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# Coffee: From Origin to Taste History, Production, Consumption, And Sensory Analysis of Coffee

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## Abstract

Coffee is one of the most consumed beverages in the world, with historical, cultural, and economic significance. In Brazil, the largest producer and the second-largest global consumer, coffee plays a fundamental role in agribusiness and national identity. In recent decades, the market has undergone significant transformations, with the rise of specialty coffees and the strengthening of the so-called coffee waves, which have brought new insights into quality, sustainability, and sensory experience. Sensory analysis has emerged as an essential tool for understanding the attributes of the beverage, differentiating varieties, preparation methods, and consumption profiles. This review article addresses: (i) the historical trajectory of coffee; (ii) production and consumption in Brazil and worldwide; (iii) the quality and sensory attributes of the beverage; (iv) the main sensory analysis methodologies applied to coffee; (v) the potential health benefits related to bioactive compounds; and (vi) future prospects for the sector. The goal is to offer a comprehensive overview that combines science, market, and consumer behavior, contributing to the appreciation of coffee farming and to understanding Brazil's role as a global benchmark for quality coffee.

**Keywords:** CATA; consumption; sensory analysis; specialty coffees; Pernambuco

## Introduction

Without a doubt, coffee is one of the most appreciated beverages by the Brazilian population. According to the Brazilian Coffee Industry Association-ABIC, Brazil is the largest coffee producer in the world, with production reaching 3.7 million tons in 2020, 25% higher than in 2019 [1]. With this expressive production, Brazil, the world's largest exporter, accounts for approximately 29% of exports, 15% of which are specialty coffees [2]. Although most of the export volume is commodity coffee (with low added value), this scenario has changed due to the growing demand for products with greater typicity and market value [3].

These demands from the importing market have led Brazilian coffee farmers to explore specialty and gourmet coffees [4]. Moreover, both national and international coffee shops have prioritized the purchase of beans with differentiated cultivation and processing, offering consumers unique sensory experiences.

The valorization of specialty and gourmet coffees as complex products, appreciated for their sensory characteristics and intrinsic physicochemical composition, associated with the preference for beans from small regions of production with typicity, food safety, and reduced environmental impact, characterizes the Third Wave of Coffee [5-6].

Since early 2020, we have been experiencing a transition between the Third and Fourth Wave of the coffee market. The latter is characterized by the migration from physical stores (coffee shops, bars, and restaurants) to e-commerce of beans and ground coffee, brewing utensils, subscription clubs, and online courses [7]. Critical awareness regarding origin, quality, and product safety intensified after the pandemic, leading to new quality demands, largely due to increased emphasis on sustainability [8].

Coffee quality is associated with its complex chemical composition, including carbohydrates, lipids, nitrogen compounds, vitamins, minerals, phenolic compounds, and alkaloids. Moreover, the presence of bioactive compounds, such as chlorogenic acid, provides antioxidant activity [9], with consequent beneficial effects on human health (reduction of cardiovascular and metabolic disease risk, and prevention of non-communicable degenerative diseases) [10-11]. Thus, health

claims such as energizing and phytotherapeutic effects have influenced consumers' beverage choices [12].

Beyond its health benefits, sensory attributes are important quality parameters (aromas, acidity, body, bitterness, and astringency), expressed differently depending on terroir [13]. Different extraction methods have been used to intensify these attributes by modifying chemical composition [14]. Among extraction methods, filtered brews (Melitta®, Hario V60®, and Koar®) enhance flavor complexity and reduce acidity compared to espresso, allowing consumers to appreciate the beverage's intricacy [15].

Sensory analysis is an important tool for determining consumer-perceived attributes, contributing to improvements in coffee quality. It has been widely used across the coffee production chain for validating the final product's quality [16]. For consumers, product choice is strongly linked to the acceptance of sensory attributes. In this context, focusing on consumption trends is a strong marketing strategy and a way to differentiate coffee. Therefore, sensory analysis methodologies that consider the many factors inherent to each consumer and/or product must be explored [17].

Consumer participation in faster and more flexible sensory methods, such as the Check-All-That-Apply (CATA) method, enables the sensory characterization of foods and beverages, including coffee. In CATA, attributes are described in colloquial language, allowing consumers to quickly and easily select perceived attributes that they consider appropriate to characterize a product [18-19]. This methodology has been widely used in consumer-based descriptions of sensory attributes in foods and beverages [19-24].

In summary, the growing recognition of specialty coffees in Brazil reflects both the search for sensory quality and for sustainability and health benefits. The use of sensory analysis methodologies, such as CATA, makes it possible to understand consumer preferences with precision, guiding strategies for product differentiation and improvement. Thus, studies in this area are essential to strengthen the competitiveness of Brazilian coffee in the global market and to promote increasingly sustainable production aligned with contemporary demands.

