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Production, Quality, and Biological Effects of Oolong Tea (*Camellia sinensis*)

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Oolong tea is a semi-fermented Chinese traditional tea that dates back centuries and now its unique characteristics are attracting more and more consumers worldwide. The formation of Oolong tea's special quality is attributed to the proper processing of the fresh tea leaf. The quality of Oolong tea can be evaluated by aroma, flavor, color, and appearance with aroma and flavor being the two most important quality indices. The formation of the distinct aroma of Oolong tea depends largely on the decomposition of lipids and carotenoids. However, other compounds that can be hydrolyzed and/or oxidized also contribute to Oolong tea's special aroma. During the processing of Oolong tea, some major flavor compounds are formed by the oxidation of catechins, amino acids, and sugars. The flavor of Oolong tea is complex due to the interaction of many different flavor compounds. Oolong tea exhibits antioxidant, anticancer, antiobesity, prevention of atherosclerosis and heart disease, antidiabetes, and antiallergic effects. Management of environmental factors, selection of tea cultivars and improvements in tea production needs to be emphasized to ensure the high quality of Oolong tea. The exact mechanisms responsible for the beneficial health effects of Oolong tea are not known.

Keywords Oolong tea, antioxidant, aroma, flavor, biological activity

Introduction

Oolong tea (*Camellia sinensis*) is a partially fermented Chinese tea that is oxidized in the range from 10 to 70% during processing. Oolong tea was first produced in the early Song Dynasty (960–1279) but became popular in the Ming Dynasty (1368–1644).[(1)] The major types of Oolong tea, '*Wuyi Mountain Rock*', '*Anxi*', '*Guangdong Dan Chong/Phoenix Mountain*' and '*Taiwan*' listed in Table 1 are from four different production regions of China. The production and consumption of Oolong tea worldwide has increased over the past decade and in mainland China, and the production of Oolong tea nearly doubled in the period from 2000 to 2007(Table 2).

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Table 1
The major distribution of Oolong tea and major cultivars[1]

Regions	Major products
North Fujian Province	*Wuyi Rock, Shuixian* (*Narcissus*)*, Da Hong Pao* and *Rou Gui* (*Cinnamon*)
South Fujian Province	*Tieguanyin* (*Iron Goddess*)*, Qilan* (*Orchid*) and *Shuixian* (*Narcissus)*
Taiwan	*Wudong* and *Baozhong*
Guangdong Province	*Phoenix Dancong; Phoenix Narcissus* and *Lingtou Dancong*

Table 2
Oolong tea production ($\times 10^3$ tones) in China (excluding Taiwan)

Year	2000	2001	2002	2003	2004	2005	2006	2007
Production	67.6	70.1	75.9	76.9	87.0	100	116	127

Source: China statistical yearbook (2000–2007)[2].

The quality of Oolong tea can be assessed by color, aroma, flavor, and appearance.[2] For example, '*Wuyi Mountain'* and *'Phoenix Mountain'* Oolong teas exhibit a dark green or brown color while the color of '*Tieguanyin*' Oolong is bright to dark green. These color attributes, along with aroma, flavor, and appearance, are used to evaluate the overall quality of Oolong tea. The production of high quality Oolong tea requires expert knowledge and skill to properly carry out the complex processing procedures that are summarized in Fig. 1. When the green tea leaves are fermented, the operator must have in-depth knowledge and experience to identify the best time to stop the fermentation. Among the processing procedures, tossing and rolling are the crucial steps in the formation of high quality Oolong tea.

The Quality of Oolong Tea

The attributes of Oolong tea can be partially correlated with the levels of certain flavor compounds. The aromas of Oolong tea are due to linalool, geraniol, 2-phenylethanol, benzyl alcohol, methyl salicylate, linalool oxides, (Z)-3-hexenol, and others.[4,5,6,7] The characteristic aromas of Oolong tea are nerolidol, jasmine lactone, methyl jasmonate, and indole.[8] Furthermore, the flavor of Oolong tea infusion is related to a combination of various compounds, such as catechins (bitterness), amino acids (freshness), soluble sugar (sweetness), theaflavins (briskness), and thearubigin (mellowness).[3,9] In addition, the color of Oolong tea infusion can be determined by the major combinations of flavone, catechins, theaflavins, and thearubigins.[10] According to Roberts,[11] the appearance of the leaves in Oolong tea can be related to the proportion of chlorophyll, xanthine, and carotene.

