ANTIOXIDANT CAPACITY AND PHYSICOCHEMICAL PROPERTIES OF GREEN TEA AS INFLUENCED BY TYPES OF BREWING WATER

by

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LIST OF ABBREVIATIONS

Abbreviations	Definitions
a*	Red/green coordinate
AAS	Atomic Absorption Spectrometer
AK	Alkaline Ionized Water
ANOVA	Analysis of Variance
b*	Yellow/blue coordinate
DDC	Daily Demand Coverage
DPPH-SA	2,2-diphenyl-1-picrylhydrazyl Free Radical scavenging activity
FC	Flavonoid Content
FRAP	Ferric Reducing Antioxidant Power
L*	Lightness
Lipton-AK	Lipton green tea infusion brewed with alkaline ionized water
Lipton-MG	Lipton green tea infusion brewed with magnetized water
Lipton-MN	Lipton green tea infusion brewed with mineral water
Lipton-TP	Lipton green tea infusion brewed with tap water
g	gram
GAE	Gallic Acid Equivalent
MG	Magnetized water
mL	microlitre
MN	Mineral water
TPC	Total Phenolic Content
TWG-AK	TWG green tea infusion brewed with alkaline ionized water
TWG-MG	TWG green tea infusion brewed with magnetized water
TWG-MN	TWG green tea infusion brewed with mineral water

TWG-TP	TWG green tea infusion brewed with tap water
MG	Magnetized water
RNI	Recommended Nutrient Intake
R^2	Determination of coefficient
QE	Quercetin Equivalent

KAPASITAS ANTIOKSIDAN DAN SIFAT FISIKOKIMIA TEH HIJAU DENGAN BERBAGAI JENIS AIR PENYEDIAAN

ABSTRAK

Sebagai minuman kedua paling popular yang digemari di seluruh dunia, populariti teh hijau didorong oleh promosi kesihatan manusia yang didedahkan oleh berbagai-bagai kajian. Jenis air yang digunakan untuk membuat infusi teh hijau dijangka dapat mempengaruhi sifat fisikokimia dan kapasitas antioksidan teh hijau. Dalam kajian ini, dua jenama teh hijau yang dikelaskan premium dan standard (TWG 1837 Green Tea dan Lipton Pure Green Tea) dinilai dan dianalisasi secara perbandingan dengan menggunakan air paip (TP), air alkali terionisasi (AK), air magnet (MG), dan air mineral (MN). Warna (L *, a *, b * dan h^{o}), pH, potensi redoks, jumlah pepejal terlarut, kandungan mineral, kandungan total fenol, kandungan flavonoid dan DPPH digunakan sebagai parameter untuk memeriksa pengaruh jenis air dan jenama teh hijau. Secara umum, hasil penelitian menunjukkan aktiviti antioksidan kedua-dua jenama teh hijau ini tidak menunjukkan perbezaan yang signifikan ($p< 0.05$) walaupun perbezaan antara harga kedua-dua jenama teh hijau tersebut amat ketara. Lipton-MG mencatatkan kandungan total fenol (48.32 mg GAE/mL) dan flavonoid (2.00 mg QE/mL) yang tertinggi, menunjukkan kapasitas antioksidan yang terbaik, yang mungkin disebabkan oleh struktur air magnet. Namun, hasil menunjukkan bahawa kandungan mineral dan pH dapat mempengaruhi kesan pengekstrakan polifenol daripada daun teh hijau. Ringkasnya, pilihan air untuk membuat infusi teh hijau mempunyai pengaruh yang ketara terhadap sifat fisikokimia dan sifat antioksidan. Penyelidikan yang berterusan perlu dijalani untuk memberikan pemahaman yang mendalam tentang mekanisme pengekstrakan sebatian dan atribut sensori rasa yang yang diutamakan oleh peminum teh.

ANTIOXIDANT CAPACITY AND PHYSICOCHEMICAL PROPERTIES OF GREEN TEA AS INFLUENCED BY TYPES OF BREWING WATER

ABSTRACT

As the second most popular beverage favoured by people around the world, the popularity of green tea is due to its promotion of human health unfolding with myriads of studies. It is expected that the physicochemical and antioxidant activity of green tea infusion could be affected by the types of brewing water used, particularly some pre-treated water. In this study, premium and standard grades from two different brands (TWG 1837 Green Tea and Lipton Pure Green Tea) of green tea were evaluated and comparatively analysed which were individually brewed with tap water (TP), alkaline ionized water (AK), magnetized water (MG), and mineral water (MN). The colour (L*, a*, b*and h°), pH, oxidation-reduction potential, total soluble solids, mineral content, and antioxidant properties (Total Phenolic Content (TPC), Flavonoid Content (FC) and DPPH scavenging assay) were used as parameters to examine the influence of brewing water and the brand of green tea. In general, results indicated negligible disparities ($p< 0.05$) in antioxidant properties between these two grades of green tea despite the significant price difference. Lipton-MG recorded the highest TPC (48.32 mg GAE/mL) and FC (2.00 mg QE/mL), showing the highest efficiency in extracting polyphenolic compounds, which presumably was likely to be attributed to the water structure of magnetized water. However, results reflected that the mineralization and pH of brewing water could influence the degree of extraction of polyphenolic compounds from green tea leaves. In short, the choice of brewing water of green tea infusion has a marked influence on the physicochemical properties and antioxidant properties. Continued researches are required to provide an in-depth understanding on physic-based mechanism of the extraction and perceived flavor to tea drinker.

