The drink commonly named “coffee” is produced after the roasting of beans of *Coffea* (see the chapter on roasting). The roasted beans are ground, and the powder obtained is extracted with hot water in order to make the beverage. This chapter describes the grinding and extraction processes; the resulting beverage is then characterized chemically.

### Grinding

In coffee industry jargon, grinding refers to the process of breaking down the coffee beans into a powder (Illy and Viani, 2005). This is carried out by a device called a coffee grinder, and the product obtained is called ground coffee. The main objective of grinding is to increase the exchange surface of coffee material with water, facilitating the transfer of soluble substances present in the coffee bean to the aqueous “extract”, which will become the so-called “coffee” beverage (Andueza *et al.*, 2003).

#### Influence of Particle Size

The average particle size distribution (usually abbreviated to PSD) of the powder influences the efficiency of the extraction: the smaller the particle, the bigger the specific surface, and the better the extractability of the compounds that give to coffee the properties for which it is appreciated (von Blittersdorff and Klatt, 2017). An example of a particle size distribution obtained by laser diffraction is given in Figure 21.1 (Primavera *et al.*, 2014).

However, there can be two drawbacks if the particles are too small. Firstly, this can increase the percolation time or even block percolators or filters. Indeed, the size of the particles will also determine how easily water will flow through the coffee powder during extraction, and very fine particles (usually below 100 μm) will block the pathways for water and impede the separation of the spent ground coffee from the extract by clogging the filter pores. In this case, the contact time between the water and the ground coffee will be increased, resulting in an over-extraction of some compounds, imparting bitterness and astringency in particular (Baggenstoss *et al.*, 2008a; Folmer, 2016).

Secondly, it has been shown that the finer the average particle size, the faster the rate of extraction by water of soluble solids and volatile components of the coffee (Clarke *et al.*, 1987). Thus, small and irregular particles can release their soluble substances too fast and lead to a beverage that is often considered “too concentrated”. Also, these particles can pass through the pores and end up in the cup (Folmer, 2016).

On the other hand, Puhlmann and Habel (1989) showed that coarsely ground coffee results in the appearance of large channels between particles. During the extraction, water flows in these channels at high speed (in particular with percolation methods); the bigger the particles, the easier and the faster the water flow will be (Folmer, 2016). For some brewing techniques, the contact time between the water and the ground coffee may be too short for the compounds to be appropriately extracted with coarsely ground coffee.

![Figure 21.1](image_url)

**FIGURE 21.1** Particle size distribution for two different commercially available coffee blends. (Primavera *et al.*, 2014)
All this explains why the grinding process aims to create an appropriate PSD, balancing the water flow, neither too fast nor too slow, for which the particles should not be too large or too small, and diffusion, which increases with the decreasing size of the particles. Each coffee preparation method requires a particular PSD (Clarke, 1987; Puhlmann and Habel, 1989; Baggenstoss et al., 2008b; Folmer, 2016; von Blittersdorff and Klatt, 2017). The “appropriate” grind size can be obtained by operators and baristas in part by choosing the appropriate mill for the intended brewing method. The different main grinding methods are described in the following section.

Different Grinding Methods

There are two main types of grinding techniques, which differ according to their application: (1) “impact grinding”, designed for on-demand grinding, and (2) “gap grinding”, designed to work 24 hours a day, 7 days a week, for industrial application (von Blittersdorff and Klatt, 2017).

Impact grinding is carried out by rotating blades colliding at high speed (between 1000 and 9000 rpm) with the particles encountered in their path. Since the ground coffee remains between the blades even after being ground and therefore undergoes many impacts, this technique does not easily control the particle size, and the size distribution of the powder is dependent on the duration of the operation. That is why it is only used for small-scale grinders, for commercial use at the point of sale, or in grinders for private use (Illy and Viani, 2005).