The Aromas of Oolong Tea

Oolong tea has many different kinds of aromas and these different aromas are directly related to the type and extent of processing given to the tea leaves.[8,12] For example, nerolidol, geraniol, jasmine lactone, methyl salicylate, isoeugenol, limonene, and indole are the

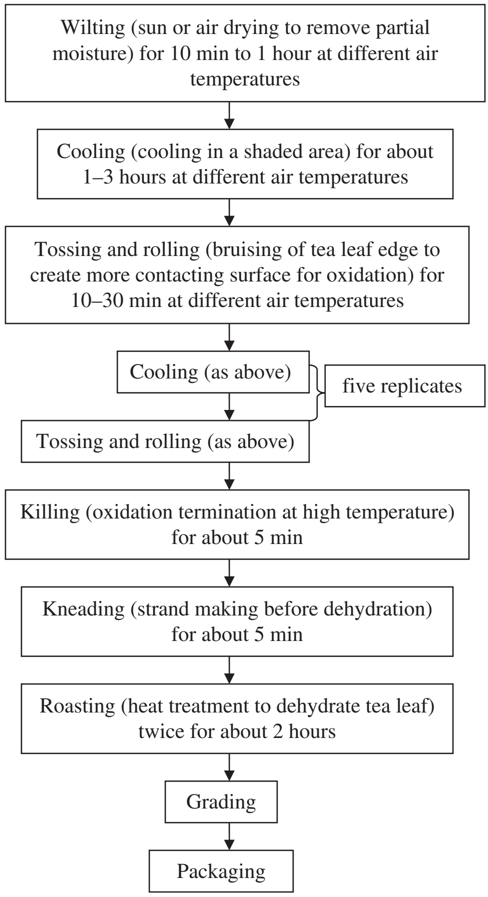

Figure 1. A general procedure for Oolong tea production.

major volatile compounds in a high-grade Duhng-diing Oolong tea. In a low-grade Oolong tea, linalool, linalool oxide, benzylaldehyde, phenylacetaldehyde, cis-jasmone, hexenyl hexanoate, methyl salicylate, and indole are the major volatile compounds.[13] The formation of these volatile compounds has been investigated extensively, and mainly involves the transformation of higher fatty acids into alcohols and aldehydes, the decomposition of carotenoid into aromatic compounds, and, to a lesser extent, many other hydrolysis and oxidation reactions.[8,14]

Transformation of Higher Fatty Acids into Alcohols and Aldehydes. The degradation of lipids occurs at the rolling and fermentation stages of Oolong tea processing. More than 60% of all lipid fractions are degraded during tea manufacture.[14] When the leaves are macerated, the lipid-degrading enzymes are released. The tossing and rolling breaks down the lipoprotein membrane structure/storage lipids and releases the fatty acids, which then undergo further degradation.[15] For example, the dehydration of tea leaves increases the activity of the lipoxygenase enzyme, which in turn catalyzes the oxidation of polyunsaturated fatty acids.[16]

Polyunsaturated fatty acids have been identified as precursors of C_6 aldehydes and short chain alcohols in tea.[17] Many higher fatty acids, especially the unsaturated higher fatter acids, such as oleic, linoleic, and linolenic acids, are present in the leaves of Oolong tea. Linoleic and linolenic acids, the two dominant free fatty acids in the tea leaves, have been shown to decrease during the processing of Oolong tea.[13] At the same time, the levels of C_6 aldehydes, which are considered to be detrimental volatile flavor compounds, are found to increase during the processing of Oolong tea. Accordingly, the presence of C_6 aldehydes such as hexanal and hexenal can result in a decline in tea flavor index.[14]

Decomposition of Carotenoids into Aromatic Compounds. Tea carotenoids are mainly composed of carotenes (α-carotene and β-carotene) and xanthophylls. Much of the α-carotene is hydroxylated to lutein, while some of the β-carotene is converted to corresponding xanthophylls by way of zeaxanthin during the processing of Oolong tea.[18] Many of the aroma compounds formed during tea processing are derived from carotenes,[14] which makes them important precursors in the development of Oolong tea aromas.

