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Beverages of Coffee and Phytochemicals Present in *Coffea arabica and Coffea canephora* – A Review

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Abstract

Coffee plant which belongs to *Rubiaceae* family, generally grows along the equator in tropical and subtropical areas. The generic name, coffee, covers about 100 species of plants, but the two main species used for making beverages are called *Coffea arabica* (**Arabica**, accounting for 60-70% of the world's production) and *Coffea canephora* (**Robusta**). Coffee plant contains phytochemicals such as sugars, proteins, organic acids, flavonoids and polyphenols, *etc*. Coffee is a reputed folk medicinal plant containing phytochemicals, which exhibit mainly antioxidant, anticancer, and anti-diabetes properties. Caffeine is one of the most controversial phytochemicals present in coffee. Caffeine amount per 100 mL of coffee brew from medium roasted coffee can vary from 50 mg to 380 mg. A typical cup (240 mL) of coffee can contain 70-140 mg of caffeine and if one drinks more than 4 cups of coffee per day, he or she is considered to be addicted to caffeine, which may cause caffeinism. Nowadays decaffeinated coffee beverages are popular among people as it consists of extremely low caffeine content; about 1 mg per 100 mL. Decaffeination can be achieved by using organic solvents, carbon dioxide, water, or using different absorbents. Lots of coffee beverages are categorized by the brewing method and most of them are prepared

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by mixing the brew in water, milk or ice-cream. The scope of this overview is to discuss the importance of the types of phytochemicals present and the types of coffee beverages.

Keywords: *Coffea arabica/canephora, phytochemicals, coffee, caffeine, decaffeination, beverages*

Introduction

"Coffee" is one of the most popular beverages in the world, prepared from roasted coffee beans. Main types of coffee beverages available in the market are ready to drink coffee (which can be consumed directly), instant coffee (derived from brewed coffee beans), and roasted coffee. Coffee has become popular due to a number of reasons such as habits, needs and hunger, health, pleasure, tradition, natural concerns, sociability, price, weight control, variety seeking, *etc.* (Acidri et al, 2020; Seninde & Chambers, 2020; Qader et al, 2020; Nigra et al, 2021; Gottstein et al, 2021; LIczbiṅski & Bukowska, 2022). Coffee is also known as "kahwah, kawa or gawah" in Arabic and Kiswahili, "café" in French, "caffe" in Italian, "kaffee" in German, "koffie" in Dutch, "buni" in Afrikaans and "boon, bun, or bunna" in Ethiopian (Teketay, 1998). "Coffee-leaf tea" is a beverage prepared by infusing coffee leaves in the hot water and some countries consider this as a traditional drink (*e.g.,* "copi daon" in Indonesia, "giser" in Yemen, "kuti, jeno, or jenuai" in Ethiopia) (Bizzo et al, 2015; Chen, 2019).

The coffee plant contains various types of phytochemicals including polyphenols, alkaloids and flavonoids, which may exhibit antioxidant, antitumor, anti-inflammatory, anti-carcinogenic, anti-diabetes, and hepatoprotective properties (Qader et al, 2020; Gottstein et al, 2021; Acidri et al, 2020; Seninde & Chambers, 2020; Nigra et al, 2021).

America has the largest market for coffee which is up to 16% of the total coffee consumers all over the world, while Brazil is a close second with 13% (DePaula & Farah, 2019). Most of the Europeans consume coffee when compared to Asians (DePaula & Farah, 2019). In Britain, daily consumption of coffee is about 70 million cups and approximately 70% of cups are prepared by instant coffee, which are made from dried and powdered coffee beans (Van Doorn et al, 2015; Deotale et al, 2022).

In 2020, the coffee industry was worth over 100 billion US dollars (Acidri et al, 2020). More than 60% of the world's coffee production depends on Arabica while the rest on Robusta (Chen 2019; Acidri et al, 2020). Arabica is cultivated in South America (mainly Brazil) and upland and mountain areas of East Africa, while Robusta comes from West African and South Asian countries (Samoggia & Riedel, 2019) [20].

Arabica coffee (seeds are longer in shape) fetches a higher price than Robusta coffee (small, round shaped beans), as Arabica beans consist of (i) low amounts of **chlorogenic acids** (**CGAs**) and caffeine (ii) lesser astringent flavor and acidity of its brew, and (iii) high organoleptic properties (Ramalakshmi & Raghavan, 1999; Seninde & Chambers, 2020; Gottstein et al, 2021).

History

Since 575 ACE coffee has been cultivated by Ethiopians, then it spread to Yemen around 1400 AD (Ramalakshmi & Raghavan, 1999). In pre-Islamic days, solid coffee had been on common use as chocolate bars (similar to the chocolate bar of Morden consumption) and it was introduced to Arabia by Africans. In Cairo, coffee was used as currency. In early African religious and marriage practices, coffee was served as a ceremonious drink (Teketay, 1998). France introduced this plant to West Indies in 1725 AD and afterwards it spread to South America (DePaula & Farah, 2019). In the 17^{th} century, the Dutch introduced coffee cultivation to Java, Surinam and Sri Lanka (Teketay, 1998; DePaula & Farah, 2019). Then only, the coffee cultivation expanded to Africa and India (DePaula & Farah, 2019). However, coffee cultivation was not successful in Sri Lanka due to the coffee leaf rust disease (Teketay, 1998).

