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Effect of Catechin and Phenolic Composition on the Antioxidant Capacities of Different Types of Tea (*Camellia sinensis*)

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ABSTRACT

Medicinal plants are the world's most abundant source of organic compounds and are used as pharmaceutical intermediates. Tea (*Camellia sinensis*) is the world's most popular beverage, using various processing methods, six different types of tea have been produced—black, green, oolong, white, dark, and yellow—with distinct flavors and aromas. The nature of the final product is determined by the reactions that occur during the manufacturing process. The fermentation processes can affect the chemical composition since catechins in the green tea can be condensed to theaflavins in the black tea due to the oxidation processes. This will affect the antioxidant activities of tea as well as other pharmacological activities. Several studies showed the differences in these activities between different types of tea. In this review thirteen studies are searched to compare their results about the chemical composition of different types of tea (e.g., white, green, oolong, and black tea) and the relationship with their antioxidant activities. The results demonstrate that fermentation plays a crucial role in altering the polyphenol profile of tea. Data from the first, second, third, and fourth studies showed that both oolong and green tea had higher levels of total catechins than black tea, and both tea kinds had larger concentrations of individual catechins (EGCG and EGC) than black tea. Additionally, data from the fifth, sixth, seventh, and eighth studies demonstrated that green tea was greater than black tea in terms of total flavonoids and phenols. Furthermore, all the retrieved first, fifth, ninth, eleventh, and twelfth studies demonstrated that the green tea has higher antioxidant activity than black tea. Oolong tea, being semi-fermented, exhibits intermediate antioxidant activity. Catechins are the primary contributors to antioxidant capacity in green tea, whereas black tea's antioxidant activity is more dependent on theaflavins and thearubigins.

Keywords: Green vs. black tea, tea's catechins, theaflavins, thearubigins, tea's polyphenols.

INTRODUCTION

Medicinal plants are the world's most abundant source of organic compounds and are used as pharmaceutical intermediates. Due to their abundance of phytochemicals-chemicals or bioactive components found naturally in any part of a plant. These phytochemicals have gained widespread popularity due to their numerous medicinal applications, which help combat a wide range of diseases, such as cancer, arthritis, and asthma. Phytochemical analysis aims to identify the source of pharmacologically active chemical compounds, as well as to identify novel bioactive compounds in plant materials that may contribute to their quantification (Gaibimei et al, 2018). *Camellia sinensis* is a species of small, evergreen tree or shrub belonging to the Theaceae family of flowering plants. Tea can be made from its leaves, buds, and stems. Tea (*Camellia sinensis*) is the world's most popular non-alcoholic beverage. Green, albino, and yellow tea plants are often classified according to the amount of anthocyanins and chlorophyll they contain. Additionally, using various processing methods, six different types of tea have been produced-black, green, oolong, white, dark, and yellow-with distinct flavors and aromas. Diverse tea varieties can meet specific consumer needs and contribute to the

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advancement of the tea industry (Camargo et al, 2016). In general, tea contains different bioactive compounds such as alkaloids (caffeine, and theophylline), volatile compounds, flavonoids, aminoacids, and polyphenols (catechin, epicatechin, and epicallogatechin). These bioactive compounds making tea an important beverage with essential economic and health benefits. Several researches proved that tea has many of important pharmacological activities such as antioxidant, antimicrobial, heart protection, cancer prevention, and antiallergic prosperities (Di Paola et al, 2005; Amić et al, 2003; Maeda-Yamamoto et al, 2004). The nature of the final product is determined by the reactions that occur during the manufacturing process. This will affect the chemical composition, color, aroma, and taste. The bulk of tea produced worldwide falls into one of three categories: fermented (black tea), semi-fermented (oolong tea), or unfermented (green tea) (Reeves et al, 1987). The fermentation processes can affect the chemical composition since catechins in the green tea can be condensed to theaflavins in the black tea due to the oxidation processes (Obanda et al, 2004). This will affect the antioxidant activities of tea as well as other pharmacological activities. Several researches study the differences in these activities between different types of tea.

Camellia sinensis leaves are used to produce various teas through different processing methods. The main types of tea derived from *Camellia sinensis* include green tea, black tea, white tea, and oolong tea. Each type of tea has its unique characteristics and flavours, making them popular among tea enthusiasts worldwide (Wang et al, 2023). The level of enzymatic oxidation associated with the processing of different tea varieties varies. Black tea is fully fermented, white tea is lightly fermented, oolong tea is partially fermented, and green tea is unfermented. Microbial fermentation is used in the processing of Pu'erh tea (Li et al, 2013). Tea leaves undergo various chemical changes depending on the type and extent of fermentation during processing. As a result, the phytochemical composition of tea can vary greatly, depending on the tea variety and the fermentation method used (Wang et al, 2019).

Plant family of *Camellia sinensis*

Theaceae, the tea family, is a family of flowering plants comprising shrubs and trees, including the economically important tea plant, and the ornamental camellias. It can be described as having 40 genera. Eight genera are currently accepted (Plants of the world online 2025). The three main natural hybrids that constitute the cultivated tea varieties are: Tea sinensis (L.) or Kuntze (also known as the Chinese type), Tea assamica (Master's) (also known as the Assamese type), and Tea assamica lasciocalex (also known as the Cambodian or Southern type). Plants in this family have simple, alternately spirally branched, toothed, and usually glossy leaves (Erxu et al, 2009). The foliage is evergreen in most genera. The flowers are usually large, bright, pink or white, and often fragrant. (Luna & Ochoterena, 2004). The corolla is pentamerous, rarely polychaete, while the calyx has five or more sepals, often constant throughout the fruiting period. The ovary, often hairy, gradually narrows to form a style, which may be cleft or branched. In most cases, the carpels are opposite the petals, or sepals in the case of Camellia (Khaing et al, 2018). The fruits may be indivisible bracts, sporocytic capsules, or sometimes pome-like. The seeds are few, sometimes winged, or wingless and naked or covered with pulp in some genera (Kubitzki, 2013). Members of this family are native to Southeast Asia, Malaysia, tropical South America, and the southeastern United States. The southeastern United States is home to species from three genera: Franklinia, Gordonia, and Steuarchia. Franklinia is endemic to the region, and according to some interpretations, Gordonia, which formerly included Asian species, migrated into Polyspora. (Stevens et al, 2004). The purpose of the present review is to investigate the effect of fermentation process on the polyphenolic composition and the antioxidant capacities of different types of tea by collecting data from several previous studies and comparing their results.