## The Origin of Coffee

The coffee plant was initially classified in 1735 by Antoine Jussieu as Jasminum arabicum, due to the visual and olfactory similarity of the shrub's flowers to jasmine, and was reclassified in the mid-18th century by Linnaeus as the genus Coffea [25-26]. However, botanists of this period were unable to agree on a precise system for its designation and classification, mainly due to the wide variation in plants and seeds within the genus Coffea [27]. There are at least 25 important species, all native to tropical Africa and some islands in the Indian Ocean, Madagascar in particular [28].

In 1753, Linnaeus classified the main cultivated species as Coffea arabica, despite its Ethiopian origin [29]. Coffea arabica is native to the Abyssinian Mountains, present-day Ethiopia, on the African continent. Some suggest that this species received the name Arabica due to its adaptation to high altitudes, and is found in Central and South America, cultivated primarily in Brazil and other countries in Africa and East Asia [30-31].

The oldest writings that allude to coffee come from manuscripts from Yemen, dating back to the year 575. The writings tell the legend of Kaldi, a goat herder from Ethiopia who observed the stimulating effect that the fruits had on his flock. By tasting these macerated fruits, Kaldi confirmed their stimulant potential. Over time, the narrative gained several versions, one of which tells of a monk who, upon observing Kaldi and his goats, decided to study the effects of the coffee fruit. Thus, evidence shows that coffee was first cultivated in Islamic monasteries in Yemen [32].

An event symbolizing the roasting process, which only developed in the 14th century, was also added to the legend. This version claims that one of the monks, finding the drink made from the macerated fruits too bitter, threw them into the fire, generating a delicious aroma. After roasting, the fruits were placed in water to cool and later tasted by other monks. They felt energy and mental clarity, once perceived by kaldi, and from then on, they began using this preparation to stay awake during night prayers [28][31].

Whether these legends are true or not, what is known is that coffee has been, and still is today, prepared and consumed in a variety of ways. The term coffee is known by many names among various peoples around the world. It arrived in England (1598) as "caffe." The Turkish term by which it became well-known is "kahveh," while the Arabic word for this beverage is "qahwa" [33].

## Trajectory: From Origins to Consecration in the Brazilian Scene

Africa was the territory of origin of this renowned fruit, but it was the Arabs who initially mastered the technique of planting and exporting it [28]. The habit of drinking coffee as a pleasurable beverage, whether at home or in collective settings, took off in 1450, with the introduction of the drink to the city of Mecca, the holy city of Muslims. However, it was Turkey that initiated the development of the habit of drinking coffee as an act of sociability, culminating in the opening of the world's first coffeehouse in 1475, the Kiva Han, in Constantinople (present-day Istanbul, Turkey), marking the beginning of widespread consumption of the beverage [29].

Although the spread of the coffee plant had long remained under the exclusive control of the Arabs, the already roasted beans, on the other hand, spread throughout the world. Coffee arrived in Christian Europe in 1615, via the port of Venice, Italy, a city that maintained relations with the Turks in the early modern era. Coffee was only consumed publicly in Europe in the mid-17th


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century, as it was initially considered an exotic beverage with medicinal properties, used only by the wealthiest classes due to its therapeutic properties. Coffee beans were distributed in pharmacies in Venice [31].

The Italians were the first to commercialize coffee in Europe, and the Dutch were the pioneers in its production outside of Arab countries. From Yemen, the seeds still coated with parchment, allowing them to germinate and become seedlings, were brought by the Dutch [31]. The Dutchmanaged to smuggle the fresh fruits to their Asian colonies (Java, Ceylon, and Sumatra) and later to the Dutch Antilles in Central America [34].

In France, coffee began to be introduced in 1644 to the port of Marseilles by merchants accustomed to drinking the beverage in the East. In 1699, in Paris, the Turkish ambassador, Suleiman Aga, presented Louis XIV with coffee beans and held ritualistic celebrations that marked the period. Around 1713, the borough master of Amsterdam offered King Louis XIV a seedling, which was taken to the Jardin des Plantes in Paris. In 1715, the seedling was transferred to the Isle of Bourbon, where it acclimated and guaranteed the French possession of the product [29].

A curious fact expresses the value that coffee held in the mid-8th century: French infantry captain Gabriel Mathieu de Clieu, who, during the Atlantic crossing with the aim of introducing coffee to the Antilles (Central America), reportedly used his own supply of drinking water for daily irrigation of the only plant that survived the long and difficult crossing. The coffee tree was planted at his residence, where it was maintained in suitable conditions for propagation. In 1726, Clieu obtained his first coffee crop in Martinique/Antilles, originating from this French matrix. Coffee was increasingly closer to Brazil, as this seedling would be the origin of our coffee plantations [29][35].

Besides its historical importance, in economic terms, coffee was the third largest commodity in the world at the end of the 19th century. Initially, the beverage was consumed by Europeans and produced in their tropical colonies. Beginning in 1900, the Americas began to play a central role in both coffee production and consumption [31].