The decomposition of carotenoids occurs by way of an enzymatic reaction that takes place during withering and fermentation, and also by a pyrolytic reaction during firing.[19] However, the extent of the carotenoid degradation in tea was shown to be much less than in isolated carotenoids, which was believed to be due to the presence of antioxidants such as polyphenols and catechins.[20] The rates of degradation of the various carotenoids can be put into the following order: β-carotene > zeaxanthin > lutein. The β-ionone is a major degradation product of β-carotene while α-ionone is the degradation product of 3-hydroxy-5, 6-epoxyionone. 3, 5-Dihydroxy-4, 5-dihydro-6, 7-didehydro-α-ionone, linalool, ketones, and other terpenoid aldehydes are all degradation products present in Oolong tea. The compounds produced from carotenoids contribute some of the major aromas of Oolong tea.[18]

Hydrolysis of Primeverosides and Glucosides and Oxidation of Alcohol, Catechins and Amino Acids. In the processing of Oolong tea, a series of enzyme-catalyzed and chemically catalyzed hydrolysis reactions are prevalent. The hydrolysis reactions contribute to the development of the good tea flavor related to the strong 'roasted aroma' of Oolong tea. The aroma precursors for the hydrolysis reactions are mainly primeverosides and glucosides with primeverosides present in greater abundance than glucosides in most tea cultivars.[21] β-D-Glucopyranosides and β-primeverosides

(6-O-β-D-xylopyranosyl-β-D-glucopyranoside) with aglycons have been identified and quantified in fresh tea leaves.[4,5,6,22,23] Meanwhile, 26 synthetic glycosides with the aglycons of the main tea aroma compounds, e.g., (Z)-3-hexenol, benzyl alcohol, 2-phenylethanol, methyl salicylate, geraniol, linalool, and four isomers of linalool oxides, were synthesized in the laboratory. These compounds were used as standards for the direct qualitative and quantitative determination of the glycoside aroma precursors in different tea cultivars.[22] The aroma precursors are found in higher amounts in young tea leaf and decrease in concentration as the tea leaf matures.[21] Glycosidase activity also decreases as tea leaf grows, but remains high in the stems.[21] During the manufacturing process, the primeverosides and glucosides are hydrolyzed by primeverosidase and glycosidase respectively. The hydrolysis products contribute to the alcoholic floral aromas of tea.[7] Hydrolysis of primeverosides and glucosides occurs during the rolling stage.[24]

The oxidization of alcohols, catechins, and amino acids are important reactions in the processing of teas. During Oolong tea processing, alcohols are oxidized into aldehydes and organic acids, while geraniol is oxidized into citral and 6-octadienoic acid and phenylethanol is oxidized into phenylacetaldehyde and phenylacetic acid.[9] The catechins can interact with amino acids through the 'Strecker reaction' to release aldehyde or oxidize into polyphenols. At the rolling and drying stage, some amino acids are easily oxidized into ketonic and carboxylic acids, then into aldehydes and alcohols.[9]

Transformation of Amino Acids. The amino acid contents have been found to first decrease because of the transformation of amino acids, and then to increase because of the degradation of proteins during tea processing.[13] During the processing of Oolong tea, the amino acids can be transformed into aromatic compounds by the Maillard reaction.[9] Meanwhile, leucine could be transformed into α-ketoisocaproate, then into isoamyl alcohol. Furthermore, some soluble sugars can interact with amino acids and form aromatic compounds such as pyrazines and pyrroles by the Maillard reaction. Significant increases in the amounts of nitrogen-containing compounds, especially pyrazines and pyrroles, occur as the thermal treatment increases.[9] Although the total content of the volatile compounds in Oolong tea increased during the thermal treatments, the content of some floral or woody type volatile compounds such as *trans*-geraniol, *cis*-jasmone, linalool, linalool oxide, and β-ionone decreased after thermal treatments.[25]

The Taste of Oolong Tea

Some of the major flavor compounds formed during the processing of Oolong tea includes mainly oxidative products of catechins, amino acids, and sugars. The flavor of Oolong tea infusions depend largely on the combination of these flavor compounds. Six catechins and catechin gallates, i.e., (+)-catechin (C), (−)-gallocatechin (GC), (−)-epicatechin (EC), (−)-epicatechin gallate (ECG), (−)-epigallocatechin (EGC) and (−)-epigallocatechin gallate (EGCG) have been identified in Oolong tea.[26] The catechins are associated mainly with bitterness and astringency of Oolong tea infusions. The esters of catechins and their combinations are the dominant components that determine the taste of Oolong tea infusions. Upon heating, the catechins undergo epimerization and *cis-trans* isomerization (Fig. 2). Some of the isomerization reactions occur at the C-2 position of the flavan-3-ol. For example, EGCG, EGC, ECG, and EC can turn into (−)-gallocatechin gallate (GCG), GC, (−)-catechin gallate (CG), and C, respectively.[27] The esters of catechins can also be hydrolyzed into monomeric catechins and Gallic acid when heated (Fig. 3).[13] In addition, catechins can be oxidized into theaflavins (TF), thearubigin (TR), and theabrowning (TB). TR and TB, are the products of oxidization of TF.[11] Catechins and their oxidation products are mainly responsible for the flavor and astringent character of Oolong tea.[10]

