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The effect of processing and preparation on the caffeine content in coffee and tea

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled the effect of processing and preparation on the caffeine content in coffee and tea independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague

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Erika Tadevosjanová

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Abstract

Caffeine is a chemical compound obtained through extraction processes of plants or synthesis of urea and uric acid. Caffeine is one of the most consumed drugs in the world, with its presence in plants such as *Coffea arabica* and *Coffea canephora, Camellia sinensis, Paullinia cupana, Ilex paraguariensis, Theobroma cacao, and Cola acuminata*. Caffeine's most significant role is as an adenosine receptor antagonist, as well as a cardiac stimulant and mild diuretic. It can be used as an ingredient in analgesics, diet aids, cold and flu medicines, and in the food industry in soft and energy drinks. Caffeine consumption may come with various side effects or possible health complications depending on each individual. These complications include heart attack, cancer, birth defects, high blood pressure, irregular heart rhythms, anxiety, etc.

The aim of this literature review was to determine the effect of the processing and preparation of coffee and tea on caffeine content. Factors such as processing method, growing conditions, or type of the plant may influence caffeine content in the plant. Some factors (coarsely roasted coffee beans, high temperature of water, long time of extraction, and higher coffee to water ratio) showed increased caffeine content, while other processing factors (prolonged extraction time, higher temperature and degree of the roasting, fermentation) showed decreased caffeine content in Arabica and Robusta coffee. Tea processing methods showed different effects in each type of tea, some factors showed increased caffeine content in all of the investigated types of tea (infusion time), some showed decreased caffeine content or no effect (drying). This literature review provides insight into how processing and preparation methods can affect caffeine content in coffee and tea and contributes to the field of food science.

Key words: Methylxanthine, human health, harvesting, brewing techniques, roasting, rolling, withering

Abstrakt

Kofein je chemická sloučenina, kterou lze získat extrakčními procesy rostlin nebo syntézou močoviny a močové kyseliny. Kofein je jednou z nejužívanějších drog na světě. Je přítomen v rostlinách jako jsou *Coffea arabica* a *Coffea canephora, Camellia sinensis, Paullinia cupana, Ilex paraguariensis, Theobroma cacao a Cola acuminata.* Nejvýznamnější rolí kofeinu je antagonista adenosinových receptorů, dále srdeční stimulant nebo také jako mírný diuretikum. Může být použit jako složka v analgetikách, pomocníků při hubnutí, lécích proti chřipce a nachlazení a v potravinářském průmyslu v nealkoholických a energetických nápojích. Konzumace kofeinu může být spojena s různými vedlejšími účinky či zdravotními komplikacemi v závislosti na každém jednotlivci. Mezi tyto zdravotní komplikace může patřit infarkt, rakovina, vrozené vady, vysoký krevní tlak, nepravidelný srdeční rytmus, úzkost a mnoho dalších.

Cílem této literární rešerše bylo zjistit vliv zpracování a přípravy kávy a čaje na obsah kofeinu. Obsah kofeinu v rostlině mohou ovlivňovat faktory, jako například způsob zpracování, podmínky pěstování nebo druh rostliny. Některé faktory (hrubě pražená kávová zrna, vysoká teplota vody, dlouhá doba extrakce a vyšší poměr kávy k vodě) prokázaly zvýšený obsah kofeinu, zatímco jiné faktory (prodloužená doba extrakce, vyšší teplota a stupeň pražení, fermentace) prokázaly snížený obsah kofeinu u kávy Arabica a Robusta. Metody zpracování čaje prokázaly různé účinky u každého typu čaje, některé faktory prokázaly zvýšený obsah kofeinu ve všech typech čajů (doba louhování), některé zase prokázaly snížený obsah kofeinu nebo žádný účinek (sušení). Tato literární rešerše poskytuje náhled na to, jak mohou procesy zpracování a přípravy ovlivnit obsah kofeinu v kávě a čaje a přispívá do oblasti potravinářských věd.

Klíčová slova: Methylxanthin, lidské zdraví, sklizeň, techniky přípravy, pražení, válení, vysoušení

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C.	*Coffea*
Cam.	*Camellia*
CVD	Cardiovascular disease
EEG	Electroencephalographic

1 Introduction

Caffeine was discovered in plants of tea and coffee in the beginning of the 19th century. The first caffeine extraction from coffee was conducted in 1820; however, coffee has already been acknowledged as a human beverage around the year 850 AD in Abyssinia because of the energizing effect of wild coffee berries on goats. Caffeine in tea was discovered in 1827, and a couple of years later also in mate and cola seeds.

Caffeine is an alkaloid with a purine structure. In its pure form, caffeine represents an odourless, bitter, and white powder. After caffeine consumption, it enters the gastrointestinal tract, then the bloodstream, and is consequently distributed throughout the entire body, including the blood-brain barrier, placenta, fetus, and amniotic fluids. Caffeine can be found in breast milk or semen. A few hours after consumption, caffeine is eliminated from the body through urine. With an annual consumption of 120 000 tonnes, caffeine is perceived as one of the most used drugs around the world. Caffeine is used in soft and energy drinks, as well as in various foods and in pharmacology. Its most important role is as an antagonist of adenosine receptors. Caffeine binds to these receptors and reduces feelings of sleepiness.

Caffeine can be found in fruits, leaves, or seeds in tea (*Camellia sinensis*), coffee (*Coffea arabica, Coffea canephora*), cola (*Cola acuminata*), cocoa (*Theobroma cacao*), guarana (*Paullinia cupana*), and mate (*Ilex paraguariensis*). The caffeine content in these sources significantly differs depending on various factors, such as type and part of the plant, processing and preparation methods, or growing conditions. Generally, tea leaves contain about 0.5-3.5%, and coffee beans contain about 1-5% of caffeine. However, the caffeine content in brewed coffee and tea can vary according to the raw materials quality or the method of preparation.

2 Aims of the Thesis

The goal of this thesis is to determine the effect of processing and preparation steps on the caffeine content in coffee and tea. Aside from processing and preparation methods, information about other factors influencing caffeine content is included. The aim of this thesis is to summarize information on plants sources of caffeine, used as foods and beverages, with the main emphasis on coffee and tea, and their health impact on individual groups. The aim is to produce a summary of scientific text suitable for future studies focusing on the comparison of caffeine concentration levels during various processing and preparation methods.

3 Methodology

Information for this thesis was searched on scientific databases, such as Google Scholar (hhttps://scholar.google.com/) and Web of Science (https://webofscience.com/). Used texts include many books, scientific research papers, websites, and even bachelor's thesis or doctoral dissertations concerning caffeine content in coffee, and tea. All sources are listed in 'References'. Selected key words include caffeine, caffeine content, *Coffea arabica*, *Coffea canephora*, *Camellia sinensis, Paullinia cupana, Ilex paraguariensis, Theobroma cacao, Cola nitida,* coffee processing, tea processing, harvesting, brewing, roasting, rolling, withering, health consequences of caffeine.

4 Literature Review

4.1 Caffeine

Caffeine, or 1,3,7- trimethylxanthine, is a purine alkaloid (Mazzafera et al. 1991) extracted from plants (Lin et al. 2023). Caffeine is well-known for its presence in the fruits, leaves, and seeds of various plants, such as tea, coffee, cocoa, cola, and guarana (EC 1983). Pure form of caffeine is an odourless, bitter, white powder soluble in water and organic solvents. The melting point is up to 236°C, and the sublimation temperature at atmospheric pressure reaches 178 °C (Chou & Benowitzt 1994). Caffeine is reportedly one of the most widely used drugs globally (Mccusker et al. 2003), and its consumption is around 120 000 tonnes annually. Caffeine's role is as a cardiac stimulant, mild diuretic, and additive in popular carbonated beverages. It also fulfils its role in pharmacology, as an ingredient in analgesics, diet aids, and cold or flu medicines (EC 1983).

Ninety-nine percent of caffeine consumed through beverages is absorbed by gastrointestinal tract; however, food can slow down the absorption owing to gastric emptying delay. Caffeine does not store in any organs and can be found in breast milk. Additionally, it is able to cross the placenta and blood-brain barrier. Caffeine's most significant role is presumably adenosine's antagonist, which is substance that promotes sleep. However, caffeine attaches to adenosine receptors and lowers sleepiness (Chou & Benowitzt 1994; Reichert et al. 2022). Throughout the whole human body, specifically in the brain, heart, blood vessels, kidneys, gastrointestinal tract, etc., an adenosine hormone (purine-based) is present. Adenosine engages with two receptors, which are high-affinity A1 and low-affinity A2 and is known for its local release (Chou & Benowitzt 1994).

Caffeine can be acquired through solid phase or liquid-liquid phase extraction via isolation and purification processes from tea, coffee, cocoa, cola, and guarana plants (Mumin et al. 2006). Caffeine can also be acquired from urea or uric acid synthesis (Zubair et al. 1986; Budavari 1996). The price of the caffeine extraction process from tea and coffee is significantly costly compared to the chemical synthesis. However, chemical synthesis is not allowed to be used in beverages and food due to the presence of unfavourable chemical components. Pure caffeine can be found in food and beverages, and it forms through the coffee and tea decaffeinating process (Yang & Wang 1999). The molecular structure of caffeine and adenosine is depicted in Figure 1.

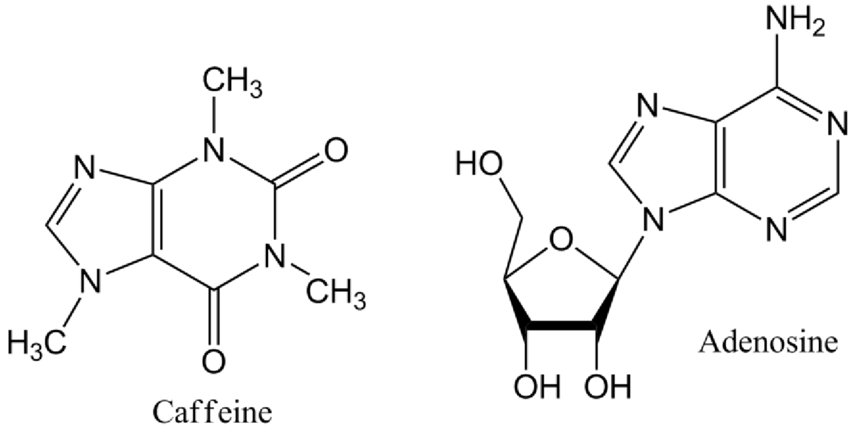

Figure 1. Molecular structure of caffeine and adenosine

Source: Wikimedia (2011)

During the beginning of 19th century, caffeine was discovered in tea (*Camellia sinensis*) and coffee (*Coffea arabica*) plants (Ashihara & Crozier 2001). German researchers Runge and Von Giese performed the first extraction from coffee seeds in 1820 (Runge 1820; Von Giese 1820). In 1827, caffeine was also found in the tea leaves, under the name "thein" (Oudry 1827). Caffeine in mate was discovered in 1843 and in cola seeds in 1865 (Stenhouse 1843; Daniell 1865). In the beginning of the 20th century, carbonated soft drinks emerged and used cola seed (*Cola acuminata*) as a flavouring and caffeine source. Energy drinks, which have become popular, use natural caffeine sources like guarana (*Paullinia cupana*), green tea (*Cam. sinensis*) and yerba mate (*Ilex paraguariensis)* (Frary et al. 2005).

Coffee is recognized as one of the most important cash crops exported by developing countries. Coffee beans are obtained from the cotyledons of seeds of the genus *Coffea*. The seeds of *C. arabica* (Arabica coffee) make up 70% of the global market, whereas *C. canephora* (Robusta coffee), which has a more bitter taste than Arabica, is primarily used for preparation in instant coffees or espresso to create the "the crema" (Crozier et al. 2012). The crema, a thick, brown layer of frothy bubbles covering espresso beverage, is a factor, that differentiates brewed and espresso coffee (Illy & Viani 2005).