In Brazil, coffee cultivation has evolved significantly throughout the country's historical and economic development, especially in terms of production location. Coffee arrived in Brazil in 1727, in the city of Belém, brought from French Guiana by Francisco de Melo Palheta [36]. Cultivation began in the northern region of the state of Pará in the 18th century, with small plantations limited to the North and Northeast of the country [37]. Some experiments took place, without much visibility, in states such as Ceará, Alagoas, Goiás, Pernambuco, and Paraíba.

The state of Bahia, the largest producer of the Northeast, achieved prominence from 1778 onwards with modest commercial production, beginning in Caravelas, but reaching greater expansion near Ilhéus, where coffee crops were planted alongside cocoa [29]. Under favorable conditions, the crop initially established itself in the Paraíba River Valley, starting a new economic cycle in Brazil in 1825.

At the end of the 18th century, coffee production in Haiti (until then the world's leading exporter) entered a crisis, and Brazil strategically increased its production significantly, beginning to export the product more regularly [38]. In addition to this, the end of the sugarcane cycle in the 18th century favored the cultural and economic value of coffee in the lives of Brazilians, contributing significantly to the country's economy for over 100 years. In a relatively short space of time, coffee became the staple product of the Brazilian economy [39].

## Coffee and the Brazilian Economy

For a long time, coffee was the country's main source of wealth, and foreign exchange revenues fueled development, with the creation of cities and the expansion of urban centers in the interior of Rio de Janeiro, São Paulo, Minas Gerais, and Paraná. By 1850, Brazil was already the world's largest producer, accounting for 40% of total production [40]. The beginning of coffee research in Brazil is linked to the founding of the Campinas Agronomic Station in 1887 by Emperor Pedro II, now the Campinas Agronomic Institute (IAC), to provide technical support for the development of national coffee production [41]. The destruction of approximately 70 million bags of coffee (60 kg) in Brazil between 1931 and 1943, resulting from the acquisition of warehouse stocks and new coffee harvests, led to a slowdown in the decline in prices. By the end of World War II, coffee production in Brazil had decreased from 24.5 million bags in 1930 to 14.4 million bags in 1945. During this period, price fluctuations on the New York Coffee Exchange clearly demonstrated Brazil's direct dependence on and influence over the global coffee market [42].

In the 1990s, Brazil's coffee economy was experiencing a crisis due to the decline in commodity value on the world market. With the deregulated sector, new consumption patterns created a scenario that led coffee producers to consider quality and productive sustainability as differentiators,enabling the emergence of specialty coffees [43].

This new vision of the productive sector contributed to the appreciation of coffee in recent years, lending credibility to coffees characterized by a balanced set of aromas and flavors and the absence of defects [44]. These sensory quality attributes are associated with the origin of the coffee and depend primarily on the soil and climate conditions of the crop, the cultivar's genotype, the production system, post-harvest treatment, and processing [45].

Since the dawn of simple commercial transactions, coffee has been an extremely important product in the global economy [46], being the second most traded product in the world, surpassed only by oil [30]. Thus, the coffee segment represents approximately 12% of the international coffee market [47].


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Globally, in the 2019-2020 harvest year, global production reached 167.9 million bags, and the five largest coffee-producing countries during this period were: Brazil with 59.6 million bags; Vietnam with 31.2 million bags; followed by Colombia (13.9 million bags), Indonesia (9.4 million bags), and Ethiopia (7.8 million bags). In the 2020-2021 crop year (June), there was growth in the segment, but Brazil continues to dominate the sector with a production increase of over 12%, followed by Vietnam and Colombia [48]. In the first nine months of the 2024/25 crop year (July 2024 to March 2025), Brazilian coffee exports reached 36.88 million bags [49].

This production volume is a consequence of investments in coffee farming. Brazil has an area planted with Arabica coffee of 1.75 million hectares, which corresponds to 81.3% of the existing area under coffee crops [50]. Arabica beans represent more than 72% of total coffee production and present sensory quality characteristics valued for the balance of desirable compounds, determining a superior quality standard and enabling the production of a beverage with high commercial value [50]. Arabica coffee production in Brazil is concentrated in the Southeast region, which accounted for approximately 89.1% of the national production in 2024, followed by the Northeast with 2.7%, according to the most recent survey of the Companhia Nacional de Abastecimento [51].

Bahia (Northeast of Brazil) sranks fourth in coffee production, with an estimated gross revenue of R$1.67 billion [52]. Pernambuco, the second-largest producer of Arabica coffee in the Northeast region, has approximately 4,800 hectares cultivated with coffee, generating R$8.5 million in GVP annually. Taquaritinga do Norte, in the Pernambuco Agreste region, is the largest producer of Arabica coffee in the state, followed by the city of Triunfo, in the sertão region [53].

## Coffee Consumption in Brazil

Beyond historical and coffee production issues, it is important to highlight that, from November 2017 to October 2018, domestic coffee consumption in Brazil reached 21 million bags, representing a 4.80% increase compared to the previous period. These figures increase per capita consumption to 6.02 kg/year of raw coffee and 4.82 kg/year of roasted and ground coffee, maintaining Brazil as the second-largest coffee consumer in the world, behind only the United States [54]. It is important to note that 95% of households in the country have coffee and 83% of Brazilians consume the beverage daily [28].

