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Leaves of *Camellia sinensis*: Ordinary Brewing Plant or Super Antioxidant Source?

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ABSTRACT

Tea (*Camellia sinensis*) is well known not only for its taste and aroma, but also for its health benefits, considered to be a medicine. The manuscript presents tea species profile and chemical composition, its occurrence and possible usage directions. A great number of tea origin substances have been reported to possess antioxidant properties as trapping agents and free radical quenchers, presenting a wide range of health benefits for human health and wellness. Tea polyphenols are the main constituents responsible for a tea's properties and specific taste and are also the major group of constituents that can be used as direct supplements and as very potential food antioxidants in different systems. The main tea polyphenols are flavonols or catechins, in particular epicatechin, epicatechin-3-gallate, epigalocatechin and epigalocatechin-3-gallate. The world literature presents many studies showing the antioxidant activity contributions of polyphenols; however within this review detailed information on the specificity of tea polyphenols will be presented. Tea polyphenols are reported to be strong antioxidants in living organisms and lipid systems, including fish and vegetable oils, and animal fat. This paper reviews what is known of green tea species, its leaf processing and changes that occur in tea components and highlights the potential of green tea, its health benefits and bioavailability. Current possible mechanisms of polyphenol antioxidant activity are also described. The world's food industry needs new sources of natural substances presenting antioxidant activity that are acceptable to consumers, and which increase the shelf life and quality of food.

Keywords: tea, Camellia sinensis, polyphenols, catechins, antioxidant activity, bioavailability
Abbreviations: C, (+)-catechin; **EC**, (-)-epicatechin; **ECG**, (-)-epicatechin gallate; **EGC**, (-)-epigallocatechin; **EGCG**, (-)-epigallocatechin gallate; **GA**, gallic acid; **GC**, (+)-gallocatechin

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INTRODUCTION

Constituents of plant origin such as polyphenols are the subject matter of much research because of their possible beneficial properties in the human body. A diet rich in polyphenols may be helpful in scavenging free radicals, taking part in major degenerative diseases. Although the average polyphenol daily intake is approximately one gram, it is still growing as human habits change over the years, as the result of a "healthy lifestyle" (Scalbert and Williamson 2000; Gramza *et al*. 2005a; Gramza and Korczak 2005). Tea leaves as an everyday beverage could be a source of polyphenols, especially catechins, a decisive group for their antioxidative activity. The main green tea polyphenols are catechins: (+)-catechin C, (-)-epicatechin EC, (+)-gallocatechin GC, (-)-epigallocatechin EGC, (-)-epicatechin gallate ECG, (-)-epigallocatechin gallate EGCG (Balentine *et al*. 1997).

The biosynthetic pathway of catechins in tea plant is shown in **Fig 1**. Catechin is synthesized through malonic acid and shikimic acid metabolic pathways, starting from glucose pool. EGC is produced by hydroxylation of EC, whereas ECG and EGCG are produced by esterification of catechins with gallic acid, derived from an intermediary product of the shikimic acid metabolic pathway (Chu and Juneja 1997; Hara 2001).

There are many mechanisms of antioxidant activity of tea plant phenols, like oxygen scavenging, chelating metal ions, absorbing UV radiation, decomposing peroxides and non-radical products or partial regenerating of primarily

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antioxidants (Gramza and Korczak 2005).

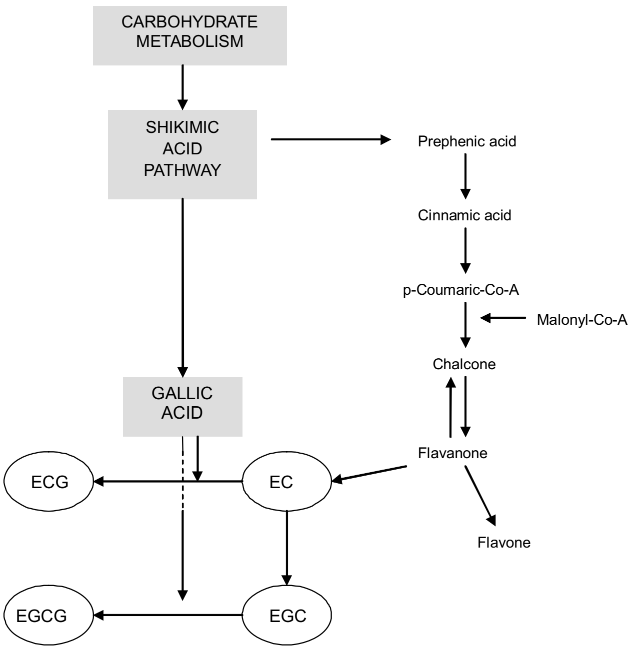

Fig. 1 Biosyntethic pathway of catechins in tea plant.