Origin and geographical distribution of *Camellia sinensis*

Camellia sinensis is native to East Asia which probably originated in the borderlands of southwestern China and northern Myanmar. During the Tang Dynasty in China, tea became a popular recreational drink and was later adopted by other East Asian countries. In the 16th century, Portuguese traders and priests brought it to Europe. As its popularity grew, the English began cultivating tea on a large scale in British India in the 17th century. China is considered the birthplace of the tea plant, which is now grown worldwide in many countries, including India, Indonesia, Sri Lanka, Kenya, Turkey, Vietnam, Japan, Iran, Argentina, and others. China is one of the largest producers and exporters of tea. In 2018, it produced 2.616 million tons of tea, the world's

largest crop, and exported 365,000 tons, the second largest quantity. Chinese tea is highly regarded in the global market and is sought after by consumers worldwide. Although it typically requires humidity and abundant rainfall during the growing season, it can be grown in subtropical and tropical climates. Nearly all commercial tea plantations are located on hillsides or highlands, where natural drainage is available. (Heiss & Heiss, 2007).

Morphological Characteristics of *Camellia sinensis*

Camellia sinensis, an evergreen tree or shrub, can grow to a height of 10–15 meters in the wild and 0.6–1.5 meters in cultivation. The leaves are 5–30 cm long and about 4 cm wide. They are light green, short-stemmed, leathery, alternate, lanceolate, with a toothed margin, and smooth or hairy underneath. Young leaves are hairy, while mature leaves are smooth, leathery, and bright green. The fragrant white flowers, 2.5–4 cm in diameter, can be found singly or in clusters of two or four. The flowers produce reddish-brown capsules and numerous stamens with a yellow anther. The fruit is a triangular, smooth, round, flattened capsule with three cells, each containing a single seed the size of a small walnut (Jin et al, 2014).

Tea Manufacturing Process

After being picked from the garden, tea leaves are brought to the industry and put through a number of processing steps. The quality of the final product relies on each step of the tea-processing methods. Processing a green leaf carefully and appropriately usually brings forth its full potential. Tea is made via withering; cutting; fermentation; drying; and; sorting, grading, and packaging (Aaqil et al, 2023; Harbowy et al, 1997)

Withering

After gathering of tea leaves, the first step done in the manufacturing of tea is withering. Freshly harvested tea leaves are lead out so that air can flow over them. Partially removing the moisture from the leaves is the aim of withering process as well as preparing leaves for the next steps. The withered leaf is passed through a sifter with a number 4 screen or larger to get rid of sands and tiny stones (Witono et al, 2015). The process by which the leaves become soft or elastic and lose their moisture and stiffness is known as physical withering. In order to role tea and achieve the proper look and feel, this is the highly desirable conditions (Teshome, 2019). The chemical process starts as soon as the leaves split from the plant. The withering process depends on temperature and time. Several chemical changes will occur during this process such as the fragmentation of large molecules into smaller one which increase the flavoring substances, as well as the amount of caffeine will increase and the permeability of cell membrane will also enhanced, which largely impact the combining of polyphenols, enzymes, and oxygen for fermentation (Zhang et al, 2019).

Cutting

The leaves pass through the gap between two stainless steel rollers. These rollers are firmly screened to rotate in opposing directions. The crushing, tearing, and cutting processes are all done by the roller teeth. The leaf is torn on and cut by the teeth's sharp edges (Witono et al, 2015).

Fermentation

The most important step in the manufacturing of tea is fermentation since most of the beneficial attributes are created through this step. The more historical term during the production of black tea is known as fermentation since during it, the color; aroma; and flavors are all created from the oxidizing and fragmentation of lipids, carotenoids, and terpene-glycosides (Teshome et al, 2019; Roberts et al, 1958). The generated substances are termed as theaflavins and thearubigins. The fermentation process generally takes from 1 hour and 15 minutes to 2 hours. This will depend on how fast the leaves could be fermented. By rolling the leaf, the tea liquor is made, which started the fermentation process. The liquor's mellow flavor is a result of intricate fermentation process, which also includes the oxidation of polyphenols and modification of other substances. Under the right condition, the beverage becomes bright and brisk and acquires the proper color and strength (Turkmen & Velioglu, 2019).

Drying

Drying is the final step in the tea-making process. In this process several changes occurs including consecutive bulk and heat transfer—a bulk or temperature loss, and a temperature gain or heat. During drying, air that has warmed up is the most feasible medium for heat and bulk transfer (Teshome, 2019; Witono et al, 2015). The drying process aims to halt the fermentation process and maintain the ideal attribute, as well as to remove moisture from the leaf particles and create a stable, manageable, and transportable end product (Teshome, 2019).