The significant increase in coffee consumption in Brazil is a result of the expansion of coffee shops, which has boosted the supply of differentiated products with higher sensory quality. Consumers are becoming more demanding regarding this beverage, seeking to learn more about its benefits, preparation methods, producing regions, and producers [54].

Regarding consumption for the 2023/24 crop year, the United States Department of Agriculture (USDA) estimates global demand growth of approximately 1.1% compared to the previous period, increasing from 163.9 million bags to 166.3 million bags of 60 kg each. The four largest coffee consumers in the world are the European Union (46.3 million bags), the United States (27.3 million bags), Brazil (23.5 million bags), and Japan (8.1 million bags) [55].

The COVID-19 pandemic, which significantly affected Brazil from March 2020, led state authorities to temporarily suspend non-essential activities, including food services such as coffee shops. Social isolation prompted Brazilians to explore new ways to continue their sensory and gastronomic experiences with coffee, including recreating coffee shop experiences at home [56].

According to the Brazilian Coffee Industry Association (ABIC), [57] the Northeast region ranked second in coffee consumption in Brazil in 2017, following the Southeast region. In 2024, the Northeast consumed 5.89 million 60 kg bags of coffee, accounting for 27% of the country's total consumption, as reported by the United States Department of Agriculture [58].

The increase in demand will be driven by population growth, increased purchasing power, and improved quality of national brands, including superior and gourmet brands [59]. Improvements in coffee quality and productive adaptation of coffee trees are directly related to several agronomic parameters, including the plant and crop management.

## Coffee Plant Morphology

The coffee plant belongs to the Kingdom Plantae, Division Magnoliophyta, Class Magnoliopsida, Order Gentianales, Family Rubiaceae, and Genus Coffea. The Rubiaceae family comprises more than 11,000 species grouped into 630 genera that grow in tropical or subtropical regions, most of which are trees and shrubs that grow in the lower areas of forests [60]. Other members of the family include gardenias and plants that produce quinine and other useful substances, but the Coffea genus is the most important member in economic terms [61]. Of the Coffea genus, the Eurocoffea section stands out, bringing together the most important coffee species.

The bush generally grows 2 to 2.5 meters tall, but can reach 10 meters in height. Soil and climate factors and agronomic management influence the plant's development, including: latitude and altitude, temperature, rainfall, solar radiation intensity, soil characteristics, and the cultivation system [31].

Coffee planting has been gaining momentum among producers, who seek to add value to the bean. Of the one hundred species in the genus Coffea, two produce fruits of economic importance: Coffea arabica and Coffea canephora, generically known as Arabica and Robusta [28]. Among the most widely cultivated species,


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Arabica coffee (*Coffea arabica L*) is less resistant to humidity and pests. Robusta, on the other hand, is more bitter, less aromatic, more astringent, and fuller-bodied; it is more resistant to disease and heat [62].

*C. arabica* is a self-pollinating tetraploid (44 chromosomes) with two distinct botanical varieties: Arabica Typica and Bourbon. Historically, the variety cultivated in Latin America and Asia was Typica, while the Bourbon variety, cultivated on the European continent, reached South America and, later, East Africa, via the French colony of Bourbon. Because C. arabica is self-pollinating, these varieties tended to be genetically stable. However, spontaneous mutations with desirable traits have been cultivated for their merits and exploited for crossbreeding purposes [61].

## The Different Brazilian Varieties

According to Bressani [28], the productive potential of many commercial cultivars (cultivated varieties) is excellent. Among the new varieties, some originate from man-made hybridizations and others are the result of natural mutations.

These include:

Typica: one of the most iconic coffee varieties in the world. Its origins date back to the birthplace of Arabica coffee, Ethiopia. In 1727, the

- Typica plant arrived in northern Brazil, in Belém do Pará, reaching southern Brazil between 1760 and 1770;
- Bourbon Vermelho: Originating from Réunion (an island in the Indian Ocean), it came to Brazil in the 1950s and surpassed the productivity of the national or typica (Arabica) cultivar;
- Yellow Bourbon: A cultivar highly appreciated for its intense sweetness; it emerged in 1930 from the selection of a natural hybrid between the red Bourbon and the yellow Bourbon from Botucatu;
- Caturra: Also originating from a genetic mutation of Bourbon, observed in 1935 from the selection of a natural hybrid between the yellow Bourbon and the yellow Bourbon from Botucatu;
- Mundo Novo: It emerged from a natural hybridization of the Sumatra cultivar with the red Bourbon and was first found in Brazil in the late 19th century;
- Maragogipe: A cultivar originating from a natural mutation of the typica, discovered in 1970 in Bahia. It produces the largest grains of any known variety;
- Catuaí: Result of a cross between Mundo Novo and Caturra, selected in 1949 in Brazil. Currently, it is one of the most widely planted varieties in the country;
- Yellow Icatu and Red Icatu: Hybridization carried out at the IAC (Agronomic Institute of Campinas) between a Robusta and an Arabica cultivar, the result of which was crossed with Mundo Novo and then with Catuaí.