TEA SPECIES' PROFILE AND CHEMICAL COMPOSITION

Tea is grown in many regions of the world, mainly in China, India, Japan and on Ceylon island (Weisburger 1997; Fernandez *et al*. 2002). According to ancient Chinese mythology, the tea plant was discovered thousands years ago in South-East Asia. Aboriginal tea leaf infusions had been considered for medicine, and became a most popular beverage all over the world many centuries later. The tea leaf market is very differentiated and diverse. Basic tea division consists of green, oolong and black (Kakuzo 1987; Harbowy and Balentine 1997; Chen *et al*. 2006a).

The tea plant is taxonomically classified as *Camellia sinensis* (L.) of the *Theaceae* family. The genus *Camellia* incorporates more than 80 species in its taxonomy (Sealy 1958). The genus *Camellia* is classified into eight sections of which Thea comprises *C. sinensis*, *C. taliensis*, *C. irrawadiensis*, *C. grocilipes* and *C. pubicosta*. Presently cultivated tea belongs to *Camellia sinensis*, classified into two varieties: *assamica* and *sinensis* (Chu 1997).

The meaning of the word tea is applied widely. Apart from green, oolong and black tea *C. sinensis* flavourful leaf infusions, several herbal, fruit and aromatized beverages not related to *Camellia* spp. infusions are also called tea.

Chen *et al*. (2006b) provide a detailed description of molecular methodologies to try and discern between the world's tea species and show how molecular biology and functional genomics could elucidate the genetic composition of tea, including the floral aroma formation-related genes.

The average world tea consumption is about 120 ml/day/person (Mukhtar and Ahmad 1999), but the tea consumption preferences are different in various regions of the world. Tea consumption is very specific in countries where tea is grown, the Japanese and Northern China inhabitants prefer the healthiest – green tea; oolong tea is mainly consumed in Taiwan and Southern China, most Europeans and Americans prefer black tea. According to the average world production of tea which is nearly three million tons, over 70% of the annual output is black tea while green tea accounts for about 20% (Tea Council 2001).

The tea plant is an evergreen shrub or tree from the Theaceae family, species *Camelia*. There are two basic botanical varieties: Chinese tea shrub (*Camelia sinensis*) as well as the Indian tea tree (*Camelia assamica*) (Sanderson 1972; Anonymous 2000). Leaves of tea are shiny and dark green, growing opposite and round. Its flowers are large, coloured white, pink or red and fruits are small and brown (Chu and Juneja 1997).

Tea harvesting lasts throughout the year, but tea brewing's quality is influenced by time. The most aromatic and delicate teas are from the spring collecting, top grade expensive teas however, are gained from young leaflets of top twigs and undeveloped leaves, showing uncommon suitable taste and aroma features (Bokuchava and Skobeliva 1980; Chu and Juneja 1997). There are many processed tea leaf classifications, one is based on different fermentation degree: non-fermented (green), semi-fermented (oolong) as well as totally fermented (black). The main tea production process consists of four basic stages. After manual or automated collection the tea shrub or tea leaves undergo partial withering, afterwards the leaves undergo roasting to inactivate oxidative enzymes, rolling up, drying and sorting. As a result gentle and constringent green tea is produced. The process of black tea production is more complicated. The leaves also undergo withering while the first fermentation processes occur, than rolling up and further fermentation. The next step of fermented leaves is roasting, blocking enzyme (polyphenol oxidase and glycosidase) activity, until the appearance of the dark-brown or black colour and suitable aroma (Chu and Juneja 1997; Lin *et al*. 1998). Partially fermented oolong tea undergoes a considerably shorter fermentation time than black tea. There are also other well known teas like white (non-fermented), yellow (very lightly fermented) and red (*Pu-erh* tea), which, after the fermentation process undergo a long-term storage (**Fig. 2**; Balentine *et al*. 1997).

Concerning chemical composition, tea leaves mainly consist of proteins and carbohydrates, including cellulose fibers, almost insoluble in water (**Table 1**; Chu and Juneja 1997).

Other components are amides, nucleic protein acids and amino acids, like theanine and glutamic acid as well as arginine and aspartic acid (Chu and Juneja 1997; Juneja *et al*. 1999). Specific sensory features of tea are given by low molecular mass compounds leached from tea leaves with hot water. Tea leaves contain vitamins like A, B_1, B_2, K, niacin and ascorbic acid, athough the fermentation process causes their decomposition resulting in their lower quantities (Graham 1992).

Tea leaves consist of mineral elements like Zn, Fe, Mg, Cu, Na, K as well as Ni, P and Ca (**Table 2**; Tsushida and Takeo 1977; Chu and Juneja 1997; Fernandez-Caceres *et al*. 2001; Ferrara *et al*. 2001).