Gap grinding is based on the passage of the beans through a space between mobile tools, called “cutting tools” (von Blittersdorff and Klatt, 2017). The geometry of the blades results in a gradual reduction in the width of the space during rotation, forcing the particles to come into contact with the two blades. Depending on the shape of the cutting surfaces, a compression or a shear strain is applied. There are usually a number of grinding stages; Figure 21.2 shows one pair of rolls but there are generally many in succession in a roller grinder (between five and ten).

With this technique, the average particle size is more homogeneous and easier to control than with impact grinding. Moreover, the process can be done continuously, hence lending itself to industrial application (Illy and Viani, 2005; Baggenstoss et al., 2008a).

Beside the type of grinder used, other parameters influence the grinding process; the main ones are described in the following section.

Parameters Influencing the Grinding Process

One of the important variables influencing the grinding process is the quality of the coffee beans, as this raw material can come from different botanical varieties and different producing countries, where it undergoes different drying and processing methods. As a result, the miller is confronted with beans with a variable chemical composition, and this results in differences of resistance to grinding. In addition, as coffee is an agricultural product subject to the variability of climate and natural evolution, the hardness and water content of the beans can differ between batches. It has been shown that coarser particles are obtained from coffee beans with high moisture content upon grinding (Baggenstoss et al., 2008b).

During the roasting process, coffee beans change their textural properties, losing strength and toughness, and becoming progressively more brittle, due to chemical, physical and structural modifications (see chapter on roasting). Pittia et al. (2001) showed that the typical brittleness of roasted coffee beans seems to be related both to the decrease of density and to the water loss. Indeed, the density of green coffee beans is between 550 and 700 g/L, while the density of roasted beans is reduced to 300–450 g/L (Schenker et al., 2000). According to grinding tests with beans with different water contents (Puhlmann and Habel, 1989; Andueza et al., 2003), the proportion of fine particles is larger when the water content is lower. So, beans become more and more brittle during the roasting process, and depending on the roasting conditions (temperature, time and roasting speed), the coffee will be more or less hard to grind. In conclusion, grinding natural products such as coffee beans generates many particles of different sizes and shapes. The PSD can be characterized after grinding by different methods; techniques such as sieving, image analysis and laser diffractometry can be used to measure the fineness of grains (von Blittersdorff and Klatt, 2017).

Extraction and Characteristics of the Resulting Beverage

The goal of extraction is to bring into contact the solid particles and the solvent (water) with a view to performing a mass transfer of soluble compounds into the solvent. Then the resulting solution
Coffee Preparation

is separated from the residual solid, often by filtration. The mechanism of extraction is favored by an increased specific surface (surface per unit volume of solids), and thus a decreased radial distance that must be traversed within the solids; this can be controlled by the grind size, as discussed in the grinding section.

Numerous coffee extraction methods exist. The so-called brewing methods are generally characterized by the extraction pressure of the water, the extraction process and tool, and the volume of the extract obtained. The pressure of water used for coffee extraction, except for coffees made by infusion (because the soluble coffee particles will only diffuse freely in the solution), is not an independent variable; it is the result of the equilibrium between the applied force on top of the coffee bed (through the water) and the resistance of the coffee bed against water percolation. Each extraction method has its own driving force and its typical coffee bed properties. As a result, each technique is characterized by its own range of extraction pressures.

The most common methods are: expresso (or espresso), percolation, filtered, moka, French press, and boiled coffee (Illy and Viani, 2005):

- Expresso is a concentrated beverage of 20 to 40 mL, brewed by forcing hot water (temperature 90–100 °C) at high pressure (from 9 up to 19 bars) through finely ground coffee, with a contact time in the order of seconds. It is generally prepared immediately before consumption (Farah, 2012; Gloess et al., 2013; Folmer, 2016). To prepare an expresso, the external force is delivered by a pump, allowing higher pressures to build up than with other methods.
- Percolation is an infusion method, which consists of distributing the ground coffee evenly in a filter placed on a support; hot water is then poured over the coffee in a circular motion towards the center of the filter (Farah, 2012).
- For boiled coffee (also called Greek coffee or Turkish coffee), the water is poured over finely ground coffee or sprayed into a saucepan and heated; when the water starts to boil, the mixture is poured, unfiltered, directly into the cup, and only the upper part of the product is consumed (Farah, 2012).
- For the Italian press, or moka pot, water is placed at the base of the kettle, which contains a pressure valve. When the kettle is heated, the water flow through the ground coffee is continuously pressurized to the top compartment (Farah et al., 2012). For moka preparation, lower pressures than for expresso are generated by a steam/vapor pressurized chamber.
- The French press consists of mixing coarsely ground coffee and hot water in a special machine equipped with a mesh piston. After a few minutes of infusion, the piston is pressed to trap the coffee grounds at the bottom of the cup, and the upper infusion is poured into the cup (Farah, 2012).