CHAPTER 1
INTRODUCTION

1.1 Research Background

In recent years, there has been a significant growth in the global tea production industry from 2007 to 2016 by an annual rate of 4.4 % (FAO, 2018). Consequently, there is an upward trend observed in tea prices as reported by FAO where the surge is expected to continue, owing to the high demand in developing and emerging countries. Tea is widely consumed and produced in different countries, though in varying amounts; it is widely acknowledged that, besides water, tea is the most consumed drink in the world (Katiyar and Mukhtar, 1996).

Tea which its scientific name is known as *Camellia sinensis* is the most frequently consumed drink apart from water. There is a plethora of tea varieties, differed by processing methods, mainly due to its degree of fermentation. The proportion of different teas produced and distributed worldwide is 78% for black tea, 20% for green tea and 2% for oolong tea (Chan et al., 2007). China, which is the largest manufacturer of green tea, accounts for around 2,777,200 tonnes of total tea global production followed by India and Kenya (FAO, 2019).

Green tea is at the forefront of nutritional, pharmaceutical and therapeutic studies. This is due to its high content of crucial therapeutic compounds which exhibit high biostability compared to other compounds found in various other sources. These compounds are so ubiquitous that they can demonstrate a wide range of effects (Cao et al., 2019; Kokubo et al., 2013; Lambert and Elias, 2010; Sumpio et al., 2006; Yuan et al., 2011). The technological application of green tea in food has successfully shown some viable results in the food industry which drove the effort in exploring the potential in practice for preventive and medicinal use of green tea.

In the wellness and healthy eating world, there are a surfeit of health beneficial drinking water that were being unveiled continuously by manufacturers. Additional health benefits brought by these beverages can be achieved by fortifying with functional ingredients or undergoing certain treatment on drinking water. There are many processing methods used in the production of these drinking water such as treatment with some minerals, electrolysis, irradiation, magnetization, and others. As green tea has been regarded as a health-promoting beverage, its effect might be optimized by brewing it with these water.

Given the global popularity of green tea, it is critical to figure out the factors influencing the physicochemical parameters and antioxidant properties activity of green tea brew as influenced by brewing water using instrumental analysis. As the green tea beverage industry has been growing, much attention has been given to the brewing condition of green tea to obtain the optimal result of consuming green tea in daily lives. In this study, the influence of brewing conditions and brands of green tea were comprehensively examined by evaluating the differences in selected parameters.

1.2 Rationale of the study

It has been long known that one of the crucial aspects affecting the quality attributes of a green tea infusion is brewing water (Li et al., 2015). Different studies have been done to discuss the effect of water quality on green tea infusion, showing that there was escalating interest to improve the quality of green tea infusion (Danrong et al., 2009; Saklar et al., 2015; Sharpe et al., 2016). But few papers dealt with water like magnetized water and alkaline ionized water.

Considering the increasing attention in the health benefits of green tea and health-promoting water, the present study aimed to collect information and discover more about the brewing condition of green tea infusion, particularly changes caused by the water structure and composition of the brewing water. Various aspects involved in the brewing condition of green tea have been studied including brewing time, temperature of the brewing water, pH of the brewing water and the like. However, little is known about the effects of water composition on the quality attributes of the final tea infusion, albeit brewing water acts as the vehicle of green tea in the brew (Danrong et al., 2009).

To this end, through this study, the influence of the type of brewing water on the physicochemical properties and antioxidants activity of the green tea infusion was investigated instrumentally. A study conducted by Franks et al. (2019) established the importance of choice of brewing water in steeping green tea after comparing the influence of water in green tea and black tea infusions as catechins in green tea proactively interacted with components of water, causing the flavour profile of the infusions to be affected by the water composition. Thus, it is highly relevant to bridge the gap between these four types of water as brewing water to green tea brewing methods in understanding the influence of brewing water in making tea infusion.

As a result of water treatment such as filtration, magnetization and ionization, the physical and chemical properties of brewing water changes which can influence characteristics of the final tea infusion. It was expected that these brewing waters extract green tea leaves differently, each showing different results in physicochemical properties and antioxidant activity of the brew. Different brands of green tea were also regarded as an influencing factor. Since a premium grade (TWG 1837 Green Tea) and a standard grade (Lipton Pure Green Tea) of green tea was comparatively analyzed, it was hypothesized that the quality attributes of the premium grade green tea should be surpassed the standard grade green tea.

Adopting the index of antioxidant capacity of green tea samples can help in providing a clearer indication of the possible therapeutic and curative properties of the tea infusions, albeit debate regarding the association between in vitro and in vivo antioxidant parameters often occurs (Sharpe et al., 2016). Determining the quality characteristics of different green tea infusions are also highly significant as these results can help in providing details on the positive aspects of green tea. The results of this study might be helpful in providing a better understanding to make a cup of green tea as the physicochemical properties and antioxidant activity of the infusion are directly related to the quality attributes of this beverage.