Researches showed however that the metal content in

Fig. 2 Tea leaves as a result of different fermentation process: (A) white; (B) green; (C) yellow; (D) red (oolong); (E) black.

Table 1 General chemical components of tea leaves (based on Chu and Juneja 1997).

Kind of tea (100 g)	Protein (g)	Lipid (g)	Carbohydrates	
			Sugar (g)	Fiber (g)
Green	24.0	4.6	35.2	10.6
Oolong	19.4	2.8	39.8	12.4
Black	20.6	2.5	32.1	10.9

Table 2 General inorganic elements of tea leaves (based on Tsushida and Takeo 1977; Chu and Juneja 1997; Fernandez-Caceres *et al.* 2001; Ferrara *et al.* 2001).

Minerals (mg)	Kind of tea (100 g)		
	Green	Oolong	Black
Zn	63	44	73
Fe	20	32.4	17.4
Mg	120-300	27.8	34.4
Cu	2.7	1.04	4.05
Na	3	7	3
K	2.200	1.800	2.000
Ni	1.3	1.9	1.3
P	280	230	320
Ca	440	310	470

tea leaf infusion depends on the temperature and power of infusion as well as the kind of tea (Wei *et al.* 1989; Tascioglu and Kok 1998).

Tea is differentiated by its pigments. Green tea's main pigment is chlorophyll, that of black tea, orange theaflavins and of brown, thearubigens (Bailey and Nursten 1993; Opie *et al.* 1993; Balentine 1997; Higashi-Okai *et al.* 2001; Gramza *et al.* 2004), which appear during green tea fermentation, which chemical proprieties allowing researchers to claim that these compounds are identical to melanin (Sava *et al.* 2001).

Another important group of tea constituents are the alkaloids, which include caffeine (theine), theophylline and theobromine (Nakatani 1997; Schulz *et al.* 1999). It was found that the fermentation process does not influence the caffeine level in leaves (Lin *et al.* 1998). Its higher content however, was found in fermented teas: up to 4.8% of dry weight and about 3.8% in green tea (Fernandez *et al.* 2002). It was stated that the differences in substance levels result from tea kind and leaf structure, influencing further leaching kinetics (Wang *et al.* 2000a, 2000b; Khokhar and Magnusdottir 2002).

Tea leaves as other plant products could be a good source of polyphenolic substances, positively influencing human health (Bravo 1998; Kaur and Kappor 2001). Polyphenols, secondary metabolites of the vegetable world, are not synthesized in the human body. Their action is mainly based on protecting plants against ultra-violet irradiation, pathogens and pests, antioxidative activity and giving colours, attractive for insects (Parr and Bolwell 2000). Polyphenolic substances are divided into four groups, among which the most important is the group of flavonoids and flavanols, in which the catechins fall. The occurrence of phenolic groups in polyphenol molecules, related to carbons of the aromatic ring, are its common feature (Dreosti 2000). The degree and position of hydroxylation have a basic meaning for polyphenols antioxidant activity, with the presence of two hydroxyl groups in the B ring being very favourable (Gramza and Korczak 2005).

TEA POLYPHENOLS

Plant products are very good sources of polyphenols (Ho *et al.* 1997; Hollman and Arts 2000), often called bioflavonoids or vitamin P, because of their wide spectrum of biological influence in living organisms (Dreosti 1996; Czeczot 2000). Fresh leaves of green tea consist of flavonoids and phenolic acids, making up to 30% of its dry weight but only 10% of the dry weight of black tea (Wang *et al.* 2000a). The most important tea leaf polyphenol group is the flavonoids (Hollman 2001), among them the most important is epigallocatechin gallate (EGCG), which occurs only in tea leaves (Graham 1992; Chu and Juneja 1997). There are three basic polyphenol groups in tea leaves: catechin, theaflavins and thearubigenes (Hagerman and Carlson 1998; Yanishlieva-Maslarowa and Heinonen 2001). Green tea contains large quantities of simple flavonoids, which transform to complexed forms of theaflavins and thearubigens during the fermentation process (Graham 1992; Balentine *et al.* 1997). Flavanols occur in plant tissues both in a monomeric form, the catechins, and polymers, as proantocyanidins (Spencer *et al.* 1988). Other compounds like tannins are responsible for the specific astringent infusion's aroma and taste (Chung *et al.* 1998; Hagerman *et al.* 1998; Kallithraka *et al.* 2000; Riedl and Hagerman 2001). Tea leaves' catechin content is correlated with infusion quality, and the highest catechin content was found in teas from young tea leaves (Thanaraj and Seshardi 1990).