For the first time, the medicinal properties of coffee were literary described by the Persian physician, Rhazes (860–932 AD) and then by Avicenna (980–1037 AD) (Bizzo et al, 2015). According to Medicinal history; from the 4^{th} century BC to mid-19^{th} century, Hippocratic-Galenic medicines used it to control the body balance (Bizzo et al, 2015). German botanist Leonhard Rauwolf was one of the pioneers, who spread the knowledge of the medicinal value of coffee to western countries in 1998 (Teketay, 1998).

Morphology of the coffee plant

The coffee plant is a small flowering tree or shrub that grows around 9-12 m height in the wild. It belongs to the *Rubiaceae* family and grows in tropical and subtropical areas (temperature 18-22 ^{o}C) around the equatorial region at altitude 200-1200 m (Patay et al, 2016; Tritsch et al, 2022), famously known as the “coffee belt”. Major coffee producing countries can be listed as Brazil, Mexico, Guatemala, Colombia, Honduras, Vietnam, Indonesia, India, Ethiopia and Uganda (Tritsch et al, 2022). However, wild coffee can be found only in Africa and South Asia at 1300-1600 m altitude (Patay et al, 2016).

The funnel shaped white colored flower of the coffee plant has a pleasant odor (Ramalakshmi et al, 1999; Patay et al, 2016) and it takes around 200-250 days to produce ripe cherries after blossoming the flowers (Figure 1) (Klingel et al, 2020).

Figure 1. (a) Flowers of coffee (b) Ripen cherries and roasted seeds
(a) https://stock.adobe.com/lk/search?k=%22coffee+flower%22
(b) https://www.thoughtco.com/what-is-arabica-coffee-2353016

Red colored edible cherry like coffee fruit is composed of two coffee seeds (Patay et al, 2016). Even though, over 120 species of *Coffea* genus have been identified, only a few species (*e.g.*, *Coffea arabica* or **Arabica**, *Coffea canephora* or **Robusta**, *and Coffea liberica*) are well-known around the world (Figure 2) (Patay et al, 2016; Chen, 2019; Ali et al, 2022).

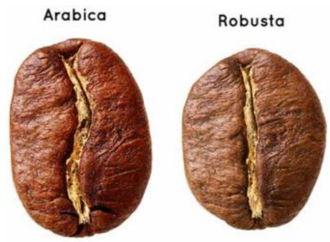


Figure 2. Coffee seeds of Arabica and Robusta
https://allannbroscoffee.com/arabica-vs-robusta/

Components of a coffee cherry

The pericarp or the wall of the ovary of the coffee cherry (Figure 3) consists of exocarp (outer skin), mesocarp, pectin layer and the endocarp. Testa or epidermis in the cherry is collectively known as the coffee silver skin (Figure 3), which covers the beans. Silver skin consists of various highly soluble fibers, higher protein content and low-fat content (Gottstein et al, 2021; Sisti et al, 2021). Coffee seed is the naturally occurring endosperm of the coffee cherry and coffee beans are the processed seeds used for mass consumption (Gottstein et al, 2021; Sisti et al, 2021).

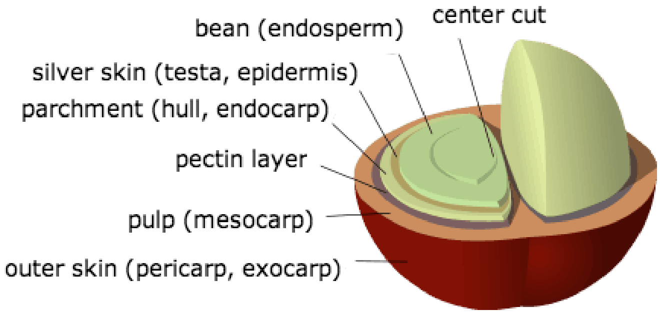
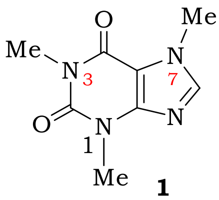


Figure 3. Components of a coffee cherry
https://www.craftcoffeeguru.com/coffee-bean-anatomy/

Exocarp has a leathery texture, and green color cherry turns to red after ripening. Mesocarp is also known as the soft pulp with sweet taste, which covers the pectin layer. Coffee pulp contains carbohydrates, proteins, minerals, tannins, polyphenols and caffeine (1,3,7-trimethyl xanthine) **1** (Figure 4) (Sisti et al, 2021). The endocarp is the innermost layer of the pericarp, which is also called parchment or hull (Klingel et al, 2020).



1

Figure 4. The chemical structure of caffeine **1**

Processing of coffee

Firstly, these coffee seeds are prepared for roasting (Ramalakshmi & Raghavan, 1999). This preparation is achieved by either dry (sun drying) or wet (washing) process (Ramalakshmi & Raghavan, 1999). In the drying process, cherries are sun dried and the husk is removed as coffee chaff (*i.e.*, the dried skin). Pulping, fermentation, washing, drying and removing the parchment are the main steps in the wet process (Ramalakshmi & Raghavan, 1999). However, both processes end up with polishing, sorting and grading beans (Ramalakshmi & Raghavan, 1999). Coffee pulp is the by-product of the wet process, and the by-product of the dry process is coffee husk/chaff (Sisti et al, 2021).