## Coffee Growing in Brazil

Coffee is one of the most important agricultural products in the world, being produced in different countries and under diverse processing conditions. These conditions lead to a huge variety of beverages, depending on the selection of cultivars, blend types, processing technologies, storage procedures, choice of extraction method, and other factors [63].

The demand for coffee continues to expand, following a trend observed globally. According to Lee; Jung; Mong [64], food quality measures include healthiness, flavor, customization, price equity, and convenience. According to Illy and Viani [65], coffee quality is evaluated based on appearance, purity, flavor, and aroma, the latter two being the most important characteristics, as they refer to the beverage's sensory quality. Thus, it is possible to understand that coffee adds tangible and intangible values, namely: origin, cultivation method, and social responsibility to the community that produces it. Thus, soil and climate conditions and agronomic management are important and differentiated depending on the species [28].

The first factor that must be taken into consideration to define coffee quality is its species [66]. Coffea arabica, with "Typica" and "Bourbon" as pioneer varieties, was taken from southern Ethiopia to Yemen. After spreading throughout Southeast Asia, a single plant from Indonesia was cultivated in Amsterdam, giving rise to the Typica variety [67]. From these varieties, many lineages and cultivars were developed, such as Caturra (Brazil and Colombia), Mundo Novo (Brazil), Tico (Central America), San Ramon dwarf, and Jamaican Blue Mountain [68].

Some coffee characteristics are inherent to the genotype, serving as an indication of species or cultivars. Therefore, genotype plays an important role in determining the quality of the beverage. This means that even when grown under the same environmental conditions, different cultivars can produce coffees with marked variations in flavor and aroma [69]. Furthermore, when a cultivar has a genetic predisposition to express distinct beverage qualities, it will continue to be recognized for its characteristic flavor and aroma, even if there are changes in the intensity of certain sensory attributes in response to environmental variations [70].

## Coffee Fruit Formation and Harvesting

From its formation, which occurs with flower set, to full ripening, the coffee fruit goes through several phases, all of which are crucial for obtaining healthy, large cherries. The mature coffee fruit consists of the husk (epicarp or exocarp), pulp or mucilage (mesocarp), parchment (endocarp), and seed (endosperm) surrounded by a silvery film (spermoderma) [71].


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In the fruit, everything between the husk and the parchment is pulp and, in this case, mucilage or gum [72]. All these parts of the fruit are important for obtaining quality seeds. Therefore, according to Marcelina and Couto [31], the main characteristics of the parts that make up the coffee fruit are:

**Exocarp (Epicarp):** the outer layer of the fruit, popularly known as the husk. When ripe, depending on the cultivar, it may be reddish or yellow in color.

**Mesocarp (Pulp):** also called mucilage, it is a sweet, gelatinous substance located between the exocarp and the endocarp.

**Endocarp**: also known as parchment, is leathery and surrounds the seed.

**Seed**: slightly attached to the endosperm, surrounded by a silvery film and green internally.

Each fruit of the Coffea genus has two seeds, that is, two coffee beans in an oval-shaped pod with one flat side. For this reason, it is called a flat bean. Flat beans come from well-developed fruits, with a length greater than their width and a central vertical groove [73]. However, occasionally, the coffee cherry has only one bean, which characterizes the more rounded shape of the fruit, and this type is known as a "peaberry" [74].

The seed, the part of the fruit used in processing for coffee production, according to Carvalho [75], is composed of:

**Spermoderma**: the film that surrounds the endosperm, which is silvery or brown depending on the species.

Endosperm: The largest tissue in the seed, blue-green or pale yellow in color (depending on the species), composed of water, amino acids, proteins, caffeine, lactones, triglycerides, sugars, dextrin, pentosans, galactomannans, cellulose, caffeic acid, chlorogenic acids, and minerals.

**Embryo**: Located on the convex surface of the seed, measuring 3 to 4 mm, it is composed of a hypocotyl and two cotyledons.

Coffee harvesting can be done manually, semi-mechanized, or mechanized. Manual harvesting is the most selective and can be either a picking method with individual harvesting of ripe fruits, or a concentrated harvest (stripping), with all the fruits from each branch removed at once and placed on cloths or sieves. Semi-mechanized harvesting uses portable or traditional stripping machines without pickers, while mechanized harvesting uses complete self-propelled harvesters or tractor-drawn harvesters [31].

The selective harvesting method ensures that the fruit has already undergone all the enzymatic reactions that will balance the acidic, bitter, and sweet flavors. They are appreciated as high-quality beverages [31]. The coffee cherries undergo post-harvest processes to remove the coffee beans from the cherry and dry them [74].