FACTORS INFLUENCING TEA LEAVES' POLYPHENOL CONTENT DURING PROCESSING

During the fermentation of tea leaves the activity of polyphenol oxidase causes the oxidation of catechins to quinones, further undergoing polymerization to bisflavans and more complexed structures of theaflavins, thearubigens and higher molecular mass compounds (Stagg 1974; Bailey and Nursten 1993; Halder *et al.* 1998; Lin *et al.* 1998; Tanaka *et al.* 2002). Another consequence of fermentation is a gradual lowering of the flavanol content; however the alkaloid content does not change significantly (Schulz *et al.* 1999; Sava *et al.* 2001). Tea leaves with an occurrence of suitable quailtative features are dried to inhibit further oxidation reactions, which is the indispensable factor for product stability during storage (Dougan *et al.* 1979; Temple *et al.* 2001).

There are many studies on the quantity of catechin extracted during the brewing of tea leaves. It was found that a rise in catechins content was proportional to temperature and period of brewing time increase, and the highest quantity of catechins was extracted at 77-80°C (Chen *et al.* 1996a; Khokhar and Magnusdottir 2002). Results showed that a high water temperature and tea leaf infusion (120°C, 30 min) causes epimerization of C, EGCG, ECG, EGC and EC, undergoing conversion to suitable epimers: (-)-gallocatechin gallate (GCG), (-)-catechin gallate (CG), (-)- gallocatechin (GC) as well as (-)-catechin (Wang *et al.* 2000; Chen *et al.* 2001). The results of Chen *et al.* (1998, 2001) suggest that an increase in the pH causes an increase in catechin degradation, while acid pH resulted in its large stability (Zhu *et al.* 1997; Friedman and Jurgens 2000).

The way of preparing tea leaf infusions for consumption depends on the regional traditions or country. There are many possible ways in which people drink tea; in Ireland, England and Canada tea is often consumed with milk. There is no correlation between milk proteins and a decrease in green tea polyphenol activity (Hara 1997; van het Hoff *et al.* 1998; Hollman *et al.* 2001). Other authors have examined the possibility of biological activity of tea modification by the addition of milk (500 mL freshly brewed black tea with milk) (Lorenz *et al.* 2007). The induction of vasorelaxation in rat aortic rings and increased endothelial nitric oxide synthase were obtained in individuals who consumed pure black tea. All those effects were inhibited by the addition of milk to the tea infusion. The authors suggested that probably milk proteins, the casseins formed complexes with tea catechins, resulting in no positive effect on vascular function.

TEA LEAF CATECHINS

Flavan derivatives in a group of flavonoids, the catechins are distinguished by a high degree of heterocyclic ring oxidation and good water solubility (Sanderson *et al.* 1976). Green tea catechins appear in leaves in the form of gallic acid esters, mainly as C, EC, GC, ECG, EGC, and EGCG (Graham 1992; Ninomiya *et al.* 1997; Dreosti 2000; Gramza *et al.* 2006). One of the most active antioxidant compounds is EGCG, consisting of eight active free groups (OH). It was found that black tea consists of a smaller amount of catechins, but a larger quantity of gallic acid than in green tea (Khokhar and Magnusdottir 2002). The catechin content in a cup of green tea leaves is high and might be as dispersed as 90-400 mg of polyphenolic antioxidants, of which 200 mg is EGCG (Graham 1992; Mukhtar and Ahmad 1999). Tea consumers must be aware not only of the quality of tea leaves, but also of the infusion preparation instructions to obtain the best brew possible.

THE MECHANISM OF ANTIOXIDANT ACTIVITY OF TEA POLYPHENOLS

Polyphenols are strong antioxidants which were found to act as antiradical compounds, blocking free radicals (Rice-Evans *et al*. 1997; Toschi *et al*. 2000; Gramza and Korczak 2004); reducing compounds delivering hydrogen of hydroxyl groups (Yanishlieva-Maslarowa 2001); metal chelators, creating complex compounds with metals (Miller *et al*. 1996; Gramza *et al* 2005c); inhibiting oxidative activity of the oxidase group of enzymes and the active oxygen atom (Opie *et al*. 1993; Salah *et al*. 1995).

The oxidation reactions are complex in character, and polyphenol activity is a result of the kind and number of substituents. The first step is hydrogen separation from the hydroxyl group and the creation of fenoxyl radicals, which further undergo oxidation to compounds classified as being the most reactive of all natural products, the semiquinones, and then to the ortho- and paraquinones, or participate in reactions with radicals such as dimerisation, radical substitution, and reactions with different radicals (Gramza and Korczak 2005). Brown, high-molecular compound polymerization of the quinones is a major pathway of their transformation in food. As a result of nucleophilic substitution amines join quinones, and its products undergo transformation to brown melanin (Tanaka *et al*. 2002).