1.3 Objectives

1. To evaluate the effect of brewing water in extracting the tea to cause differences in the physicochemical properties and antioxidant activity of premium green tea and standard green tea infusion.
2. To provide better insights regarding the ideal aqueous brewing water for green tea using instrumental analysis.

CHAPTER 2
LITERATURE REVIEW

2.1 Green Tea
2.1.1 Brief history and introduction

For millennia, green tea has been a widely consumed beverage around the world and renowned for its powerful rejuvenating qualities. Tea culture can trace its heritage back to at least one thousand years from time immemorial. The plant *Camellia sinensis* was initially grown in China and in Southeast Asia and the Chinese had been growing and drinking it for thousands of years before Europeans (Cooper, 2012; Mukesh et al., 2012; Rappaport, 2017). These days, the cultivation of tea can be found in more than 30 countries around the world (Chaturvedula and Prakash, 2011). Tea drinking culture is a tradition in Asia as a mindful and Zen practice (Hicks, 2001). Based on an ancient Chinese medical book named the Pen T'sao, Emperor Shen Nung is the one who discovered tea (Gianfredi et al., 2018; Mukhtar and Ahmad, 1999). According to Chinese Mythology, brewing tea leaves in boiling water was discovered by a matter of chance, as some of the tea leaves happened to be blown into hot water (Mahmood et al., 2010). Since centuries ago, people in China, Japan, India, and other tropical and sub-tropical countries have been drinking green tea to boost their health, improve blood flow and boost immune system (Balentine et al., 1997; Harbowy et al., 1997). In ancient China, tea has been famous and regarded as a luxury and lavish commodity because of its medicinal uses, flavour, nutritional beliefs, and aroma (C. Cabrera et al., 2006; Thasleema, 2013).

Green tea originated in the southern part of China 3,000 years ago (Shi and Schlegel, 2012). Initially, the way people consumed green tea was by eating and chewing, mainly for its appealing taste (De Almeida et al., 2009). Most research agreed that the birthplace of the tea bush is primarily located in the Yunnan and Sichuan districts (Thasleema, 2013). In Japan, tea was first introduced during the 8th century by Buddhist monks, Saicho and Kukai, who studied Buddhism in Tang China for a while. The green tea was found to relieve fatigue and reduce tiredness after they meditated and studied for long hours (Ross, 2007). In 1211, a Japanese Buddhist priest Eisai wrote about the health benefits of tea in his book "Kissa-yojoki" where green tea was described as a miraculous medicine for longevity and health (Sadakata et al., 1992). Japanese regarded tea as a spiritual pursuit where simplicity in life was celebrated through a tea ceremony called the art of Chanoyu (Ross, 2007).

The nomenclature of tea started in the late 16th century when a German naturalist, named Engelbert Kaempfer, traveled to Japan and discovered native tea drinking habits among the Japanese. Then, he decided to call tea bush “thea” which carries the meaning of “goddess” in Greek. However, there was confusion in the tea bush's naming since another Swedish botanist, Carl Linnaeus, named the tea bush *Camellia sinensis* in 1753 (Hara, 2001). Then, in 1958, a British botanist, J. Robert Sealy, came out with the Sealy Classification, which classified all the plants under the genus of *Camellia*.

2.1.2 Processing and Consumption

Green tea is the tea produced from bush *Camellia sinensis* which is categorized as a member of the family *Theaceae*. As it is unfermented tea, it consists of a higher amount of catechins than other variants of teas. Green tea is consumed in the form of an infusion of the processed dried leaves of *Camellia sinensis* (Mukesh et al., 2012). The tree of the tea plant is a small, perennial evergreen shrub with many branches (Gruenwald, 2004). When the shrub is ready to be cultivated, its height will be around 0.6 – 1.5 m (Mahmood et al., 2010). The tender leaves are then harvested for the production of green tea (Ahmed and Stepp, 2013; Islam et al., 2014).

There are two common methods of harvesting fresh tea leaves in tea manufacturing: manual hand plucking or mechanical plucking. Hand plucking is more inefficient, labour intensive and time consuming but widely preferred due to the uniformity of the tea leaves harvested. Hand-plucking fresh tea leaves from China is used to make premium green teas (Chaturvedula and Prakash, 2011). Processing of the tea leaves is one of the most crucial factors determining the quality characteristic of the final tea infusion and transforming the fresh tea leaf into types of tea (Ahmed and Stepp, 2013).

Produced from the plants of the genus *Camellia*, tea can be found in three types, namely green tea, oolong tea, and black tea (Anandh Babu and Liu, 2008; Chaturvedula and Prakash, 2011; Hara, 2001). Each of these teas is characterized by the processing that the tea leaves undergo and differentiated from each other by the degree of fermentation of the tea leaves, dependent on the fermentation methods employed, which causes oxidative and enzymatic changes (Filippini et al., 2020). Figure 2.1 illustrated processing methods of these three types of teas in a simplified diagram. Among these teas, green tea is often most studied due to its potential health benefits, since it contains the highest amount of catechins (Gianfredi et al., 2018). Green tea is harvested when the leaves are more mature and it will be promptly processed upon harvest to avoid degradation due to biochemical changes (Ahmed and Stepp, 2013; Reygaert, 2018).

