cholesterol than (-)-epicatechin gallate and (-)-epigallocatechin gallate, respectively. These observations strongly suggest that heat-epimerized catechins may be more hypocholesterolemic than tea catechins. In experiments of Raederstorff *et al.* [2003], after 4 weeks of treatment, the total cholesterol and low density lipoprotein plasma levels were significantly reduced in the group of rats fed 1% EGCG when compared to the non-treated group. In an *in vitro* biliary micelle model, the addition of 55 μmol to 1300 μmol of EGCG not only decreased cholesterol solubility in a dose-dependent manner in these micelles but also altered the size of the mixed lecithin/taurocholate/cholesterol micelles as demonstrated by light scattering. This study provided evidence suggesting that the cholesterol-lowering effect of green tea is mainly elicited by EGCG. It was suggested that one of the underlying mechanisms by which EGCG affects lipid metabolism is by interfering with the micellar solubilization of cholesterol in the digestive tract, which then in turn decreased cholesterol absorption. The findings of Loest *et al.* [2002] provided direct evidence that green tea has a profound inhibitory effect on the intestinal absorption of cholesterol and in ovariectomized (OX) rats. The supplementation of black tea polyphenols in the lard-cholesterol diet decreased lipid levels in rats and increased the fecal excretion of total lipids and cholesterol [Matsumoto *et al.*, 1998].

ANTIBACTERIAL AND ANTIVIRAL ACTIVITY

There are numerous studies on the antimicrobial activity of tea extracts, catechins and other polyphenols (Table 4).

ECG reduced oxacillin resistance in methicillin–resistant *Staphylococcus aureus* (MRSA) at concentrations below the MIC [Stapleton *et al.*, 2004a]. Substitution of the gallate group of ECG with 3-*O*-acyl chains of varying lengths C_4–C_{18} led to enhanced anti-staphylococcal activity with chain lengths of C_8 and C_{18}. 3-*O*-octanoyl catechin was bactericidal against MRSA as a result of membrane damage. ECG was found also as an agent to combat beta-lactam resistance in *S. aureus*. Modulation of beta-lactam resistance by ECG significantly enhanced the activities of flucloxacillin and the carbapenem antibiotics imipenem and meropenem against 40 MRSA isolates, with MIC (90) values for the antibiotics reduced to the susceptibility breakpoint or below [Stapleton *et al.*, 2004b].

The proanthocyanidin fraction separateted from the crude tea extract had pronounced effect on *Escherichia coli* K12, as noted by the *ca*. two log reduction [Amarowicz *et al.*, 2000].

Green tea catechins can act as inhibitors of some enzymes important for microorganisms. EGCG was effective in inhibiting protein tyrosine phosphatase (PTPase) activity in *Proveta intermedia* at 0.5 μmol, and related species at 5 μmol [Okamoto *et al.*, 2003]. The catechin oligomers isolated from oolong tea extract markedly inhibited glucosyltransferase (Gtase) from *Streptococcus sobrinus* 6715 [Hamada *et al.*, 1996]. Inhibitory effect of green tea catechins on cysteine proteinases (Arg-gingipain and Lys-gingipain) in *Porphyromonas gingivalis* was observed by Okamoto *et al.* [2004].

Arakawa *et al.* [2004] observed a reactive oxygen species that was generated from the catechins as the bactericidal mechanism. EGCG reacted with the dissolved oxygen in aqueous solution, resulting in the generation of hydrogen peroxide. The results of Yoda *et al.* [2004] indicate that the structure of the bacterial cell wall and different affinities of EGCG with various cell wall components are responsible for different susceptibilities of *Staphylococcus* and Gram--negative rods to EGCG. The results suggested that the inhibitory effect observed is due to the presence of galloyl moiety in the structure. In the presence of a non-lethal concentration of Cu(II), washed *Escherichia coli* cells were killed by (-)-epigallocatechin (EGC) and (-)-epicatechin (EC) [Hoshino *et al.*, 1999]. These authors suggested that the recycling redox reactions between Cu(II) and Cu(I), involving catechins and hydrogen peroxide on the cell surface, must be of significance to the mechanism of killing. As the degree of polymerization of catechin increased, GTase was inhibited more effectively. The experiments of Ikigai *et al.* [1993] demonstrated that bactericidal catechins primarily act on and damage bacterial membranes. The observation that the Gram-negative bacteria are more resistant to bactericidal catechins than Gram-positive bacteria can be

TABLE 4. Antimicrobial activity of green tea polyphenols.

Compound tested	Species	Effects	References
Green tea catechins	*Helicobacter pylori*	Weak inhibition of *Helicobacter pylori* growth.	Shin *et al.* [2005]
EGCG	*Legionella pneumophila*	EGCG enhanced the *in vitro* resistance of alveolar macrophages to *Legionella pneumophila* infection by selective immunomodulatory effects on cytokine formation.	Yamamoto *et al.* [2004]
EGC	*Staphylococcus aureus*	EGC showed a weak activity against *Staphylococcus aureus*; substitution of the gallate group of ECG with 3-*O*-acyl chains of varying lengths led to enhanced antistaphylococcal activity.	Stapleton *et al.* [2004]
EGCG	*S. aureus*, *S. epidermidis, S. hominis, S. haemolyticus*	Minimum Inhibitory Concentrations (MICs): 50–100 μg/mL.	Yoda *et al.* [2004]
Lung Chen tea, ECG, EC	*Helicobacter pylori*	The MIC_{90} for Lung Chen was 0. 25–0.5% (w/w) and these of ECG and EC were 50–100 and 800–1600 μg/mL, respectively.	Yee & Koo [2000]
Aqucous extracts of tea	30 bacterial species	Tea extracts were bactericidal to staphylococci and *Yersinia enterocolitica* at well below "cup of tea" concentration. In black tea extracts, theaflavin and its gallates are the antibacterially active components.	Yam *et al.* [1997]
Geen and black tea	*Mycoplasma*	At a concentration of 0.2%, green tea and black tea showed microbicidal activities against *M. pneumoniae* and *M. orale* but not against *M. salivarium.*	Chose *et al.* [1992]
Green tea, black tea, and EGCG	*Bordetella pertussis*	Green tea, black tea, and EGCG might act as prophylactic agents against *Bordetella pertussis* infection.	Horiuchi *et al.* [1992]
Green tea extract, EGCG, and theaflavin digallate (TF3)	Methicillin resistant *Staphylococcus aureus* (MRSA)	20% tea extract, EGCG (63 μg) and TF3 (125 μg) added to one mL of culture medium each inhibited the growth of all strains of MRSA and food with poisoning *S. aureus* tested.	Toda *et al.* [1991]
Green tea catechins and theaflavins	21 phytopathogenic bacterial species	Tea catechins as well theaflavins showed a marked inhibitory effect against phytopathogenic bacteria.	Fukai *et al.* [1991]
Green tea catechins	*Staphylococcus aureus*, *Vibrio cholerae*	EGC, ECG, EGCG inhibited the growth of *Staphylococcus aureus* and *Vibrio cholerae*.	Toda *et al.* [1990]

explained, to some extent, by the presence of negatively charged lipopolysaccharide.