Effective radical scavenging acivity of polyphenols is a result of the presence of the *o*-dihydroxy structure in the B ring, resulting in higher stability of the radical form which participates in electron delocalization; the 2,3 double bond conjugated with the group 4-oxo in the C ring participates in electron delocalization from the B ring and the highest radical-scavenging ability of the 3,5-hydroxy group with the 4-oxo group in the A and C rings (Salah *et al*. 1995; Burda and Oleszek 2001).

BIOAVAILABILITY AND ABSORPTION OF TEA LEAVES' COMPONENTS

Pharmacological proprieties of green tea leaf infusion has been well-known for centuries, and confirmed by recent studies (Sato and Miyata 2000; McKay and Blumberg 2002; Wu and Wei 2002). Absorption and metabolism of polyphenols depends highly on its chemical structure, and it was not considered important because of the presence o the β-glycoside form (Price and Spitzer 1994; Hollman 2001). Food polyphenols are absorbed from the digestive tract, penetrating the blood and binding with albumins, which probably mask their antioxidant activity. In the stomach flavonoids undergo hydrolysis to simpler constituents, become absorbed and work as antioxidants (Arts *et al*. 2001, 2002). An important determinant of flavonoid bioavailability is the sugar particle, glucose whose presence allows for the increase in absorption of the flavonoids occurring in the form of glycosides. Absorption of catechins occurring in food in the form of aglycones has not been explained yet (Hollman and Arts 2000). Metabolization of flavonols and flavanols occurs mainly in the liver and large intestine (Takahashi and Ninomiya 1997; Rechner *et al*. 2002), where it is subjected to glucuronidation and sulfatation of phenolic groups and methylation of catecholic groups (Manach *et al*. 1999). Another way of not absorbing polyphenols is the secretion of bile into the small intestine and disintegration by colon bacteria (Griffith and Smith 1972). Many studies showed that a definite quantity of polyphenolic compounds after consumption remain in the body, suggesting that frequent green tea infusion consumption permits maintenance of high EGCG levels (Nakagawa *et al* 1997; Saganuma *et al*. 1998; Yang *et al*. 1998).

There are studies showing the negative influence of tea drinking on mineral administration in the human body. It was stated that tea consumption resulted in the slowing down of iron absorption (Disler *et al*. 1975) and increase of anaemia (Merhav *et al*. 1985). Another result is the lowering of the total nutritious value of food, because condensed tannins inhibit trypsin and block proteins (Los and Podsetek 2004). Unlike condensed tannins, low polymerized phenols practically do not inhibit trypsin activity (Quesada *et al*. 1996), and tannins also show a high resistance to digestive tract pH and the presence of bile acids and protease (Hagerman *et al*. 1998).

There are studies showing the partial absorbtion of polyphenols in human body tissues, suggesting propable health advantages of drinking tea brews (Dreosti 1996). There is no data showing the direction of tea polyphenol consumption, or limitations in its daily intake. The positive side is that no data has been observed on the toxic effect of tea polyphenol overdose (Takahashi and Ninomyia 1997). Nevertheless to clear up any misunderstandings it was stated that polyphenol activity and the effect in the human body depends on factors such as lifestyle and can possibly be masked by specific factors of the examined population (Yang 1999). There is much research, but polyphenol activity, bioavailability and metabolism has not yet been explained.

PROPERTIES OF TEA POLYPHENOLS IN BIOLOGICAL SYSTEMS

Recently research is focusing on the protective potential of substances naturally occurring in food with respect to their possible influence in the human body. Scientists examined the correlations between diets rich in fresh plant products and the mortality rate by different diseases (Yamane *et al*. 1996; Parr and Bolwell 2000; Sato and Miyata 2000). Strong and diverse biological proprieties of polyphenols, especially the flavonoids turned special attention to tea leaves and its brews.

Tea therapeutic value is well known (Ramarathan *et al*. 1995; Yang and Landau 2000; McKay and Blumberg 2002). It was found that according to the activity of tea polyphenols in scavenging superoxide radicals, tea could be a helpful tool in preventing oxidative stress-related diseases, responsible for cellular membrane disintegration and other degenerative diseases (Halliwell *et al*. 1995; Unno *et al*. 2000).

An indispensable component of life, oxygen, undergoes a transformation to reactive oxygen species (superoxide anion radical ($O_2^{\bullet-}$), hydroxylic radical ($OH^{\bullet}$) and hydroperoxide (H_2O_2) (Frankel 1998; Squadriato and Peyor 1998). The human organism possesses a very effective defensive system against oxidative stress induced by reactive oxygen species, which unfortunately diminish with aging, and leading to disturbances in red-ox balance (Osawa *et al*. 1995; Sato and Miyata 2000; Wu and Wei 2002). Many reports confirmed very strong antioxidative properties of flavanols isolated from green, black and red tea leaves (Xie *et al*. 1993; Vastag 1998). It was stated that flavonoids' antioxidant activity is probably based on the protection by endogenous antioxidants (vitamin E, ascorbic acid, and glutathione) against oxidation, delaying transformation of ascorbic acid into dehydroxyascorbic acid and protecting against the influence of free radicals (Chen *et al*. 1998; Noorozi *et al*. 1998). However the antioxidative efficiency of a compound depends on the degree of absorption and metabolism in living cells. Flavonoids' antioxidant activity *in vivo* could be lower because of biotransformation in the digestive tract (Lonchampt *et al*. 1989).