The type of extraction method used depends on geographic, cultural and social context, as well as on personal preferences (Petracco, 2008).

The following paragraphs describe the general chemical composition of the resulting beverage and then the impact of the coffee preparation method (the brewing method, pressure, temperature and coffee/water ratio used) on the composition of this resulting coffee extract. The final section is devoted to the impact of this chemical composition on the organoleptic properties.

Chemical Composition of the Extract

Different factors affect the brew’s composition, including not only the ground roast coffee composition but also the brewing method, the proportion of coffee to water, the temperature and composition (hardness) of water, the time of contact between coffee and water, and the filter material. Here we present only the compounds that are generally present in a coffee extract.

The brewed coffee is mainly composed of water, non-volatile acids, soluble saccharides, protein, caffeine and melanoids (Barter, 2004). The amount of soluble solids in the brewed coffee is generally between 2 and 6 g/100 mL (Farah, 2012; Chu, 2012).

A more detailed description of the different main compounds is as follows:

Saccharides: polysaccharides comprise up to 15% of the total solids of the coffee brew (Díaz-Rubio and Saura-Calixto, 2007). Galactomannan [1] and arabinoxylan of type II [2] are the predominant polysaccharides of coffee brews (Nunes and Coimbra, 2001; Gniechwitz et al., 2008; Bekedam et al., 2008). Single-dose coffee capsules have been shown to contain galactomannans as the predominant polysaccharides over arabinoxylan (Lopes et al., 2016).
According to Petracco et al. (2008), a typical amount of soluble fibers in expresso coffee is 800 mg/100 mL, and a regular percolation method produces approximately 200 mg/100 mL of these. Similarly, Díaz-Rubio and Saura-Calixto reported 470–750 mg soluble fiber in 100 mL brewed coffees (Díaz-Rubio and Saura-Calixto, 2007).

D-Mannose [3], followed by D-galactose [4], are the main residues of polysaccharides from single-dose expresso coffee. L-Arabinose [5], D-glucose [6] and L-rhamnose [7] are present in lower amounts (Lopes et al., 2016).
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Organic acids: approximately 80–100% of chlorogenic acids (Figure 21.3) from the beans are extracted in home coffee brewing, resulting in between 35 and 175 mg chlorogenic acids/100 mL cup of coffee (Clifford, 1997).

In addition to free chlorogenic acids and those incorporated by melanoids, Díaz-Rubio and Saura-Calixto (2007) reported that 8.7–10.5 mg chlorogenic acids and their derivatives are associated with soluble fiber in 100 mL brewed coffee.

The acidity of coffee is also due to non-aromatic organic acids such as acetic [8], formic [9], malic [10], citric [11] and lactic [12] acids, as well as chlorogenic and quinic acids [13]. The pH varies from approximately 5.2 in a brew made from light roast to 5.8 in a brew made from dark roast (Kurt and Speer, 1999).

Nitrogenous compounds: caffeine [14], trigonelline [15] and nicotinic acid [16] are also compounds from the roasted beans that are soluble in hot water. Typical amounts in brewed coffee prepared with medium roasted coffee are 50–100 mg for caffeine, 40–50 mg for trigonelline and about 10 mg nicotinic acid. Trigonelline tends to be completely degraded in dark roasts, whereas nicotinic acid content is formed during roasting (Perrone et al., 2008).
Lipids: the lipid fraction of coffee brew is mainly composed of triglycerides (Figure 21.4) and bioactive diterpenes. Triacylglycerols account for approximately 75% (w/w) of total coffee lipids in freshly brewed coffee, whereas free fatty acids account for only approximately 1% (Trugo, 2003).