Coffee was for the first time acknowledged as a human beverage around the year 850 AD because of the stimulating effect of wild coffee berries on goats in Abyssinia. This discovery resulted in public appeal of many consumers who desired increased alertness and ability to stay awake for a longer time without sleep, due to its caffeine content. Nevertheless, caffeine can also cause displeasing symptoms, and excessive consumption leads to a state of anxiety and excitement. Caffeine dosage affects everyone differently. A single cup can cause some people high discomfort, resulting in insomnia and a racing mind. However, some people who can drink the same coffee amount without any side effects may have developed a tolerance to coffee (Crozier et al. 2012). Considering these side effects and belief that caffeine may a have negative impact on our health, a desire for decaffeinated beverages has risen (Mazzafera et al. 1991).

4.2 Caffeine sources

The key sources of caffeine, prepared as infusions, include coffee (*C. arabica and C. canephora)* and tea (*Cam. sinensis*). ěCoffee is consumed all around the world; however, tea primarily in highly populated countries (China, India, and the United Kingdom). Additional minor sources come from cocoa (*Theobroma cacao*), mate (*Ilex paraguariensis*), cola seeds (*Cola acuminata*), and guarana (*Paullinia cupana*). The amount of consumption may vary depending on the region (Mazzafera et al. 2009). It is also important to consider the fact that caffeine content in these products significantly differs, depending on countless factors such as preparation method, brewing, and processing (Komes et al. 2009).

Some products consumed by the younger generation contain synthetic caffeine (Ahluwalia & Herrick 2015) for the purpose of enhancing arousal, alertness, energy, and mood. Caffeine was present in the past primarily in beverages such as soda and energy drinks. However, over time it has been added to various kinds of foods and also non-food products like chewing gum, juice, cookies, hot sauce, eye cream, lip balm, etc., to enhance these kinds of effects (Nehlig 1999).

4.2.1 Coffea

Coffee beans are the seeds of evergreen plant and remain green throughout the year. This plant, of tropical origin, is part of the *Rubiaceae* family and belongs to the genus *Coffea* L. (Davis et al. 2011). After six new coffee species have been recently discovered in Madagascar, the total number of *Coffea* genus species is considered to be 130 (Davis & Rakotonasolo 2021).

The *Rubiaceae* botanical family includes various coffee species, such as *C. arabica, C. canephora, C. excelsa C. liberica, and C. stenophylla.* Out of all the plants containing caffeine, only *C. arabica* and *C. canephora* gained worldwide recognition (Blank et al. 1991; Mazzafera et al. 2009; Park 2015). Arabica coffee is a more preferred choice due to its distinctly alluring aroma. On the other hand, the aroma of Robusta beans is less captivating and often find application in the production of instant coffee blends or as a filler in roast and ground blends. According to studies, Arabica has a sweeter caramel roast aroma, whereas Robusta has more earthy, spicy roast aroma. These two coffee species differ in chemical composition. Arabica coffee beans contain more lipids, but on the other hand, Robusta coffee beans contain more caffeine and chlorogenic acids (Blank et al. 1991; Park 2015). This variation in chemical composition results in notably diverse flavour post-roasting. The blend's ratio of these two varieties determines the coffee's quality (Alves & Silva 2011). Quality is also based on various criteria like bean size, colour, shape, processing method, harvest, flavour, defect presence, and chemical composition (Pacetti et al. 2015).

The coffee drupe, called as coffee fruit, cherry, or berry, starts as a green, unripe fruit, that modifies colour to red-violet, dark red, yellow, or orange when it ripens (Esquivel & Jiménez 2012). The fruit is composed of an exocarp, mesocarp, endocarp, silver skin, and endosperm (bean). The outer layer, or exocarp of the fruit can be also referred to as the peel. The mucilage, or mesocarp forms the flesh of the coffee fruit and is tough in its unripe form. The next part is in the most inner part of the fruit, the hull endocarp, which envelopes the coffee bean. The spermoderm, or the silver skin, is the skin of the seed. The endosperm covers the embryo and contains oils and proteins, enriching embryo with starch supplies (Bastian et al. 2021).

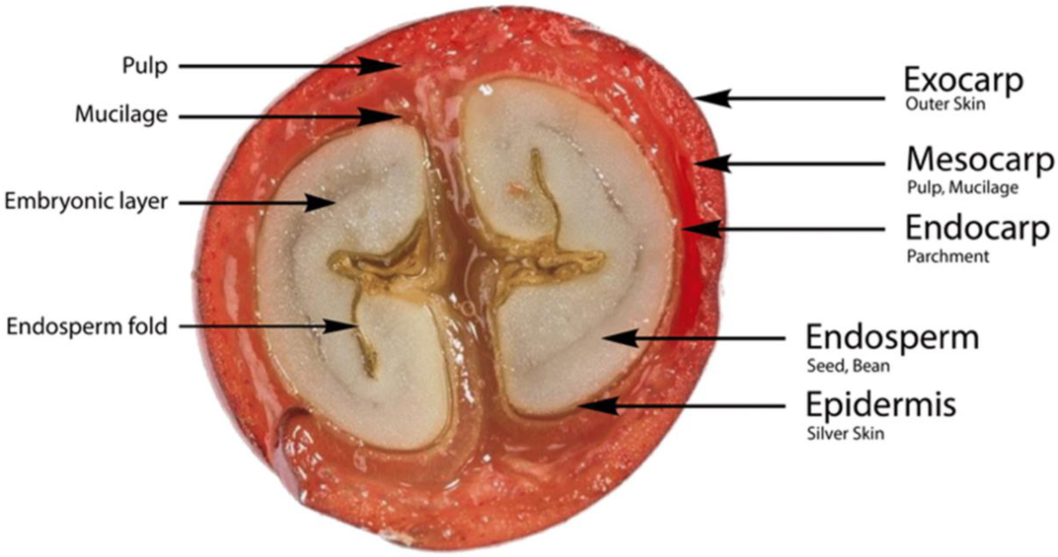

Figure 2. Coffee fruit anatomy

Source: (Bastian et al. 2021)

Arabica coffee, known as *Coffea arabica* L.*,* is a type of coffee distinctive for its small seeds (Yu et al. 2023) and holds globally a significant position as highly precious and exportable commodity. It serves as an important source of employment and income in tropical countries (Hu et al. 2022). Arabica coffee reaches a price twice or more that of Robusta coffee because of its supreme quality. Nevertheless, production comes with significantly higher costs due to the requitements like soil quality, climate conditions, crop management, primary processing, and the control of various pests and diseases. These include devastating coffee leaf rust and berry diseases (van der Vossen et al. 2015). The historical background of *C. arabica* is associated with cultivated specimens expanding in Yemen for nearly seven centuries. Afterwards, the expansion of these plants started from Yemen to Java and the Holland at the end of 17^{th} century and subsequently to the New World in the beginning of the 18^{th} century (Meyer 1965).

Figure 3. *Coffea arabica*

Source: Ing. Olga Leuner, Ph. D. (2023)

Coffea canephora Pierre ex A. Froehner (syn. *Coffea robusta*), or Robusta coffee, can be found in tropical countries such as Indonesia, Vietnam, and from Sub-Saharan Africa to Brazil. It originated in central and western sub-Saharan Africa. Robusta and Arabica coffee may vary in a few aspects, including their origin, geographical distribution, genome conformation, ploidy level, genetic variability, morphology, physiology, phenology, chemistry, organoleptic quality, industrial uses, market segments, and price (Montagnon et al. 1998).

Table 1 displays characteristics that even though *C. arabica* and *C. canephora* share general similarities, there are significant differences.

Table 1. Main differences between *Coffea arabica* and *Coffea canephora*

Source: (Campuzano-Duque et al. 2021)

	***C. arabica,* Arabica**	***C. canephora,* Robusta**
Origin	Ethiopia, Sudan, Kenya	Guinea and Congo
Altitude of origin in meters above sea level (masl)	1300–2000	0–1000
Genetic variability	Low, due to its origin from few plants and its self-pollinating condition.	High, due to outcrossing (natural interbreeding between and within populations).
Genetic structure	Segmental allotetraploid (cross *C. eugenioides* *C. canephora*). Amphidiploid	True Diploid with polymorphic populations and highly heterozygous heterotic groups
Number of chromosomes	2n = 4x = 44	2n = 2x = 22
Fertilization and compatibility	Self-pollinated (more than 90% autogamous) and self-compatible	Self-incompatible gametophytic type of monogenic nature and synchronized flowering
Plant type	Shrub	Tree and/or shrub
Growth habit	Erect	Umbrella shape
Propagation type	Sexual (seed)	Asexual (cuttings-clonal) and sexual (seed)
Canopy structure	Pyramidal	Irregular
Root type	Deep-rooted	Shallow-rooted
Symbiotic associations	Dependent to obligate	Dependent, mycorrhizae obligate
Stem type	Uni-caulate (woody)	Multi-caulate (woody)
Grain-colour (before roasting)	Greenish tone	Pale and yellowish tone
Grain-shape (dry)	Larger, oval, flat and elongated	Small, rounded, oval or elliptical; notable tips; domed or convex
Retention of grain by the plant	Lower	Higher
Inflorescences (number)	Lower (2–3 peaks/crotch)	Higher (3–5 peaks/crotch)
Flowering (regularity)	Regular (after rains)	Irregular
Flowering (months)	9	10-11

Table 1. continued

	C. arabica, **Arabica**	*C. canephora,* **Robusta**
Photoperiod sensitivity (hours)	Short days (13.5)	Shorter days (11.0)
Grain earliness (months from anthesis to fully ripe)	6–8 (earlier)	9–11 (later)
Time to induce the inactive flowering-period (months)	2–4	2–4
Biannual production	Present	Absent
Latitude range (degrees)	Less than 10 N and 10 S	Between 10 N and 10 S
Optimal temperature (°C)	18–21	22–30
Saccharose (%)	8.0	4.0 (less than 50%)
Chlorogenic acid (%)	Green grain (6.4–7.1);semi-ripe grain (4.7–7.9); ripe grain (5.5–6.9)	Semi-ripe grain (7.8–8.0); ripe grain (8.2–10.6)
Trigonellin (dry matter basis)	0.79–1.06	0.66–0.68
Market segment	Premium and mainstream	Instant, blended coffees, washed
Optimum precipitation (mm)	1500–2000	2000–3000
Relative humidity required (%)	70%	85%
Altitude for cultivation in meters above sea level (masl)	1000–2000	0–700
Genetic improvement scheme	Hybridization, inbreed, backcross (*per* autogamy)	Reciprocal recurrent selection (*per* allogamy)
Yield (kg/ha) of green coffee	Usually lower performing (1500–3000)	Higher performing (2300–4000) with intense production 6000
Cherry (fresh): green coffee	Lower (4:1 to 5:1)	Higher (5:1 or above)
Rust resistance	Susceptible	Wide resistance spectrum (source of resistance in Timor hybrid
Nematode resistance	Susceptible	Source of genetic resistance
Planting density	High	Low
Cup quality	Subtle taste, aromatic	Stronger taste, fragrant
Caffeine content average (%)	1.7	3.4 (2× more content)
Isoflavones (micrograms)	40	285 (7× more concentrated)
Total reducing sugars (%)	0.10	0.40 (4× higher)
Production cost	Higher	Lower
Price	High	Low

When observing the statistics depicted in Table 1, it is evident that Arabica is dominating with 6.1 million tons (about 5.54 million tonnes), which is 64% of global production in year 2020/2021. On the other hand, Robusta only produced 4.4 million tons (about 3.99 million tonnes), accounting for a 36% share (Campuzano-Duque et al. 2021).

Despite the fact that *Coffea* plants are originated in Africa, Arabica and Robusta coffee farms can be found in numerous tropical nations around the globe (Sean 1997). A significant number of consumers can be found in high income nations, whereas production takes place in low income or lower middle income nations, playing a crucial role in their economics. Coffee holds a prominent position as the world's most beloved beverage and is second after the crude oil in global trade. Coffee reaches an annual consumption of approximately 500 billion cups, and the coffee industry is regarded to hold an estimated worth exceeding 100 billion dollars on a global scale (Sujaritpong et al. 2021).