The differentiation of green tea, black tea, Oolong tea, white tea, and *Pu-erh* tea is based on their contents of free amino acids. The best differentiating amino acids are glutamic acid, asparagine, serine, alanine, leucine, and isoleucine.[28] Theanine is one of the most important amino acids, which can effect the flavor of Oolong tea infusions. Theanine can effectively counteract the bitterness and astringency by increasing the sweetness of the tea infusion. In addition, γ-aminobutyric acid is another important flavor compound in Oolong tea infusion. In the processing of Oolong tea, the content of proteins in the leaf decreases because the proteins are hydrolyzed into amino acids which in turn can be degraded into flavor compounds.[9]

Purine alkaloids are secondary metabolites derived from purine nucleotides[29], such as xanthine, caffeine, theobromine, and theophylline (Fig. 4).[30,31] The purines are important stimulating compounds in tea infusion. The contents of purines differ in tea leaves with different maturities. They are high in young tea leaves and low in old leaves.[9]

In the tea leaf, the soluble carbohydrates consist of monosaccharides, disaccharides, and oligosaccharides. The polysaccharides are starch, cellulose, hemicellulose, and pectin.

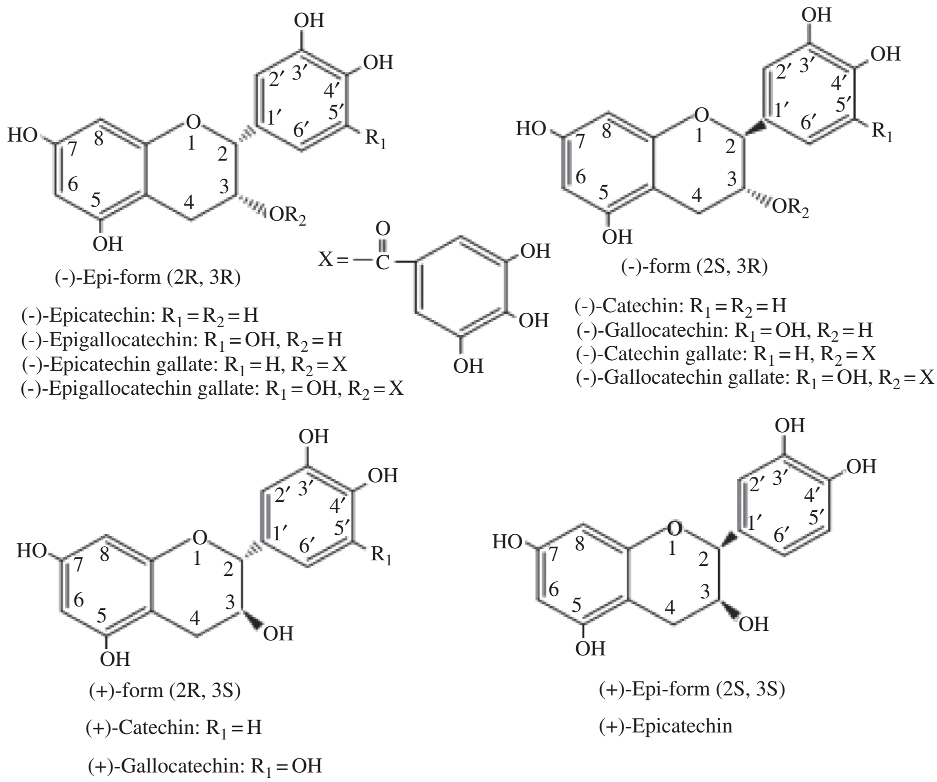

Figure 2. Chemical structures of tea catechins and their epimers and isomers.