Nonetheless, fermented tea like black tea demonstrated greater advantages as it can be easily exported across different regions. Among all the other teas, green tea is still widely preferred in the East, while the West showed a greater liking towards black tea (Prasanth et al., 2019; Reygaert, 2018). As compared to other types of tea, the history of green tea is the longest, and it is widely consumed in approximately 160 countries every day (Shi and Schlegel, 2012).

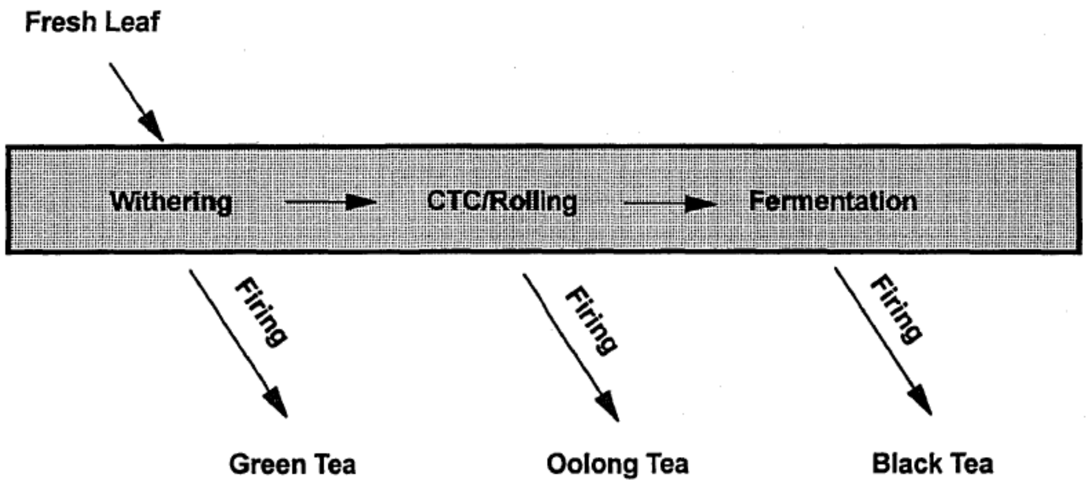

Figure 2.1: Processing methods of green tea, oolong tea and black tea (Balentine et al., 1997)

Changes occurred in the fresh tea leaves during processing due to a biochemical reaction which lowered its bitterness, extended its shelf life, deactivated enzymes and added sweetness to the tea (Franks et al., 2019). The main steps involved in the manufacturing of green tea are spreading out, fixing, rolling, shaping and lastly drying (Ahmed and Stepp, 2013). A flowchart of processing steps of green tea was illustrated in Figure 2.2. The main purpose of green tea processing is to preserve the catechins in tea leaves where the tea leaves are not fermented (Jo and Byun, 2009).

Without undergoing fermentation, the colour of catechins in green tea leaves are preserved to be colourless whereas the colours of oolong tea and black tea are darker due to the colour conversion during tea fermentation (Balentine et al., 1997). The fermentation process in the manufacturing of oolong tea and black tea is the polyphenol oxidase mediated oxidation where the catechins was converted to theaflavins and polymeric thearubigins (Lambert and Elias, 2010).

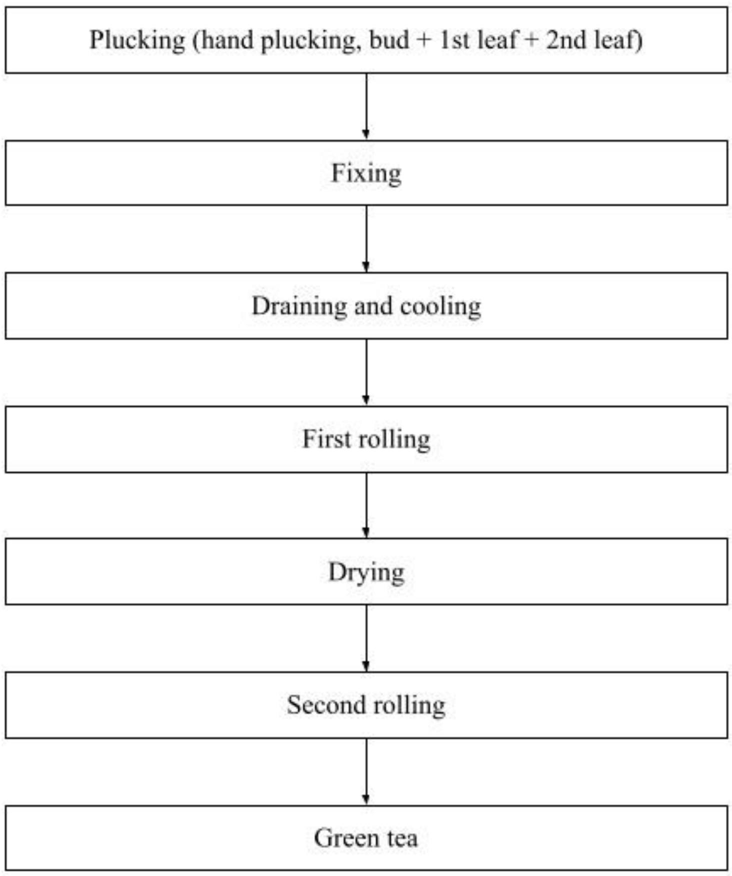

Figure 2.2: Detailed flowchart of green tea leaves.
(Yadac et al., 2020)