Sorting, Grading, and Packaging

After drying, tea must be grading in order to be produced in a way that producers and clients will find it suitable (Witono et al, 2015). Several processes are needed to separate tea particles into various sizes and shapes to meet the trade demands. Because machine sorting is not enough, hand sieves must be used (Teshome, 2019). After the tea has been sorted into a proper grade; it bagged into suitable packages to keep the quality from deteriorating during transferring (Shinde & Datta, 2015)

Types of tea

Camellia sinensis leaves are used to produce various teas through different processing methods. The main types of tea derived from *Camellia sinensis* include green tea, black tea, white tea, and oolong tea. Each type of tea has its unique characteristics and flavours, making them popular among tea enthusiasts worldwide (Wang et al, 2022). The level of enzymatic oxidation associated with the processing of different tea varieties varies. Black tea is fully fermented, white tea is lightly fermented, oolong tea is partially fermented, and green tea is unfermented. Microbial fermentation is used in the processing of Pu'erh tea. Tea leaves undergo various chemical changes depending on the type and extent of fermentation during processing. As a result, the phytochemical composition of tea can vary greatly, depending on the tea variety and the fermentation method used (Wang et al, 2018).

Green Tea

Green tea is known for its delicate flavour and numerous health benefits. It undergoes minimal oxidation during processing, which helps to retain its natural green colour and fresh taste. The leaves are typically steamed or pan-fried to stop oxidation and preserve the tea's natural properties. To process green tea, oxidative enzymes in the tea leaves are deactivated by heating them. The tea leaves are then rolled or shaped, which coats their surface and releases plant cell sap. Dried tea is produced by drying the leaves to reduce their moisture. The antioxidants in green tea, such as catechins and polyphenols, are believed to have positive health effects, such as improving metabolism and promoting heart health (Ye et al, 2018).

Black Tea

Black tea accounts for more than 70% of the tea produced annually, while green tea accounts for only 20%, making it the most consumed tea in the world. It is known for its dark color and strong flavor. Commercial tea products are available in two types: dried tea leaves or tea bags, which require the consumer to prepare their own brew. Black tea undergoes complete oxidation during processing, which gives it a solid and malty taste. The leaves are withered, rolled, fermented, and fired to achieve the desired flavour and aroma. Black tea is often enjoyed with milk and sugar and a staple in British culture (Khokhar & Magnusdottir, 2002).

White Tea

White tea is the least processed type of tea characterized by its delicate and subtle flavours. It is made from young tea buds and leaves that are gently withered and dried. White tea is made from tea leaves that have undergone minimal processing (Chen et al, 2019). For its production, only the buds or first leaves are usually picked. For tea, the buds and leaves are withered and dried directly without heating. The withering is a prolonged process lasting 36–48 hours. The minimal processing allows the leaves to retain natural sweetness and floral notes. White tea is known for its high levels of antioxidants and is often regarded as one of the healthiest types of tea (Chen et al, 2020).

Oolong Tea

Oolong tea is a partially oxidized tea that falls between green and black tea in terms of flavour and colour. It undergoes a unique process that involves withering, rolling, and oxidation, which gives it a diverse range of flavours, from light and floral to rich and fruity (Ng et al, 2018). Tea leaves are withered by exposing them to direct sunlight, which lowers their moisture content and makes it easier for catechins to move from cell vacuoles to the cytoplasm of the cell (Zeng et al, 2020). Tea leaves are shaken three to four times at intervals to bruise the edges in the following step, shaking and setting. This starts fermentation and further breaks down the oxidases and catechins in tea leaf cells. The oxidation level can vary, resulting in different types of oolong teas with varying tastes and aromas (Ho et al, 2018).

Nutritional composition of *Camellia sinensis*

Tea contains a wide range of biologically active compounds, including carotenoids, phenolic acids, flavonoids, coumarins, alkaloids, polyacetylenes, saponins, and terpenoids, which give it its distinctive flavor and taste, in addition to its positive and protective effects on human health (Camargo et al, 2016).

Polyphenol compounds

The main bioactive components found in tea are polyphenols, which include catechins, gallic acids, theaflavins, tannins, and flavonoids.

Gallic acid is a common phenolic acid, widely found in plants and tea products. Increasing scientific interest has shown that it plays an important role in the health benefits of food. Gallic acid has also been reported to be present in black and green tea products. About 30% of the dry weight of tea leaves consists of catechins. Green tea is the primary source of these compounds, with epigallocatechin-3-gallate (EGCG) being the most abundant. Although these compounds are present in much smaller quantities, they are also present in other types of tea, such as oolong and black tea (Beecher et al, 1990). Plants contain flavonols in the form of glycosidic derivatives, such as myricetin, kaempferol, and quercetin, bound to sugars such as rhamnose, galactose, and glucose. It is reported that only 3% of the dry weight of tea leaves consists of flavonol derivatives. Needless to say, flavonol derivatives are minor compared to the amount of catechins in green tea. However, it is important to note that the concentration of these substances does not change significantly during the oxidative processing of black tea, unlike catechins (Wang & Helliwell, 2001)

Theaflavins and thearubigins

The majority of flavan-3-ols are converted to arubigins (oligomers/polymers) and/or flavins (dimers) during the oxidative processing used to produce oolong and black tea. Flavins, which give oolong and black tea their bright reddish-orange color in solution, are said to be the compounds that give these teas their color. They are also essential for the astringency of these teas. In black tea leaves, theaflavins (TFS) account for 2–6% of the dry weight, including theaflavin, theaflavin-3-gallate, theaflavin-3′-gallate, and theaflavin-3, 3′-digallate (Sang et al, 2011). Thearubigins (TRS) are the most common phenolic pigments in black tea and are believed to be polymers produced during oxidative processing. They constitute between 30% and 60% of the solids in black tea beverages due to their high solubility in hot water. Although they constitute the majority of the polyphenols in black tea, thearubigins are the least understood, and their precise structure is unknown (Haslam, 2003).

Alkaloids

Tea is one of the most important sources of alkaloids, particularly purine alkaloids (such as caffeine, theobromine, and theophylline). Caffeine is the main methylxanthine in tea products, followed by theobromine in much smaller amounts. The average person consumes about 200 mg of caffeine per day, and it is the most widely consumed stimulant in the world, found in coffee, tea, and soft drinks (Chrościńska-Krawczyk et al, 2011).