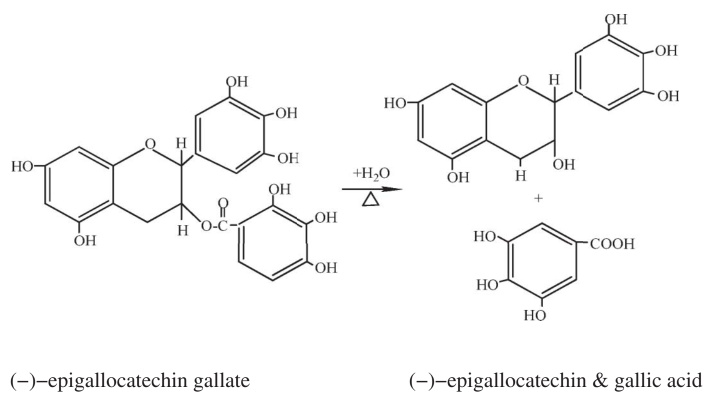

Figure 3. Hydrolysis of catechin esters.

The lignified parts and cellular walls are made up of cellulose, hemicellulose, and lignin, which are high in old tea leaves and insoluble in water. Starch accounts for 0.2–2.0% of the fresh leaf on a weight basis. During the processing of Oolong tea, starch is converted into soluble compounds and volatile flavor compounds, while pectin is changed into pectic acid. All these changes contribute to the final taste of Oolong tea infusion.[9]

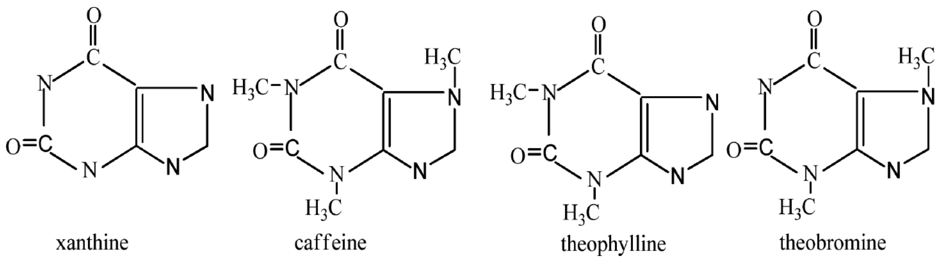

Figure 4. The derivatives of purine.

Besides the above flavor compounds, there are other bitter compounds such as flavone glycosides and anthocyanidins. Because flavone glycosides can be hydrolyzed to release their aglycone during the processing of Oolong tea, the bitterness intensity of tea infusion can be reduced. As anthocyanidins are present in high concentration in Oolong tea infusions, the tea would taste too bitter, but anthocyanidins can be turned into compounds with no bitterness by hydrolyzing their aglycone.(9)

Health Benefits of Oolong Tea

Tea polyphenols and the catechins and volatile flavor compounds have been shown to reduce the incidence of carcinogenesis, growth of bacteria, and the replication of various viruses, induce apoptosis, and exhibit antiallergic effects when an infusion of tea was used.(1)

Antioxidant Activity

Tea polyphenols, including catechins, are effective scavengers of reactive oxygen species in *vitro*. In the human body, modest transient increases in plasma antioxidant capacity have been demonstrated after the consumption of an infusion of Oolong tea.(32) Studies have also shown that the effects of Oolong tea on reducing oxidative stress problems, especially oxidative DNA damage, are promising.(32) Human studies showed that daily intake of Oolong tea results in significantly lower resting and post-exhaustive exercise levels of plasma malondialdehyde, and significantly lower resting levels of superoxide dismutase activity. These results suggest that the decrease in the lipid peroxidation level was due to the consumption of Oolong tea and its scavenging activity against free radicals.(33)

Additional in-vitro studies have shown that compounds, such as EC, ECG, EGC, EGCG, TF, TF monogallate-A, TF monogallate-B, and TF digallate have very strong antioxidant and lipoxygenase inhibiting activities.(34) In rats, EGC 3-O-gallate can inhibit the progression of renal failure by scavenging free radicals.(35) The 3”-Me-EGCG has a higher inhibitory effect on nitric oxide generation and inducible nitric oxide synthase expression when compared with EGCG, while the 4″-Me-EGCG and 4′, 4″-diMe-EGCG are less effective.(36) Besides the tea polyphenols, some of the other volatile compounds may have antioxidative activity, such as alkyl compounds with double bonds, 3, 7-dimethyl-1,6-octadien-3-ol, heterocyclic compounds, furfural and benzyl alcohol.(37)

Anticancer Effect

Studies suggest that Oolong tea extracts have a chemopreventive action against hepatocarcinogenesis and prevents the development of cancer.(38) Oolong tea has greater antimutagenic effect than green tea and black tea.[39] The anticancer mechanisms of Oolong tea extracts could be based on the inhibition of the invasion and proliferation of cancer cells by polyphenolic compounds and their antimutagenic and anti-inflammatory properties that alter the catalytic activities of P450 enzymes and glucuronosyl transferase.