Coffee is globally traded in the form of green coffee, which consists of coffee beans with or without silver skin. The production of green coffee is done through either dry or wet processing. During the wet processing, harvested coffee fruits are exposed to sunlight for drying, and then mechanical hulling occurs. Dried husks, like pulp, skin, mucilage, and parchment, are thoroughly removed with the effort of eliminating as much silver skin as possible. On the other hand, during the wet processing through the technique involving water, the separation of damaged and unripe coffee berries from their ripe counterparts occurs. This method results in the damaged and unripe berries floating, while the ripe ones sink (Belitz et al. 2008). Nevertheless, both of these methods try to eliminate the fruit skin from the coffee fruit and decrease the water content in raw coffee beans to approximately 10-12%. Green coffee produced by either of these methods results in distinctive variations in the aroma and taste of coffee beans. The flavour distinctions are because of the post-harvest treatment methods in each process (Bytof et al. 2005). There is an assumption that coffee produced by wet processing tends to have a richer aroma, and as a result, receives higher acceptance (Bytof et al. 2005; Knopp et al. 2006).

Figure 4. Green coffee beans

Source: Wikimedia (2011)

It is important to mention decaffeinated coffee, or decaf, which constitutes roughly 10% of the worldwide coffee market. Additionally, the term **"**decaffito**"** describes coffee derived from Arabica plants with coffee beans that have minimal or no caffeine content. Numerous coffee species exist on our planet, and almost 100 of them are caffeine-free. Nevertheless, humans have refrained from exploring these varieties due to their unpleasant bitter taste, caused by furokaurane diterpene glycosides (Mazzafera et al. 2009). During the decaffeination process, coffee beans stand out as a by-product. The process relies on three methods, which use water, organic solvents, and superficial fluids. Water is not the best choice during the process because of the risk of washing vital compounds away. On the other hand, method called "Swiss Water Process" plays an important role in preserving crucial elements for the sake of the final product's quality. In order to eliminate the caffeine from the aqueous extract, it flows through a charcoal bed to either a coffee extract from the first decaffeination batch or sucrose. Methylene chloride also serves for the caffeine extraction from coffee, and it removes substances that are essential for a high-quality coffee beverage too. The removal of vital compounds can be prevented by exposing coffee beans to CO_2 in liquid form and increased temperature (Mazzafera 2012).

4.2.2 Camellia sinensis

Camellia sinensis (L.) Kuntze belongs to the *Theaceae* family and *Camellia* genus. *Camellia* genus includes around 250 species. Aside from *Cam. sinensis,* other species include *Cam. japonica, Cam. reticulata, Cam. sasanqua, Cam. saluensis, C. oleifera, Cam. chekiangolomy, Cam. semiserrata*, and many others (Mondal 2011). Currently, *Cam. sinensis* is cultivated in tropical and subtropical nations, but its origin belongs to China and South and Southeast Asia (Mahmood et al. 2010).

Cam. sinensis is an evergreen plant, a shrub, or a small tree, reaches up to two meters or less when cultivated for its leaves. Tea leaves of various ages possess distinctive qualities owing to their varying chemical composition. For tea production, it is preferable to harvest young, light green leaves. As the leaves age, their colour becomes more of a dark green colour. For processing, the tip and two or three leaves are selected. The manual picking process is repeated every one or two weeks. The picking process is also conducted through machines, which may be more efficient for tea quality and may lessen leaf damage. The plant produces white and yellow-coloured flowers and the seeds of *Cam. sinensis* and *Cam. oleifera* can be used to extract both tea oil (slightly sweet seasoning) and cooking oil, which is often confused with tea tree oil (Mahmood et al. 2010; Tian et al. 2021).

Figure 5. *Camellia sinensis*

Source: Wikimedia (2011)

Tea beverage is created through the process of steeping leaves and buds of *Cam. sinensis* in hot water (Li et al. 2019). Tea can be categorized into three types based on the fermentation level during processing. These types include unfermented green tea, half-fermented oolong tea, and fermented teas like black and red tea. Fermented teas go through a fermentation stage before drying and steaming after harvesting. Black tea fermentation is initiated by a process of oxidation, which is catalysed by polyphenol oxidase enzyme. On the contrary, red, or Pu-Erh tea fermentation occurs due to microorganisms (Cabrera et al. 2006).

Tea is ranked as the second most consumed beverage following water and moreover offers variety of health advantages due to the high content of flavonoids in tea. Green and black tea consumption is linked to lower cardiovascular disease (CVD) risks, specific cancer types, better oral health, weight management, improved bone density, and increased antibacterial and antiviral activity. Additionally, flavonoids in tea may also have an impact on high blood pressure levels regulation (Li et al. 2019). There has been widespread tea consumption over the history of China, as well as in East Asian and Western regions. Variations in the human population exist due to the factors like habits, culture, genetic background, body composition, dietary preferences, and quantity and variety of tea consumption. Consequently, the impact of tea consumption across the world on diverse populations may vary (Khalesi et al. 2014; Chen et al. 2016).

Even though tea contains multiple secondary metabolites, such as catechins, caffeine, theanine and rutin, the quality of the tea is decided by three secondary metabolites. These three metabolites determining flavours, such as bitterness, astringency, and umami, are catechins, caffeine, and theanine (Sun et al. 2019).

Table 2 shows secondary metabolites found in 309 dried oolong tea leave samples. Catechin derivatives such as EGCG, EGC, EC, ECG, CG, and C were found in the tea samples. The total concentration of catechins was the highest out of all measured secondary metabolites with 119.01 mg/g. At the second place was caffeine with measured 28.58 mg/g.

Table 2. Concentrations of dominant secondary metabolites in the tea leaves

Source: (Sun et al. 2019)

Secondary metabolites	**Mean (mg/g)**	**SD (mg/g)**	**Min (mg/g)**	**Max (mg/g)**	**CV(%)**
Theanine	5.28	3.27	0.42	18.48	61.95
caffeine	28.58	7.5	12.28	53.14	26.24
rutin	6.21	3.58	1.21	27.8	57.63
Total catechins	119.01	36.73	34.4	236.84	30.86
Galloylated catechins	78.75	24.19	26.2	153.08	30.72
EGCG	58.03	18.68	15.16	110.3	32.19
ECG	20.53	7.1	6.06	42.02	34.59
Non-galloylated catechins	40.27	16.53	5.49	83.76	41.05
EGC	28.21	12.27	3.25	59.02	43.5
EC	6.56	2.58	1.22	15.47	39.31
GC	4.17	2.15	0.56	11.4	51.41
C	1.32	0.54	0.37	3.08	40.73

CV– coefficient of variation; SD – standard deviation; EGCG– epigallocatechin gallate; ECG – Epicatechin gallate; EGC – epigallocatechin; EC – epicatechin; GC – gallocatechin; C– catechin

4.2.3 Other natural caffeine sources

Paullinia cupana

Paullinia cupana Kunth, or guarana in Brazil, holds economic significance and belongs to the *Sapindaceae* tropical and subtropical family. Guarana is a shrub-type low plant with small flowers, dark green leaves, and dark green fruit. This plant also produces dark brown seeds, that are similar in appearance to the human eye and are characteristic for guarana recognition. The seeds take the first place as the most abundant botanical source of caffeine in their dried or roasted form. The caffeine content in guarana seeds surpasses that of Arabica coffee seeds by 2-5 times, with the caffeine concentration of 2.5-6% (Majhenič et al. 2007; Schimpl et al. 2013).

Products derived from guarana seeds have found application in soft drinks, concentrated beverages, and in products for the weight-loss purposes (Majhenič et al. 2007). Nevertheless, excessive consumption may harshly impact health of the human by causing anxiety, sleep disturbances and tachycardia; these consequences are attributed mainly to the rich caffeine concentration in the plant (Smith & Atroch 2010; Wikoff et al. 2017).

Figure 6. Guarana fruits

Source: Topvet (2009)

Ilex paraguariensis

Ilex paraguariensis A. St.-Hil. is an evergreen shrub-tree that belongs to the *Aquifoliaceae* family (Loria et al. 2009; Márquez et al. 2013). Among the 300 species of Ilex genus, *Ilex paraguariensis* is the most important one due to the plant's leaves, which are used for yerba mate production. The leaves are uncomplicated, with small flowers and red, black, or yellow-coloured berries (Muccillo et al. 1998).

The tree is indigenous to South America and is distributed across the southern parts of the continent, especially in Brazil, Argentina, Paraguay, and Uruguay (Márquez et al. 2013), as well as in countries such as Korea, Japan, China, and the USA, due to research into its attributes (Bracesco et al. 2011).

The yerba mate powder, derived from the leaves, is rich in caffeine and is also used as an alternative to both tea and coffee. The roasted leaves steeped in hot water are known as mate tea, which is also used as an ingredient in soft drinks (Lima et al. 2014). The powder is recognized for its medicinal attributes, such as antioxidant, anti-inflammatory, antitumor and weight-loss properties (Bracesco et al. 2011).

Figure 7. *Ilex paraguariensis* plant,

Source: Herbalgram (2018)

Theobroma cacao

Theobroma cacao L. is a small evergreen tree that (Richelle et al. 1999; Tomas-Barberán et al. 2007) belongs to the *Sterculiaceae* family. It is originated in the Amazon rainforest. Even though genus *Theobroma* contains twenty-two species, *Theobroma cacao* is the most significant one due to its seeds (Lberté 2012). These seeds, which are referred to as cocoa beans, are harvested from the pods (Schwan & Wheals 2004; Lima et al. 2011).

Due to human activity, cacao has been spread around the globe, initially to Mesoamerica and subsequently to Asia and Africa. Cacao cultivation provides the chocolate industry with cocoa liquor, cocoa butter, and powder to contribute not only to health improvements but also to an exquisite flavour (Kris-Etherton & Keen 2002). Cocoa butter, extracted from cocoa beans, also finds applications in the pharmaceutical and cosmetic sectors. It possesses specific characteristics that are incomparable with other fats (Zyzelewicz et al. 2014). It is important to mention that the cocoa beans fermentation process is necessary for the development of precursors essential for the formation of chocolate flavour. The taste of raw cocoa beans is bitter and unsavoury; that is why fermentation and drying are required to develop the cocoa flavour and aroma (Ho et al. 2014).

Figure 8. *Theobroma cacao* fruit

Source: Wikimedia (2019)

Cola nitida

The *Cola* genus species are tropical tree plants from *Sterculiaceae* family included into *Malvaceae* family. They originated in coastal areas in West Africa. At the present, *Cola nitida* (Vent.) Schott & Endl. is cultivated across a broad geographical range, from Senegal to Nigeria, as well as in the West Indies and South America (Akoegninou et al. 2006; Dah-Nouvlessounon et al. 2015). There are approximately 140 species, with 40 *Cola* species found in West Africa. In Nigeria, the most significant *Cola* species are *Cola nitida* and *Cola acuminata* (Asogwa et al. 2006; Onomo 2006).

The seeds of Cola species, or cola nuts are suitable for consumption but difficult to digest (Olaoye 2022). The cola seeds are well-known for their high caffeine concentration, as well as theobromine, kolanin, L-epicatechin, and d-catechin (Lowor et al. 2010; Erukainure et al. 2017). Each seed contains about 1-1.5% caffeine per weight. The flavour is distinctly bitter, and this bitterness is caused by secondary metabolites and polyphenolics (Lowor et al. 2010). *Cola nitida* seeds are generally chewed or used for their stimulant effects by inhabitants. They also play an important role during social and ceremonial activities in Africa. Even a small amount of cola seed can have a positive impact on cognitive functions, weight loss, reduce the urge for sleep, hunger, and thirst. Cola seeds are also widely used for essential oils, drugs, softs drinks, wines, candies, and for pharmaceutical products (Jayeola 2001; Dah-Nouvlessounon et al. 2015).