Tea leaves flavonoids show also germicidal and antiviral proprieties. It was stated that both green and black tea leaves components damage bacteria's cellular membrane, which was used in the treatment of diarrhea, cholera and typhus infections [Shetty *et al.*, 1994]. Its anticarious proprieties as well as antiviral and against HIV virus were also shown [Otake *et al.*, 1991; Gupta *et al.*, 2002; Nakane & Ono, 1989]. It was proved that epicatechin and epigallocatechin gallates from tea leaves inhibit the RNA opposite transcriptase, playing an essential part in HIV viruses replication. Moreover, it was stated that free epicatechin and epigallocatechin did not show similar influence.

OTHER BIOLOGICAL PROPERTIES

Investigations into thermogenic tea properties showed synergistic action of caffeine and catechins, possibly stimulating the thermogenesis. It was stated that individuals, consuming tea extract containing 90 mg EGCG, three times daily, burned 266 kcal/day more than the group without the addition of catechins. It enabled the presumption that this property might be helpful in overweight and obesity control [Dullo *et al.*, 2000]. Tea polyphenols showed also strong inhibition of lipases *in vitro*, causing reduced triacylglycerols lipolysis [Juhel *et al.*, 2000].

Catechins can also inhibit the release of some allergic reactions factors such as: leucotrienes, prostaglandins, by modifying activities of multiple enzymes taking part in inflammatory states of the human body [Middelton *et al.*, 1998].

Green tea catechins can influence the endocrine system [Kao *et al.*, 2000]. EGCG considerably lowered food consumption level, body mass, estradiol, testosterone and leptine levels in the rats studied. It was also found that catechins can modulate steroid hormones concentration in the body, which is possibly an essential element in anticancerogenic prophylaxis [Strom *et al.*, 1999]. Black tea polyphenols – theaflavins – also show beneficial influence on living organism. They are strong antioxidants protecting healthy cells of rat liver against oxidative stress, and preventing DNA damages [Feng *et al.*, 2002].

The studies of Yamamoto *et al.* [2004] showed that EGCG enhanced the *in vitro* resistance of alveolar macrophages to *Legionella pneumophila* infection by selective immunomodulatory effects on cytokine formation. Furthermore, the tobacco smoking-induced impairment of alveolar macrophages regarding antibacterial as well as immune activity was also recovered by EGCG treatment. These results indicate that EGCG may be a potential immunotherapeutic agent against respiratory infections in immunocompromised patients, such as heavy smokers.

Green tea polyphenols are known to prevent dental caries. The effects of these compounds on cariogenicity were

observed in *in vitro* tests. Catechins inhibited the growth of cariogenic bacteria *Streptococcus mutans* and *S. sobrinus* [Sakanaka *et al.*, 1989]. The addition of tea polyphenols to a diet or to drinking water reduced the appearance of caries in rats [Sakanaka *et al.*, 1992]. Chewing gums containing tea polyphenols was found effective in decreasing dental plaque formation in humans [Sakanaka *et al.*, 1996].