Oolong tea extract can result in loss of viability, apoptosis, and cell cycle arrest at the G_1 phase in cancer cells, but not in normal cells. At a concentration of 0.04% Oolong tea extract had a strong inhibitory effect on the invasion and proliferation of hepatoma and murine B16 melanoma cells.[40,41] The induction of apoptosis and cell cycle arrest are important mechanisms in the inhibition of human stomach cancer cells and these cells can be inhibited with Oolong tea extracts containing polyphenol trimers as the main component.[42] Several catechin compounds are also believed to induce apoptosis in human hystiocytic lymphoma U937 cells. Studies have shown that catechins with a pyrogallol-type structure in the B-ring can induce apoptosis of cancer cells but catechins without a pyrogallol-type structure lack the activity.[43] The trihydroxyl structure of the B ring is essential for EGCG to exert the suppressive effects and the hydroxyl groups on both the 4′-position in the B ring and the 4″-position in the gallate are crucial for the cell surface binding activity of EGCG.[44]

Oolong tea extract, as an anticancer agent, could act as a nucleophile to scavenge electrophilic mutagens and thereby prevent the appearance of cancer. The compounds EGCG, GC, and caffeine were shown to have antimutagenic activity by the Ames test using the bacterium *Salmonella typhimurium*.[45] The antimutagenic effects of Oolong tea extracts against mutagens such as N-methyl-N'-nitro-N-nitrosoguanidine, folpet, 2-acetylaminofluorene, benzo[a]pyrene, 9-aminoacridine, aflatoxin B-1, N-nitroso-N-methylurea, and captan were different.[45] Oolong tea extracts inhibited the mutagenicity of 2-amino-3-methylimidazo (4,5-f) quinoline, 3-amino-1, 4-dimethyl-5H-pyridol (4,3b) indole, 2-amino-6-methyldipyrido (1,2-a:3′,2′-d) imidazole, benzo [α] pyrene, and aflatoxin B_1, with 90% effectiveness when these five mutagens were present at a dosage level of 1 mg per plate.[38,46] Furthermore, the antigenotoxic effect of Oolong tea extract on 1-nitropyrene (1-NP), 2-nitropyrene (2-NF), 3-nitropyrene (3-NF) and 2,4-Dinitrophenol (DNP) is the strongest among the different teas.[47]

Oolong tea extract exhibits a higher anti-inflammatory activity than green tea or black tea extracts. Tissue inflammation can contribute to cancer development by inducing oxidative damage and promoting cell growth. Inflammation has been shown to play a role in the initiation and/or progression of other cancers, including liver, bladder and gastric cancers.[48] The active components with anti-inflammatory activity were found to be catechins, and Oolong tea tannins (the oxidative products of catechins in Oolong tea).[49]

Since P450 enzymes and glucuronosyl transferase are the major agents responsible for the metabolism of many carcinogens, the anticarcinogenesis effects of tea consumption may be due to an alteration in the catalytic activities of the P450 enzymes and glucuronosyl transferase.[50] The effects of genotoxic carcinogens such as heterocyclic amines are reduced by Oolong tea extracts. Oolong tea extracts can inhibit the formation of reactive oxygen species and radicals and induce cytochromes P450 1A1, 1A2, and 2B1, and glucuronosyl transferase, which can produce glucuronide. The increased formation of glucuronides represents an important mechanism in detoxification.[50]