## Post-Harvest Processing

Coffee beans are generally harvested with a moisture content between 30 and 65% (wet basis weight), depending on their ripeness. Therefore, they are subject to favorable conditions for rapid deterioration. Therefore, before being stored, coffee must undergo pulping and drying processes [76]. In Brazil, coffee is dried on patios or in mechanical dryers, or a combination of both [77].

Among the production stages, post-harvest activities are responsible for up to 60% of the quality of the coffee beverage, as they directly affect the constituents present in the beans [78]. During the post-harvest process, coffee cherries are transformed into green coffee beans. These processing steps are extremely important because they also allow for changes in the composition of the bean and, consequently, the coffee beverage, as described below.

### Pulping

The coffee cherries are pulped, with the mucilage (mesocarp and epicarp) removed, and the beans are then considered parchment coffee. This step can be performed dry, wet, or a mixed process. The choice of method is decisive for the quality of the coffee bean, as it depends on the region's climatic conditions, the availability of capital, technology, equipment, consumer market requirements, water use permits, and the availability of wastewater treatment technology [76].

In the dry process, the fruit is dried in its entirety, producing whole coffees called coco or terreiro. Therefore, the term "Natural Coffee" given to the product obtained by the dry process is appropriate, as it keeps the constituent parts intact [79]. This method produces coffees in the following colors: green and greenish, generally associated with natural coffees that have been properly dried, and yellow, yellowish, straw-colored, leaden, muddy, and whitish colors usually indicate drying and/or storage problems [73]. This processing has the advantages of lower investment in infrastructure, water use, and environmental licensing. However, it has the disadvantages of longer drying times and increased space occupied by drying yards, dryers, and warehouses, as well as lower coffee standardization [80].

Wet processing involves removing the skin, pulp, and/or mucilage from the ripe fruit, substrates conducive to the development of microorganisms that can cause fermentation that is detrimental to the final quality of the product [81]. On the other hand, wet processing allows for the separation of more uniform batches (microlots), reduces drying time, and leads to a better-quality final product when well-controlled.

However, the cost of implementing a wet processing unit is high for family-based coffee growers, often making the acquisition of individual equipment unfeasible [82]. The wet method produces coffees with a blue-green and cane-green color, with a


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silvery skin. According to Marcelina and Couto [31], it is possible to differentiate between hulled, demucilaged, and pulped coffee cherries:

**Hulled**: Considered a variation of the wet process, where the ripe fruits are mechanically hulled, but the mucilage remains adhered to the fruit's parchment. Removing the hull and retaining the mucilage provide a beverage with balanced acidity and a lighter body.

**Pulping**: This type of coffee is obtained after hulling the coffee cherries and occurs through spontaneous fermentation in concrete tanks, where the coffee remains immersed in water for a period that can vary from 12 to 36 hours. The objective of fermentation is the hydrolysis of the mucilage.

**Demucilation**: This coffee is obtained immediately after the pulping of the cherries, using specific equipment called "mechanical demucilators." Their use ensures the removal of some or all mucilage, avoiding fermentation tanks during the process.

## Drying

Drying can be defined as the simultaneous transfer of energy and mass between the product and the drying air. It consists of removing excess water from the grain through evaporation, usually caused by forced convection of heated air, thus maintaining its quality during storage [83]. Since the osmotic process of water evaporation occurs during drying, this non-immobilized liquid would be conducive to the development of fungi and bacteria [84].

It is important to emphasize that drying is a critical step in preserving quality and can alter important parameters such as color, aroma, flavor, texture, and nutritional properties [85]. However, expected changes in the volatile compound profile will have a positive impact on coffee acceptance by providing expressive and distinctive aromas and flavors [86]. Thus, after pulping, parchment coffee (parchment and beans) is dried using various methods. In Brazil, two basic methods are used for drying coffee: drying in the sun or using mechanical dryers [31].

On drying terraces, the coffee is exposed to the sun and must be turned, either manually or mechanically, to ensure greater uniformity in the drying of the beans. This method has the disadvantages of low yield, longer drying times, and unwanted climate variations, making it susceptible to fungal and bacterial attacks, and may result in loss of quality due to fermentation [87].

However, this method uses only solar energy, a clean, renewable energy source that does not incur additional costs for the producer, justifying its use over other systems that use electricity, firewood, or fossil fuels, which, in addition to increasing production costs, cause greater damage to the environment [88].

Alternatives for optimizing natural drying are related to the way the coffee is laid out for drying, such as the suspended drying rack. This method uses a type of table with ventilation on the sides and an open top, without direct contact with the soil, drying for 30 to 35 days. However, it has only been used for small production volumes [89].

When mechanical dryers are used, the coffee is usually pre-dried in the sun, and these dryers are used to complete the process with greater precision and accuracy. One of the main advantages of mechanical dryers over sun-drying coffee is the removal of uncontrolled environmental variables that can affect coffee quality, improving precision and minimizing delays. Mechanical dryers allow the producer greater control throughout the drying process. In the case of Arabica beans, natural drying gives the final beverage more body and sweetness, as the sugars in the pulp migrate to the bean during drying.