Initial step of all coffee beverages in the market (*e.g.*, caffè americano, café latte, espresso, macchiato, Irish coffee, *etc.*) is roasting of seeds (Ramalakshmi & Raghavan, 1999). During the initial drying phase, endothermic reactions occur and around 130 °C green beans turn into yellowish color due to the caramelization of sucrose (Seninde &

Chambers, 2020; Grzelczyk et al, 2022). Beyond 160 °C, these beans get changed into brown color and the volume of the bean is also increased, due to accumulation of large quantities of gases produced during the pyrolytic reactions (Grzelczyk et al, 2022). Around 190 °C, flavor is formed by undergoing endothermic and exothermic reactions (Seninde & Chambers, 2020; Grzelczyk et al, 2022). Some of the free amino acids and peptides undergo Strecker degradation (Seninde & Chambers, 2020; Grzelczyk et al, 2022). Other amino acids and sucrose undergo Millard reactions and they give the unique dark brown color to the bean (Seninde & Chambers, 2020; Nigra et al, 2021; Grzelczyk et al, 2022). The chemical reactions that occur during roasting are pyrolysis, hydrolysis, oxidation, reduction, decarboxylation, polymerization, *etc.* (Acidri et al, 2020; Seninde & Chambers, 2020). Coffee silver skin is a solid by-product that can be obtained from roasting process of the coffee cherry (Sisti et al, 2021).

After roasting, these heated soft coffee beans are rapidly cooled using air or water to cease the exothermic reaction before grinding (Seninde & Chambers, 2020). Not only roasting, but brewing method also determines the aroma, taste and the quality of the coffee cup (Acidri et al, 2020; Seninde & Chambers, 2020; Nigra et al, 2021). Cupping is a common sensory evaluation method used to analyze the aroma, flavor, aftertaste, acidity, sweetness, uniformity, *etc.* (Seninde & Chambers, 2020; Edelmann et al, 2022). Spray drying, freeze drying, spray freeze drying, conductive hydro-drying are some of the drying techniques that are used to prepare instant coffee powder from the natural coffee extract (Deotale et al, 2022).

Decaffeination

Nowadays people prefer to consume decaffeinated coffee products, which contain very low caffeine content (*i.e.,* more than 97% of caffeine present in beans is removed); 0.3-0.5 mg/100g in decaffeinated ground roasted coffee, and 0.7-0.9 mg/100g in decaffeinated instant coffee (DePaula & Farah, 2019). Green beans are soaked in a solvent during the decaffeination process; as a result, caffeine binds to CGAs and is released into the solvent (Farah, 2012). In the old days, decaffeination was achieved using organic solvents like trichloroethylene, ethyl acetate, *etc.* (Farah, 2012). Caffeine can be extracted into water at elevated temperatures at atmospheric pressure, as solubility of caffeine in water increases with temperature (Pietsch, 2017). Liquid carbon dioxide (at 6.5-7 MPa and 20-25 °C) is also used to extract caffeine from coffee beans. At present, the use of supercritical carbon dioxide (around at 25 MPa pressure and 100 °C temperature) has become the most popular and the safest method for decaffeination (Ramalakshmi & Raghavan, 1999; Farah, 2012; Pietsch, 2017). Disadvantages of the decaffeination process of coffee beans are (i) mass loss of beans, (ii) remaining solvent residues, and (iii) changes in aroma of beans (Pietsch, 2017).

Phytochemical constituents

Phytochemicals are special chemical compounds produced by plants through primary and secondary metabolic pathways and are useful in building up a self-defense system against microorganisms and several plant diseases (Patay et al, 2016).

During roasting, the quantity of bioactive compounds (structures are shown in Figures 5 and 6) such as **caffeoylquinic acids** (**CQAs**) (*i.e.,* 3-CQA **2a**, 4-CQA **2b**, 5-CQA **2c**), di-CQAs (*e.g.*, 3,4-diCQA **3a**, 3,5-diCQA **3b**, 4,5-diCQA **3c**), salicylic acid **4**, trigonelline **5**, cafestol **6**, kahweol **7** decreases and new phytochemicals such as melanoidins, chlorogenic lactones, gallic acid **8**, nicotinic acid **9** and flavonoids are formed (Tritsch et al, 1998; Nigra et al, 2021).