Figure 9. *Cola nitida*

Source: Hodge W.H. (2023)

4.3 Health consequences of caffeine consumption

Caffeine has served as a stimulant and dietary supplement, being most popular in the tea and coffee for centuries. However, there has been a significant rise in concerns regarding the health consequences of caffeine beverage consumption. The consequences may include heart attacks, irregular heart rhythms, anxiety, fibrocystic breast conditions, cancer, and birth defects. Caffeine also raises blood pressure, plasma catecholamine levels, plasma renin activity, serum free fatty acid levels, urine production, and gastric acid secretion, also influences mood and sleep (Curatolo & Robertson 1983).

However, coffee contains hundreds of distinct chemical compounds, so to expect caffeine to stand as the only player of pharmacological import would be an oversimplification. Other compounds, such as chlorogenic acid, may even surpass caffeine in terms of quantity (Curatolo & Robertson 1983). These compounds found in coffee also include cafestol or kahweol and bring various positives, such as neuroprotective, antioxidant or, anti-inflammatory benefits (Islam et al. 2018). The compounds react with drugs and have an impact on metabolism, dispersion, and their elimination, which may cause therapeutic efficacy, inefficacy, or even toxic responses (Belayneh & Molla 2020).

Nevertheless, caffeine remains the most meticulously studied component of coffee, responsible for the stimulatory attributes that have driven the beverage to its vital status (Curatolo & Robertson 1983).

4.3.1 Caffeine consumption

The recommended daily amount of caffeine consumption differs according to gender and age. For adults, the suggested amount of caffeine intake is about 400-450 mg per day. For pregnant woman, it is 300 mg per day, and for children at the age of 4-6, it is 45 mg of caffeine per day (Knight et al. 2004).

Despite the caffeine's popularity and its appearance in countless beverages such as coffee, tea, soft drinks and, prescribed medications, cases of acute caffeine toxicity have occurred. Caffeine overdose resulting in fatality is not that common in adults. It requires excessive caffeine intake, which is approximately 5 to 10 grams, whether infused intravenously or orally. This amount is same as 75 cups of coffee, 125 cups of tea, or 200 servings of cola beverages and can lead to restlessness, tachycardia, seizures, unconsciousness, and life-threatening complications due to intense shock. Moreover, complications linked with lungs can occur, such as pulmonary swelling and atelectasis (collapsed lungs), ventricular fibrillation, and heart-lung complications. Even though there have been no fatal cases, doses around 100 mg per kilogram of body weight result in comparable effects in infant and children (Stavric 1988; Kerrigan & Lindsey 2005). Excessive amount may also lead to addiction, nutrient deficiencies, and a negative impact on the body's nutrient absorption (Escott-Stump 2008).

4.3.2 Pharmacokinetics

After being consumed, caffeine travels from gastrointestinal tract into the bloodstream and reaches its peak level in 1 to 1.5 hours. Caffeine is distributed throughout the entire body, including the blood-brain barrier, placenta, amniotic fluid, and the fetus, that is developing, as well as breast milk or seminal fluid (Berger 1988; Arnaud 1999). After being consumed, most of the caffeine is metabolized and only a minor percentage is excreted from the body through urine numerous hours post-consumption. As caffeine does not provide any important nutrients for the body, it is optional in one's dietary intake. Caffeine can additionally arouse the brain and nervous system (Escott-Stump 2008; Petrovic et al. 2016).

4.3.3 Central nervous system

Caffeine impacts the central nervous system, affecting psychomotor skills, EEG patterns (electroencephalographic), sleep, emotional state, behaviour, and cognitive abilities. These outcomes contribute to the caffeine's popularity in Western cultures. Caffeine also enhances alertness and reduces the time it takes for motor reactions when exposed to various stimuli, such as auditory and visual ones (Stavric 1988). However, the belief that caffeine cancels out the sedative effects of alcohol on the central nervous system is incorrect (Fillmore et al. 2002).

The impact of caffeine on both objective and subjective aspects of sleep has been thoroughly researched. Caffeine consumption within 30 to 60 minutes before bedtime may cause a prolonged time it takes to fall asleep, reduce the duration of sleep, and degrade sleep quality (Roehrs & Roth 2008). However, some of these effects vary depending on the dose of caffeine, but the belief "caffeine disrupts sleep" is indeed well-founded. The impact of caffeine to the sleep disturbance also varies among individuals (Karacan et al. 1976).

Caffeine influences emotional state of individuals, who have noticed increased level of attentiveness or feeling of unease. Research has uncovered that individuals who regularly consume coffee experience pleasant stimulation and enhanced alertness, while those, who do not regularly drink coffee describe unpleasant stimulation and nervousness. Similar to how caffeine influences sleep, the impact on mood appears to be influenced by individuals due to the differences in sensitivity to the substance or the development of tolerance over time (Goldstein et al. 1969).

4.3.4 Cardiovascular system

There is evidence that proves a negative relationship between coffee consumption and the risk of CVD. Conversely, countless studies demonstrate that caffeine intake may prevent CVD risks. However, caffeine is not the only factor that plays a role in the development of CVD risks. There are multiple factors such as age, gender, caffeine tolerance, smoking, or alcohol consumption that take part in this matter (Papaioannou et al. 2005).

An appropriate amount of coffee and tea intake showed in a study from 2020 lower risk of coronary artery disease and type 2 diabetes when compared to high and no caffeine intake. The safest amount of caffeine consumption from coffee was found to be 120-180 mg per day for coronary artery disease (Said et al. 2020). Research examining the relationship between coffee consumption and possible CVD outcomes has been conducted in the beginning of the 21st century. These CVD outcomes include stroke, heart failure, and CVD-related mortality in general (Nieber 2017). While the results of the research have not shown a direct connection between coffee consumption and an elevated risk of CVD, a meta-analysis from the year 2014 proved the opposite (Ding et al. 2014). A study conducted in 2003 showed that an intake of more than 5 cups of coffee a day (less than 500 mg of caffeine daily) reduces the risk of CVD (Nawrot et al. 2003). The meta-analysis however showed that consuming a moderate amount, that means 3 to 5 cups of coffee daily, may reduce the possibility of CVD (Malerba et al. 2013). Another study by Liu et al. showed that consumption of 4 cups of coffee per day may result in higher mortality rates, but among individuals under the age of 55 (Liu et al. 2013).

4.3.5 Reproductive system

A significant number of women decrease their caffeine consumption during pregnancy, with some experiencing an aversion to it. However, many women are still dependent of caffeine consumption. Caffeine can be found in numerous foods and medications consumed by 75% of pregnant women and more (Eskenazi 1999). A significant number of conducted research has revealed that caffeine intake at levels around more than 300 mg per day could have harmful effects on specific reproductive and developmental aspects during the certain pregnancy period (Dlugosz & Bracken 1992). However, one study concluded that women who maintain a moderate caffeine intake (approximately less than 5-6 mg per kilogram of body weight per day) and who do not smoke, or drink alcohol are unlikely to experience any reproductive issues (Christian & Brent 2001).

When a pregnant mother consumes caffeine, it is absorbed through the digestive system, then passes over the placental barrier, and is distributed throughout fetal tissues, including the central nervous system. Furthermore, due to the prolonged half-life of caffeine in the fetus and newborn, fetal, infant, and pregnant woman exposure to caffeine is significantly heightened in contrast with non-pregnant adults and older children (James & Paull 1985; James 1991; Dlugosz & Bracken 1992).

4.3.6 Gastrointestinal system

Caffeine consumption in general may cause gastrointestinal disturbances. Caffeine has an ability to enhance gastric acid production, which may lead to worsened gastro-oesophageal reflux and stomach ulcers (Boekema et al. 1999). The gastrointestinal tract has been subjected to thorough examination, with a main focus on whether coffee exhibits stimulatory or inhibitory effects on the mechanism. On one hand, evidence shows that coffee consumption may reduce a risk of specific cancers, including liver, hepatocellular, and breast cancers. On the other hand, coffee seems to heighten the risk of lung cancer, while risks of elevated cancers, such as pancreas, bladder, ovaries, and prostate remain a debatable matter (Ludwig et al. 2014; Wierzejska 2015). Nevertheless, racial, gender, and geographic factors may influence the results of findings, leading to conflicting interpretations (Micek et al. 2019).

4.3.7 The effect on vitamin and minerals absorption

It is important, to monitor our daily caffeine intake because caffeine has the ability to disrupt nutrient assimilation. Caffeine interferes with the absorption of calcium in the digestive system and reduces the amount of calcium stored in bones. It also interferes with vitamin D, which leads to higher possibility of osteoporosis and influences B-vitamin metabolism. Caffeine has a disruptive effect on the ability of body to assimilate iron and decreases the assimilation of manganese, zinc, copper, magnesium, potassium sodium, phosphate. According to some research, it also influences vitamin A absorption (Escott-Stump 2008).

4.4 The effect of processing and preparation on caffeine content

Depending on several factors, such as type of plant, processing methods, and growing conditions, caffeine content in different types of plants may vary. Generally, tea leaves contain around 0.5-3.5% of caffeine, and coffee beans have around 1-5% caffeine content (Takeda 1994; Yamanishi et al. 1995; Spiller 1998). The content of caffeine in brewed coffee and tea can significantly change depending on the quality of the raw material and the preparation method. In an 8-ounce serving of coffee (approximately 237 mL), caffeine levels range from 50 to 300 mg, whereas brewed tea contains less caffeine, between 20 and 60 mg and lower solids content, which is also a contributing factor that causes this difference (Bunker & McWilliams 1979; Bell et al. 1996; Astill et al. 2001; Higdon & Frei 2006). Various neuroprotective and metabolic advantages linked with coffee and tea consumption are related to the caffeine content in these drinks. This relation is due to the various effects of caffeine, including its capability to arouse the central nervous system, boost metabolic activity, and hypertensive responses (Acheson et al. 1980; Curatolo & Robertson 1983; Leonard et al. 1987).

Table 3 and 4 show caffeine content in 100 grams of various tea and coffee beverages. Figure 12 shows that the highest caffeine content in coffee beverages is in instant coffee (powder), which is 3344 mg, and the lowest caffeine content is in decaffeinated instant coffee, which is 1 mg. Tea beverage with the highest caffeine content is in yerba mate, Chimarrão (26 mg), and the lowest in infused mate tea (5 mg), as depicted in Figure 13.

Table 3. Caffeine content in various coffee beverages

Source:(Rocha et al. 2022)

	Caffeine (mg/100 g or mL)	**SD (mg)**	**CV (%)**	**Min (mg/100 g or mL)**	**Max. (mg/per unit)**	**Serving (mg/per unit)**	**Common Household Serving**
Coffees							
Brewed Coffee, Arabica	30	13	41	11	54	45	1 coffee cup (150 mL)
Powder Coffee, Arabica	1165	163	14	1050	1280	117	1 tablespoon (10 g)
Powder Coffee, Blend	1444	283	20	1270	1770	144	1 tablespoon (10 g)
Espresso Coffee	279	144	52	177	380	112	1 espresso cup (40 mL)
Capsule Coffee	64	30	47	30	125	64	1 capsule (6 g)
Instant Coffee (soluble), powder	3344	N. A.	N. A.	N.A.	N.A.	67	1 coffee spoon (2 g)
Instant Coffee (soluble), diluted	36	14	39	20	45	54	1 coffee cup (150 mL)
Decaffeinated Brewed Coffee	2	N. A.	N. A.	N. A.	N. A.	3	1 coffee cup (150 mL)
Decaffeinated Capsule Coffee, Nespresso	3	N. A.	N. A.	N. A.	N. A.	N. A.	1 capsule (6g)
Decaffeinated Instant Coffee	1	1	106	0	2	2	1 coffee cup (150 mL)
Frappuccino Coffee, Starbucks	25	2	9	23	26	88	1 tall cup (350 mL)
Cappuccino Coffee	32	6	18	28	36	48	1 coffee cup (150 mL)
Brewed Coffee, Arabica with milk (80% coffee: 20% milk)	24	N.A.	N.A.	9	43	48	1 cup (200 mL)

Table 4. Caffeine content in various tea beverages

Source: (Rocha et al. 2022)

	Caffeine (mg/100 g or mL)	**SD (mg)**	**CV (%)**	**Min (mg/100 g or mL)**	**Max. (mg/per unit)**	**Serving (mg/per unit)**	**Common Household Serving**
<u>Teas and infusions</u>							
Green tea, infused	20	2	12	17	21	40	1 tea cup (200 mL)
Black Tea, infused (English breakfast; Earl Grey)	18	5	30	12	32	36	1 tea cup (200 mL)
Mate Tea, infused	5	2	47	3	6	10	1 tea cup (200 mL)
Yerba Mate, Chimarrão	26	15	58	14	52	91	1 chimarrão gourd (350 mL)
Yerba Mate, Tereré	24	12	45	17	36	84	1 tereré gourd (350 mL)
Rooibos Tea (red), infused	16	N. A.	N. A.	N. A.	N.A.	32	1 tea cup (200 mL)
Iced Tea	6	1	18	4	7	18	1 bottle (300 mL)

N.A. – not available; CV – coefficient of variation; SD – standard deviation

4.4.1 Coffee processing

In general, coffee processing is a period from the separation of coffee bean from the coffee fruit to the stage before roasting (Bytof et al. 2000). Coffee processing involves harvesting, processing, and post-harvesting, which includes pulping, hulling, cleaning, sorting, grading, storage, and many others, that affect coffee quality (Hicks 2002; Haile & Hee Kang 2020).