The major diterpenes present in coffee are cafestol [17], kahweol [18] (Ratnayake et al., 1993; Urgert et al., 1995; Gross et al., 1997) and sterols. The major category of sterol, accounting for approximately 93% of total sterols in coffee, is 4-desmethylsterols (Farah, 2012; Speer, 2006), including compounds such as campesterol [19], stigmasterol [20] and sitosterol [21] (Itoh et al., 1973; Farah, 2012; Ratnayake et al., 1993; Chu, 2012).
Proteins: the protein content of coffee ranges from 16.93 to 29.70 mg per cup of expresso coffee (Lopes et al., 2016).

Melanoidins: melanoidins are water-soluble, high-molecular-weight polymers (Ledl and Schleicher, 1990; Nunes et al., 2012). Gniechwitz et al. (2008) isolated different fractions of coffee, including those containing melanoidins, and estimated their molecular weights to be between 3 and 22 kDa. The composition and structure of melanoidins from food sources are still being discussed. Melanoidin molecules have been shown to be made up of many different residues, including sugars, proteins and phenolic compounds (Nunes and Coimbra, 2001; Moreira et al., 2015). The high structural diversity of melanoidins makes their analysis and quantification difficult. Since melanoidins are composed of very diverse material, their level is usually determined by calculating the difference between the amount of high-molecular-weight material (HMWM) and the amount of polysaccharides and protein. The melanoidin content of regular expresso coffees analyzed ranged from 69.8 to 145.6 mg per cup, calculated as the difference in the mass between the total HMWM in the fraction and the mass of protein and polysaccharides (Lopes et al., 2016).

Minerals: coffee beans contain about 4% minerals, of which 40% is potassium (K). The other metals found in coffee are sodium (Na), calcium (Ca), magnesium (Mg), iron (Fe) and manganese (Mn). These elements are mainly present in the form of cations and can therefore be extracted in coffee brew (Antonio et al., 2011; Valentin and Watling, 2013; Stelmach et al., 2015).

Impact of the Coffee Preparation Method

Impact of the Brewing Method

The impact of the brewing method on the chemical composition, in particular on the quantity of caffeine [14], chlorogenic acids and non-aromatic acids, has been the subject of numerous studies (Peters, 1991; López-Galilea et al., 2007; Fujioka and Shibamoto, 2008; Pérez-Martínez et al., 2010; Gloess et al., 2013). Figure 21.5 shows the distribution of fatty acid content, caffeine and chlorogenic acids according to different extraction methods obtained by Gloess et al. (2013).

According to these studies, it appears that the levels of caffeine [14] and chlorogenic acids vary with the brewing method. In general, the concentration of the extracted compounds in the brew was highest for expresso, followed by the moka extraction (Gloess et al., 2013; López-Galilea et al., 2007; Peters, 1991). Indeed, the highest concentration of caffeine was measured in expressos (21.0 ± 0.4 mg/10 mL), and the lowest was for filter coffee (4.7 ± 0.1 mg/10 mL) (Gloess et al., 2013). Lower or higher values can be found depending on the type of coffee used: different variety or origin, for example (Peters, 1991, López-Galilea et al., 2007). In the case of the chlorogenic acids, again expressos had the highest concentrations (Balakrishnan et al., 1961; Gloess et al., 2013).

Moreover, when compared with other common coffee beverages, the acrylamide [22] concentration was higher in expressos (Alves et al., 2010b). However, comparing the different brewing methods...
showed that espresso contained more isoflavones [23] (∼170 μg/30 mL) than a cup of press-pot coffee (∼130 μg/60 mL), but less than a moka coffee (∼360 μg/60 mL), and amounts similar to those of a filtered coffee cup (∼180 μg/120 mL) (Alves et al., 2010a). Costa et al. (2010) observed that the total mineral extraction achieved by expresso machines and electric coffee makers was higher than that for all other percolation methods.