REFERENCES

1. Acker S.A., Van Balen G.P., Van den Berg D.J., Bast A., Van der Vijgh W.J., Influence of iron chelation on the antioxidant activity of flavonoids. Biochem. Pharmacol., 1998, 56, 935–943.
2. Ahmad N., Feyes D.K., Nieminen A.L., Agrawald R., Mukhtar H., Green tea constituent epigallocatechin-3--gallate and induction of apoptosis and cell cycle arrest in human carcinoma cells. J. Natl. Cancer Inst., 1997, 89, 1881–1886.
3. Amarowicz R., Shahidi F., Antioxidant activity of green tea catechins in a β-carotene-linoleate model system. J. Food Lipids, 1995, 2, 47–56.
4. Amarowicz R., Pegg R.B., Bautista D.A., Antibacterial activity of green tea polyphenols against *Escherichia coli* K12. Nahrung, 2000, 44, 60–62.
5. Amarowicz R., Shahidi F., Presence of two forms of methylated (-)-epigallocatechin-3-gallate in green tea. Nahrung, 2003, 47, 21–23.
6. Amarowicz R., Maryniak A., Shahidi F., TLC separation of methylated (-)-epigallocatechin-3-gallate. Czech J. Food Sci., 2005a, 23, 36–39.
7. Amarowicz R., Pegg R.B., Troszyńska A., Shahidi F., Assessment of the antioxidant activity of green tea extracts using a meat model system. ACS Symposium Series, 2005b, in press.
8. Arakawa H., Maeda M., Okubo S., Shimamura T., Role of hydrogen peroxide in bactericidal action of catechin. Biol. Pharm. Bull., 2004, 27, 277–281.
9. Baatout S., Jacquet P., Derradji H., Ooms D., Michaux A., Mergeay M., Study of the combined effect of X-irradiation and epigallocatechin-gallate (a tea component) on the growth inhibition and induction of apoptosis in human cancer cell lines. Oncol. Rep., 2004, 12, 159–167.
10. Baek S.J., Kim J.S., Jackson F.R., Eling T.E., McEntee M.F., Lee S.H., Epicatechin gallate–induced expression of NAG–1 is associated with growth inhibition and apoptosis in colon cancer cells. Carcinogenesis, 2004, 25, 2425–2432.
11. Bailey R.G., Nursten H.E., The chemical oxidation of catechins and other phenolics: a study of the formation of black tea pigments. J Sci. Food Agric., 1993, 63, 455–464.
12. Balentine D., Tea and health. Crit. Rev. Food Sci. Nutr., 1997, 37, 691–692.
13. Balentine D.A., Wiseman S.A., Bouwens L.C.M., The chemistry of tea flawonoids. Crit. Rev. Food Sci. Nutr., 1997, 37, 693–704.
14. Banerjee S., Manna S., Saha P., Kr Panda C., Das S., Black tea polyphenols suppress cell proliferation and induce apoptosis during benzo(a)pyrene-induced lung carcinogenesis. Eur. J. Cancer Prev., 2005, 14, 215–221.
15. Bhattacharyya A., Mandal D., Lahiry L., Sa G., Das T., Black tea protects immunocytes from tumor-induced apoptosis by changing Bcl-2/Bax ratio. Cancer Lett., 2004, 209, 147–154.
16. Bhattacharyya A., Lahiry L., Mandal D., Sa G., Das T., Black tea induces tumor cell apoptosis by Bax translocation, loss in mitochondrial transmembrane potential, cytochrome c release and caspase activation. Int. J. Cancer, 2005, in press.
17. Borska S., Gebarowska E., Wysocka T., Drag-Zalesinska M., Zabel M., Induction of apoptosis by EGCG in selected tumour cell lines *in vitro*. Folia Histochem. Cytobiol., 2003, 41, 229–32.
18. Cao G., Sofic E., Prior R.L., Antioxidant capacity of tea and common vegetables. J. Agric. Food Chem., 1996, 44, 3426–3431.
19. Chen C.-W., Ho C.-T., Antioxidant properties of polyphenols extracted green and black teas. J. Food Lipids, 1995, 2, 35–46.
20. Chen C.C., Shi L.L., Chen C.C., Effect of extraction temperature and time on polyphenol contents and composition and sensory quality of oolong tea infusion. Food Sci. Taiwan, 1996a, 23, 285–298.
21. Chen Z.Y., Chan P.T., Ma H.M., Fung K.P., Wang J., Antioxidative effect of ethanol tea extracts on oxidation of canola oil. J. Am. Oil Chem. Soc., 1996b, 73, 375–380.
22. Chen Z.Y., Zhu Q.Y., Tang D., Huang Y., Degradation of green tea catechins in tea drinks. J. Agric. Food Chem., 2001, 49, 477–482.
23. Chen Z.Y., Zhu Q.Y., Wong Y.F., Zhang Z., Chung H.Y., Stabilizing effect of ascorbic acid on green tea catechins. J. Agric. Food Chem., 1998, 46, 2512–2516.
24. Chosa H., Toda M., Okubo S., Hara Y., Shimamura T., Antimicrobial and microbicidal activities of tea and catechins against *Mycoplasma*. Kansenshogaku Zasshi. 1992, 66, 606–611.
25. Chu D.C., Juneja L.R., General chemical composition of green tea and its infusion. 1997, *in*: Chemistry and Applications of Green Tea (eds. T. Yamamoto, L.R. Juneja, D.C. Chu, M. Kim). CRC, New York, pp. 13–22.
26. Chung K.T., Wong T.Y., Wei C.I., Huang Y.W., Lin Y., Tannins and human health: a review. Crit. Rev. Food Sci. Nutr., 1998a, 38, 421–464.
27. Chung H.Y., Yokozawa T., Soung D.Y., Kye I.S., No J.K., Beak B.S., Peroxynitrite-scavenging activity of green tea tannin. J. Agric. Food Chem., 1998b, 46, 4484–4486.
28. Chyu K.Y., Babbidge S.M., Zhao X., Dandillaya R., Rietveld A.G., Yano J., Dimayuga P., Cercek B., Shah P.K., Differential effects of green tea-derived catechin on developing versus established atherosclerosis in apolipoprotein E-null mice. Circulation, 2004, 25, 109, 2448–53.
29. Davies M.J., Judd J.T., Baer D.J., Clevidence B.A., Paul D.R., Edwards A.J., Wiseman S.A., Muesing R.A., Chen S.C., Black tea consumption reduces total and LDL cholesterol in mildly hypercholesterolemic adults. J. Nutr., 2003, 133, 3298–3302.
30. Di Carlo A., Lamassa M., Pracucci G., Basile A.M., Trefoloni G., Vanni P., Wolfe C.D.A., Tilling K., Ebrahim S., Inzitari D., Stroke in the very old. Clinical presentation and determinants of 3-month functional outcome: a European perspective. Stroke, 1999, 11, 2313–2319.