Coffee fruits harvesting

During harvesting of coffee fruits, it is essential to divide fruits at various maturing stages to make sure that overripe or underripe fruits would not spoil the taste of the product (Poltronieri & Rossi 2016). Selective coffee harvesting provides better maturity uniformity in batches and favours the post-harvest procedures, leading to the best final quality of coffee (Paulo et al. 2016).

One of the major difficulties faced by growers is knowing when to start the crop because of the plant shape, non-uniform maturity, and high moisture content of the fruits during mechanical operation upon collecting by vibration (Júnior et al. 2018).

Mechanical harvesters have been constructed to collect mature fruits, that are not tightly attached to the plant. This coffee fruits picking is accomplished by setting conditions involving vibration and speed. Colour classifiers have been developed to distinguish unripe green fruits from the ripe yellow and red ones. Also, machines that help with high-quality harvest by screening red ripe fruits by colour. In cases where wet processing is included, water is used to separate fruits by its concentration, and pulping machines are used to pulp the ripe fruits. Fruits go through a process of skin, pulp, and mucilage separation after their gathering (Poltronieri & Rossi 2016). It is essential to understand the dynamics and the parts of the plant that are supposed to be harvested in order to create effective harvesters (Júnior et al. 2018).

Caffeine content in coffee does not seem to be influenced by the use of machinery; however, what significantly influences caffeine content are post-harvest processing techniques, such as dry and wet techniques, roasting, drying, and others (Rodriguez et al. 2020), which are going to be discussed further in the next chapters.

Coffee fruits processing

The center pair of seeds in the coffee fruit must first be removed from the external layers, which involve skins, mucilage, and pulp, before the coffee beans are ready for storage and roasting (Varadharaju et al. 2001). Consequently, the drying process occurs for the preservation purpose (Coradi et al. 2014).

The flavour development is significantly influenced by various fruit outer layer removal techniques. Depending on the mature coffee fruits' processing techniques, coffee bean cultivation around the world is categorized as "dry natural," "pulped natural," "wet hulled," or "fully washed". The techniques depend on the climate in various regions (Hailemichael 2009). Natural coffees typically possess substances that activate flavour and cause reduced acidity and more fruity hints when comparing to washed coffees (Poltronieri & Rossi 2016).

Table 5. Coffee fruit processing methods regarding various climates

Source: (Poltronieri & Rossi 2016)

Dry climate ←			→ **Wet climate**
"natural"	**"honey"**	**"pulped natural"**	**"washed"**
Dried in the fruit, no water is used	Removal of shin and pulp using some water	Removal of skin, pulp and mucilage using some water	High amounts of water are used
Fermentation bright	Minimum fermentation	Not fermented	Controlled fermentation (more acid)

Wet method

There are two methods around the globe for processing coffee beans from coffee fruits. The first one is "wet" method for Arabica coffee bean processing, used in regions like Colombia, Central America, and Hawaii. The specific techniques are various, but the general process involves hand-selecting ripe coffee fruits from the bushes, mechanical depulping, and finally, a brief water wash ranging from 24 to 48 hours. The aim of water wash, or fermentation, is elimination of the mucilage layer. The next step in order is drying, using sun or machine to reach a moisture content of approximately 12%. Microorganisms take part in breaking down the pectinaceous mucilage by releasing pectinases. The most important step in achieving the great coffee quality seems to be thorough, homogenous selection of ripe fruits and efficient processing (Pee & Castelein 1972; Amorim & Amorim 1977; Jones & Jones 1984; Puerta 1996).

These water-based processing techniques include pulped natural, honey, and fully washed techniques, which have gained popularity due to meeting the demands the market has for coffee aroma. It's important to note that the washed techniques do not always lead to enhancement of coffee aroma (Brando 2009; Wintgens 2012; Cafe imports 2016). During the drying process in the pulped natural method, the coffee is left in bags in order to reach 40% of a moisture level, and the proceeding drying can be very delicate. There is a mucilage coat left that dries and envelopes the bean and which impacts the flavour of the coffee. In general, pulped natural coffee is known for its extremely sweet flavour and balanced acidity. This processing technique is widely used in Brazil. During the semi-dry processing of honey coffee, coffee beans are dried in sun or shade, which results in red, yellow, and black honey coffee. These types depend on the thickness of the mucilage, and therefore, on the period of drying. Yellow honey is covered by 25% of mucilage and takes about 8 days do get dry, red honey by 50% of mucilage and takes 12 takes to get dry. Black honey has the longest drying time, with 30 days and 100% of mucilage (Wintgens 2012; Cafe imports 2016).

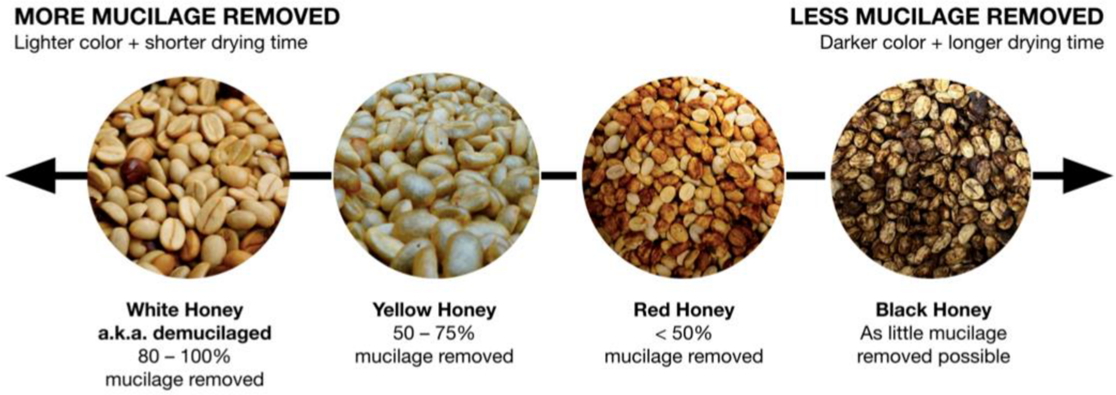

Figure 10. Honey coffee beans

Source: Big island coffee roasters (2023)

Wet-hulled or semi-washed techniques are known in Indonesia for the process when the mucilage is rinsed off in a semi-wet process and is dried to a 30-50% moisture level. Washed/fully washed-wet process, used in most regions around the globe, is a traditional technique for processing Arabica coffee and also for the minor share of Robusta coffee. During this process, a coat resembling honey is around the bean, which is after fermentation rinsed off (Wintgens 2012; Cafe imports 2016). After that, drying and storing for at least one month period occurs for the purpose of uniform moisture distribution (Brando 2009; Wintgens 2012).

Dry method

The second method used for Robusta coffee beans is the "dry" or natural fermentation method in countries such as Brazil and Ethiopia. When the majority of coffee fruits are developed, they are picked from coffee bushes by hand or machine. The coffee beans collection consists of various types of unripe green fruits, overripe dark brown raisin-like fruits, and dried shrunken ones. The fruits are then layered (the thickness is about 10 cm) on the ground, accumulated at night, and spread out every day. After the sun-drying process for about 10 to 25 days, natural microbial fermentation happens. During the fermentation, the secretion of enzymes occurs which also disintegrates the pulp and mucilage. The fermentation also causes the secretion of ethanol, acetic, lactic, butyric, and other acids. Although the presence of butyric and propionic acids leads to the lower quality of the bean because of their dispersion into the bean

(Amorim & Amorim 1977). It is important to note the risks of spoiling and overwhelming of mycotoxin organisms, which could be due to excessive fermentation or extended fermentation time because of the sun deficiency and increased humidity. After the fermentation process, dry coffee bean fruits are enveloped by parched skins but without the pulp or mucilage. However, the parched skins are mechanically detached from the bean and preserved with a content of moisture of 11-12% (Silva et al. 2000). The end product presents distinctive fruity and cherry flavours (Brando 2009).

Two studies where the effects of wet and dry processing on caffeine content were studied did not show any correlation (Joët et al. 2010; Ribeiro et al. 2016). In another study, the impact of storage of roasted beans for 12 months at 5°C on caffeine content was examined. During the examination, conventional and organic coffee were used. Caffeine content rose a little in conventional coffee from 5.26 to 5.41 mg/g. On the other hand, significant escalation was detected in organic coffee, where the caffeine content increased from 4.61 to 8.55 mg/g due to caffeine and theaflavin breakdown while storing (Bilge 2020).

4.4.2 Coffee preparation

Coffee preparation consists of stages, such as roasting, grinding, brewing, until the stage of turning the coffee beans into liquid coffee beverage (Pazmiño-Arteaga et al. 2022).

The way that coffee is prepared is a significant element that impacts the caffeine content in the drink. However, it is important to mention the variability in caffeine content among different coffee beverages (Schreiber et al. 1988). Caffeine intake may be affected by the numerous variations in the coffee-making process. Caffeine concentration is impacted by the proportion of coffee grounds to water, keeping the proportion of coffee grounds to water volume consistent, the quantity of coffee, the grinding process (at home and in a store), and the boiling of coffee grounds (McCue 1995; Moukheiber 1995). Additional brewing methods such as coarseness of grinding, the extraction duration, vapor pressure (in case of espresso coffee), the volume of water, and water temperature may also have an impact on caffeine content (Olechno et al. 2021).

Coffee beans roasting

During the roasting process, coffee goes through structural, physical, and sensory alternations. It is a process that differs around the globe, but in general, coffee is subjected to high heat depending on various factors such as roaster type, coffee beans origin, and aroma and flavour characteristics (Latosińska & Latosińska 2017).

Figure 11. Roast comparison chart

Source: Heirloom coffee (2012)

The chemical composition of the roasted beans strongly affects the quality of coffee, which is impacted by the chemical structure of green beans and the processing after harvesting, such as roasting, grinding, drying, and storage (Andriot et al. 2004). As mentioned, coffee is subjected to high heat through a roasting process from 160 to 240°C for approximately 8 to 20 minutes, depending on the characteristics of the final product. During the roasting process of Italian-style coffee, the temperature is from 200 to 240°C (Lerici & Nicoli 1990). The coffee flavour is defined by the mixture of chemicals that are formed during the process of roasting process (Franca et al. 2002), during which several reactions and thermal decompositions happen. In general, the size of beans becomes two times bigger than the original size, there is a weight-loss of 15% to 25%, and the colour alters (Latosińska & Latosińska 2017).

Coffee beans roasting process has two main phases. First phase is drying phase, when the temperature of the bean is less than 160°C, and the roasting phase, during which the bean reaches up to 260°C. Pyrolytic reaction occurs when the temperature climbs to

190°C, leading to oxidation, reduction, hydrolysis, polymerisation, decarboxylation, and several other reactions. The coffee beans changes mentioned, such as changes in colour, volume, form, mass, and others like changes in density and evaporative constituents, happen because of the roasting phase. Coffee beans are being roasted in great volumes, often in hundreds of kilograms. The roasting phase is stopped using water or air stream in order to cool the coffee down and to prevent over-roasting, which determines the product's quality (Baggenstoss et al. 2007; Latosińska & Latosińska 2017).