Usually, the extraction of water-soluble components, including chlorogenic acids, caffeine [14], nicotinic acid [16], soluble melanoidins and hydrophilic volatile compounds, is greater at higher temperatures and pressures (Trugo and Macrae, 1984). More specifically, the effectiveness of extraction process scales higher temperatures and pressures (Trugo and Macrae, 1984).

The brewing method also impacts the lipid content, even though the content is very low (below 0.2%, w in all cases (Ratnayake et al., 1993), contrary to what is sometimes published in popular literature about coffee.

Although the lipid content can vary depending on the brewing method, the method of preparation of the brew and filtration had no important influence on the lipid composition (Ratnayake et al., 1993).

During paper filtration, lipids remain mainly in spent coffee grounds, and the brew and filter paper retain only 0.4% and 9.4%, respectively, of the total lipids recovered (Ratnayake et al., 1993). Oil droplets are likely to be retained in filters made of paper or similar types of materials. The high pressure used to make expresso and the absence of a filter made of paper or other compounds, such as 4-O-cafeoyl quinic acid and 3-O-cafeoyl-γ-quinide (Figure 21.3), are washed out in the first few seconds of the extraction process under high pressure, while other compounds, such as 4,5-O-dicaffeoyl muco-quinide or tocopherol, are released rather slowly, and less water-soluble compounds, like chlorogenic acids or isoflavones [23], show strong retention by the ground coffee material. This type of compound can therefore be found in larger or smaller quantities in extracts depending on the quantity of water used.

The extraction of some water-soluble compounds, like caffeine, tocopherols and chlorogenic acids, increases when the coffee/water ratio is higher (Andueza et al., 2003; Alves et al., 2010a) (Figure 21.3), are washed out in the first few seconds of the extraction process under high pressure, while other compounds, such as 4,5-O-dicaffeoyl muco-quinide or tocopherol, are released rather slowly, and less water-soluble compounds, like chlorogenic acids or isoflavones [23], show strong retention by the ground coffee material. This type of compound can therefore be found in larger or smaller quantities in extracts depending on the quantity of water used.

Impact of Coffee/Water Ratio

The impact of the coffee/water ratio on the extraction of the constituents of coffee has been the subject of numerous studies (Blumberg et al., 2010; Alves et al., 2010a; Gloess et al., 2013), which have shown that some of the water-extractable components, such as 4-O-cafeoyl quinic acid and 3-O-cafeoyl-γ-quinide (Figure 21.3), are washed out in the first few seconds of the extraction process under high pressure, while other compounds, such as 4,5-O-dicaffeoyl muco-quinide or tocopherol, are released rather slowly, and less water-soluble compounds, like chlorogenic acids or isoflavones [23], show strong retention by the ground coffee material. This type of compound can therefore be found in larger or smaller quantities in extracts depending on the quantity of water used.

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In addition, the acidity can vary with the brewing method (Peters, 1991; Verardo et al., 2002; López-Galilea et al., 2007). The pH of regular and decaffeinated coffees ranged from 4.95 to 5.99 and from 5.14 to 5.80, respectively (Fujikura and Shibamoto, 2008). Expresso is the most acidic brew (pH 5.51) and French press coffee is the least acidic brew (pH 5.92) (Gloess et al., 2013).

The extraction method therefore has a significant impact on the resulting chemical composition of the coffee beverage. Other factors play a role, such as pressure, temperature used and water quantity.
Furthermore, factors such as the method of brew preparation, the degree of roast, brew volume and temperature of extraction affect the saccharide composition of expresso coffee. Coffees with low water content were extracted more effectively than high-moisture coffees, and percolation was slower (Baggenstoss et al., 2008a).

### Organoleptic Properties of the Resulting Beverage

The flavor of coffee is based primarily on odorant and taste compounds, but some trigeminal and proprioceptive effects also occur. Over 1000 volatile compounds have been identified in roasted coffee, but not all of these compounds have been found to be relevant in terms of the odor (Akiyama et al., 2005). Only 5% of these compounds (~50) may be responsible for the odor of coffee. These compounds include pyrazines [25], furans, aldehydes, ketones, phenols and sulfur compounds, among others (Toci and Boldrin, 2018).