Amino acids

One of the most important factors affecting the quality of tea is the type and concentration of amino acids, which range between 1% and 4%. Of the 26 amino acids identified in tea so far, 20 are proteinogenic and six are non-proteinogenic. The most abundant are theanine, glutamic acid, arginine, serine, and aspartic acid. The two main active amino acids found in tea are theanine and gamma-aminobutyric acid, which have a marked protective effect on the nervous system (Abe et al, 1995). Despite the lower GABA content, theanine accounts for about 50% of the total amino acid content. It was found that there is no significant difference between the amino acid composition of black and green tea when they used an amino acid analyzer to measure the amount of free amino acids in different tea varieties (Chen et al, 2017).

Saponins

Saponins, a class of natural terpenes or steroid glycosides, have diverse biological functions and aid in plant defenses and communication. Tea seeds and flowers have been found to be rich in oleanan-type terpene saponins. Furthermore, sapogenins and approximately 90 saponins have been identified in various tissues of Chinese tea, such as wood (19 saponins), leaves (12 saponins), flowers (24 saponins), and seeds (58 saponins). These compounds exhibit numerous bioactive properties, such as cleansing, foaming, anti-inflammatory, antimicrobial, anticancer, neuroprotective, gastroprotective, and anti-allergic properties (Chen et al, 2022).

Carbohydrates

Tea contains small amounts of monosaccharides and disaccharides, including glucose, fructose, galactose, sucrose, and others, which accounts for its sweetness. Most of the carbohydrates in tea are insoluble polysaccharides, including cellulose, starch, and pectin (Du, 2003).

Mineral Elements

Ash, a term used to describe the inorganic matter found in tea, consists primarily of certain mineral elements and their oxides. The amount of ash is used to assess the quality of tea exports. Phosphorus and potassium are the most common mineral elements, followed by trace elements such as zinc, copper, and fluorine, as well as calcium, magnesium, iron, manganese, aluminum, sulfur, and silicon. Scientists have paid considerable attention to this topic due to its importance in the physiological processes of the tea plant and the human body (Zhao et al, 2011).

Others

Green tea also contains a certain amount of vitamins, including vitamins B, C, and E; enzymes, including glucosidase and lipoxidase; and chlorophyll, a natural edible pigment that is very safe, in addition to the chemical components mentioned above. (Guan et al, 2017).

Pharmacological activities of *Camellia seninsis*

Tea consumption has been shown to have immunomodulatory, anti-diabetic, anti-cancer, anti-oxidant and antibacterial effects, and benefits for digestive health (Drivelos et al, 2016; Cabrera et al, 2006; Sinija &Mishera, 2008).

Anti-obesity and anti-diabetic Properties

Tea polyphenols influence neuroendocrine appetite regulation, reduce the emulsification and absorption of fats and proteins, facilitate digestion, inhibit adipocyte differentiation and proliferation, reduce fat production, and promote lipolysis and metabolism. According to previous research, drinking tea reduces the risk of diabetes, lowers fasting blood sugar levels, and helps control obesity (Zafar et al, 2016).

Neuroprotective effects

According to epidemiological research, drinking tea significantly reduces the risk of Alzheimer's and Parkinson's diseases. The primary reason for its neuroprotective effects is the ability of theanine to control extracellular glutamine concentration and prevent L-glutamic acid from binding to glutamate receptors in the brain (Yılmaz et al, 2020).

Antimicrobial properties

Tea catechins, such as epicatechin, epigallocatechin gallate, and epigallocatechin, have antimicrobial properties. They damage bacterial cell membranes, inhibit fatty acid synthesis, and inactivate enzymes. Epicatechin gallate, epigallocatechin gallate, and gallocatechin have broad-spectrum antibacterial properties (Bai et al, 2016; Khaing et al, 2018).

Cardioprotective and anti-Cancer properities

According to previous research, drinking tea reduces cardiovascular risk factors, such as hyperlipidemia, hypertension, and hyperglycemia, which are inversely associated with the onset of cardiovascular disease. Furthermore, tea polyphenols also reduce the risk of skin cancer. Epigallocatechin gallate (EGCG) has been shown to help prevent oral cancer by inactivating mitochondrial reactive oxygen species and other reactive oxygen species. The effectiveness of radiotherapy for patients receiving EGCG was significantly enhanced (Sun & Yan, 2014).

Antioxidant properties

Due to their high antioxidant content, polyphenols have been shown to improve mammalian health. Laboratory tests have shown that tea polyphenols reduce malondialdehyde (MDA) levels in rat serum and increase levels of catalase (CAT), glutathione peroxidase (GPx), and superoxide dismutase (SOD)(Camargo et al, 2016).

Total polyphenols, catechins and antioxidant activity of different types of tea

Carotenoids, phenolic acids, flavonoids, coumarins, alkaloids, polyacetylenes, saponins, and terpenoids are just a few examples of the bioactive substances found in tea that impart its distinctive flavor and taste, as well as its positive and protective effects on human health. Through different processing methods, six distinct types of tea have been produced—black, green, oolong, white, dark, and yellow—with a variety of flavors and aromas. One of the most important factors influencing tea quality is the manufacturing process, which greatly influences the type of tea and its chemical composition (Shao et al, 2022). Flavan-3-oleates, known as catechins, are the main polyphenolic compounds found in tea and include (-)-epicatechin (EC), (-)-epigallocatechin (EGC), (-)-epicatechin gallate (ECG), (-)-epigallocatechin gallate (EGCG), (-)-gallocatechin (GC), and (-)-gallocatechin gallate (GCG). Green tea contains significant amounts of catechins. Catechins with three hydroxyl groups in the B ring (positions 3', 4', and 5') are known as gallocatechins based on their chemical structure, while gallate catechins are characterized by a gallic acid substitution at position 3 of the ring (Peterson et al, 2005). EGCG makes up between 10% and 50% of catechins and is the most potent due to its interaction with galactin and hydroxyl. Catechins make up between 6% and 16% of dried green tea leaves. Another class of polyphenolic compounds found in both black and oolong teas is called TFs and TRs (Pelillo et al, 2002).