The roasting process results in a 30% decrease in caffeine content. A small amount of caffeine disappears because of sublimation, during which the temperature reaches 178°C. The caffeine loss is allegedly because of the increased temperature. Increased temperature influences caffeine content in both Arabica and Robusta coffee beans. Within 10 minutes of bean roasting, the temperature reaches 185°C, resulting in a small loss in caffeine content. However, when the temperature reaches up to 240°C, the decrease in caffeine content is much higher. That means that the higher roasting temperature results in a higher caffeine loss (Casal et al. 2000). Microwave roasting has shown lower caffeine loss (10.38%, from 2.12 to 1.90 g/100 g) compared to conventional roasting. A combination of techniques has shown extended caffeine preservation with just an 8% loss (Mohammad Salamatullah et al. 2021).

It is also believed that roasting to darker levels shows lower caffeine content, and early beans processing may also impact caffeine content (Latosińska & Latosińska 2017). Light roasted coffee beans proved to have more caffeine (6.42 mg/g) than medium (5.77 mg/g) or dark-roasted ones (2.63 mg/g), which contained the lowest caffeine concentration (Król et al. 2020).

Coffee beans grinding

Coffee beans grinding is the last step before brewing. The grinding process must be done before brewing because of the chemical substances that are secreted during the process (Rhinehart 2009; Severini et al. 2018).

Grinding homogeneity is important part in achieving uniform coffee quality. There is also importance in the size of the ground particles, which are affected by the brewing method that is going to be applied (Rhinehart 2009; Severini et al. 2018).

Grinding is affected by different coffee beans, moisture levels, and roasting degree. Coffee species, such *as C. arabica* and C. *canephora,* that come from different regions and vary in processing methods lead to difference in coffee beans firmness. Due to coffee expansion while roasting, there is a decrease in cell-wall flexibility and an increase in fragility. In contrast with light roasting, coffee beans undergoing dark roasting become tougher (Illy & Viani 1995).

The best combination of grinding coarseness and brewing technique enables the broadest surface exposure to water which results in high coffee brew quality. Overly fine grind may result in reduced extraction, a small amount of bitter and over-extracted coffee due to inadequate particles saturation. Conversely, over-coarsening also causes reduced extraction, resulting in under-extracted coffee because some surface areas are unable to hold water and enable emulsification and solubilization of coffee components. Medium-coarse grind is appropriate for filter coffee, boiled coffee, and Neapolitan coffee, fine grind for espresso, and overly fine grind is suitable for Turkish coffee (Illy & Viani 1995; Lingle 1996).

Four coffee grinding methods exist. First one is burr-grinding, where the coffee is smashed between wheels or conical grinding constituents. Mills that work by manual and electric means are used. Smashing causes coffee oils emission, resulting in a rich and smooth taste. Burr mills ensure consistent coffee bean size, which results in uniform extraction during brewing, suitability for commercial and domestic use, and low cost. The mills are suitable for countless brewing mechanisms, such as drip, espresso, percolators, French press, and others. The second method is chopping, which chops beans through the blades in a blade grinder or home blender. Even though the grinding is not even, when compared with burr grinders, the cost is lower**.** Chopping creates coffee powder ideal for drip coffee makers, but not pump espresso machines. The next method is roller grinding, which is due to its size and cost used for the large-scale production of coffee only. The beans are ground between wavy rollers, resulting in more uniform grinding and less heat generation in comparison with other methods. The last grinding technique is pounding, which creates powder-like coffee ideal for Turkish or Arabic coffee. The powder is formed by a mortar and pestle ("what is coffee grinding" n.d.).

Grinding degree impacting caffeine content in coffee beverages was observed. In a study, three coffee grinding degrees with the possible influence on caffeine content were examined. These degrees were: fine, fine-coarse, and coarse. Brews such as espresso, Turkish coffee, and American coffee showed that the caffeine content increased with the coarseness of the coffee. Caffeine concentrations were (Derossi et al. 2018):

Espresso coffee

2.47 mg/mL (fine) < 2.68 mg/mL (fine-coarse) < 2.92 mg/mL (coarse)

Turkish coffee

2.01 mg/mL (fine) < 2.10 mg/mL (fine-coarse) < 2.21 mg/mL (coarse)

American coffee

1.43 mg/mL (fine) < 1.57 mg/mL (fine-coarse) < 1.65 mg/mL (coarse)

On the other hand, a converse effect was observed in a different study, where the caffeine content increased with the fine grind in Arabica and Robusta coffee in espresso beverages. The same effect was also observed in filtered and boiled coffee. Measured caffeine concentrations in beverages were (Bell et al. 1996; Andueza et al. 2003):

Espresso coffee

3.05 mg/mL (coarse) < 3.19 mg/mL (fine) < 3.80 mg/mL (very fine)

Filtered and boiled coffee

0.20 mg/mL (coarse) < 0.35 mg/mL (medium) < 0.40 mg/mL (fine)

It was also detected that caffeine content in coffee beverage prepared by using a dripper increased with the decreasing particle size of coffee powder, from coarse to fine (Jeon et al. 2017).

Coffee brewing

After coffee beans are grinded to diverse sizes, which helps to enhance various coffee brewing techniques, brewing takes place (Simmerman 2013). Coffee brewing is a process of solid-liquid extraction, where water gets in a close contact with roasted and ground coffee and extracts compounds, that are soluble in water. Depending on the method used, insoluble components might also be present. Volatile and non-volatile flavour components are drawn from the ground coffee and are distributed into the coffee beverage (Steen et al. 2017). There are two types of coffee brewing methods, these are high and low-temperature methods (Janda et al. 2020; Cordoba et al. 2020; Muzykiewicz-Szymańska et al. 2021).

High-temperature methods are for instance espresso, Turkish coffee, basic infusion, and filtered methods such as Aeropress, V60, and French Press (Caprioli et al. 2014; Muzykiewicz-Szymańska et al. 2021). Espresso is a very popular brew, and ground coffee has to go through fast infusion with hot water with the use of percolator so that strong cup of coffee can be created (Caprioli et al. 2014; Kim & Kang 2018; Angeloni et al. 2021). While basic infusions are made by blending ground beans with hot water (temperature is about 85-96°C) and steeping for about 3-5 minutes, Turkish coffee is made by boiling coffee in water (Janda et al. 2020; Muzykiewicz-Szymańska et al. 2021). Among the filtered methods, is V60 the most famous one. During this process, ground coffee comes into a contact with hot water, that has 96 to 98°C and the water is in a device that has cone shape. Water is poured into the V60 in order to form a small hollow in the center of the ground coffee (Angeloni et al. 2019; de Figueiredo Tavares & Mourad 2020).

Second type is brewing methods that use low temperature during the extraction. These methods are cold drips, cold French press, or an immersion (Cordoba et al. 2019; Rao et al. 2020). Owing to the countless advantages, such as elevation of the mood, enhancement of metabolism, reduced risk of heart diseases, Parkinson's and Alzheimer's disease, diabetes type 2, and the ability to digest the cold coffee more easily than the hot one, this product has gained popularity in markets around the world. However, it is important to mention the risks that the low temperature causes. The extraction is slower and due to that, a soaking process takes longer time, around 8 to 24 hours (Rao & Fuller 2018; Claassen et al. 2021). In conclusion, it is better to search for different methods for the cold extraction, that could decrease duration of the extraction (Stanek et al. 2021).

Brewing duration and amount of extracted coffee beans influence caffeine content in coffee beverages. The longer the coffee is brewed, the larger amount of caffeine is extracted from the beans, resulting in higher caffeine content (Sheu et al. 2009).

A study compared caffeine concentrations in coffee using different coffee methods: percolation (using high-pressure coffee makers), percolation (using two low-pressure coffeemakers and a mocha coffeemaker), and filter coffee makers. Results showed higher caffeine content in coffee beverage prepared by using filtration than in the beverage prepared by percolation, due to the longer duration and larger amount of extraction (Mccusker et al. 2003; Caprioli et al. 2015). On the other hand, caffeine concentrations in Arabica and Robusta brews were lower when prepared by a filter coffee machine than in an espresso machine (0.571 ± 0.001 g/l and 1.153 ± 0.004 g/l) < (1.414 ± 0.020 g/l and 2.533 ± 0.020 g/l) (Ludwig et al. 2012).

On the other hand, in a different study, the concentration of caffeine in coffee prepared in an espresso machine decreased from 0.330 ± 0.020 to 0.410 ± 0.020 g/l (Merecz et al. 2018). However, prolonged extraction time proved to make the caffeine concentration in prepared Arabica and Robusta coffee lower (Caprioli et al. 2015).

4.4.3 Tea processing

Production of the tea starts with tea plucking, consequently tea leaves processing must occur to turn harvested tea leaves into green, oolong or black tea. Different harvesting methods and processing influences quality of the final tea. Tea can be categorized according to the extent of oxidation and fermentation, which decides whether the tea turns into black, oolong, green, or white type (Preedy 2012).

Distinctive aroma and flavour are developed through the processing steps. The processing generally consists of withering, kill-green, rolling, fermentation, drying, and so on. Each step influences the tea's chemical structure and tea quality. Withering makes moisture content in tea leaves lower, elevates permeability of cells, hydrolase activity, and substance hydrolysis (Yılmaz et al. 2020). Kill-green, or fixation deactivates enzymes like polyphenol oxidase and peroxidase, it can be achieved through steaming, sun-drying, or pan-firing. This step prevents tea leaves from oxidative browning (Donlao & Ogawa 2019). The rolling step supports fermentation and disrupts structure of the cells, and the drying process decreases moisture content in lea leaves and generates flavour components (Chen et al. 2018; Hua et al. 2021). Drying includes finish-firing and roasting, both include heat treatment, and the taste of tea intensifies due to the amino acids and sugars pyrolysis reaction. Nevertheless, not all of the teas are treated by final-firing or roasting (Gebely 2024).

Caffeine content in tea depends on countless factors, such as the type of tea, water temperature, time of infusion, quantity of the used tea leaves, harvest time, used fertilizer, climate factors, and tea processing (Wilson 2021). Because tea is processed from different plant parts, caffeine content varies according to the parts. Leaves and buds, that are young, consist of higher caffeine content than older leaves and stems (Lin et al. 2003). As already mentioned, various steps during tea processing have an impact on caffeine content. Water with higher temperature and longer steeping time while brewing results in increased caffeine content in prepared tea. In the case of green tea, caffeine and tea polyphenol levels reach its peak when the water temperature reaches more than 90°C, conversely, when the water has 60°C, only half of the caffeine and polyphenol levels will be emitted (Wei & Dong 2003). A study in China has shown that during fermentation process, caffeine content in tea leaves rises when microorganisms are used. This rise in caffeine concentration differs in black (27.57%) and green tea (86.41%). According to researchers, the growth of microorganisms and chemical composition of the tea influenced the change in caffeine content levels (Wang et al. 2005).

Black tea

Black tea includes processing steps, such as plucking, withering, leaf distorting, fermentation, firing, grading, packing, and storage (Deb & Jolvis Pou 2016).

At first, tea leaves are hand-plucked to avoid any mechanical damage and processed under ideal conditions so that the quality is maintained (Palmer-Jones 1977; Tanton 1979; Owuor et al. 1987; Mahanta et al. 1993). Plucking standard also influences quality of the black tea. Coarse plucking standard lowers quality (Owuor et al. 1987, 1990; Owuor 1989, 1990), which leads to a reduction of theaflavin and that can cause production of black tea with reduced aroma (Owuor et al. 1987; Owuor 1990). In Kenya, the plucking standard is two leaves and a bud (Othieno 1988), although some farmers pluck leaves that are coarser, which can allegedly lead to increased harvest, but it also leads to decreased tea quality (Odhiambo 1989; Owuor & Odhiambo 1994).