Studies showed that almost 30% of cancer could be the result of incorrect nutritional habits, explaining why a suitable diet manipulation may be a strong tool in cancer prevention (Weisburger 1996; Jankun *et al*. 1997). Many studies stated that green tea anticancerogenic properties are related to the presence of flavonoids, especially the catechins, EGCG (Kinlen *et al*. 1988; Oguni *et al*. 1988; Ahmad *et al*. 1997; Katiyar and Mukhtar 1997; Mukhtar and Ahmad 1999; Swiercz *et al*. 1999; Smith and Dou 2001). Knowledge about the anticancerogenic properties of tea polyphenols could be essential in a strategy against tumours (Fujiki *et al*. 1998), unfortunately no clear anticancerogenic mechanism had been found yet.

Another important activity of tea polyphenols is their germicidal properties, helping to lower the pathogen (*Escherichia coli*) population, but without influencing the lactic acid bacteria *Lactobacillus* and *Bifidobacterium* existing large intestine (Sakanaka *et al*. 1989; Okubo and Juneja 1997). It was found that both green and black tea leaf components possibly damage bacterium's cellular membrane, was and have been used in the treatment of diarrhea, cholera and typhus infections (Toda *et al*. 1990; Sheety *et al*. 1994). It was proved that only EC and EGC gallates from tea leaves inhibit RNA reverse transcriptase, playing an essential part in HIV virus replication (Nakane and Ono 1989; Gupta *et al*. 2002). Theaflavins, black tea polyphenols, protected rats' healthy liver cells against oxidative stress, and prevented DNA damage (Feng *et al*. 2002). Other observations suggested that the consumption of more than three tea leaf infusion cups daily as a possible protecttive factor against breast tumours in its early stage (Inoue *et al*. 2001). Another investigation showed that the consumption of more than 10 cups of green tea infusion daily results in a decrease in blood cholesterol level (Imai and Nakachi 1995). Tea flavonoids help to protect the low density lipoprotein (LDL) fraction against oxidation, by antiplatelet properties and by activation of prostaglandin synthesis (Acker *et al*. 1998; Hodgson *et al*. 1999; Sung *et al*. 2000).

Research also showed that individuals consuming tea extract three times daily burned 266 kcal/day more than the control group (i.e. without the addition of catechins), which allowed authors to presume a helpful component in overweight and obesity control (Dullo *et al*. 2000). Research on the property of thermogenic tea showed the synergistic action of caffeine and catechins (Dullo *et al*. 1999). Kao and co-workers found that green tea catechins influence the endocrine system. EGCG considerably lowered food intake, body mass, estradiol, testosterone and leptine levels in studied rats. It was found that EGCG may interact specifically with a component of a leptin-independent appetite control pathway (Kao *et al*. 2000). Tea flavonoids showed inhibittive activity in the release of some allergic reactions factors, such as leucotrienes and prostaglandins, by modifying the activity of enzymes taking part in inflammation of the human body (Middelton *et al*. 1998).

Among the tea constituents caffeine, or theine is a very important alkaloid that does not accumulate in the body (Graham 1997). Caffeine is a trimethyl derivative of purine 2,6-diol, first discovered in coffee by Runge in 1820. A similiar component isolated from tea was named theine (Ukers 1935). Caffeine and theine were identified as the same component, and as a result the name theine was dropped (Chu and Juneja 1997). It is responsible for central nervous system and myocardium stimulation, and the acceleration of the removal of toxic substances from organisms (Battig 1986; Passmore *et al*. 1987; Woodward and Tunstall-Pedoe 1999). Reasonable and safe caffeine consumption like 4 cups of tea leaves brewing daily does not cause an increase in the incidence of heart disease (Myers 1991).

The undeniable benefits of tea drinking have been proved with tea consumption method called *Chan-you*. It is a traditional brewing method based on infusion preparation from powdered green tea leaves, flooded with small portions of hot water and beaten to consistency of cream (Sadakata *et al*. 1992).