CD (Cherry Pulped), like natural, has more body and is less likely to be fermented, since it has not been exposed to all the harsh conditions on the tree. In the pulped or washed system, the coffee is slightly more acidic and has less body, as its pulp and mucilage have been removed and the sugar has not migrated to the bean. Robusta has been improving with the washed and CD systems, as both have the advantage of reducing or eliminating undesirable flavor traits, such as the earthy taste characteristic of the variety [28].

## Roasting

Although roasting is not a fully standardized process and many variations are used, the simplest description is based on evaluating the color of the prepared beans [90]. Medium roasting is most recommended for high-quality beans because it enhances the sensory profile and preserves essential oils. Lower-quality coffees generally undergo a very intense roasting process, leaving the beans extremely dark and oily, with the aim of masking potential defects [91].

The kinetics of chemical reactions that occur during roasting, such as the Maillard reaction, pyrolysis, and caramelization, are determined by specific conditions such as temperature and time, with little data on the effect of pressure variations [92]. After the roasting process, the chemical compounds in the beans will result in the formation of flavors and aromas that characterize the beverage. It is important to emphasize that coffee quality should not be confused with consumer preference, since the intrinsic quality of the bean is determined by the interaction of genetic, environmental, and processing factors, and consumer preference is determined by socioeconomic, cultural factors, and specific knowledge related to the coffee beverage [93].

## Grading

At this stage, the coffee passes through a sorter, which may or may not be attached to the processing machine, responsible for sorting the beans by size. The beans pass through a set of sieves with holes measuring 8 to 19/64ths of an inch, separating 13 to 19 beans known as flat beans and 8 to 12 mocha beans [31].


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To standardize the quality and, consequently, the sales value of Brazilian coffee, green coffee is classified according to a table adopted by the Official Coffee and Commodities Exchange, adopted as the official standard in Brazil. This classification has two tables that allow for the classification of coffees based on the defects found in a sample. The type directly influences the final price paid to the coffee grower for each bag of coffee [73]. The classification and sensory characterization of coffees traded on the Official Coffee and Commodities Exchange are governed by Normative Instruction No. 08, dated June 11, 2003, of the Ministry of Agriculture, Livestock, and Supply (MAPA), which aims to define the identity and quality characteristics for the classification of Raw Bean Processed Coffee [94].

After classification by type and defects, classification is carried out by beverage type.

The standards for coffee classification in Brazil are based on Federal Decree No. 27,173 of September 14, 1949, and on resolutions issued annually by the Central Bank. Coffee is classified by type and quality characteristics. For Brazilian coffee, the official classification presents seven beverage scales, namely for *Coffea arabica* and four for *Coffea canephora*. According to Ordinance No. 49 of the Ministry of Agriculture, Livestock, and Supply, dated March 25, 2008, in Brazil, the cup test must be performed by qualified classifiers (tasters) who are duly registered with the Ministry [95].

In addition to the degree of roast, the grain size of the ground product is another parameter that influences coffee homogeneity [96], causing variations in physical and chemical properties [97] and altering its sensory characteristics depending on the surface area and contact time with the extracting liquid [98]. Grinding results in a powdered product that can have different particle sizes depending on market needs. Each preparation method requires uniform grinding of the beans to ensure the best possible enjoyment of the beverage [28].

## Extraction

During the final stage, beverage extraction, soluble compounds are leached from the roasted and ground coffee beans with hot water. The extract is generally filtered to remove undissolved solids from the final beverage before consumption. Beverage extraction methods are divided into percolation and pressure [99]. The final beverage result for the consumer is strongly affected by the extraction method; despite its importance, few studies are found in the literature [100].

Percolation, the simple passage of heated water over ground coffee, uses a support and a paper or cloth filter to contain the powder. Percolation methods generally give coffee greater sweetness and acidity, and less body, due to the greater retention of solids by the filter and the contact time of the extracting liquid with the ground coffee [101]. In these methods, pre-infusion is mandatory. The first 30 to 45 seconds of water poured over the coffee causes it to expand, known as bloom. This moistens the coffee and allows the release of carbon dioxide, allowing extraction to continue [31]. These methods extract different beverages depending on the type of support used, due to the varying contact time of the water and coffee, resulting in specific sensory characteristics. Among the models, we can mention Mellita®.

This method was discovered almost 100 years ago by German housewife Amelie Auguste Melitta Bentz, created to try to standardize coffee flavor – as complaints were that the cloth filter, due to its successive uses, gave a different flavor to each coffee preparation. Furthermore, unwanted remaining coffee residues were removed by filtration using paper [102]. Melitta Group KG is one of the largest companies in Germany and the world, led by Melitt's grandsons, Thomas and Stephen, producing more than 160 coffee products and with branches spread across over 100 countries. Melitta's coffee division in Brazil is the company's largest, accounting for 65% of its total revenue, while the coffee filter segment represents 30%, and other products, 5% [102].