Studies have shown that tea possesses anti-inflammatory, anti-allergic, anti-cancer, antibacterial, metabolic-boosting, hypoglycemic, and hypolipidemic properties, as well as refreshing, anti-fatigue, and antioxidant properties (Kumar et al, 2022). In particular, catechins, which constitute approximately 80% of total tea polyphenols, are excellent natural antioxidants capable of scavenging lipids and oxidizing free radicals. The free radical-scavenging ability of tea polyphenols, thanks to the phenolic hydroxyl group attached to the flavan-3-ol structure, has been linked to tea's

potential to treat diseases caused by free radicals, sparking widespread research interest (Amić et al, 2003).

Numerous human conditions, such as cancer, artherosclerosis, arthritis, ischemia, damage to the central nervous system (CNS), gastritis, dementia, renal disorders, and AIDS, are known to be exacerbated by free radicals. Environmental pollutants, radiation, chemicals, toxins, physical stress, and the oxidation of food and medications all produce free radicals on a continuous basis. Numerous plant phenolics are said to possess antioxidant qualities that surpass those of vitamins E and C. In addition, currently available synthetic antioxidant like butylated hydroxyl anisole (BHA), butylated hydroxytoluene (BHT) and gallic acid esters have been suspected to cause or prompt negative health effects and hence the need to substitute them with naturally occurring antioxidants (Pourmorad et al, 2006). There is therefore an increased quest to obtain natural antioxidants with broad-spectrum action. Previous studies on tea types have mostly focused on the differences between the chemical composition among tea types and the correlation between the polyphenolic content and the antioxidant capacities.

METHODS

Search strategy

In the present review thirteen previous experimental studies are retrieved and these studies are searched in Google Scholar. These researches focusing on the studying of the phenolic and catechin composition in different types of tea (e.g., white, green, oolong, and black tea) and the relation of these components with the antioxidant activity of tea types. The subjects of these studies are divided into three categories: catechins content of different tea types, total phenols and flavonoids content of tea types, and contribution of individual components into the overall antioxidant activity of tea types. The outcomes of these studies were summarized in figures drawn by Microsoft Excel version 2010, using column and pie chart to compare values across the data collected from these studies.

Catechins content of different tea types

The selected first study found that oolong tea had higher total polyphenol content than green, black, and pu-erh teas. Furthermore, compared to oolong and green teas, pu-erh tea had significantly lower levels of ester catechins (ECG, EGC, and EGCG). To evaluate the antioxidant activity of different tea varieties, DPPH, ABTS, and the ability of superoxide dismutase to scavenge oxidative free radicals were tested. The IC50 value was used to compare the antioxidant capacity of different tea varieties; the lower the IC50 value, the higher the antioxidant capacity. Different tea varieties showed the ability to scavenge DPPH free radicals as follows: oolong > green > black > pu-erh, while oolong > green > pu-erh > black showed the ability to scavenge superoxide anions and ABTS free radicals (Ye et al, 2024).

The second study found that the total catechin content in green tea was significantly higher ($P<0.05$) than in oolong and black tea. This clearly demonstrates that the amount of catechins in the final product was affected by the level of fermentation during the manufacturing process. According to this study, the antioxidant activity of white and green tea was significantly higher ($P<0.05$) than that of black tea. A statistically significant correlation ($P<0.001$) was found between antioxidant activity and total catechins ($r = 0.959$). The most potent antioxidant was found to be EGCG ($r = 0.989$, $P<0.001$). Antioxidant activity was also significantly influenced by the content of EC, EGC, C, and ECG. Thus, tea extracts with higher concentrations of EGCG, EC, EGC, C, and ECG exhibited higher antioxidant activity. However, black tea demonstrated high DPPH free radical scavenging activity and some antioxidant activity in this study. This activity was attributed to TFS and TRS. Interestingly, TFS, an important phenolic product in black tea, demonstrated greater free radical scavenging activity than some of its predecessors, including ECG, EGC, EC, GA (r =

In the third study, different catechins were determined, the higher level of ECG was found in white tea followed by oolong, green, and black tea. EGCG was higher in green than oolong and white with lower level found in the black tea, while total flavonoids were higher in black followed by oolong>green>white (Chen et al, 2023).

In the fourth study, the level of catechin was higher in green than yellow, white, and black tea. The study demonstrated also that yellow tea has the higher level of ECG while green tea has the higher level of EGCG among the other investigated tea types (Sun et al, 2020). Some of the results of the above discussed four studies (Table I).

Total phenols and flavonoids content of tea types

The selected fifth study examined different brands of black and green tea in terms of their bioactive components and antioxidant t activity.

Table I. Composition of catechins and polyphenols in different types of tea in the selected first, second, third, and fourth studies.