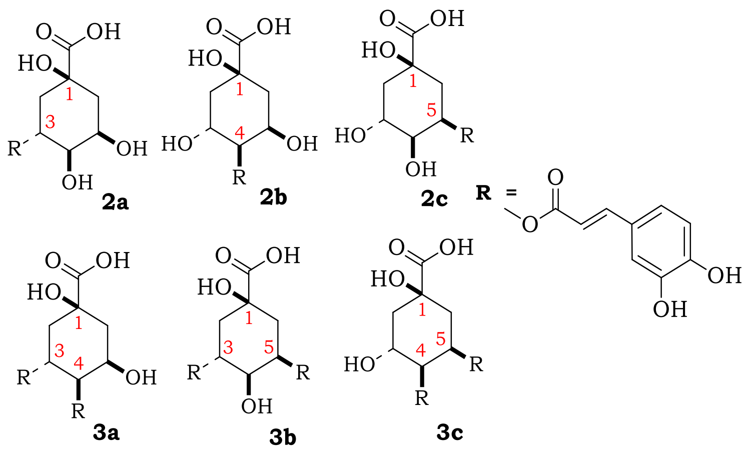


Figure 5. Structures of CQAs **2a-c** and di-CQAs **3a-c**

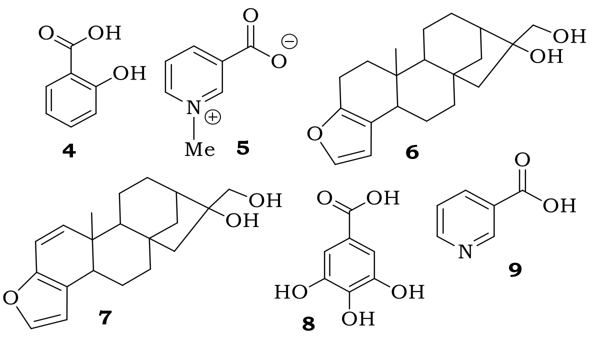
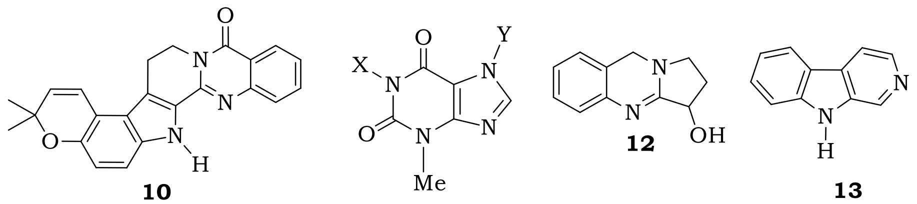


Figure 6. Structures of salicylic acid **4**, trigonelline **5**, cafestol **6**, kahweol **7**, gallic acid **8**, and nicotinic acid **9**

The most abundant bioactive compounds in green coffee beans are caffeine, polyphenols, trigonelline, CQAs, cafestol and kahweol (Yeretzian et al, 2019; Nigra et al, 2021). Roasted coffee is mainly composed of caffeic acid, melanoidins, and nicotinic acid (Nigra et al, 2021).

Alkaloids

Caffeine and trigonelline **5** (Figure 6) are the main alkaloids present in coffee seeds (Nawrot et al, 2003; Farah, 2012; Chen, 2019; Munyendo et al, 2021; Ali et al, 2022). Trigonelline is synthesized from nicotinic acid, and 100 mL of medium roasted coffee brew contains 40-50 mg of **5** (Nawrot et al, 2003; Chen, 2019). It also contributes to the aroma of coffee as it thermally degrades into pyrrole and pyridine derivatives (Seninde et al, 2020). Fontanesine B **10**, theophylline **11a**, vasicine **12** and beta-carboline **13** are some of the alkaloids present in coffee beans (Figure 7) (Ali et al, 2022). Theobromine **11b**, and theophylline are other alkaloids extracted from coffee leaves (Chen, 2019).



11a X = Me, Y = H
11b X = H, Y = Me

Figure 7. Structures of fontanesine B **10**, theophylline **11a**, Theobromine **11b**, vasicine **12**, and beta-carboline **13**

Caffeine

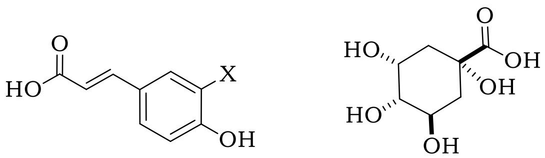
Caffeine **1** was discovered by Friedrich Runge and it dissolves well in boiling water (Teketay, 1998; DePaula & Farah, 2019). Caffeine is quite stable to heat thus, roasting of coffee seeds does not reduce the caffeine content (Farah, 2012). A typical cup of coffee (240 mL or 8 oz.) contains 70-140 mg of caffeine (Ramalakshmi & Raghavan, 1999; Acidri et al, 2020). However, this can be varied from 50 - 380 mg per 100 mL of coffee brew obtained from medium roasted coffee beans (Nawrot et al, 2003).

Moderate daily-intake of caffeine, *i.e.*, up to 400 mg, is not harmful (which is equivalent to 6 mg/kg of body weight) (Nawrot et al, 2003; Mitchell et al, 2013). If one consumes more than 500-600 mg of caffeine daily (or more than 4 cups of coffee), he or she is considered addicted to coffee, which can cause caffeinism (Nawrot et al, 2003). The overdose of caffeine can cause restlessness, anxiety, irritability, sleep disturbances, vomiting, diarrhea, headache, *etc.* The lethal dose of caffeine for an adult is considered to be 150-200 mg/kg) (Nawrot et al, 2003; Mitchell et al, 2013; Munyendo et al, 2021). Maximum caffeine concentration in blood is reached within 1-1.5 h after consumption and half-life of caffeine is 5 h. It passes through biological membranes easily (mostly *via* passive diffusion) (Nawrot et al, 2003; Mitchell et al, 2013). Thus, coffee is not recommended for pregnant women and breast-feeding mothers (Nawrot et al, 2003; Patay et al, 2016). The recommended caffeine dosage for mothers-to-be is less than 300 mg of caffeine per day (equivalent 4.6 mg/kg) (Nawrot et al, 2003; Mitchell et al, 2013). However, the caffeine content varies from coffee species to species (Arabica - 0.7-1.6 g/100 g, Robusta - 1.8-2.6 g/100 g) and brewing method (DePaula & Farah, 2019).

Polyphenols

Hydroxy cinnamic acid derivatives

Chlorogenic acids (CGAs) are the foremost phenolic compounds that can be obtained from leaves, fruits and seeds during maturation process (Moeenfard et al, 2014; Chen, 2019; Munyendo et al, 2021). In 100 mL of home brewed coffee, the amounts of CGAs present in Arabica and Robusta are 35–100 mg and 35-175 mg, respectively (Farah, 2012). CGAs are water soluble and naturally occur as mono or diesters of caffeic acid **14a**, ferulic acid **14b** and *p*-coumaric acid **14c**, which are derived from *trans*-cinnamic acid, bonded to quinic acid **15** (Figure 8) (Moeenfard et al, 2014; Chen, 2019; Ali et al, 2022; Galarza & Figueroa, 2022).