TEA POLYPHENOLS IN BODY WEIGHT REGULATION

Overweight and obesity represent a rapid threat to populations' health in an increasing number of countries (WHO 2000). According to medical and nutrition knowledge obesity raises the risk of hypertension, coronary heart disease, non-insulin dependent diabetes mellitus and certain forms of cancer (Stunkard 1996). Classical weight reduction can be achieved by decreasing the energy intake (low caloric diet), behavioral modification and increasing energy expenditure by exercising (Chantre and Lairon 2002; Diepvens *et al*. 2005). Due to the low success rates of classical body weight reduction methods, much research has been focused on the indication of natural herbal nutrients, which could support a reduction in body weight. On the basis of many epidemiological studies it seems that both green and oolong tea possess such benefits (Chen *et al*. 1998; Wu *et al*. 2003).

Sato and Miyata (2000) demonstrated a lower frequency of obesity among people who drank four cups of green tea per day. Wu *et al*. (2003) demonstrated an inverse relationship between habitual tea consumption (350 ml green tea beverage per day) and body weight, especially for subjects who had maintained the habit of tea consumption for more than 10 years. Chen *et al*. (1998) observed that Chinese women who drank four cups of 2 g Oolong tea infusion per day lost over a kilogram of body weight during a six-week period.

There are also research data about the beneficial effects of weight reduction due to treatment with green and oolong tea extracts. Research conducted in France showed that a three-month consumption of green tea extract with a dose of 270 mg of EGCG effectively reduced body weight by 4.6% in obese men and women (Chantre and Lairon 2002). Nagao *et al*. (2005) indicated that administration of 690 mg catechins from green tea for twelve weeks significantly reduced body weight (2.4 kg) in overweight people. Chan and co-workers (2006) reported that body weight of obese volunteers was reduced by 2.4% after green tea treatment for three months, although the difference was not significant. A recent study, however showed that weight maintenance after weight loss was not affected by green tea treatment as compared with the placebo (Westerterp-Plantenga *et al*. 2005). Other research showed that oolong tea prevented an increase in body weight and parametral adipose tissue in mice fed with a diet containing 40% beef tallow for 10 weeks (Han *et al*. 1999).

An interesting aspect is whether a reduction in body weight caused by a change of body fat can be achieved in non-obese people such as professional athletes who must control their body fat content. Unpublished data results showed that judo athletes after sixth weeks of green tea extract supplementation (athletes ingested 509.9 mg EGCG and 36.9 mg caffeine daily) lost 0.5 kg of their original body weight; simultaneously the body fat loss was 1.3 kg ($p < 0.05$) (Bajerska-Jarzebowska 2006). Shimotoyodome *et al*. (2005) also showed that dietary green tea extracts and regular exercise, when combined, could stimulate fat reducetion, and attenuate obesity induced by a high fat diet in mice.

Scientists suggest that both green and oolong tea components may promote body weight and fat loss by stimulating thermogenesis (Dulloo *et al*. 1999, 2000; Komatsu *et al*. 2003; Berube-Parent *et al*. 2005). The first thermogenic effect of green tea was attributed to its caffeine content (Astrup *et al*. 1990). However Dulloo *et al*. (2000) reported that green tea extract stimulates brown adipose tissue thermogenesis to a much greater extent than that which can be attributed to its caffeine content *per se* in rats. In another study the same group of authors found that green tea extract ingestion increased 24 h energy expenditure by 4% (328 kJ) in 10 healthy men, reflecting green tea's stimulatory effect on thermogenesis (Dulloo *et al*. 1999). The catechins in green and oolong teas may stimulate thermogenesis and fat oxidation through an inhibition of catechol *O*-methyl-transferase, an enzyme that degrades noradrenaline (Borchardt and Huber 1975). Wrisez and Lambert (2001) also indicated that other polyphenolic compounds like tannins and tannic acids had been reported to exert an influence on lipid metabolism in rats. Kao *et al*. (2000) found that rats which were intraperitoneally injected 15 mg of EGCG daily (82 mg/kg of body weight) consumed up to 60% less food after seven days of daily injections.

Green tea and oolong tea are regarded as the most active plants for body weight reduction, however there is still a need for more well-designed and controlled clinical studies to validate this effect.

PROPERTIES OF TEA POLYPHENOLS IN FOOD

Edible fats, oils and lipid-containing products (fats) undergo oxidation processes, causing a sequence of unfavorable changes, like rancidity, colour and texture changes and a decrease in nutritious value (Gray 1978; Frankel 1998).

Research showed no antioxidant to be active in all food products, because of processing stability, mixing ability, activity in different food systems and agreement with legal standards (Houlihan and Ho 1985; Giese 1996). Recent studies showed the need for natural antioxidants, suggesting the limitation of synthetics, with regard to their toxicity and cancerogenic potential (Barlow 1990; Prior and Cao 2000a, 2000b; Kaur and Kappor 2001). The use of tea leaf extracts is still growing, contributing also to quality and safety improvement of food products.