31. Dougan J., Glossop E.J., Howard G.E., Jones B.D., A study of the changes occurring in black tea during storage. Report G116 Tropical Products Institute London, 1979.
32. Dreosti I.E., Bioactive ingredients: antioxidants and polyphenols in tea. Nutr. Rev., 1996, 54, S51–S58.
33. Dulloo A.G., Seydoux J., Girardier L., Chantre P., Vandermander J., Green tea and thermogenesis: interactions between catechin-polyphenols, caffeine and sympathetic activity. Int. J. Obes. Relat. Metab. Disord., 2000, 24, 252–258.
34. Feng Q., Torri Y., Uchida K., Nakamura Y., Hara Y., Osawa T., Black tea polyphenols, theaflavins, prevent cellular DNA damage by inhibiting oxidative stress and suppressing cytochrome P450 in Cell Cultures. J. Agric. Food Chem., 2002, 50, 213–220.
35. Fernandez P.L., Pablos F., Martin M.J., Gonzales A.G., Study of catechin and xantine tea profiles as geographical tracers. J. Agric. Food Chem., 2002, 50, 1833–1839.
36. Friedman M., Jurgens H.S., Effect of pH on the stability of plant phenolic compounds. J. Agric. Food Chem., 2000, 48, 2101–2110.
37. Fujiki H., Saganuma M., Okabe S., Sueoka N., Komori A., Sueoka E., Kozu T., Tada Y., Suga K., Imai K., Nakachi K., Cancer inhibition by green tea. Mutat. Res., 1998, 402, 307–310.
38. Fujita Y., Yamane T., Tanaka M., Kuwata K., Okuzumi J., Takahashi T., Fujiki H., Okuda T., Inhibitory effect of (-)-epigallocatechin gallate on carcinogesis with N-ethyl--N'-nitro N-nitrosoguanidine in mouse duodenum. J. Jap. J. Cancer Res., 1989, 80, 503-505.
39. Fukai K., Ishigami T., Hara Y., Antibacterial activity of tea polyphenols against phytopathogenic bacteria. Agric. Biol. Chem., 1991, 55, 1895–1897.
40. Gadow A., Joubert E., Hansmann C.F., Comparison of the antioxidant activity of rooibos tea (*Aspalathus linearis*) with green, oolong and black tea. Food Chem., 1997, 60, 73–77.
41. Geleijnse J.M., Launer L.J., Hofman A., Pols H.A., Witteman J.C., Tea flavonoids may protect against artherosclerosis: the Rotterdam Study. Arch. Intern. Med., 1999, 159, 2170–2174.
42. Graham H.N., Green tea composition, consumption and polyphenol chemistry. Prev. Med., 1992, 21, 334–350.
43. Gramza A., Pawlak-Lemańska K., Korczak J., Wąsowicz E., Tea extracts as free radicals scavengers. Pol. J. Environ. Stud., 2005, in press.
44. Guo Q., Zhao B., Shen S., Hou J., Hu J., Xin W., ESR study on the structure-antioxidant activity of tea catechins and their epimers. Bioch. Bioph. Acta, 1999, 1427, 13–23.
45. Gupta S., Hstak K., Ahmad N., Lewin J.S., Mukhtar H., Inhibition of prostate carcinogenesis in TRAMP mice by oral infusion of green tea polyphenols. Proc. Natl. Acad., 2001, 98, 10350–10355.
46. Gupta S., Saha B., Giri A.K., Comparative antimutagenic and anticlastogenic effects of green tea and black tea: a review. Mutat. Res., 2002, 512, 37–65.
47. Halder J., Tamuli P., Bhaduri A.N., Isolation and characterisation of polyphenoloxidase from indian tea leaf (*Camellia sinensis*). J. Nutr. Biochem., 1998, 9, 75–80.
48. Hamada S., Kontani M., Hosono H., Ono H., Tanaka T., Ooshima T., Mitsunaga T., Abe I., Peroxidase-catalyzed generation of catechin oligomers that inhibit glucosyltransferase from *Streptococcus sobrinus*. FEMS Microb. Lett., 1996,143, 35–40.
49. Han C., Xu Y., The effect of Chinese tea on the occurrence of esophageal tumor induced by *N*-nitrosomethylbenzylamine in rats. Biomed. Environ. Sci., 1990, 3, 35–42.
50. Hara Y., Influence of tea catechins on the digestive tract. J. Cell Biochem., 1997, 67, 52–58.
51. Hashimoto F., Nonaka G., Nishioka I., Tanins and related compounds. CXIV. Structures of novel fermentation products, theogallinin, theaflavonin and desgalloyl theaflavonin from black tea, and changes of tea leaf polyphenols during fermentation. Chem. Pharm. Bull., 1992, 40, 1383–1389.
52. Hastak K., Agarwal M.K., Mukhtar H., Agarwal M.L., Ablation of either p21 or Bax prevents p53-dependent apoptosis induced by green tea polyphenol epigallocatechin-3-gallate. FASEB J., 2005, 19, 789–791.
53. Harada N., Takabayashi F., Oguni L., Hara Y., Anti-promotion effect of green tea extracts on pancreatic cancer in golden hamster induced by *N*-nitroso-bis(2-oxopropyl) amine. 1991, *in*: Proceedings of the International Symposium on Tea Science, Kurofune Printing Co. Ltd., Shizuoka, p. 200.
54. Harbowy M.E., Balentine D.A., Tea chemistry. Crit. Rev. Plant Sci., 1997, 16, 415–480.
55. Hertog M.G., Feskens E.J., Holman P.C., Katan M.B., Kromhout D., Dietary antioxidant flavonoids and risk of coronary heart disease: the Zutphen Elderly Study, Lancet, 1993, 342, 1007–1011.
56. Ho C.T., Chen C.W., Wanasundara U.N., Shahidi F., Natural antioxidant from tea. 1997, *in*: Natural Antioxidants. Chemistry. Health Effects and Applications (ed. F. Shahidi). AOCS Press Champaign, Illinois, pp. 213–223.
57. Hodgson J.M., Proudfoot J.M., Croft K.D., Puddey I.B., Mori T.A., Beilin L.J., Comparision of the effect of black and green tea *in vitro* lipoprotein oxidation in human serum. J Sci. Food Agric., 1999, 79, 561–566.
58. Hodgson J.M., Puddey I.B., Burke V., Watts G.F., Beilin L.J., Regular ingestion of black tea improves brachial artery vasodilator function. Clin. Sci. London, 2002, 102, 195–201.
59. Horiuchi Y., Toda M., Okubo S., Hara Y., Shimamura T., Protective activity of tea and catechins against *Bordetella pertussis*. Kansenshogaku Zasshi., 1992, 66, 599–605.
60. Hoshino N., Kimura T., Yamaji A., Ando T., Damage to the cytoplasmic membrane of *Escherichia coli* by catechin-copper (II) complexes. Free Radic. Biol. Med., 1999, 27, 1245–1250.
61. Hsu S., Farrey K., Wataha J., Lewis J., Borke J., Singh B., Qin H., Lapp C., Lapp D., Nguyen T., Schuster G., Role of p21WAF1 in green tea polyphenol-induced growth arrest and apoptosis of oral carcinoma cells. Anticancer Res., 2005, 25, 63–67.
62. Ikeda I., Kobayashi M., Hamada T., Tsuda K., Goto H., Imaizumi K., Nozawa A., Sugimoto A., Kakuda T., Heatepimerized tea catechins rich in gallocatechin gallate and catechin gallate are more effective to inhibit cholesterol absorption than tea catechins rich in epigallocatechin gallate and epicatechin gallate. J. Agric. Food Chem., 2003, 51, 7303–7307.