Harvesting of fresh green tea leaves is by hand, through the whole year with the 7-14 days period. During the withering process, biochemical and physiological alterations occur. These alterations collaborate with the rolling and fermentation process and affect quality of the resulting product. Withering influences raise in amino acid, carbohydrate, and caffeine content, heightened activity of polyphenol oxidase, weakened pectinase activity, and chlorophyll degradation. Depending on the state of tea leaves, the interval of tea leaves spread varies. Tea leaves are distributed in thin layers in trays, tats, or open loft systems at intervals of 16 to 20 hours. In order to dehydrate the leaves and dry them up, hot air is blown from the underneath of the system (Srikantayya 2003).

After the withering process, leaves deformation, which is rolling or cutting, takes place. Rolling helps to extract juice out of leaves. The leaf is damaged, twisted, and then shattered into smaller parts. Depending on withering level, tea type, speed of roller, conditions of rolling and temperature, the time of rolling varies from 15 to 60 minutes, and the number of rolling is from 2 to 5. For non-wither teas, distorting Versatile modern machines, such as Legg-cut, CTC or Rotorvane are used. It was proved that withering process of black tea increases caffeine content; however, the following steps, such as drying and fermentation (yeast), may decrease caffeine content (Cloughley 1983; Wang et al. 2008b).

Next and the most important step is fermentation, where chemical and biochemical changes occur. The duration is various, from 45 minutes to 3 hours. The tea leaves are laid out on the floor in fermentation room in thin layers (5-8 cm) on tray racks. The temperature is around 24°C to 27°C, and the colour of the leaf alters from green to coppery red one. At the end phase of fermentation, there is a reduced bitterness in taste, and a certain captivating scent develops. The fermentation rate is determined by theaflavin and thearubigin ratio, which is ideally 1:10. Flavanols, which include 25%-30% of the dry content of tea, define tea quality (Mudgil & Barak 2018). It was detected that increase in caffeine content was not steady during the various fermentation processes. Moreover, mold fermentation showed increased caffeine content in tea leaves, whereas yeasts decreased caffeine content (Wang et al. 2008b).

The last step of tea processing is grading and storage, and according to the grain size, different grades are acquired. During this last step, chemical changes occur, and through a few weeks, a green colour and roughness are being completely lost. In case tea is kept in cool place, away from moisture and oxygen, it can last rich in flavour for more than 1 year (Mudgil & Barak 2018).

Green tea

Green tea is non-fermented tea, and the Japanese-style processing steps include harvesting, withering, steaming, rolling, or shaping, and drying. Chinese green tea production is very similar to the Japanese one, although the differences are that Chinese-style tea is produced by pan-firing and in the drying process. Japanese-style tea is dry-heated for the enzyme's deactivation, on the other hand, Chinese type of tea is exposed to steaming. The withering process is two times longer than that of white tea, it is around 4 to 5 hours (Mudgil & Barak 2018). The major contrast in the green tea making process is the negligence of oxidation, which ensures that the colour of the tea stays green. To make sure, that the leaf does not go through the fermentation process (oxidation), the steaming of the tea leaf takes place. Enzyme activity is supressed, and oxidation does not occur (Preedy 2012).

In order to achieve the best green tea quality, it is essential to pluck and process buds with two leaves or shoots with three leaves and tea leaves that are soft and homogeneous. Consequently, the shoots are laid out in trays made of bamboo for 1 to 3 hours to boost the tea quality and to release grass-like scent (Sandeep et al. 2011).

The next step is withering, where the tea leaves are left to wither for a few hours (4 to 12) so that the moisture content can be reduced to about 30% (Sanderson & Grahamm 1973). During withering, several physical and chemical changes occur that affect membrane permeability, the tea aroma, and flavour (Sanderson & Grahamm 1973; Nagalakshmi 2003). As mentioned in black tea withering, there are also biochemical changes in sugar, organic acids, and aromatic substances levels, as well as an increase in caffeine content and a decrease in lipids, fatty acids, carotenoids, and chlorophylls (Tomlins & Mashingaidze 1997). The most common withering method is through air blowing (Singh et al. 2014).

The next step is fixing, which halts the enzymatic reaction, the leaves do not go through the fermentation process, and the green colour of the leaves is maintained. Fixing can be through pan-frying or steaming. Pan-fixing involves temperature that are more than 180°C, whereas during steaming, the temperature is only 100°C, and the leaves are in a rotating drum, where hot steam is added within 2 minutes. Too much steam ruins the leaves, and too little can start the fermentation process (Xua & Changa 2008).

During the drying process, about 50% of the leaf's moisture content is lost. The rotation of leaves occurs in a metal or wooden drum for approximately 30 minutes at 55°C, using warm air. It is important to control the drying temperature, so that there is not burnt taste or loss in tea quality (Xie et al. 2006). Methods such as vacuum pump, hot air drying, vacuum drying with a blast oven, microwave drying, or microwave vacuum drying are used (Lou 2002).

In the next step, leaves go through rolling in a rolling machine within 10 minutes. Then the leaves go through cleaner to get rid of any impurities, Rotor vane, and then the Curl-turn-cut machine, so that the particles can become even smaller. During the last step of the rolling process, components go through roll breaker so that the twisted balls created because of the slow fermentation can be removed (Naheed Z. et al. 2007).

The final step includes letting leaves in contact for 30 minutes with hot air. Then the tea leaves are placed between two rotating metals for about 15 minutes so that the final rolling process can happen. At the very end, leaves are polished by a polisher, where they are pressed against the hot plate. It is a significant step for the tea appearance (Singh et al. 2014). The caffeine increase was detected in green tea processing during withering; however, shaping and firing caused slight loss in green tea caffeine content (Astill et al. 2001).

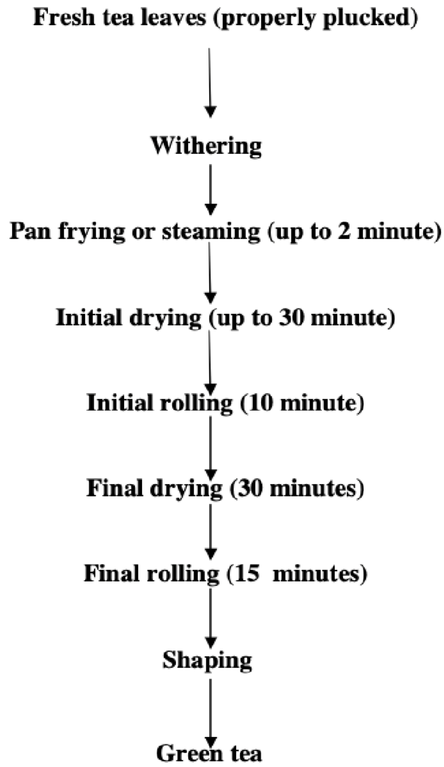

Figure 12. Steps of Green tea processing

Source: (Singh et al. 2014)

White tea

White tea is a type of green tea, that is produced in China in Fujian province (Unachukwu et al. 2010) and is characteristic with its minimal processing (Hilal & Engelhardt 2007; Kosińska & Andlauer 2014). Because of the minimal processing, white tea is perceived as the oldest type of tea. Following processing methods result in the production of other tea varieties. Due to minimal processing, not that much time and work are needed compared to other tea types. It also preserves the gentle, subtle, and slightly sweet taste of white tea and facilitates the maintenance of phytochemicals at a high level, which may possibly contribute to the health benefits of white tea (Mao 2013). Primarily, white tea is produced from young buds covered in silvery hair and immature leaves that have never been exposed to sunlight to avoid chlorophyl development. Buds and leaves for white tea production are collected every spring once a year (Kosińska & Andlauer 2014).

White tea can be divided into 4 groups, depending on the different collecting and type of raw material. These groups include Yin Zhen Bai Hao (Silver Needle), Bai Mu Dan (White Peony), Gong Mei (Tribute Eyebrow) and Shou Mei (Noble, Long-Life Eyebrow). Silver Needle, produced from single buds of big white tea types, and White Peony, produced from leaves of white tea or narcissus white two or three types have the finest quality (Lin et al. 2017), while Tribute Eyebrow and Noble, Long-Life Eyebrow belong to the ones with the lower quality (Ilgaz & Polat 2012). It is important to mention that white tea made with young leaves and buds, for instance, Silver Needle, could possibly contain more caffeine due to the caffeine's role as an insecticide to protect new growth. The plant's bitter taste due to the caffeine production protects leaves and bunds from predators, such as insects or birds (Jing Tea 2022).

White tea does not go through fermentation, rolling, or roasting process after being picked, steamed, and dried. The ideal conditions for harvesting include a sunny morning with the sun at the adequate height so that the remained moisture in the buds is eliminated. That means that there is no harvesting during rainy or chilly days (Mao 2013). First, skilled collectors pluck young and soft tea leaves and buds (Evelyn 2022). Then, withering occurs, where the fresh leaves are spread out to wither and be air-dried in the shade, under sunshine, or in a temperature-controlled room so that the moisture evaporates, and the exquisite taste develops (Pettigrew 2004; Evelyn 2022). Subsequently, sorting occurs so that only leaves with the best quality are picked. At the end thorough packaging takes place (Evelyn 2022).

Yellow tea

Due to the great quality, distinctive silky and refreshing flavour, and positive health effects, yellow tea has recently become well-known in Western countries (Wang 2011; Kujawska et al. 2016). Yellow tea is mainly cultivated in China, and despite all teas are being processed from leaves of the *Cam. sinensis* plant, the yellow tea processing method differs from other teas (Wang 2011). The yellow tea processing method is similar to the processing of green tea, but there is one more additional step known as "sealed yellowing". Thermochemical reactions and enzymes that are exogenous cause significant alternations in yellow tea ingredients. After that, the tea gets more fresh and soothing taste in contrast with other teas. Process called "sealed yellowing" leads to the formation of a colour known as "three yellows" (yellow dry tea, yellow infusion, and yellow brewed leaves) and creates sweet taste, which is also different in contrast with the grassy taste of green tea (Wang et al. 2013). Because of the diverse origin of lea leaves cultivation, various processing methods are required to match the standards of different tea types. Nevertheless, the majority of yellow teas go through the same processing steps. These steps include withering, fixing, rolling, sealed yellowing, and drying, where the "sealed yellowing" is the crucial step for yellow tea processing (Xu et al. 2018).

A fresh tea leaf with an original yellow colour is plucked from an albino tree and is subsequently processed in the same way as green tea leaves (Yang et al. 2010). As mentioned earlier, for the yellow tea processing is crucial step "sealed yellowing," which turns the tea from green colour to a unique yellow one and is necessary to make the tea recognizable from other tea varieties (Huang 2001). Throughout the "sealed yellowing" process, chlorophyll and polyphenols in the leaves undergo oxidation, cracking, and transformation process, which is impacted by humidity and heat. That results in unique yellow leaves colour. During this process, the content of ester catechins is decreased, resulting in a more soothing and fresher taste (Yang & Zhou 2013).

Tea processing, maturation of the leaves, plant species, origin of the plant, and agricultural methods have a significant impact on chemical structure and flavour of the tea (de Mejia et al. 2009). The study where the Chromatography method was used, compared caffeine content in the same amount (dry powder made of 20 g tea in a ratio of 1:10 of liquid to material) of fermented, half-fermented and non-fermented teas. The results showed that the fermentation influences caffeine content. Because unfermented green tea, light-fermented yellow tea and white tea undergo a light fermentation or no fermentation process, the caffeine content isn't that high in comparison with fully fermented teas, such as black tea or pu'erh tea. The results of the study can be seen in table 6 ("Effect of Fermentation on Caffeine Content in Tea – teavivre" n.d.).