2.1.2a Green Tea Processing: Fixing

Fixing is the crucial quality determining steps in green tea processing (Huajie Wang et al., 2020). It is the key step in distinguishing green tea with other tea. By steaming or firing, polyphenol oxidase in the tea leaves are inactivated, inhibiting the enzymatic oxidation of catechins which are the major polyphenolic compounds (Anandh Babu and Liu, 2008). Through the fixing process, the enzymes which are accountable for degrading the colour pigments in fresh tea leaves are inhibited (Chacko et al., 2010). Thus, by reducing the enzymatic activities in green leaf, the green colour of the tea leaves can be preserved, producing a dry and stable end product (Chacko et al., 2010; Singh et al., 2014).

The main difference between steaming and firing is the temperature used during the processing. A published work by Wang et al. (2000) applied a steaming protocol of 95-100 °C for 15-30 s and pan firing protocol of 160-230 °C for 10-12 min to inactivate the enzymes. It was also suggested that the sensory characteristics of steamed green tea outshined pan fried green tea, coupled with better storage stability. During the steaming process, tea leaves will be placed on pierced steamers where the steam from boiling water is used to heat the leaves (Singh et al., 2014). On the contrary, for the frying process, the fresh tea leaves will be roasted on an iron pan while being gently agitated on the pan.

2.1.3 Green Tea Composition

Green tea primarily constitutes proteins, alkaloids, amino acids, carbohydrates, minerals, polyphenols , lipids and trace elements (Kar and Saloni, 2016; Reygaert, 2018). Carbohydrate such as cellulosic fiber is the main component of green tea leaves followed by protein (Kar and Saloni, 2016). Starch content in green tea is the key factor influencing the quality of green tea leaves (Kar and Saloni, 2016). Contributing largely to the starch content would be the time of harvest as the starch content of tea leaves is higher in the afternoon compared to those harvested in the morning (Chu and Juneja, 1997).

Some amino acids and nitrogenous compounds can also be found in green tea where 25% of these compounds originate from caffeine (Kar and Saloni, 2016). Caffeine, well-known as a central nervous system stimulant, is the primary purine alkaloid produced from tea plants (Wei et al., 2019). The caffeine content of tea is approximately 5%, higher than the caffeine content in coffee beans (Kar and Saloni, 2016). The composition of amino acids in green tea consists of 20 types of amino acids, mainly made up of theanine, glutamic acid, aspartic acid and arginine (Hung et al., 2010). These compounds play important roles contributing to the umami taste of green tea (Hung et al., 2010).

2.1.3a Polyphenols

Among all the chemical components of tea, polyphenols have been recognized to be primarily responsible for health-beneficial effects of drinking tea (Sharangi, 2009). In addition, green tea leaves consist of naturally occurring polyphenols which are naturally occurring organic compounds, contributing to 25% to 30% of the dry weight (Balentine et al., 1997; Chacko et al., 2010). Flavonoids are the polyphenols which can be found abundance in tea, approximately 80% of total phenolic content of tea (Franks et al., 2019). These bioactive compounds are produced during plant metabolism. The structure of flavonoids is a chalcone structure where it is made up of two six carbon rings connected via a three-carbon unit in the configuration C6–C3–C6 (Hodgson and Croft, 2010; Lorenzo and Munekata, 2016).

The polyphenols content of green tea is higher than black tea since polyphenols content in black tea is 10% of its dry weight (Wang et al., 2000). It has been established that polyphenols are the most significant biologically active component in tea leaves (Reto et al., 2007). These compounds are responsible for the beneficial effects of green tea such as anticarcinogenic, antioxidative, and antimutagenic properties. Catechins are also one of the most important and abundant flavonoids where flavonoids are the polyphenols found in tea leaves (Cabrera et al., 2006; Reygaert, 2018). The oxidation degree of heterocyclic rings in catechins were the highest, making it readily soluble in water (Michalowska et al., 2005).

There are various factors influencing the catechins content in the tea leaves such as the location of the tea plantation, harvest time, post-harvest processing, storage, brewing methods and growth condition, causing wide variation in the amount of catechins found in different brands of green tea (Burana-osot and Yanpaisan, 2012; Franks et al., 2019; Saklar et al., 2015). Green tea consists of four main active catechins namely (-)-epicatechin (EC), (-)-epigallocatechin (EGC), (-)-epicatechin-3-gallate

(ECG), and (-)-epigallocatechin-3-gallate (EGCG) where EGCG accounts for 60% of the total catechins content (Burana-osot and Yanpaisan, 2012; Franks et al., 2019; Reto et al., 2007; Reygaert, 2018).

Catechins are the major components of total flavonoids of green tea, contributing to 80% to 90% of the total amount of flavonoids (Anandh Babu and Liu, 2008). Catechins are highly effective in neutralizing reactive oxygen and nitrogen species in the human body (Cabrera et al., 2006). The bioavailability of catechins is an important factor to be considered in order for them to exhibit its beneficial properties (Reygaert, 2018). Metabolic reactions of catechins in the human digestive system converted them from their native form to their metabolites such as glucuronide and sulfate conjugates or methyl epicatechins (González-Manzano et al., 2009). These metabolites each possess different biological targets and roles in the human body.