14a X = OH
14b X = OMe
14c X = H

15

Figure 8. Structures of caffeic **14a**, ferulic **14b**, *p*-coumaric **14c** and quinic acids **15**

Four types of CGAs are mainly found in coffee beans and each composed of three isomers; caffeoylquinic acids (CQA; 3-CQA **2a**, 4-CQA **2b** and 5-CQA **2c** - most abundant), **feruloylquinic acids** (Figure 9) (**FQA**; 3-FQA **16a**, 4-FQA **16b** and 5-FQA **16c**), **dicaffeoylquinic acids** (**diCQA**; 3,4-diCQA **3a**, and 3,5-diCQA **3b** and 4,5-diCQA **3c**) and *p*-coumaroylquinic acid (*p*-CoQA; 3-*p*-CoQA, 4-*p*-CoQA and 5-*p*-CoQA) (Chen 2019; Higashi 2019; Ali et al, 2022; Tritsch et al, 2022). These phytochemicals enhance the acidity, astringency and bitterness of brewed coffee (Moeenfard et al, 2014; Chen, 2019; Higashi, 2019).

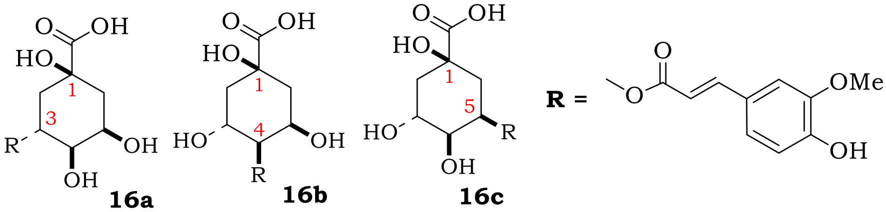


Figure 9. Structures of 3-FQA **16a**, 4-FQA **16b**, and 5-FQA **16c**

Other acids and phenolic compounds

Several acids such as maleic **17**, syringic **18** contribute to the acidity of coffee brew (pH 5.2-5.8) (Nigra et al, 2021; Tritsch et al, 2022; Ali et al, 2022). Caftaric acid **19**, gentisic acid **20**, benzoic acid, 3-OH-benzoic acid and protocatechuic acid are some of the phenolic acids present in coffee leaves (Figure 10) (Chen et al, 2019).

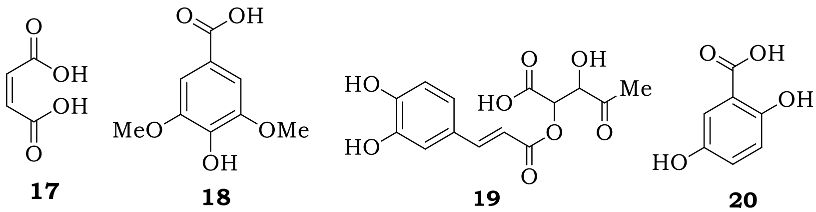


Figure 10. Structures of maleic acid **17**, syringic acid **18**, caftaric acid **19**, and gentisic acid **20**

Flavonoids

Catechins (Figure 11) (catechin **21**, epicatechin or EC **22**, epigallo-catechin-3-gallate or EGCG **23**, epicatechin-3-gallate or ECG **24**, epigallochatechin or EGC) are some of the flavonoids isolated from coffee beans and leaves. According to the European commission, the amount of ECGC should be less than 700 mg per liter of coffee-leaf tea, yet ECGC is a useful bioactive compound to reduce type-2 diabetes, cardiovascular complexions (Tritsch et al, 2022; Ali et al, 2022).

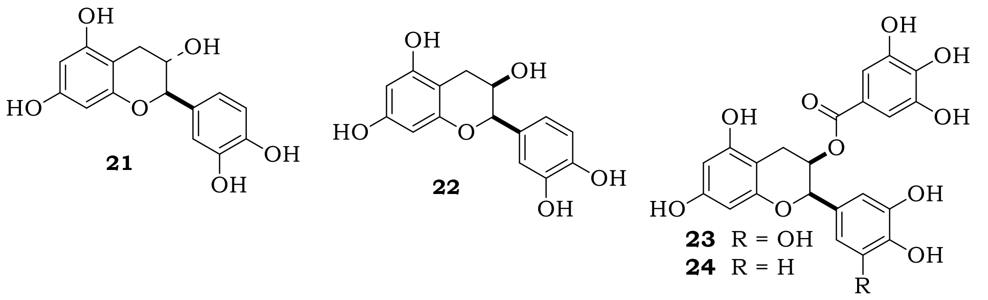


Figure11. Structures of catechin **21**, EC **22**, EGCG **23**, and ECG **24**

Myricetin, fisetin, patuletin **25**, luteolin, apigenin, quercetin **26** (and its glycosides) and kaempferol **27** (Figure 12) (and its glycosides) are some other flavonoids found in coffee beans (Ali et al, 2022).