	Component	Oolong tea	Green tea	Black tea	Puerh tea	References
1st study	EGC mg/g	8.75	7.39	0.54	----	Ye et al, 2024
	C mg/g	0.53	0.35	-----	----	
	EGCG mg/g	20.78	22.57	1.53	----	
	ECG mg/g	10.38	16.24	0.65	----	
	Total catechins mg/g	56.49	53.63	10.81	9.36	
	Polyphenols %	13.03	11.14	6.07	5.09	
	Flavonoids %	1.19	1.16	1.00	1.81	
2nd study	EGC mg/g	2.31	5.47	1.12	1.73	Karori et al, 2007
	EGCG mg/g	4.37	6.78	2.82	5.53	
	ECG mg/g	1.03	0.57	0.99	1.5	
	TFS mg/g	6.81	0.46	11.61	0.85	
	TRS mg/g	8.75	5.59	10.30	1.75	
	Total catechins mg/g	9.49	14.93	3.07	10.20	
	Total Polyphenols mg/g	26.15	26.85	20.65	21.13	
3rd study	GC mg/g	2.31	1.55	0.95	0.42	Chen et al, 2023
	ECG mg/g	23.95	22.01	1.36	24.06	
	EGCG mg/g	46.43	83.9	3.57	29.33	
	EP mg/g	2.62	4.50	1.14	26.54	
	Total flavonoids mg/g	2.34	1.87	2.94	0.31	
4th study	C mg/g	9.9	13.4	2	5.9	Sun et al, 2020
	EP mg/g	36.3	21.4	1.7	7.8	
	GC mg/g	3.7	9.1	-----	3	
	ECG mg/g	57.1	51.3	5	38.1	
	EGCG mg/g	49.8	56.6	2.5	40	

* Catechin (C), Epicatechin (EP), Gallocatechin (GC), Epigallocatechin (EGC), Epicatechin gallate (ECG), Epigallocatechingallate EGCG), Theaflavins (TFS), Thearubigins (TRS).

With the exception of flavonoids and caffeine, green teas were found to contain higher concentrations of bioactive components and to exhibit significantly higher levels of antioxidant activity than black teas (Table II). The scavenging ability of a sample is established by estimating the reduction of these radicals in both tests (ABTS and DPPH free radicals). In both tests, green tea was found to have noticeably higher scavenging activity. Both black and green tea outperformed the control in terms of scavenging activity, whereas green tea outperformed black tea in terms of antioxidant activity.

Both Green and black tea considerably increased the percentage of inhibition at varied concentrations. At 20 ppm, the highest mean value of percent inhibition for black tea was found to be 98.50%; similarly, at 20 ppm, the highest inhibition for green tea was found to be 99.07%. Green tea's higher TPC (total phenolic content) which is the primary factor for increased scavenging activity because of the strong correlation between TPC and scavenging activity. Different reactions of the two tests (DPPH and ABTS) to antioxidants are observed. Black tea demonstrated less scavenging activity than both standard and green tea, although green tea fared noticeably better. The difference in inhibition between black and green tea was found to be substantial at all concentrations. Green tea inhibited most (90.58%) at 100 ppm, while black tea had the highest inhibition (86.70%) at 80 ppm. The distinction in scavenging free radicals is due to the variance in composition of plant materials, such as phenolic compounds (Rahman et al, 2021). In the sixth, seventh, and eighth studies the results revealed that the green tea has higher level of total phenols and total flavonoids than the black tea (Izzreen & Fadzelly, 2013; Zhang, et al, 2019; Kopjar et al, 2015).

Table II. Comparison of total phenols and total flavonoids content between black and green tea in the selected fifth, sixth, seventh, and eighth studies.

	Tea type	Total phenols (mg/g gallic acid)	Total flavonoids (mg/g quercetin)	References
5th study	Black	242.46	61.81	Rahman et al, 2021
	Green	763.42	31.87	
6th study	Black	76.92	33.70	Izzreen & Fadzelly, 2013
	Green	80.27	35.17	
7th study	Black	101.29		Zhang, et al, 2019
	Green	252.65		
8th study	Black	1139	326	Kopjar et al, 2015
	Green	2262	1557	

Table III. Antioxidant activity of different tea types in first, fifth, ninth, eleventh, twelfth, and thirteenth studies

	Antioxidant activity	Green	Black	White	Oolong	References
1st study	DPPH inhibition %	77	73			Ye et al, 2024
5th study	DPPH inhibition %	90.58	86.7			Rahman et al, 2021
9th study	DPPH inhibition%	67.3	28.9	47.9		Nuryana et al, 2020
11th study	DPPH inhibition%	82.32	55.48	92.91	87.20	Rohadi & Putri, 2019
12th study	ABTS μmol TEAC/g DW	414.57	368.29			Chai et al, 2020
	DPPH μmol TEAC/g DW	301.67	275.39			
13th study	IC_{50}	0.487	5.005			Widowati et al, 2015

*(TEAC) trolox equivalent antioxidant capacity, (DW) distilled water

Contribution of individual components into the overall antioxidant activity of tea types

In the ninth study, the antioxidant activity of a tea sample was studied using DPPH as a stable free radical. The results showed that green tea, among the samples tested (white tea at 47.9% and black tea at 28.9%), had the highest DPPH scavenging capacity (67.3%), demonstrating the strongest antioxidant activity (Nuryana et al, 2020). Antioxidant activity of tea is affected by many natural polyphenols: catechins, oxyaromatic acids, tannins, flavonols, thearubigins, theaflavins, etc. The tenth study evaluated the concentrations of each component of black and green tea and their contribution to total antioxidant activity. HPLC-MS was used to identify the compounds present in the tea. Antioxidant activity was measured using ABTS.

In green tea, catechins are the major contributors to antioxidant activity, while in black tea, oxyaromatic acids are more important than flavonoids (Yashin et al, 2005). In the eleventh study the results demonstrated that the white tea has the higher DPPH inhibition activity than the other investigated types (oolong, green, and black) (Rohadi & Putri, 2019). In the twelfth study, both ABTS and DPPH inhibition activities were higher in green tea than oolong (Chai et al, 2020). The thirteenth study revealed that green tea has higher antioxidant activity than oolong tea IC_{50} (0.487 and 5.005), respectively (Widowati et al, 2015) (Table III).