63. Ikigai H., Nakae T., Hara Y., Shimamura T., Bactericidal catechins damage the lipid bilayer. Bioch. Bioph. Acta, 1993, 1147, 132–136.
64. Imai K., Nakachi K., Cross-sectional study of the effect of drinking green tea on cardiovascular and liver diseases. Brit. Med. J., 1995, 310, 693–696.
65. Inoue Y., Trevanich S., Tsujimoto Y., Miki T., Miyabe S., Sugiyama K., Izawa S., Kimura A., Evaluation of catechin and its derivatives as antioxidant: recovery of growth arrest of *Escherichia coli* under oxidative conditions. J. Sci. Food Agric., 1996, 71, 297–300.
66. Inoue M., Tajima K., Mizutani M., Iwata H., Iwase T., Miura S., Hirose K., Hamajima N., Tominaga S., Regular consumption of green tea and the risk of breast cancer recurrence: follow-up study from the Hospital-based Epidemiologic Research Program at Aichi Cancer Centre (HERPACCO) Japan. Cancer Lett., 2001, 167, 175–182.
67. Jankun J., Selman S.H., Swiercz R., Skrzypczak-Jankun E., Why drinking green tea could prevent cancer. Nature, 1997, 387, 561.
68. Juhel C., Armand M., Pafumi Y., Green tea extract (AR25) inhibits lipolysis of triglycerides in gastric and duodenal medium *in vitro*. J. Nutr. Biochem., 2000, 11, 45–51.
69. Kada K., Kaneko S., Matsuzaki T., Matsuzaki Y., Hara T., Detection and chemical identification of natural bio--antimutagens. A case of the green tea factor. Mutation Res., 1985, 150, 127–132.
70. Kajimoto G., Antioxidative components and antiseptic components in tea leaves. I. Antioxidant action and antiseptic action of materials extracted from the green tea with alcohol and water. Nippon Shokuhin Kogyo Gakkaishi, 1963, 10, 13–20.
71. Kao Y.H., Hiipakka R.A., Liao S., Modulation of endocrine systems and food intake by green tea epigallocatechin gallate. Endocrinology, 2000, 141, 980–987.
72. Katiyar S.K., Mukhtar H,. Tea antioxidants in cancer chemoprevention. J. Cell Biochem., 1997, 67, 59–67.
73. Kelli S.O., Hertog M.G., Feskens E.J., Kromhout D., Dietary flavonoids, antioxidant vitamins, and incidence of stroke: the Zutphen study. Arch. Intern. Med., 1996, 156, 637–642.
74. Khan W.A., Wang Z.Y., Athar M., Bickers D.R., Mukhtar H., Inhibition of the skin tumorigenecity of (+) 7β, 8α-dihydroxy-9α, 10α-epoxy-7,8,9,10-tetrahydrobenzo-(a)pyrene by tannic acid, green tea polyphenols and quercetin in Sencar mice. Cancer Lett., 1988, 42, 7–12.
75. Khokhar S., Magnusdottir S.G.M., Total phenol, catechin and caffeine contents of teas commonly consumed in the United Kingdom. J. Agric. Food Chem., 2002, 50, 565–570.
76. Kiehne A., Lakenbrink C., Engelhardt U.H., Analysis of proanthocyanidins in tea samples. Z. Lebensm. Unter. Forsch. A, 1997, 205, 153–157.
77. Kim M., Masuda M., Cancer chemoprevention by green tea polyphenols. 1997, *in*: Chemistry and Applications of Green Tea (eds. T. Yamamoto, L.R. Juneja, D.C. Chu, M. Kim). CRC, New York, pp. 61–73.
78. Kinlen L.J., Willows A.N., Goldbatt P., Yudkin J., Tea consumption and cancer. Br. J. Cancer, 1988, 58, 397–401.
79. Kondo K., Masaaki K., Miyata N., Suzuki T., Toyoda M., Mechanistic studies of catechins as antioxidants against radical oxidation. Arch. Bioch. Bioph., 1999, 362, 79–86.
80. Kono S., Shinchi K., Ikeda N., Yanai F., Imanishi K., Green tea consumption and serum lipid profiles: a cross-sectional study in northern Kyushu, Japan. Prev. Med., 1992, 21, 526–531.
81. Korsmeyer S.J., Regulators of cell death. Trends Genet., 1995, 11, 101–105.
82. Kuhn D., Lam W.H., Kazi A., Daniel K.G., Song S., Chow L.M., Chan T.H., Dou Q.P., Synthetic peracetate tea polyphenols as potent proteasome inhibitors and apoptosis inducers in human cancer cells. Front Biosci., 2005, 10, 1010–1023.
83. Kundu T., Bhattacharya R.K., Siddiqi M., Roy M., Correlation of apoptosis with comet formation induced by tea polyphenols in human leukemia cells. J. Environ. Pathol. Toxicol. Oncol., 2005, 24, 115–128.
84. Kuo K.L., Weng M.S., Chiang C.T., Tsai Y.J., Lin-Shiau S.Y., Lin J.K., Comparative studies on the hypolipidemic and growth suppressive effects of oolong, black, pu-erh, and green tea leaves in rats. J. Agric. Food Chem., 2005, 53, 480–489.
85. Kuroda Y., Hara Y., Antimutagenic and anticarcinogenic activity of tea polyphenols. Mut. Res., 1999, 436, 69–97.
86. Li Y., Comparative study on the inhibitory effect of green tea, coffee and levamisole on the hepatocarcinogenic action of diethylnitrosamine. Chinese J. Cancer, 1991, 13, 193–203
87. Li C., Xie B., Evaluation of the antioxidant and pro-oxidant effects of tea catechin oxypolymers. J. Agric. Food Chem., 2000, 28, 6362–6366.
88. Liang Y., Xu Y., Effect of pH on cream particle formation and solids extraction yield of black tea. Food Chem., 2001, 74, 155–160.
89. Liang Y., Lu J., Shang S., Effect of gibberelins on chemical composition and quality of tea (*Camellia sinensis* L). J. Sci. Food Agric., 1996, 72, 411–414.
90. Liao J., Yang G.Y., Park E.S., Meng X., Sun Y., Jia D., Seril D.N., Yang C.S., Inhibition of lung carcinogenesis and effects on angiogenesis and apoptosis in A/J mice by oral administration of green tea. Nutr. Cancer, 2004, 48, 44–53.
91. Liebert M., Licht U., Bõhm V., Bitsch R., Antioxidant properties and total phenolics content of green and black tea under different brewing conditions. Z. Lebens. Untersuch. Forsch. A, 1999, 208, 217–220.
92. Lin J.K., Lin C.L., Liang Y.C., Lin-Shiau S.Y., Juan I.M., Survey of catechins, gallic acid and methylxanthines in green, oolong, pu-erh and black teas. J. Agric. Food Chem., 1998a, 46, 3635–3642.
93. Lin Y.L., Cheng C.Y., Lin Y.P., Lau Y.W., Juan I.M., Lin J.K., Hypolipidemic effect of green tea leaves through induction of antioxidant and phase II enzymes including superoxide dismutase, catalase and glutathione S-transferase in rats. J. Agric. Food Chem., 1998b, 46, 1893–1899.
94. Loest H.B., Noh S.K., Koo S.I., Green tea extract inhibits the lymphatic absorption of cholesterol and alpha-tocopherol in ovariectomized rats. J. Nutr., 2002, 132, 1282–1288.