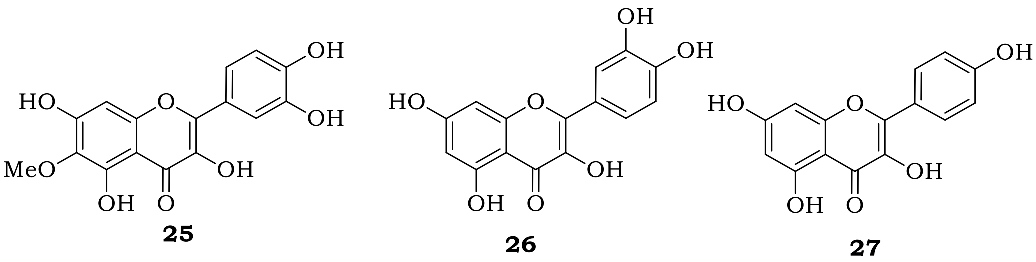
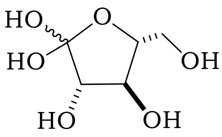


Figure 12. Structures of patuletin **25**, quercetin **26** and kaempferol **27**

Sugars

Fructose **28**, glucose **29**, arabinose **30**, (Figure 13) ribose, mannose and oligosaccharides are present in coffee seeds (Nigra et al; 2021). Upon roasting, 97% of the sucrose content in green coffee seeds is reduced as carbonyl groups in fructose and glucose combine with hydroxyl groups in amino acids (Farah, 2012). Various types of odorants are formed during caramelization through Strecker and Millard reactions (Nigra et al; 2021). During roasting, polymeric melanoidins are also formed; about 500-1500 mg of melanoidins are present in 100 mL of coffee brew obtained from medium roasted coffee beans (Farah, 2012; Nigra et al, 2021).



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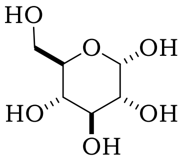

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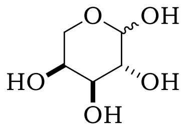

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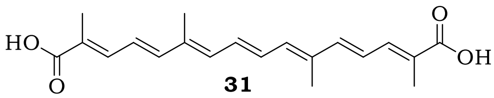
Figure 13. Structures of fructose **28**, glucose **29**, and arabinose **30**

Other phytochemicals

Crocetin **31** (Figure14) is a carotenoid (*i.e.*, a diterpenoid) which shows antioxidant, anti-inflammatory anti-diabetic and anti-cancer properties (Ali et al, 2022). Coffee seeds and leaves contain carotenoids, lipids, fatty acids (*e.g.*, linolenic **32**, oleic, arachidic, palmitic, steric, *etc.*), phytosterol such as sitosterol **33**, and vitamins (B and C) (Farah, 2012; Ahsan & Bashir, 2019; Maxiselly et al, 2022; Ali et al, 2022). The xanthan, mangiferin **34** (Figure14) is found in leaves and fleshy fruit parts (Chen, 2019). There is 0.8 mg of lipids present in 100 mL of coffee brew prepared from medium-roasted coffee (Farah, 2012).



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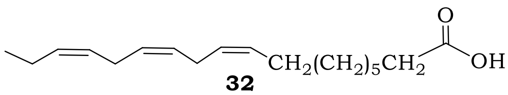

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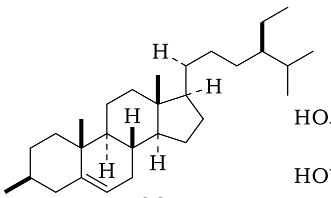

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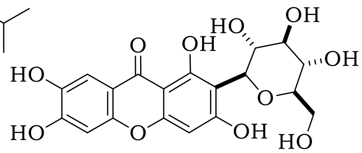

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Figure 14. Structures of crocetin **31**, linolenic acid **32**, sitosterol **33** and mangiferin **34**

Melatonin **35** and serotonin **36** (Figure15) are hormones that are detected in coffee beans; melatonin is well-known for scavenging free radicals from biological systems (Ali et al, 2022).

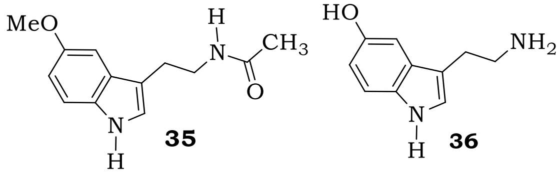

Figure 15. Structures of melatonin **35** and serotonin **36**

Volatile compounds

Various volatile compounds (Figure 16) are present in coffee beverages which are classified as (i) acids (2-methylbutyric acid **37a**, 3-methylbutyric acid **37b**); (ii) aldehydes (acetaldehyde **38**, propanal **39**, 3-methylbutanal **40**); (iii) esters (ethyl-2-methylbutyrate **41a**, ethyl-3-methylbutyrate **41b**); (iv) furan derivatives (furfural **42a**, 2-furfuryl methyl sulfide **42b**, furfuryl formate **42c**); (v) sulfur-based compounds (thiols, thiophenes), *etc*. They collectively contribute to the characteristic aroma of a particular coffee beverage. For example, esters are giving fruity fragrance to the coffee aroma, while propanal adds pungent and earthy smell to it (Yeretzian et al, 2019; Galarza & Figueroa, 2022).