Antiobesity Effect

Oolong tea is believed to be beneficial in decreasing human body fat. The fat-decreasing mechanisms are related to the inhibition of pancreatic lipase activity by catechins and the synergistic effects (different entities cooperate advantageously for a final outcome) of thiamin, arginine, caffeine, and citric acid. The catechins from Oolong tea, especially EGCG, appear to have antiobesity properties. The mechanism of their action can be related to certain pathways such as through the modulations of energy balance, endocrine systems, food intake, lipid and carbohydrate metabolism, the redox status, and activities of different types of cells (i.e., fat, liver, muscle, and β-pancreatic cells).(51) The inhibition of growth and suppression of lipogenesis may be through the down-regulation of gene expression of fatty acid syntheses in the nucleus and stimulation of cell energy expenditure in the mitochondria.(51) The molecular mechanisms of fatty acid synthase gene suppression by tea polyphenols (EGCG and theaflavins) could result in the down-regulation of the EGFR/P13K/Akt/Sp1 signal transduction pathways.(51)

Theanine-3′-O-gallate in Oolong tea can effectively inhibit pancreatic lipase activity. Meanwhile, homobisflavans A and B, which are typical compounds in Oolong tea leaves, also show stronger inhibitory activities against pancreatic lipase than EGCG. (52) Therefore, the theanine-3′-O-gallate can suppress absorption of meal derived fats. The antiobesity effect of a mixture of thiamin, arginine, caffeine, and citric acid is greater than that of a mixture of arginine and caffeine, and much greater than that of arginine or caffeine alone.(53) It was demonstrated that the antiobesity effects of Oolong tea might be due partially to the effects of caffeine on noradrenaline-induced lipolysis in adipose tissue, and the inhibitory action of some other substance in Oolong tea on pancreatic lipase activity.(54)

Prevention of Atherosclerosis, Heart Disease, and Hypertension

The oxidation of LDL cholesterol, which is a risk factor for atherosclerosis and heart disease, may be inhibited by Oolong tea. One study showed that Oolong tea reduced the formation of 8-hydroxydeoxyguanosine, a marker of oxidative DNA damage.(50) Thus, Oolong tea may have beneficial effects on altering the progression of atherosclerosis in patients with coronary artery disease.(55) Furthermore, another study investigating the possible mechanisms responsible for the reduction of atherosclerosis and heart disease by Oolong tea extracts found that the excretion of lipids into feces was significantly higher in subjects that consumed polyphenol-enriched Oolong tea extract.(56) It appears that Oolong tea extracts could reduce the accumulation of lipids that causes atherosclerosis and heart disease.

It was found that Oolong tea is able to lower the levels of triglyceride better than green tea or black tea, after oral feeding to male Sprague-Dawley rats. Therefore, it has been observed that the relative weight ratios of liver to epididylmal adipose tissue are lower in Oolong tea fed groups.(57) Studies have also shown that the partially fermented Oolong tea leaves are more effective in the growth suppression of adipose tissue as compared to the nonfermented green tea leaves.(57)

Energy expenditure is significantly higher after the consumption of Oolong tea than green tea ($P < 0.05$). In comparison with green tea, Oolong tea contains approximately half the caffeine and EGCG, while polymerized polyphenols of Oolong tea are double of that of green tea. The polymerized polyphenols in Oolong tea can increase energy expenditure.(58) Therefore, more energy expenditure means less accumulation of lipid, which can therefore lessen the incidence of atherosclerosis and heart disease. Since atherosclerosis can cause hypertension, the prevention of atherosclerosis can also reduce the risk of developing hypertension. Studies have shown that habitual and moderate Oolong tea consumption, 120 ml/d or more for a 1 year period, significantly reduced the risk of developing hypertension in the Chinese population.(59)

Antidiabetes Effect

The polyphenols EC, ECG, and EGCG can inhibit the Na+/glucose co-transporter response, and result in lower glucose concentration.(60) Studies have shown that dietary Oolong tea extract can reduce plasma glucose and have a complicated impact on antioxidant systems in diabetic rats.(61) Several known compounds present in Oolong tea such as EGCG, ECG, tannins and TF, can enhance the activity of insulin and benefit people with diabetes.(62)