Table 6. Content of caffeine in tea samples

Source: ("Journal of Yunnan Agriculture University" 2015)

Content of Caffeine of the Tea Power Samples		
Type	Name	Content of Caffeine (%)
Green Tea	Dragon Well Green Tea	6.39±0.02
	Bi Luo Chun Green Tea	8.36±0.01
	An Ji Bai Cha Green Tea	7.49±0.01
Black Tea	Dian Hong Black Tea	9.18±0.01
	Ma Ge Mai Black Tea	11.58±0.01
Oolong Tea	Dong Ding Oolong Tea	6.66±0.01
	Da Hong Pao	8.17±0.01
Yellow tea	Huo Shan Huang Ya	6.94±0.01
	Meng Ding Huang Ya	8.57±0.01
White Tea	Bai Mu Dan	7.63±0.01
Pu-erh Tea	Ripened Pu-erh Brick	8.43±0.01
	Golden Buds Ripened Pu-erh	11.80±0.11
Dark Tea	An Hua Dark Tea	7.12±0.03
	Liu Bao Dark Tea	10.08±0.01

The fermentation process as well as the brewing affect caffeine content in some way. The longer brewing takes, the more caffeine tea contains. Other factors that influencing caffeine content include the parts of the plant used for tea processing, with tea buds containing more caffeine than the leaves ("Effect of Fermentation on Caffeine Content in Tea – teavivre" n.d.).

Figure 13. Steps of Yellow tea processing

Source: (Xu et al. 2018)

Oolong tea

Oolong tea is semi-fermented tea (Ma et al. 2014). The most important oolong tea processing steps include sunning and withering, fermenting, panning, rolling, firing, final firing, and packing (Chen et al. 2019). During fermentation, a natural browning process occurs owing to the oxidative enzymes in tea leaves cells. The level of oolong tea fermentation is approximately from 10% to 60%, so that the colour and taste of the tea resembles black and green tea. Fermentation causes countless changes. For instance, many flavour compositions and aromatic alcohols are created; there is also heightened activity of enzymes (Ma et al. 2014). Fermentation is also responsible for the development of fruity and floral tastes and disappearance of grassy green ones, resulting in black tea's sweet and bold flavour (Wang et al. 2008a).

There are no concrete techniques how to manufacture oolong tea. Oxidation level and processing methods are according to various gardens and tea masters (Wang et al. 2008a). After fermentation, some oolong tea types go through the panning process, which includes two steps. First, heat is applied to tea leaves so that the enzymes are deactivated, and the fermentation process stops. Then heating after drying occurs for the appearance of distinctive oolong tea flavours. During this process, equipment such as a rotary pan, panning machine, convention oven or pan frying is used. The duration depends on tea leaf type and amount. Panning ensures, that the tea's grassy scent is eliminated, but it leaves nutty smell and taste and makes sure that the tea leaves can't be broken before rolling process. At the end of panning process, the tea leaf is soft, flexible and has a strong and delightful fragrance (Zhen 2002; Hui et al. 2004; Info Taiwan 2014).

To process top tea quality, processing methods such as tossing and rolling are important (Chen et al. 2010). Tea leaves are rolled into the strips, machines or hands are used. Cell walls collapse, and juice inside leaves leaks due to the pressure. The odour is enhanced, and the oolong tea is brewed. After that, firing process occurs. Tea leaves are put into wooded barrels and consequently baked. At first, tea leaves are baked for 2 minutes and then are let to cool down. Afterward, the quantity is doubled, and baked for 6 minutes, the leaves are then cooled down again. After that, the tea leaves are simmered utill the stage, they are all dried. At the end, tea leaves are put next to oven for the whole night (Ng et al. 2018).

Colour, scent, taste, and appearance of Oolong tea determine tea quality (National Bureau of Statistics of China 2008). Processing methods demand full knowledge and expertise so that the resulting tea quality is on a high level. During the fermentation process, it is essential to determine the moment the fermentation needs to end (Chen et al. 2010). Thus, tea makers must control every tea processing step thoroughly and understand the tea substances change connected with tea scent to ensure the high tea quality. Tea makers evaluate tea aroma with sniffing, although it's individual process, because every tea maker can evaluate tea quality differently (Hong et al. 2023).

After tea processing, countless alternations in the content and constitutions of tea components occur, which may influence tea quality (Zhang et al. 2019). Withering impacts alternation and breakdown of tea components through the enzymes in tea, which leads to various tea components (Li et al. 2022). Fermentation takes part in reducing bitterness and astringency in tea leaves and creating a unique wooden aroma (Cheng et al. 2020). Drying helps the main scents of the leaves merge, resulting in unique scent attributes (Qu et al. 2019). Various tea processing steps significantly influence tea components, that are related to tea aroma. In the end, scents that are typical for each type of the tea are created (Hong et al. 2023).

Table 7. Summary of the effects of processing and preparation on the caffeine content in coffee

	Arabica coffee	**Robusta coffee**	**References**
Coarseness	↑	↑	(Andueza et al. 2003)
Water temperature	↑	↑	(Caprioli et al. 2014)
Extraction time	↑	↑	(Mccusker et al. 2003; Caprioli et al. 2015)
Prolonged extraction time	↓	↓	(Caprioli et al. 2015)
Roasting degree	↓	↓	(Król et al. 2020)
Roasting temperature	↓	↓	(Casal et al. 2000)
Coffee to water ratio	↑	↑	(Tfouni et al. 2014; Caporaso et al. 2014)
Use of espresso machine	↑	↑	(Tfouni et al. 2014; Caprioli et al. 2014)
Fermentation	↓	↓	(Badan Standarisasi Nasional (BSN) 2004; Purwoko et al. 2022)
Fertilizer use (nitrogen)	↑	↑	(Gonthier et al. 2011)
Sunlight exposure	↑	↓	(Vaast et al. 2006; Kumar et al. 2015; Worku et al. 2018)

Table 8. Summary of the effects of processing and preparation on the caffeine content in tea

	Black tea	**Green tea**	**Yellow tea**	**Oolong tea**	**White tea**	**References**
Infusion time	↑	↑	↑	↑	↑	(Suteerapataranon et al. 2009; Musilová & Kubíčková 2018)
Brewing temperature	↑	↑	↑	↑	↑	(Suteerapataranon et al. 2009; Musilová & Kubíčková 2018)
Fermentation	↑	↑	↑	↑	↑	(Kumar et al. 2018)
Rolling	No effect	↓	No effect	No effect	No rolling process	(Friedman et al. 2009; Sari & Velioglu 2013; Boros et al. 2016; Feng et al. 2023)
Withering	↑	↑	↑	↑	↑	(Astill et al. 2001; Deb & Jolvis Pou 2016)
Drying	↓	↓	No effect	No effect	No effect	(Astill et al. 2001; Xiangyang et al. 2010; Boros et al. 2016)

Table 7 compares the effects of processing and preparation on caffeine content in coffee Arabica and Robusta. As mentioned, aside from processing and preparation, caffeine content in tea and coffee depends on factors such as plant type, growing conditions, quantity of used tea, plant parts, and many other factors too. It was proven that caffeine content increases with the coarseness of both Arabica and Robusta coffee beans. The same effect was observed with the increased water temperature. An increase in water temperature led to increased caffeine content in Arabica and Robusta coffee. Long coffee brewing time duration showed higher caffeine content; however, prolonged duration of coffee brew extraction showed decreased caffeine content as well as in other compounds in Robusta and Arabica coffee. The decrease in caffeine content was also observed in both species with higher roasting temperature and roasting degree. The highest caffeine content was detected in lightly roasted coffee. A higher coffee-to-water ratio in Arabica coffee resulted in higher caffeine content as well as in Robusta coffee in the brew. The use of espresso machines also showed an increase in caffeine levels in brew in comparison with other methods in both coffees. Fermentation with yeast *Saccharomyces cerevisiae* and *Lactobacillus plantrum* reduced caffeine content in Arabica coffee, as well as fermentation with *Saccharomyces cerevisiae*, *Leuconostoc mesenteroides, Lactobacillus casei*, and *Rhizopus oryzae* reduced caffeine content in Robusta coffee. Exposure to light is an important step so that caffeine can be created. However, limited exposure to the sunlight showed decreased caffeine content in Robusta, on the other hand, increased caffeine content in Arabica coffee. The use of soluble nitrogen fertilizers proved to increase caffeine content in coffee beans. Exposure to light is an important step so that caffeine can be created. However, limited exposure to the sunlight showed decreased caffeine content in Robusta, on the other hand, increased caffeine content in Arabica coffee.

Table 8 summarizes the effects of processing and preparation on caffeine content in different tea varieties. Infusion time and brewing temperature have a similar effect on various tea types. Results of research showed that caffeine content rose when the tea infusion time was prolonged by 1 minute (29%), and when the boiling water was used in place of water at the recommended temperature, the caffeine content rose even more (66%). Fermentation, in general, proved to increase caffeine content in different types of tea. However, yeast fermentation during green and black tea processing proved to reduce caffeine content. During green tea leaf rolling, only minimal loss of caffeine was detected. Even though the loss was minimal, it depended on high temperature. Caffeine content in black tea leaves during the rolling process remained stable regardless of the rolling method. Studies do not prove whether the rolling process of white and yellow tea decreases or increases its caffeine content; however, the rolling of these tea leaves causes the start of an enzymatic reaction, which influences the chemical structure. The caffeine content of oolong tea proved to be steady during the rolling process. The withering process of yellow, white, and oolong tea generally increases their caffeine content. It is because of the fragmentation of chemical formulas into simpler ones, leading to an increase in caffeine content. Also, an increase in caffeine content during withering stage of black tea and a continuous decrease during the fermentation and drying stages from different study has been observed. Even though the drying process did not prove to directly affect caffeine content in white, oolong, and yellow tea, caffeine content in green tea and black tea was found to be slightly reduced. Microwave vacuum drying resulted in green tea with lower caffeine content, as well as phenol-ammonia ratio.

5 Conclusions

Caffeine accounts for one of the most popular drugs in the world, with high annual consumption. Caffeine can be added or used in beverages, food, or in pharmacology. Caffeine can affect human well-being according to each individual's age, sex, surroundings, and the amount or type of consumed caffeine. Fatal cases are not that common in adults, and excessive caffeine intake causes caffeine overdose, which may lead to lethal complications. The lethal amount is around 5-10 grams of caffeine. Caffeine may impact central nervous system, cardiovascular system, reproductive system, gastrointestinal system, and mineral and vitamin absorption.

Caffeine content depends on the type of coffee, with Robusta containing twice the amount of caffeine as in Arabica. Despite this fact, most of the processing methods showed the even effect in both Arabica and Robusta coffees. The caffeine increase was detected with the coarser coffee beans, increased water temperature, long extraction time, higher coffee to water ratio, use of nitrogen fertilizers, and use espresso machines. It was proved that caffeine content rose when using a coffee dripper and finer coffee grind. A study also proved that coffee beverage prepared by filtration showed higher caffeine content than coffee prepared by the percolation method. It was detected that caffeine increases in both coffee types with the brewing time. The decrease in caffeine concentrations in both Arabica and Robusta was proved to cause prolonged time of extraction, the degree of roasting (higher caffeine content in lightly roasted coffee), higher roasting temperature, and fermentation with different microorganisms. Also, the use of an espresso machine proved to lower caffeine content. However, coffee beans 'exposure to light showed a decrease in caffeine concentrations in Robusta and an increase in Arabica.

Caffeine content is different in each tea plant part. Young tea leaves and buds have a higher caffeine content. Caffeine content in black, green, yellow, oolong and white tea increased with the prolonged infusion time, boiled water usage during brewing, withering process, and fermentation. Specifically, black tea mold fermentation increased caffeine content; however, yeast fermentation as well as the drying process proved to reduce caffeine content in black and green tea. The caffeine concentrations measured in lightly fermented, or non-fermented teas found to be not as high as in fully fermented teas. The rolling process did not prove to have any effect on the caffeine concentrations in black, yellow, and oolong tea; however green tea rolling prove to slightly reduce caffeine content, as well as shaping and fixing. Because white tea does not go through rolling process, no study was conducted. No change of caffeine concentrations was also detected in yellow, oolong and white tea during the leaves drying process.

In conclusion, the study focuses on caffeine content in tea leaves and coffee beans, which is affected by processing and preparation. Even though Robusta coffee contains double the amount of caffeine compared to Arabica, both show similar responses to various processing methods. On the other hand, tea processing influences caffeine content in various tea types differently.

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