Specifically, these polyphenolic compounds are often studied previously due to its characteristic as an vital natural antioxidants (Zhao et al., 2019). The ability of a tea polyphenols to scavenge radical is highly associated with the spatial configuration and the number of hydroxyl groups of the polyphenols (Oliveira et al., 2015; Yang et al., 2018). The stereochemical changes of these phenolic compounds could be influencing the antioxidant kinetics which strongly linked to the ease of forming the dimer products during the scavenging process (Yang et al., 2018).

2.1.4 Physicochemical properties of green tea

2.1.4a Colour of green tea

Aside from fragrance and taste, the shade of tea and the colour of the infusion are two characteristics that are used to evaluate different types of tea. Green tea infusion does not contain any intensely coloured products produced resulting from the oxidation of polyphenolic compounds. Hydrophilic pigments like flavonols, anthocyanins, flavanones, and flavanols are the main determinant that influencing the colour of the green tea decoction (Zhang et al., 2017).

The desired color of green tea infusion is greenish or yellowish-green with no traces of red or brown. Green is the dominant colour of the green tea infusion and infused tea leaves which are determined by the chlorophyll profile and the ratio of chlorophyll a to chlorophyll b as the colour of chlorophyll A is dark green and the colour of chlorophyll b is yellowish-green (Chaturvedula and Prakash, 2011). The contributors for yellow colour of green tea infusion are water soluble flavonols, flavones and their glycosides which are produced during the enzymatic oxidation and condensation of catechins in green leaves. The existing empirical studies generally agreed the relationship between the colour of the final green tea infusion and the stability of oxidation of water-soluble bioactive compounds in the infusions which could be affected by ion content and pH of the brewing water (Zhang et al., 2017). It was also suggested that the stability of these colour-determining pigments can be enhanced with a brewing water with low ion content and weakly acidic.

2.1.4b Flavour of green tea

The popularity of green tea comes from its irreplaceable earthy, delicate and refreshing flavour which retains its natural and awakening punch. While reaping the health benefits of drinking green tea, the palatable and pleasing flavour of green tea has sweetened the deal even more. The most common flavor characteristic descriptors used in green tea are bitter and sweet. The bitter taste in tea is highly affected by cultivation and the catechins content of the tea (Ahmed and Stepp, 2013).

On top of that, catechins were also shown to be the main factor contributing to the characteristic bitterness and sweetness of tea brew (Franks et al., 2019; Hara et al., 1995). Glucose, sucrose, fructose, and arabinose in tea may help in yielding a sweet taste in tea. The umami characteristic of green tea is due to the presence of free amino acids in the tea (Franks et al., 2019). Some of the desired characteristics in green tea include sweet, smooth, light and delicate (Ahmed and Stepp, 2013). Catechin in green tea is also the main factor of causing astringency which is a common tactile sensation, albeit it is not a taste (Franks et al., 2019).

2.1.4c Aroma of green tea

Human nose plays the role as an aromatic guide where it is often regarded as a compelling component of five senses. As a such popular beverage, green tea is well known for its uplifting and refreshing aroma that creates feelings of calmness and serenity and helps in delivering a sense of well-being. Enjoying the serenity propelled by the fragrance of green tea has been a simple and intuitive centuries-old tradition enjoyed by people around the world. The aroma of green tea is one of the fundamental aspects to be considered in judging the quality of a green tea infusion (Wang et al., 2020). For those tea lovers, they could easily evaluate the fineness of the infusion by catching a whiff of the green tea brew.

There are various terms adopted to classify the aroma of green tea including sweet, clean, floral, chestnut-like and others (Wang et al., 2020). These aromas are mainly caused by the volatile compounds in the green tea. There are four main pathways involved in the generation of these volatile compounds, namely Maillard reaction pathway, lipids as precursors, carotenoids as precursors and glycosides as precursors (Ho et al., 2015). The processing method used in the manufacture of green tea is often regarded as the fundamental reason determining the formation of green tea aroma compounds (Ho et al., 2015). Previous findings also highlighted the significant role played by fixation and drying steps in influencing the final aroma of the tea infusions (Wang et al., 2020).

2.1.5 Green Tea: Health benefits

Due to the nutritional benefits of green tea with its high content of bioactive compounds, a great deal of attention has been given to the infusion of green tea, encouraging the worldwide popularity of green tea (Huang et al., 2017). In the past decade, the health benefits regarding green tea consumption have been extensively studied (Huang et al., 2014). The overall findings obtained from the past research has shed considerable light on the health-promoting effects of green tea combating different health complications. With increasing attention to the therapeutic effect of green tea on health, there is a remarkably steady growth of green tea consumption annually, which emphasized the wide prevalence of green tea (Nikhil and Yang, 2015).