95. Lopaczyński W., Zeisel S.H., Antioxidants, programmed cell death, and cancer. Nutr. Res., 2001, 21, 295–307.
96. Lung H.L., Ip W.K., Chen Z.Y., Mak N.K., Leung K.N., Comparative study of the growth-inhibitory and apoptosis-inducing activities of black tea theaflavins and green tea catechin on murine myeloid leukemia cells. Int. J. Mol. Med., 2004, 13, 465–471.
97. Maron D.J., Lu G.P., Cai N.S., Wu Z.G., Li Y.H., Chen H., Zhu J.Q., Jin X.J., Wouters B.C., Zhao J., Cholesterol-lowering effect of a theaflavin-enriched green tea extract: a randomized controlled trial. Arch. Intern. Med., 2003, 163, 1448–1453.
98. Matsumoto N., Okushio K., Hara Y., Effect of black tea polyphenols on plasma lipids in cholesterol-fed rats. J. Nutr. Sci. Vitaminol., 1998, 44, 337–342.
99. Matsuzaki T.L., Hara Y., Antioxidative activity of tea leaf catechins. Nippon Nogeikagaku Kaishi, 1985, 59, 129–134.
100. Middleton E. Jr, Effect of plant flavonoids on immune and inflamatory cell function. Adv. Exp. Med. Biol., 1998, 439, 175–182.
101. Mukhtar H., Ahmad N., Green tea in chemoprevention of cancer. Toxicol Sci., 1999, 52, 117–117.
102. Nakane H., Ono K., Differential inhibition of HIV reversed transcriptase and various DNA and RNA polymerases by some catechin derivatives. Nucleic Acids Symp. Ser., 1989, 21, 115–116.
103. Nakao M., Takio S., Ono K., Alkyl peroxyl radical scavenging activity of catechins. Phytochem., 1998, 49, 2379–2382.
104. Nanjo F., Goto K., Seto R., Suzuki M., Sakai M., Hara Y., Scavenging effects of tea catechins and their derivatives on 1,1-diphenyl-2-picrylhydrazyl radical. Free Rad. Biol. Med., 1996, 21, 895–902.
105. Nicoli M.C., Calligaris S., Manzocco L., Effect of enzymatic and chemical oxidation on the antioxidant capacity of catechin model systems and apple derivatives. J. Agric. Food Chem., 2000, 48, 4576–4580.
106. Nihal M., Ahmad N., Mukhtar H., Wood G.S., Antiproliferative and proapoptotic effects of (-)-epigallocatechin-3-gallate on human melanoma: possible implications for the chemoprevention of melanoma. Int. J. Cancer, 2005, 20, 114, 513–521.
107. Ninomiya M., Unten L., Kim M., Chemical and physicochemical properties of green tea polyphenols. 1997, *in*: Chemistry and Applications of Green Tea (eds. T. Yamamoto, L.R. Juneja, D.C. Chu, M. Kim). CRC, New York, pp. 23–35.
108. Nonaka G., Sakai R., Nishioka I., Hydrolysable tannins and proanthocyanidins from green tea. Phytochem., 1984, 23, 1753–1755.
109. Oguni I., Nasu K., Yamamoto S., Nomura T., The antitumor activity of fresh green tea leaf. Agric. Biol. Chem., 1988, 52, 1879–1880.
110. Okamoto M., Leung K.P., Ansai T., Sugimoto A., Maeda N., Inhibitory effects of green tea catechins on protein tyrosine phosphatase in *Prevotella intermedia*. Oral Microbiol. Immunol., 2003, 18, 192–195.
111. Okamoto M., Sugimoto A., Leung K.P., Nakayama K., Kamaguchi A., Maeda N., Inhibitory effect of green tea catechins on cysteine proteinases in *Porphyromonas gingivalis*. Oral Microbiol. Immunol., 2004, 19, 118–120.
112. Okubo T. Juneja L.R., Effects of green tea polyphenols on human intestinal microflora. 1997, *in*: Chemistry and Applications of Green Tea (eds. T. Yamamoto, L.R. Juneja, D.C. Chu, M. Kim). CRC, New York, pp 109–121.
113. Osawa T., Yoshida S., Yamashida K., Ochi H., Protective role of dietary antioxidants in oxidative stress, 1995, *in*: Oxidative Stress and Aging (eds. R.G. Cutler, L. Packer, J. Bertram, A. Mori). Birkhauser-Verlag, Basel, Switzerland, pp. 367–377.
114. Otake S., Makimura M., Kuroki T., Nishihara Y., Hirasawa M., Anticaries effects of polyphenolic compounds from Japanese green tea. Caries Res., 1991, 25, 438.
115. Paul B., Hayes C.S., Kim A., Athar M., Gilmour S.K., Elevated polyamines lead to selective induction of apoptosis and inhibition of tumorigenesis by (-)-epigallocatechin-3-gallate (EGCG) in ODC/Ras transgenic mice. Carcinogenesis, 2005, 26, 119–124.
116. Price W.E., Spitzer J.C., Variation in the amounts of individual flavanols in a range of green tea. Food Chem., 1993, 47, 271–276.
117. Price W.E., Spitzer J.C., The kinetics of extraction of individual flavanols and caffeine from a Japanese green tea (Sen Cha Uji Tsuyu) as a function of temperature. Food Chem., 1994, 50, 19–23.
118. Qanungo S., Das M., Haldar S., Basu A., Epigallocatechin-3-gallate induces mitochondrial membrane depolarization and caspase-dependent apoptosis in pancreatic cancer cells. Carcinogenesis, 2005, 26, 958–967.
119. Raederstorff D.G., Schlachter M.F., Elste V., Weber P., Effect of EGCG on lipid absorption and plasma lipid levels in rats. J. Nutr. Biochem., 2003, 14, 326–332.
120. Roedig-Penman A., Gordon M.H., Antioxidant properties of catechins and green extracts in model food emulsions. J. Agric. Food Chem., 1997, 45, 4267–4270.
121. Rudzińska M., Korczak J., Gramza A., Wąsowicz E., Dutta P.C., Inhibition of stigmasterol oxidation by antioxidants in purified sunflower oil. J. Assoc. Off. Anal. Chem., 2004, 87, 499–504.
122. Sadakata S., Fukao A., Hisamichi S., Mortality among female practicioners of Chanoyu (Japanese tea ceremony). Tohoku J. Exp. Med.,1992, 166, 475–477.
123. Saijo R., Isolation and chemical structures of two new catechins from fresh tea leaf. Agric. Biol. Chem., 1982, 46, 1969–1970.
124. Sakanaka S., Kim M., Taniguchi M., Yamamoto T., Antibacterial substances in Japanese green tea extract against *Streptococcus mutans*, a carcirogenic bacterium. Agric. Biol. Chem., 1989, 53, 2307–2311.
125. Sakanaka S., Shimura N., Aizawa M., Kim M., Yamamoto T., Preventive effect of green tea polyphenols against dental caries in conventional rats. Biosci. Biotech. Biochem., 1992, 56, 592–597.
126. Sakanaka S., Mamiya S., Kim M., Itoh K., Otoma Y., Miyaaki T., Inhibitory effect of tea polyphenols and lacitol on human dental plaque formation. Abstracts of Papers. Annual Meeting of the Agricultural Chemistry Sociaty of Japan, 1996, p. 9.
127. Salah N., Miller N.J., Paganga G., Tijburg L., Polyphenolic flavanols as scavengers of aqueous phase radicals and as chain-breaking antioxidants. Arch. Bioch. Bioph., 1995, 322, 339–346.