Antiallergic Effect

Oolong tea contains 0.34% (dry weight) EGC-3-O-(3-O-methyl) gallate (EGCG3″Me) and 0.20% EGC-3-O-(4-O-methyl) gallate (EGCG4″Me), but neither of the catechin derivatives are produced during the fermentation process.(63) Studies show that EGCG3″Me and EGCG4″Me have strong antiallergernic effects. The mechanism of the antiallergic effects of these compounds are based on the strong inhibition of EGCG3″Me and EGCG4″Me to mast cell activation through the prevention of tyrosine phosphorylation of cellular protein and histamine/leukotrienes release, and interleukin-2 secretion after Fc epsilon RI cross-linking.(63,64,65) On the other hand, EGCG″3Me treatment inhibits the Fc epsilon RI cross-linking. The high-affinity IgE receptor, Fc epsilon RI, is found at high levels on basophils and mast cells and plays a key role in a series of acute and chronic human allergic reactions. Studies suggest that EGCG″3Me could negatively regulate basophil activation through the suppression of Fc epsilon RI expression.(66) Four major tea catechins also show significant inhibitory effects on allergic properties.(67,68)

Antiseptic Effects

The Oolong tea extracts can inhibit a wide range of pathogenic bacteria, including methicillin–resistant *staphylococcus aureus and Yersinia enterocolitica*.(69) The Oolong tea extracts show an antibacterial activity against all of the oral streptococci examined, with the highest activity against S. mutans MT8148R. The antibacterial activity of Oolong tea extracts was stronger with the monomeric polyphenol-rich fraction of Oolong tea extract rather than the pure polyphenols. It was shown that some combinations of monomeric polyphenols had higher levels of antibacterial activity, which might be caused by a synergistic effect of the monomeric polyphenols, which can easily bind to the proteins of pathogens to inhibit their activity.(70)

Glucosyltransferase is an important enzyme involved in dental caries pathogenesis. A dimeric catechin molecule in Oolong tea was identified as dehydro-dicatechin A, which markedly inhibits glucosyltransferase from *Streptococcus sobrinus* 6715. As the degree of polymerization of catechin increases, glucosyltransferase is inhibited more effectively.(71) Studies also showed that the Oolong tea extract could reduce the rate of acid production by mutan streptococci and at the same time reduce their growth rate.(72) As well, Oolong tea products can decrease the cellular surface hydrophobicity of almost all the oral streptococci examined, which will inhibit bacterial adherence to the tooth surfaces.(72)

Besides the inhibition of oral streptococcus, the Oolong tea extracts can inhibit the activity of *Bacillus subtilis*, *Escherichia coli*, *Proteus vulgaris*, *Pseudomonas fluorescens*, *Salmonella sp.* and *Staphylococcus aureus*.(72) The mechanism of their action are based on the direct inactivation of the bacteria and viruses, by inhibiting their replication enzymes, induction of apoptosis, stimulation of monocytes/macrophages to produce cytokines, and the stimulation of myeloperoxidase dependent iodination of neutrophiles.(73)

Conclusions and Future Directions

Oolong tea is a partially fermented tea, major types of which can be found in different areas of China. The quality of Oolong tea is attributed to the aroma, flavor, color, and appearance, in which aroma and flavor are the two most important factors. The formation of aroma in Oolong tea depends largely on their transformation of higher fatty acids, decomposition of carotenoids, hydrolysis of primeverosides and glucosides, oxidation of alcohol, catechins and amino acids, transformation of amino acids and etc. The flavor of Oolong tea infusions depends largely on the combination of the flavor compounds, which are formed during the processing of Oolong tea, including mainly the oxidative products of catechins, amino acids, and sugars. Oolong tea exhibits antioxidant, anticancer, antiobesity, prevention of atherosclerosis and heart disease, antidiabetes, and antiallergic effects, etc.

The production of Oolong teas has increased greatly in the recent years, and is becoming more and more popular around the world. However, the quantity of research on Oolong tea is lacking when compared to that on green and black teas. This is particularly apparent when examining the quality of Oolong tea in relation to environmental factors and manufacturing procedures. The quality of Oolong tea is affected by many factors, including both controllable and non-controllable factors.[(74)] Optimization of the controllable factors is one way to increase production of high-quality Oolong tea. The characteristics of cultivars, agronomic practices, and tea processing technologies need to be integrated and studied in more detail to produce higher-quality cultivars to meet the needs of the market place, to develop new agronomic methods to increase the quality of the fresh Oolong tea leaves, and to improve Oolong tea processing technology. The application of Oolong tea for health purposes is under way, and a number of products have been produced such as tea powders and tea jams. Extraction technologies have advanced with the extraction of polyphones, caffeine, saponin, and polysaccharose from low quality Oolong tea. These activities will bring tea processing and applications into the public eye.[(75)] In the future, more and more applications for Oolong tea will emerge to satisfy new and different needs around the world.

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