2.1.5a Cardiovascular Diseases

These days, the surging rate of fatalities due to cardiovascular diseases had become markedly worrisome and alarming. Cardiovascular diseases are the global leading causes of death, which refers to the malfunction of heart and blood vessels which can cause stroke, heart failure and others (Cao et al., 2019). Findings from different studies have demonstrated the protective role of tea catechins in promoting cardiovascular health to lower the risk of cardiovascular diseases (Anandh Babu and Liu, 2008; Balentine et al., 1997; Cao et al., 2019; Curin and Andriantsitohaina, 2005; Pang et al., 2015; Stensvold et al., 1992; Wang et al., 2010). The outcome of some research also emphasized that the association of green tea consumption and cardiovascular diseases was more significant in men compared to women (Liu et al., 2016; Sasazuki et al., 2000).

Another study from China found that increasing the daily consumption of green tea to three cups can reduce the chances of fatality caused by cardiovascular diseases (Zhang et al., 2015). Multiple underlying mechanisms involving catechins were responsible for the prevention of cardiovascular diseases such as antioxidative, anti-proliferative, anti-thrombogenic, anti-hypertensive, anti-inflammatory activities and the like (Balentine et al., 1997). Anandh Babu and Liu (2008) concluded that tea catechins can exhibit the ability to scavenge free radicals, enhance blood lipid profile, activate endothelial nitric oxide, inhibit vascular inflammation, prevent atherogenesis and thrombogenesis. Being an antioxidant, catechins can decrease oxidative stress through scavenging reactive oxygen species which can prevent the formation of atherosclerotic plaque in cardiovascular disease (Curin and Andriantsitohaina, 2005; Santesso and Manheimer, 2014).

On the other hand, drinking green tea can also lower the concentration of serum lipids by reducing triglycerides and cholesterol levels in the human body (Pang et al., 2015). It has been proven that catechins exhibit the ability to inhibit the biosynthesis of cholesterol by blocking the key enzyme called squalene epoxidase (Kar and Saloni, 2016). Reducing the level of low-density lipoprotein (LDL) while increasing the level of high-density lipoprotein (HDL) is an effective way to prevent cardiovascular disease. Flavonoids in tea can also inhibit oxidation of LDL (Zhang et al., 2015). Another important polyphenol found in green tea is theaflavin where it can effectively reduce LDL and also inhibit the enzymatic activity during biosynthesis of cholesterol (Kar and Saloni, 2016). In addition, catechins also demonstrated cardiovascular protective effects by interfering with inflammatory processes which prevent thrombosis (Arts et al., 2001).

2.1.5b Obesity

In the past few decades, the rate of obesity has grown at an alarming pace especially in all the industrialized countries. This health problem could further escalate the risk of other non-communicable diseases like cardiovascular disease, type 2 diabetes, and the like. These reasons behind these health complications accompanied by obesity might be because of imbalance in expression of fat-related hormones (Bagheri et al., 2020).

Touted as a natural option to help in shedding pounds, a large number of studies were and are currently being carried out to study the effect of drinking green tea in lipid metabolism (Bagheri et al., 2020; Huang et al., 2014). Yang et al. (2001) concluded that green tea was the most effective type of tea in enhancing lipid metabolism and reducing fat absorption. The mechanism involving catechin EGCG in green tea was deemed to exhibit anti-obesity effects. Hase et al. (2001) was the first to associate the effect of tea catechins on fat metabolism. Another study done by Murase et al. (2002) also elucidated that tea catechins can reduce weight gain and fat accumulation by stimulating fat oxidation. Given that tea catechins can promote metabolism, absorption of tea catechins can inhibit fat and sugar absorption, contributing to decreased level of energy intake.

In the light of metabolism-promoting catechins, EGCG was the catechins that linked to anti-obesity effects due to its ability to inhibit acetyl-CoA carboxylase which is the key enzyme that catalyze the carboxylation of acetyl-CoA in the biosynthesis of fatty acid (Watanabe et al., 1998). Zheng et al. (2004) also found that the combination of caffeine and catechins can most effectively suppress fat accumulation compared to other chemical components of green tea. The results from this study indicated that catechins reacted synergistically with caffeine in elevating metabolic rate and boosting fat oxidation.

The proposed possible mechanism of green tea consumption in obesity prevention includes declination of food intake, decrease of blood glucose level and increased metabolism, which align with other previous findings (Siddiqui et al., 2004).

In summary, these studies provided a large body of evidence to show the effectiveness of green tea consumption in reducing the chances of weight gain and obesity. However, research on a larger scale, with a longer duration of observation and stricter controls are needed to have a clear-cut answer on the optimal amount of green tea consumption in order to treat obesity effectively (Huang et al., 2014).

2.1.5c Longevity

As a health-promoting addition in daily diet, green tea is rich in antioxidants where consumption of antioxidants are often linked with low mortality rates and longevity (Cutler, 1985). Green tea catechins are one of the most powerful and strong antioxidants which could have high potential in increasing lifespan. If the chemical components in green tea do exhibit ability in disease prevention, it is expected that green tea consumption could be effective in lowering mortality rates.