Antioxidants from tea extracts do not show similiar activity in different conditions. The improved activity of tea polyphenols in lecithin liposomes was explained by the affinity of polar catechin gallates to the polar surface of liposomal membranes, resulting in better protection against oxidation (Huang and Frankel 1997; Amarowicz and Shahidi 2003). Gallic acid shows stronger free radical-scavenging properties in a hydrous phase; catechin and epicatechin, however, are relatively more effective antioxidants in a lipid phase (Salah *et al*. 1995). Samotyja *et al*. (2004) showed a high antioxidant activity of tea polyphenols in emulsified rapeseed and sunflower oil triacylglycerol lipid systems. Other investigations showed that the antioxidant activity of tea flavonols depend on their concentration and pH of liposomal systems (Roedig-Penman and Gordon 1997; Gordon and Roedig-Penman 1998).

There is much research on tea extracts and their polyphenol antioxidant activity in bulk oils and lipids. Wanasundara and Shahidi (1996) observed that fish oils to which green tea catechins were added showed high oxidative stability compared to the addition of BHT, BHA, α-tocopherol or TBHQ. Their research concluded that the potential of catechins could be ranked as follows: ECG > EGCG > EGC > EC. Gramza *et al*. (2006) examined the antioxidative activity of green and black tea leaf extracts against the oxidation of heated sunflower oil and lard. Results showed highest antioxidant activity in a green tea ethanol extract, comparable to α-tocopherol activity. Statistical analysis of antioxidant activity of tea extracts in lipids using the Rancimat test showed the essential influence of catechin content, mainly of ECG, EC, and C. Also other tea flavonoids, myricetin and (-)-epicatechin showed high antioxidant activity in rapeseed oil (Wanasundara and Shahidi 1994). Research of Chen *et al*. (1996b) confirmed that in comparison to BHT green tea extracts inhibited the oxidation of rapeseed oils very strongly, while reasonable activity was shown by oolong tea extract; black tea did not however, show antioxidant activity in the examined conditions. Studies showed that green tea aqueous extract had a higher antioxidant activity and potential in soy and cod liver oils and lard than α-tocopherol and BHT (Koketsu and Satoh 1997).

The activity of tea extracts was also studied in food products. Chicken feed supplementation with green tea catechins influenced the preservation of α-tocopherol and to a degree, muscle oxidation (Tang *et al*. 2002). However the results of Korczak *et al*. (2004) did not show antioxidative activity of green tea extracts in frozen meat balls.

The potential protective properties of tea polyphenols on fried meat were investigated by Weisburger *et al*. (2002). Meat slices were coated on both sides with a layer of green and black tea polyphenols. The ground beef patties were treated with aqueous solutions of polyphenols (green and black tea), afterwards cooked on the grill. The experiment showed that the formation of mutagenic compounds on both sides of meat was inhibited in a dose-related fashion (Weisburger *et al*. 2002). Koketsu and Satoh (1997) investigated the antioxidant activity of green tea polyphenols in edible oils and fried noodles. Green tea polyphenols consisted of 27.1% EGCG, 19.3% GC, 16.7% GCG, 16.1% EGC, 8.1% ECG, 7.5% EC and 5.2% C. Antioxidant activity was dose dependent. Highest activity of green tea extract was evaluated in addition of 60 ppm to lard and soybean oil. The addition of green tea polyphenols (60 ppm) into fried oil improved fried noodles' oxidative stability. Tang *et al*. (2001) investigated the antioxidative effect of dietary tea catechins supplementation at various levels (50, 100, 200 and 300 mg kg^{-1}) fed on chicken breast and thigh meat susceptibility to lipid oxidation during frozen storage (-20°C) for 9 months. It was found that supplementation with tea catechins showed antioxidative effects for both meats and demonstrated to be an effective alternative to vitamin E as a natural dietary antioxidant.

Research of the activity of tea polyphenols in food products should always consider the influence of other compounds like protein, whose interactions could possibly influence its final antioxidative effect (Arts *et al*. 2002).

The enrichment of food products with tea leaf polyphenols would effectively influence their oxidative stability and their additional penetration into the human organism could possibly decrease morbidity caused by degenerative diseases.

CONCLUDING REMARKS

Tea could be an important source of dietary polyphenols possessing strong antioxidant capacity, preventing many diseases and food oxidation. The large family of plant polyphenols, which constitutes a group of different chemically structured compounds, possesses variable biological properties. Research showed tea polyphenols beneficial properties in *in vitro* and *in vivo* systems. Although there is much promising evidence, there still is a need for further investigations to understand benefits and contributions of tea polyphenols to human life.

The enrichment of food products with tea leaf polyphenols could profitably influence its oxidative stability and additional incorporation into the human body could improve lifestyles.

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