128. Sano M., Suzuki M., Miyase T., Yoshino K., Maeda--Yamamoto M., Novel antiallergic catechin derivatives isolated from oolong tea. J. Agric. Food Chem., 1999, 47, 1906–1910.
129. Sava V.M., Yang S.M., Hong M.Y., Yang P.C., Huang G.S., Isolation and characterization of melanic pigments derived from tea and tea polyphenols. Food Chem., 2001, 73, 177–184.
130. Sawai Y., Sakata K., NMR analytical approach to clarify the antioxidative molecular mechanism of catechins using 1,1-diphenyl-2picrylhydrazyl. J. Agric. Food Chem., 1998, 46, 111–114.
131. Scalbert A., Williamson G., Dietary intake and bioavalability of polyphenols. J. Nutr., 2000, 130 (8S), 2073S–2085S.
132. Schulz H., Engelhardt U.H., Wegent A., Drews H.H., Lapczynski S., Application of near-infrared reflectance spectroscopy to the simultaneous prediction of alkaloids and phenolic substances in green tea leaves. J. Agric. Food Chem., 1999, 47, 5064–5067.
133. Schwarz B., Bischof H.P., Kunze M., Coffe, tea and lifestyle. Prev. Med., 1994, 23, 377–384.
134. Sesso H.D., Gaziano J.M., Buring J.E., Hennekens C.H., Coffe and tea intake and the risk of myocardial infarction. Am. J. Epidemiol., 1999, 149, 162–167.
135. Shahidi F., Alexander D.M., Green tea catechins as inhibitors of oxidation of meat lipids. J. Food Lipids, 1998, 5, 125–133.
136. Shetty M., Subbannayya K., Shivananda P.G., Antibacterial activity of tea (*Camellia sinensis*) and coffee (*Coffe arabica*) with special reference to *Salmonella typhimurium*. J Commun. Dis., 1994, 26, 147–150.
137. Shimada K., Kawarabayashi T., Tanaka A., Fukuda D., Nakamura Y., Yoshiyama M., Takeuchi K., Sawaki T., Hosoda K., Yoshikawa J., Oolong tea increases plasma adiponectin levels and low-density lipoprotein particle size in patients with coronary artery disease. Diabetes Res. Clin. Pract., 2004, 65, 227–234.
138. Shimoi K., Nakamura Y., Tomita I., Hara Y., Kada T., The pyrogallol related compounds reduce UV-induced mutations in *Escherichia coli* B/r. Mutation Res., 1986, 239–244.
139. Shin J.E., Kim J.M., Bae E.A., Hyun Y.J., Kim D.H., *In vitro* inhibitory effect of flavonoids on growth, infection and vacuolation of *Helicobacter pylori*. Planta Med., 2005, 71, 197–201.
140. Smith D.M., Dou Q.P., Green tea polyphenol epigallocatechin inhibits DNA replication and consequently induces leukaemia cell apoptosis. Int. J. Mol. Med., 2001, 7, 645–652.
141. Spiro M., PriceW.E., Miller W.M., Arami M., Kinetics and equilibria of tea infusion-part 8: the effects of salts and of pH on the rate of extraction of theaflavins from black tea leaf. Food Chem., 1987, 25, 117–126.
142. Stapleton P.D., Shah S., Hamilton-Miller J.M., Hara Y., Nagaoka Y., Kumagai A., Uesato S., Taylor P.W., Anti-*Staphylococcus aureus* activity and oxacillin resistance modulating capacity of 3-*O*-acyl-catechins. Int. J. Antimicrob. Agents, 2004a, 24, 374–380.
143. Stapleton P.D., Shah S., Anderson J.C., Hara Y., Hamilton-Miller J.M., Taylor P.W., Modulation of beta-lactam resistance in *Staphylococcus aureus* by catechins and gallates. Int. J. Antimicrob. Agents, 2004b, 23, 462–467.
144. Steele C.M., Lalies M., Ioannides C., Inhibition of the mutagenicity of aromatic amines by the plant flavonoid (+)-catechin. Cacer Res., 1985, 45, 3573–3577.
145. Stensvold I., Tverdal A., Solvoll K., Foss O.P., Tea consumption. Relationship to cholesterol, blood pressure, and coronary and total mortality. Prev. Med., 1992, 21, 546–553.
146. Strom S.S., Yamamura Y., Duphorne C.M., Spitz M.R., Babaian R.J., Pillow P.C., Hursting S.D., Phytoestrogen intake and prostate cancer: a case – control study using a new database. Nutr. Cancer, 1999, 33, 20–25.
147. Su Y., Xu J., Ng C.H., Leung L.K., Huang Y., Chen Z., Antioxidant activity of tea theaflavins and methylated catechins in canola oil. J. Am. Oil. Chem. Soc., 2004, 81, 269–272.
148. Sung H., Nah J., Chun S., Park H., Yang S.E., Min W.K., *In vivo* antioxidant effect of green tea. Eur. J. Clin. Nutr., 2000, 54, 527–529.
149. Swiercz R., Skrzypczak-Jankun E., Merrell M.M., Selman H.S., Jankun J., Angiostatic activity of synthetic inhibitors of urokinase type plasminogen. J. Oncology Rep., 1999, 6, 523–526.
150. Tanaka T., Mine C., Inoue K., Matsuda M. Kouno I., Synthesis of theaflavin from epicatechin and epigallocatechin by plant homogenates and role of epicatechin quinone in the synthesis and degradation of theaflavin. J. Agric. Food Chem., 2002, 50, 2142–2148.
151. Tang S., Sheehan D., Buckley D.J., Morrissey P.A., Kerry J.P., Anti-oxidant activity of added tea catechins on lipid oxidation of raw minced red meat, poultry and fish muscle. Int. J. Food Scien. Tech., 2001, 36, 685–692.
152. Tanizawa H., Sazuka Y., Komatsu A., Toda S., Taniko Y., A new efficacy test of antioxidants based on air-oxidation of linoleic. Chem. Pharm. Bull., 1983, 31, 4139–4143.
153. Temple S.J., Temple C.M., van Boxtel A.J.B., Clifford M.N., The effect of drying on black tea quality. J. Sci. Food Agric., 2001, 81, 764–772.
154. Terao J., Piskula M., Yao Q., Protective effect of epicatechin, epicatechin gallate, and quercetin on lipid peroxidation in phospholipid bilayers. Arch. Bioch. Bioph., 1994, 278–284.
155. Thanaraj S.N.S., Seshardi R., Influence of polyphenol oxidase activity and polyphenol content of tea schoot on quality of black tea. J. Sci. Food Agric., 1990, 51, 57–69.
156. Tijburg L.B.M., Mattern T., Folts J.D., Weisgerber U.M., Katan M.B., Tea flavonoids and cardiovascular diseases: a review. Crit. Rev. Food Sci. Nutr., 1997, 37, 771–785.
157. Toda M., Okubo S., Hara Y., Shimamura T., Antibacterial and bactericidal activities of tea extracts and catechins against methicillin resistant *Staphylococcus aureus*. Nippon Saikingaku Zasshi., 1991, 46, 839–845.
158. Toda M., Okubo S., Ikigai H., Shimamura T., Antibacterial and anti-hemolysin activities of tea catechins and their structural relatives. Nippon Saikingaku Zasshi., 1990, 45, 561–566.