RESULTS AND DISCUSSION

According to data in the first, second, third, and fourth studies, it was shown that both oolong and green tea have higher level of total catechins than black tea and the levels of individual catechins (EGCG and EGC) were higher in both tea types than the black (Figure 1). In addition, the collected data from fifth, sixth, seventh, and eighth studies exhibited that the total phenolic and flavonoids contents were higher in green tea than black tea (Figure 2). Furthermore, the retrieved 1st, 5th, 9 th, 11th, and 12th showed that the antioxidant activity (DPPH % inhibition) of green tea was higher than oolong and black tea (Figure 3).

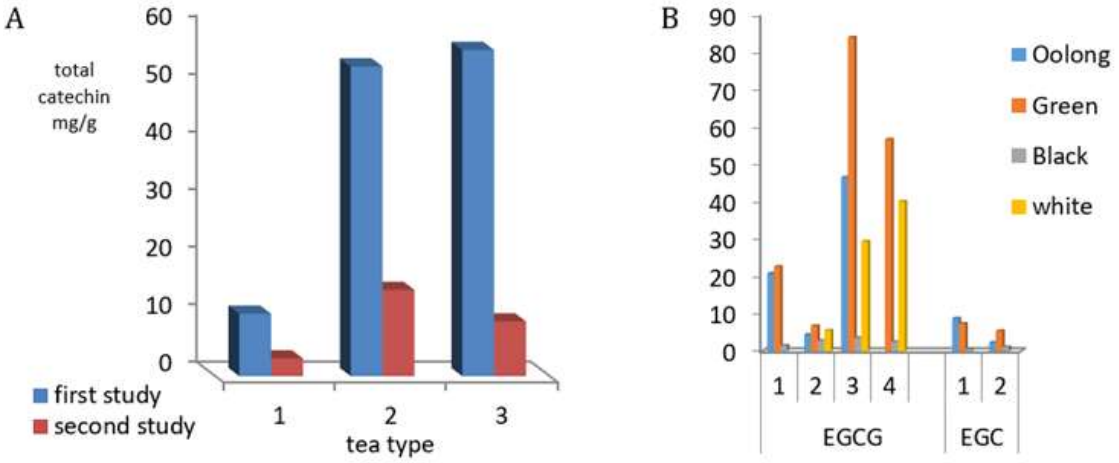


Figure 1. A) comparison of total catechins (mg/g) between black (1), green (2), and oolong (3) tea. B) comparison of EGC (epigallocatechin) and EGCG (epigallocatechin gallate) content (mg/g) between oolong , green, black, and white tea in the first (1), second (2), third (3) and, fourth (4)studies.

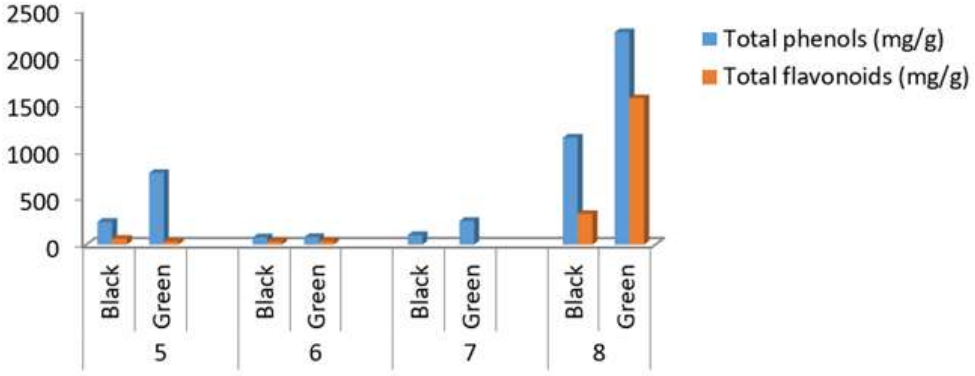


Figure 2. Comparison of total phenols and total flavonoids content between black and green tea in the 5th, 6th, 7th, and 8th studies.

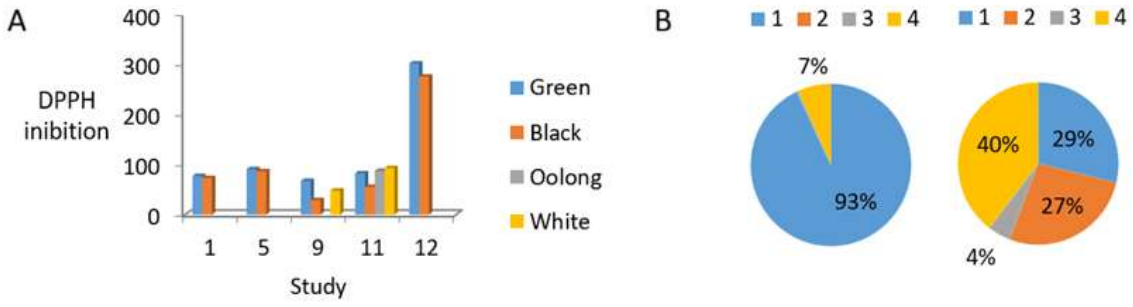


Figure 3. A) Comparison of antioxidant activity (DPPH inhibition) between green, black, oolong, and white tea in the 1st ,5th ,9th ,11th , and 12th studies. B) Contribution of individual components into the overall antioxidant activity of green tea to the left and black tea to the right (catechins 1, theaflavins 2, flavonoids 3, and oxyaromatic acid 4), data collected from the 10th study

Under the influence of heat, catechin monomers may continuously convert to catechin derivatives during tea processing. After being stabilized at high temperatures, green tea enzymes are rapidly quenched and inactivated to maximize catechin content retention by effectively preventing the oxidation of polyphenols.