A series of studies focused on the identification of the bitter-tasting molecules in coffee (Chen, 1979; Andueza et al., 2003; Charalambous et al., 2012). They suggested that the alkaloids caffeine [14] and trigonelline [15], as well as thermally generated compounds such as furfuryl alcohol [26], 5-hydroxymethyl-2-furanaldehyde [27] and pyrazines [25] (Clarke and Vitzthum, 2017), contribute to the bitter taste of coffee. Caffeine [14] and chlorogenic acid are compounds related not only to bitterness but also to astringency.

Other studies revealed that, during coffee roasting, the major polyphenols in raw coffee are thermally transformed into the bitter-tasting caffeoyl quinic acid lactones, such as 5-O-caffeoyl-muco-\(\gamma\)-quinide, 3-O-caffeoyl-\(\gamma\)-quinide, 4-O-caffeoyl-muco-\(\gamma\)-quinide, 5-O-caffeoyl-epi-\(\delta\)-quinide, 4-O-caffeoyl-\(\gamma\)-quinide, 3,4-O-dicafeoyl-\(\gamma\)-quinide, 4,5-O-dicafeoyl-muco-\(\gamma\)-quinide and 3,5-O-dicafeoyl-epi-\(\delta\)-quinide (Chen, 1979; Blank et al., 1992; Deibler and Delwiche, 2003; Adriana et al., 2005; Frank et al., 2006; Charalambous et al., 2012; Clarke and Vitzthum, 2017).

The organoleptic properties of expresso coffee, particularly its body, are affected by saccharide content and composition, since saccharides act as viscosity enhancers, guaranteeing foam stability (Nunes et al., 1998).

It has been shown that there is only a moderate correlation between pH and acidity perception (Balzer, 2008). Furthermore, some of these acids, such as chlorogenic, together with caffeine and other compounds, can also contribute to bitterness, modifying the typical bitterness–acidity balance of expresso coffees (Illy and Viani, 2005).

The fraction of HMWM recovered from coffee is responsible for the characteristic color of the brews and also has an impact on mouthfeel, flavor and aroma due to the interaction with other compounds. It is composed of saccharides (52%), proteins (10%), polyphenols (5%) and also a large number of brown compounds, the melanoidins (Coelho et al., 2014).

Blending is used to optimize odor, mouthfeel and flavor; it allows production of a coffee that provides higher cup quality than can be obtained with any of the ingredients used individually and helps to maintain consistency in the final roasted product.

There is still a poor understanding of the relationships between the odorant compounds and the various factors that affect the odorant fraction, despite the considerable number of articles that have been published on this subject. The main difficulties are deficiency of adequate analytical quantification, lack of comparisons involving the various parameters that influence the odor (Toledo et al., 2017), and a lack of uniformity in the data presented in different studies, which hinders satisfactory comparison. For example, filtered and expresso coffee beverages have been most extensively studied, mainly because these types of drinks are more widely consumed in many countries. The consumption of moka, French, and Greek or Turkish coffee drinks is more geographically restricted, so these types have been less studied. The different beverages are produced using different aqueous extraction systems that extract compounds with medium and high polarity, and coffee powder is rich in many classes of compounds with such characteristics (Toci and Boldrin, 2018).

### Conclusions

Many studies focus on the question of making a “good” coffee, and they try to identify extraction parameters that can be applied to make the “best” possible coffee. However, it should be observed that this question is not a good one, because since the goal is imprecisely defined, the way to reach it cannot be found with certainty. The definition of “good coffee” depends on culture and individual taste, so it is useless to try to find “the best process”. One needs a clear definition of the properties of the brew in order to select the right parameters.

The real question is: if you want a profile of soluble and odorous compounds, what are the methods of grinding and preparing the drink to be chosen?

### REFERENCES


Coffee Preparation