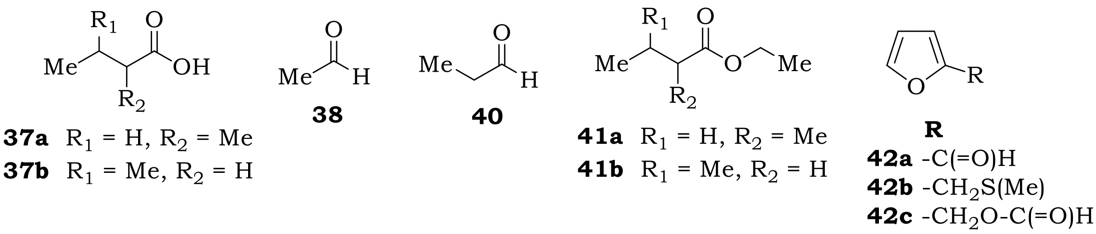

Figure 16. Structures of 2-methylbutyric acid **37a**, 3-methylbutyric acid **37b**, acetaldehyde **38**, propanal **39**, 3-methylbutanal **40**, ethyl-2-methylbutyrate **41a**, ethyl-3-methylbutyrate **41b**, furfural **42a**, 2-furfuryl methyl sulfide **42b**, and furfuryl formate **42c**

A summary of phytochemicals present in coffee is given in Table 1.

Table 1. Common phytochemicals present in coffee

Group	Name of the compound	Group	Name of the compound
Alkaloids	Caffeine **1**	Polyphenols	CQAs **2a-c**
	Trigonelline **5**		Di-CQAs **3a-c**
	Fontanesine B **10**		Mono or diesters of caffeic **14a**, ferulic **14b** and coumaric

			acids **14c**
	Theophylline **11a**		Quinic acid **15**
	Theobromine **11b**		Maleic **17**
	Vasicine **12**		Syringic **18**
	Beta-carboline **13**		Caftaric acid **19**
Flavonoids	Catechins {catechin **21**, epicatechin or EC **22**, epigallo-catechin-3-gallate or EGCG **23**, ECG or epicatechin-3-gallate **24**, EGC or epigallochatechin		Gentisic acid **20**
	Myricetin		Benzoic acid
	Fisetin		3-OH-Benzoic acid
	Patuletin **25**		Protocatechuic acid
	Luteolin	Sugars	Fructose **28**
	Apigenin		Glucose **29**
	Quercetin **26** (and its glycosides)		Arabinose **30**
	Kaempferol **27** (and its glycosides)		Ribose
Carotenoid	Crocetin **31**		Mannose
fatty acids	Linolenic **32**		Oligosaccharides
	Oleic acid		Melanoidins
	Arachidic acid	Phytosterol	Sitosterol **33**
	Palmitic acid	Vitamins	B and C
	Steric acid	Xanthan	Mangiferin **34**
Hormones	Melatonin **35**	Volatile compounds formed	2-Methylbutyric acid **37a**
	Serotonin **36**		3-Methylbutyric acid **37b**
Volatile compounds formed	Ethyl-3-methyl butyrate **41b**		Acetaldehyde **38**
	Furfural **42a**		Propanal **39**
	2-Furfuryl methyl sulfide **42b**		3-Methylbutanal **40**
	Furfuryl formate **42c**		Ethyl-2-methyl butyrate **41a**

Beverages of coffee

Coffee drinks are mainly categorized according to the brewing method (*e.g.*, espresso, cold brew, ristretto, *etc.*). Most of the coffee beverages are composed of espresso, steam and foam. Majority of the coffee drinkers in European countries consume espresso (concentrated coffee brew), while Americano (diluted espresso; hot water: espresso is about 1:3) is popular among American coffee lovers (Czarniecka-Skubina et al, 2021).

Various types of milk such as whole, semi-skimmed, skimmed, heavy cream, steamed, formed, *etc*. are added to prepare coffee beverages (Figure 17) (Rashidinejad et al, 2021). Macchiato, Vienna, mocha, cafe latte, cappuccino, breve, cortado and cafe au lait are some of the examples for milky coffee beverages (Rashidinejad et al, 2021). Casein proteins present in milk can interact with phenolic compounds, and mask certain desired qualities of coffee (Rashidinejad et al, 2021).

Figure 17. Various types of coffee beverages
https://delishably.com/beverages/Types-of-Coffee-Finding-your-Flavor

The caffeine content of the leaves depends on many factors such as processing, species, the age of the leaf, beverage preparation, *etc*. Robusta leaves consist of higher amount of caffeine when compared to Arabica species. The recommended safety daily intake of the coffee leaf tea is approximately around 600 mL, which is equivalent to 3 cups (Bizzo et al, 2015).

Green coffee beans have two-fold higher 5-CQA quantities than roasted coffee. The beverages that are prepared by green coffee have been popular for body weight loss (Samoggia & Riedel, 2019).

Medicinal applications

Coffee plant is one of the most popular ethnomedicinal plants, in many countries. Haiti uses roasted coffee seeds for anemia and root extract for measles (as a bandage for children) (Patay et al, 2016). "*Hoja*" is a beverage made from roasted coffee bean pulps and it is taken alone or with milk, butter, honey or salt (Teketay, 1998). This is a well-known Ethiopian folk medicine used for treating food poisoning, nausea and diarrhea (Patay et al, 2016). The Africans use leaf sap of Arabica to treat diarrhea and intestinal pain (Patay et al, 2016). The Cubans use fresh leaves to heal migraine, and the Nepalese consume flowers as a medicine for excessive bleeding during menstruation (Patay et al, 2016).