To minimize chemical and enzymatic reactions, wilted leaves are steamed and then rapidly dried after harvest to produce green tea. This prevents the oxidation of tea leaf catechins, which is catalyzed by the enzyme polyphenol oxidase (PPO) (Fan et al, 2016). On the other hand, tea buds are soaked to initiate oxidation by PPO before being burned during black tea processing. Catechins can condense with orthoquinones resulting from the oxidation of di- and trihydroxylated catechins at the B ring to form theaflavins (TFs). Theaflavins are analogues that give fermented black tea its reddish yellow color and enhance the brightness and strength of the tea drink (Bonheure &Wilson, 1992; Collier et al, 1973). They act as oxidizing agents, forming epimeric acids from substrates such as gallic acid. When these acids combine with theaflavins, chemically diverse compounds known as thearubigins (TRs) are formed, which give tea its color, texture, and flavor. These compounds, with a benzotropolone ring structure, are formed in the presence of molecular oxygen (Obanda et al, 2001; Leung et al, 2001).

Semi-fermented oolong tea is produced by sun-melting, sifting, rolling, and drying. This process produces the distinctive floral aroma of oolong tea. White tea, a rarer variety, is named after a specific type of tea plant and a special post-harvest processing technique that produces fine silver hairs on the dried buds. A large percentage of white tea buds are covered with fine silver hairs, giving the tea its pale white color. White tea has a pale yellow color and lacks the grassy flavor that green tea can sometimes have. Genuine white tea leaves remain fresh after being quickly steamed, dried, and lightly fermented. White tea is not rolled or crushed like black, green, or oolong tea; instead, it is quickly steamed and air-dried to preserve most of its polyphenolic compounds (Hilal & Engelhardt, 2007; Zhou et al, 2023)

This special processing produces a rare, expensive, and extremely refreshing beverage. The polyphenol contents of black, green, oolong, and white teas vary depending on the manufacturing process. Polyphenols, alkaloids (caffeine, and theobromine), amino acids, carbohydrates, proteins, chlorophyll, volatile compounds, minerals, trace elements, and other unknown substances are part of tea's complex chemical composition. Prominent among these are polyphenols, the main bioactive components of tea (Cabrera et al, 2003). The antioxidant content of different tea varieties varies greatly. Free radicals can be neutralized by the reaction of tea polyphenols with them to produce more stable phenolic free radicals. The number of phenolic hydroxyl groups in polyphenols decreases further during fermentation due to strong oxidation and conjugation (Han et al, 2022).

As a result, antioxidant capacity declines. Therefore, the overall performance of free radical scavenging capacity is in the order of: no fermentation > light fermentation > full fermentation, indicating a good dose-effect relationship between antioxidant activity and polyphenol content. Catechins with a 3', 4', and 5'-trihydroxylated substitution pattern on the B ring and/or hydroxyl group at the C-3 position of the catechin structure are the most potent radical scavengers.

By taking part in electron delocalization, a crucial aspect of the antiradical potential, this hydroxylation gives the catechin phenoxyl radical a greater degree of stability. This explains why gallocatechins, such as EGCG and EGC, which are strong antioxidants, have a high level of radical scavenging. Compared to green, white, and oolong teas, black teas showed less antioxidant activity. Because of their high oxidation potential and high concentration in the leaves, the gallocatechins are the first to be oxidized and dimerized to TFs and TRs during the manufacturing of black tea. The radical scavenging activity of black tea was also greatly enhanced by these main phenolic compounds. EGC and EGCG play a major role in the development of TFS. These are B ring trihydroxylated catechins, and because of their lower oxidation potential, they oxidize far more quickly than the B ring dihydroxylated catechins (EC, ECG, and +C). The hydroxyl groups (OH) in the TFs produced by this reaction are thought to be essential for their ability to scavenge free radicals. The remarkable antioxidant activity of black tea is expressed through these additional groups, which increase the total number of phenyl hydroxyl groups and enhance the ability of gallate-containing catechins and transcription factors to donate protons through resonance transfer (Gardner et al, 2007).

Similarly, because gallic acid is a strong hydrogen donor to DPPH, it significantly contributed to the free radical scavenging activity

of black tea. This demonstrates that the free radical scavenging efficacy of black tea was not affected by the conversion of catechins to transcription factors during processing. According to Yashin et al (2005), the total content of theaflavins and thearubigins were higher in black tea than in white, oolong, and green tea and the ability to scavenge free radicals generally corresponds to the order of the content of tea polyphenols and catechins, which together may constitute the main antioxidant active substances.

The major antioxidant components in black tea are oxyaromatic acid, TFS, and TRS, while the major antioxidant components in green tea are catechins. The major antioxidants—gallocatechins, TFS, and TRS found in fully fermented black tea were not present in high concentrations in oolong (semi-fermented) tea, which falls midway on the antioxidant spectrum between green and black tea. As a result, the antioxidant activity of this tea was midway on the antioxidant spectrum between black and green tea (Owuor et al, 2007). This review concludes that all the included studies revealed that the green, oolong, and white tea have higher antioxidant activity than black tea, Figures 2 and 3 illustrate these results.

CONCLUSION

This study highlights the differences in the chemical composition and antioxidant activities of different types of tea, including green, black, white, and oolong tea. The findings of the retrieved studies indicate that green tea has the highest polyphenol and catechin content, contributing to its superior antioxidant properties. The results also demonstrate that fermentation plays a crucial role in altering the polyphenol profile of tea, with fully fermented black tea showing a shift from catechins to theaflavins and thearubigins, which still exhibit notable antioxidant activity. Additionally, the study confirms that catechins, particularly epigallocatechin gallate (EGCG) and epigallocatechin (EGC), are the primary contributors to antioxidant capacity in green tea, whereas black tea's antioxidant activity is more dependent on theaflavins and thearubigins. Oolong tea, being semi-fermented, exhibits intermediate antioxidant activity.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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