A study in Japan elucidated that green tea consumption can exhibit life-prolonging effect and suggested that it can be consumed as a multiple targeting preventive. The observed increase in mean age at all death was 4.4 years with high consumption of green tea which is more than 10 cups a day (Nakachi et al., 2000). The effect of green tea consumption in lowering mortality rate can also be explained with the decrease relative risk of death caused by cardiovascular disease and stroke (Kokubo et al., 2013; Tanabe et al., 2008). Drinking 10 cups of green tea daily has been proven to be beneficial in the prevention of pre-mature death and adding lifespan of those aged above 80 years old (Kei Nakachi et al., 2003). Furthermore, drinking more green tea can significantly delay the onset of cancer death or all-causes of death. In the light of these studies, green tea had exhibited great potential in delaying aging process and prevention of pre-mature death.

Nonetheless, Kuriyama et al. (2006) reported the observed negative correlation of green tea consumption with all-causes and cardiovascular disease mortality. It was also highlighted that there was no significant influence of green tea consumption on cancer mortality, showing that green tea might be less effective in cancer prevention since the protective role of green tea in cancer prevention has been unclear and inconsistent (Arts et al., 2001; Imai et al., 1997; Najaf Najafi et al., 2018; Shirakami and Shimizu, 2018; Yuan et al., 2011).

2.1.5d Cancer

Various scientific and clinical research has been conducted to investigate the association between green tea consumption and chemo-preventive or synergistic effects along with chemotherapy (Fujiki et al., 2018). America Institute for Cancer Research included the discussion of the evidence on green tea for cancers but the findings was insufficient to deduce a conclusion (World Cancer Research Fund/ American Institute for Cancer Research, 2018). Green tea, when consumed as part of a balanced diet, may enhance the organism redox status, protect the cells from oxidative damage and reduce the risk of oxidative stress-related diseases. Polyphenols found in tea are commonly regarded as powerful antioxidants which can act on excess ROS production or chelating transition metals as well as upregulate the activity of antioxidant enzymes (Huang et al., 2017; Mao et al., 2017).

Anti-angiogenic and anti-proliferative properties of green tea catechins like EGCG show the potential of green tea in preventing cancer by preventing the formation of free radicals which is the main reason of cell death (Eisenstein, 2019; Filippini et al., 2020; Mao et al., 2017). The mechanism of potent EGCG chemoprevention effect on cultured cancer cells reported are neutralizing ROS which can cause damage to DNA, binding to protein to stop cell proliferation that trigger cell death and starving cancer cells to inhibit tumour growth (Eisenstein, 2019). In several studies, the effect of long-term exposure to polyphenols was proven to be effective in minimizing chronic inflammation which can be caused by persistent oxidative stress (Ma et al., 2019; Mao et al., 2017).

However, the overall finding from the various studies indicated that drinking green tea to mitigate the likelihood of cancer was inconsistent and inconclusive (Eisenstein, 2019; Johnson et al., 2012). A review by Abe and Inoue (2020) concluded that green tea can be effective in lowering the risk of some site-specific cancers including endometrial, lung, non-Hodgkins lymphoma, oral, and ovarian cancer to a certain extent, ranging from 19% to 42% decreased risk. On the contrary, for breast, oesophageal, gastric, and liver cancer, contradictory results were observed, showing the modest benefits of green tea in chemoprevention of these cancers, based on the conclusion of the review.

A systematic review studied on the breast cancer and green tea intake concluded that the results are not always perfectly consistent, which is in line with previous studies. However, the chemo-preventive qualities of green tea especially on breast cancers cannot be excluded because there were major protective effect observed (Gianfredi et al., 2018). Oze et al., (2014) explained the inconsistency of findings regarding the link between green tea consumption and oesophageal cancer might be due to thermal injury as most of the green tea are consumed at high temperature, which might cause oesophageal cancer. Gastric cancer also demonstrated similar findings where drinking too-high-temperature green tea might be increasing the chances of gastric cancer. However, it was undeniable that long term and high-dose intake of green tea infusion can be leading to lowered risk of gastric cancer (Huang et al., 2017). A recent literature review studied by Filippini et al. (2020) reviewed and summarized several findings, concluded that the association between lowered risk of liver cancer with higher green tea consumption was imprecise.

In short, even though the scientific evidence was not sufficient to prove the efficiency of green tea consumption in chemoprevention, it does still offer a spark of hope in the pharmaceutical and health industry.

2.2 Brewing water

Water is an essential part of the human diet since it involves in a variety of tasks that are crucial for proper functioning of human body (Wyrostek and Kowalski, 2021). Human body is made up of 80% of water which means the quality of drinking water is important for body health. It is also used to prepare a variety of dishes, including beverages, among which infusions of herbs, coffee, liqueurs, and tea play a prominent role. In general, water that fits for human consumption and preferred to be used in drinking or cooking is soft water which has lower amount of Mg^{2+} ion and Ca^{2+} ion (Kuroda and Hara, 2004). It should also be free from any off-odour and good for drinking.

Brewing water is one of the significant determinants affecting the final quality of tea brew (Danrong et al., 2009; Li et al., 2015; Mossion et al., 2008; Yau and Huang, 2000; Zhang et al., 2017). Several studies has been conducted to focus on the influence of brewing water on the quality of the tea infusion for the past twenty years (Danrong et al., 2009; Franks et al., 2019; Murugesh et al., 2017; Wyrostek and Kowalski, 2021; Yin et al., 2014; Zhang et al., 2017). The quality of a brewing water is depending on a few attributes including water hardness, ion content and pH (Zhang et al., 2017).