159. Vastag B., Tea therapy? Out of the cup, into the lab. J. Natl. Cancer Inst., 1998, 90, 1504–1505.
160. Vinson J.A., Dabbagh Y.A., Effect of green and black tea supplementation on lipids, lipid oxidation and fibrinogen in the hamster: mechanism for the epidemiological benefits of tea drinking. FEBS Lett., 1998, 433, 44–46.
161. Wanasundara U.N., Shahidi F., Stabilization of seal blubber and menhaden oils with green tea catechins. J. Am. Oil. Chem. Soc., 1996, 73, 1183–1190.
162. Wanasundara U.N., Shahidi F., Antioxidant and pro-oxidant activity of green tea extracts in marine oils. Food Chem., 1998, 63, 335–342.
163. Wang Z.Y., Agarwal R., Khan W.A., Mukhtar H., Protection against benzo(a)pyrene and *N*-nitrosodiethylamine-induced lung and forestomach tumorigenesis in A/J mice by water extracts of green tea and licoric. Carcinogenesis, 1992, 13, 1491–1494.
164. Wang H., Provan G.J., Helliwell K., Tea flavonoids, their functions, utilization and analysis. Trends Food Sci. Tech., 2000, 11, 152–160.
165. Weisburger J.H., Tea antioxidants and health. 1996, *in*: Handbook of Antioxidants (eds. E. Cadenas, L. Packer). Marcel Dekker, New York, pp. 469–486.
166. Xie J., Chen Q.Y., Zhou J.Y., Study on mechanism of tea polyphenols in inducing human lung cancer cell apoptosis *in vitro*. Zhongguo Zhong Xi Yi Jie He Za Zhi., 2005, 25, 244–247.
167. Xu Y., Ho C.T., Amin S.G., Han C., Chung F.L., Inhibition of tobacco-specific nitrosamine-induced lung tumorigenesis in A/J mice by green tea and its major polyphenol as antioxidants. Cancer Res., 1992, 52, 3875–3882.
168. Yam T.S., Shah S., Hamilton-Miller J.M.T., Microbiological activity of whole and fractionated crude extracts of tea (*Camellia sinensis*), and of tea components. FEMS Microb. Lett., 1997, 152, 169–174.
169. Yamamoto Y., Matsunaga K., Friedman H., Protective effects of green tea catechins on alveolar macrophages against bacterial infections. Biofactors, 2004, 21, 119–121.
170. Yamane T., Hagiwara N., Tateishi M., Akachi S., Kim M., Okuzumi J., Kitao Y., Inagake K., Kuwata K., Takahashi T., Inhibition of azoxymethane induced colon carcinogenesis in rat by green tea polyphenol fraction. Jpn. J. Cancer Res., 1991, 82, 1336–1339.
171. Yamane T., Takahashi T., Kuwata K., Oya K., Inagake M., Kitao Y., Suganuma M., Fujiki H., Inhibition of *N*-methyl-*N*'-nitro-*N*-nitrosoguanidine-induced carcinogenesis by (-)-epigallocatechin gallate in the rat glandular stomach, Cancer Res., 1995, 55, 2081–2084.
172. Yamane T., Nakatani H., Kikuoka N., Matsumoto H., Iwata Y., Kitao Y., Oya K., Takahashi T., Inhibitory effects toxicity of green tea polyphenols in cancer prevention. J. Nutr., 1996, 170, S472–S478.
173. Yanishlieva-Maslarowa N.V., Heinonen I.M., Sources of natural antioxidants: vegetables, fruits, herbs, spices and teas. 2001, *in*: Antioxidants in Food – Practical Applications (eds. J. Pokorny, N. Yanishlieva, M. Gordon). CRC Press, Woodhead Publishing, Cambridge England, pp. 210–249.
174. Yee Y.K., Koo M.W., Anti-*Helicobacter pylori* activity of Chinese tea: *in vitro* study. Aliment. Pharmacol. Ther., 2000, 14, 635–638.
175. Yen G.-C., Chen H.-Y., Antioxidant activity of various tea extracts in relation to their antimutagenicity. J. Agric. Food Chem., 1995, 43, 27–32.
176. Yoda Y., Hu Z.Q., Zhao W.H., Shimamura T., Different susceptibilities of *Staphylococcus* and Gram-negative rods to epigallocatechin gallate. J. Infect. Chemother., 2004, 10, 55–58.
177. Yokoyama M., Noguchi M., Nakao Y., Pater A., Iwasaka T., The tea polyphenol, (-)-epigallocatechin gallate effects on growth, apoptosis, and telomerase activity in cervical cell lines. Gynecol. Oncol., 2004, 92, 197–204.
178. Yoshioka H., Sugiura K., Kawahara R., Fujita T., Makino M., Kamiya M., Tsuyumu S., Formation of radicals and chemiluminescence during the autoxidation of tea catechins. Agric. Biol. Chem., 1991, 55, 2717–2723.
179. Zhang Y., Gan H., The inhibitive effect of tea polyphenols on oxidized low density lipoprotein intake in cultured rat mesangial cells. Zhongguo Zhong Yao Za Zhi., 2003, 28, 762–766 (in Chinese).
180. Zhang M.H., Luypaert J., Fernandez Pierna J.A., Xu Q.S., Massart D.L., Determination of total antioxidant capacity in green tea by near-infrared spectroscopy and multivariate calibration. Talanta, 2004, 62, 25–35.
181. Zhu Q.Y., Huang Y., Tsang D., Chen Z.Y., Regeneration of alpha-tocoferol in human low-density lipoprotein by green tea catechin. J. Agric. Food. Chem., 1999, 47, 2020–2025.
182. Zhu Q.Y., Zhang A., Tsang D., Huang Y. Chen Z.Y., Stability of green tea catechins. J. Agric. Food Chem., 1997, 45, 4624–462.

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POLIFENOLE HERBATY – ICH WŁAŚCIWOŚCI PRZECIWUTLENIAJĄCE I AKTYWNOŚĆ BIOLOGICZNA – ARTYKUŁ PRZEGLĄDOWY

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Herbata jest najczęściej spożywanym napojem na świecie. Liście herbaty są źródłem polifenoli, szczególnie katechin. Artukuł omawia zmiany chemiczne polifenoli [katechiny (C), epikatechiny (EC), galokatechiny (GC), epigalokatechiny (EGC), galusanu epikatechiny(ECG), galusanu epigalokatechiny (EGCG)] podczas procesu fermentacji herbaty oraz aktywność przeciwutleniającą, właściwości antymutagenne, antynowotworowe i anty–miażdżycowe ekstraktów związków polifenolowych herbaty i czystych katechin.