Moderate consumption of coffee, (up to 4/3 cups per day) reduces the risk of causing cancers (in kidneys, liver and colon) due to compounds such as polyphenols, essential oil and diterpenoids (Nigra et al, 2021). Coffee may reduce the risk of getting type II diabetes by 60%; because, CGA decreases the glucose production in liver while caffeine stimulates the insulin production of beta-cells in pancreas (Ahsan & Bashir, 2019; Nigra et al, 2021). However, coffee beverages increase the secretion of gastric acid levels since they are composed of high amounts of aromatic substances (Ahsan & Bashir, 2019). Coffee seeds also reduce the disorders of gall-bladder. Coffee exhibits a high antioxidant activity, antimicrobial, anticancer and hepato-protective properties, due to the presence of a large number of polyphenolic compounds (Patay et al, 2016; Samoggia & Riedel, 2019; Czarniecka-Skubina et al, 2021; Nigra et al, 2021, Mohammad et al, 2023). Green coffee beans would help to control the blood glucose level and reduce uricaemia, which identified as a cardiovascular risk (Jácome et al, 2009).

The powdered leaves and stems of the coffee plant are used against allergic reactions in the skin (Chen, 2019). The green coffee seeds are utilized as sun protectors in the cosmetic industry; linolenic acid **32** blocks harmful UV rays (Lestari et al, 2023).

“A yawn is a silent scream for coffee”; coffee is a well-known stimulant of the central nervous system and respiratory system. Thus, it may reduce the risk of causing Parkinson’s disease (Acidri et al, 2020; Seninde & Chambers IV, 2020; Nigra et al, 2021). Coffee increases the effect of paracetamol and aspirin, even though it may neutralize some of the actions of herbs (Patay et al, 2016). Cafestol **6** and kahweol **7** were found to reduce the genotoxicity as these two compounds enhance the production of low density lipo-proteins in blood (Ahsan & Bashir, 2019).

As a downside of coffee consumption, scientists have discovered that caffeine decreases the calcium level in the body (Ahsan & Bashir, 2019). One coffee cup can decrease 4-7 mg of calcium and this enhances the risk of bone fractures. High intake of coffee (500-1000 mg per day) may delay the period of conception in women (Ahsan & Bashir, 2019; Samoggia & Riedel, 2019).

Consumption of coffee may also reduce the risk of getting cancer (Patay et al, 2016). Antioxidant and anti-inflammatory activities of phytochemicals in coffee protect the human cells by preventing DNA mutations (Cornelis, 2019; Czarniecka-Skubina et al, 2021; Pintać et al, 2021; Ali et al, 2022; Montenegro et al, 2022, Shen et al, 2023). To enhance these properties, coffee is mixed with spices such as nutmeg, cardamom, ginger, cinnamon, fennel, cloves, black or ground hot red pepper by Ethiopians (Teketay, 1998).

Summary of medicinal values of some of the phytochemicals is given in Table 2 (Nigra et al, 2021).

Table 2. Summary of medicinal value of phytochemicals

Compounds	Medicinal values
Caffeine **1** (at safe level)	As an antioxidant, anticancer and anti-inflammatory agent
Trigonelline	As a hypoglycemic, neuroprotective, antitumor (anti-invasive), antibacterial, and antiviral agent
CQAs **2**, FQAs **16**, di-CQAs **3**	As an antioxidant, anticancer, anti-inflammatory, antibacterial, antipyretic, hepatoprotective, and neuroprotective agents; can help prevent retinal degeneration, obesity, and hypertension
Cafestol **6**, kahweol **7**	As anti-inflammatory, hepatoprotective, anticancer (tumor cell-inducing apoptosis and antiangiogenesis), antidiabetic, and antiosteoclastogenesis agents
Caffeic acid **14a**	As an antioxidant, antitumor, anti-inflammatory, and immune regulation agent
Melanoidins	As a antioxidant, chelating, antimicrobial, antimutagenic, anticariogenic, antihypertensive, anti-inflammatory, and antiglycative agent
Nicotinic acid **9**	For repairing DNA, suppressing tumors, and to inhibit cancer cell invasion (blocking epithelial-mesenchymal transition).
Flavonoids	As antioxidants, antiaging, anti-inflammatory, immunomodulation, cardioprotective, antibacterial, antiviral, antiparasitic, antihypertensive, antiulcerogenic, antidiabetic, anticancer, and hepatoprotective agents

Generally, consumption of coffee is not recommended for people who suffer from high blood pressure, coronary heart disease, kidney and certain neurological diseases, stomach ulcers, hyperthyroid, *etc.* (Chen, 2019; Nigra et al, 2021). It is better to avoid taking strong coffee beverages during pregnancy and lactating (Ahsan & Bashir, 2019).

Conclusions

Coffee is generally prepared using roasted coffee beans. Coffee cherries are subjected to wet or dry processing to obtain coffee beans. During roasting, exothermal and endothermal reactions occur in seeds that changes the amounts of phytochemicals present in coffee beans. Instant coffee powder is prepared by drying and powdering the roasted coffee seeds. Alkaloids such as caffeine, trigonelline, theobromine, and theophylline, polyphenols (*i.e.,* mainly CGAs), flavonoids (*e.g.,* catechins), sugars, tannins, hormones, and carotenoids are present in coffee beans and leaves. These compounds exhibit antioxidant, anti-inflammatory, anticancer, anti-diabetes, antimicrobial, hepatoprotective, and cardio protective properties. Caffeine is the most controversial alkaloid present in coffee, which can have a negative effect upon excessive consumption. The decaffeination process has been introduced to remove caffeine to a safe level for daily consumption. Prominently, leaves and seeds are applied as folk medicine. Coffee is not recommended for pregnant and lactating mothers; higher consumption of coffee may lead to bone fractions. However, moderate consumption of coffee is recommended.

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