However, the longer extraction time of the Mellitta® filter holder, compared to other holder models (Hario V-60® and Koar®), results in a beverage with a more pronounced bitterness [103]. The most appropriate grind for this percolation method is medium to medium-fine, since the finer the grind, the more intense and faster the extraction. The beverage generally takes 4 to 8 minutes to filter, due to the holder's vertical grooves and the paper filter design. All these stages of the process lead to a final assessment of the quality of the coffee, influenced by roasting, grinding, and preparation of the beverage, followed by the tasting of a sample [104].

## Coffee Quality in Brazil

The Coffee Quality Program (PQC) was created by the Brazilian Coffee Industry Association (ABIC) in 2004 and certifies the quality of the final product through a sensory analysis methodology performed by trained judges who classify and differentiate roasted and ground coffee into three categories: Traditional, Superior, Gourme and specialty classified according to aroma (ground and beverage), acidity, body, astringency, and bitterness. The coffee quality category is determined according to the product's Overall Quality (OQ) score on a scale of 0 to 10 [28] [105].

Traditional coffees offer acceptable quality at an affordable price for daily consumption and are comprised of Arabica, Robusta/Conilon, or blends. Coffea canephora contains twice the caffeine content and grows in places where Arabica coffee does not grow.It is therefore used as a less expensive substitute for Arabica in commercial coffee blends and in almost all instant coffee products [106]. High quality for conilon coffees can be


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achieved using the natural processing method (dry) with the addition of *Saccharomyces cerevisiae* yeast, for a fermentation time of 120 h [107]. Grain blends are widely used when it is desired to maintain uniformity in product characteristics. These blends can include beans of different species, varieties, and harvests, aiming to standardize the coffee. Conilon coffee provides a beverage with lower sensory quality compared to Arabica. However, conilon is an attractive product for commercial blends, as it reduces costs and adjusts the beverage to consumer preferences or habits [108]. Pimenta, Angelico, Chalfoun [109] says that a growing portion of the population has preferred coffee preparation that is more geared toward specific quality standards and, consequently, differentiated sensory characteristics, such as:

**Organic**: coffee produced without the use of chemicals, aiming to protect and respect the environment, assist workers, respect consumers, and obtain certifications. All of this results in a beverage with distinct sensory characteristics.

**Certified Origin**: related to the regions of origin of the plantation, as some quality attributes are associated with the cultivated area and the production process, terroir, which is reflected in the sensory results of the beverage.

Fair Trade: coffee that adheres to the concepts dictated by international certifying bodies.

This type of product is intended for consumers who have strong socio-environmental values and the coffee growing conditions, in addition to presenting remarkable sensory characteristics.

Specialty coffees undergo several post-harvest processing steps, strictly controlled to produce excellent and distinctive flavors [110]. Since the 1990s, the quality of a cup of coffee has been closely linked to the term "specialty coffee" [111]. According to the BSCA, "coffee quality attributes cover a wide range of concepts, from physical characteristics, such as origins, varieties, color, and size, to environmental and social concerns, such as production systems and the working conditions of the coffee workforce." [112].

Furthermore, specialty coffees are obtained from defect-free beans (black, green, burnt, and green-black), resulting in a clean final beverage, meaning it has no undesirable defects, fermentation, or bitter taste. It acquires a pleasant aroma, flavor, and long-lasting aftertaste. Specialty coffee beans, unlike traditional ones do not present exogenous primary defects (pieces of wood and stones) and have flavors that differentiate these coffees from other beverages, with floral, citrus, and chocolatey notes, adding value to the product [113].

## Coffee Growing Regions on the Rise in Brazil

Coffee plantations in Brazil cover vast areas of land in different producing regions, primarily in the states of Minas Gerais, São Paulo, Espírito Santo, and Paraná, where soil and climate conditions are more favorable [4]. Climatic conditions, soil composition, and altitude largely determine which variety will thrive best in a given region. Climatic diversity is a determining factor in coffee quality, as it provides variations in the chemical composition of the bean, affecting acidity, body, sweetness, and aroma [117].

Furthermore, in Brazil, coffee production is carried out under strict labor and environmental laws, seeking to respect biodiversity and the workers involved in coffee production [116]. Brazilian Arabica coffee producers seek to preserve forests and native fauna, control erosion, and protect water sources, striving to achieve an environmental balance between flora, fauna, and coffee production. An example of the cultivation method used in Pernambuco is the shade-based system, which involves growing coffee trees alongside native flora that provides shade for the plant, thus preserving native trees and promoting environmental sustainability [117].

Coffee cultivation in Pernambuco has stood out in the Agreste and Zona da Mata regions, with an emphasis on the production of high-quality Arabica coffee. Cities such as Taquaritinga do Norte, Garanhuns, Brejo da Madre de Deus, Bom Conselho, Belo Jardim, São Bento do Una, and Triunfo are recognized for their coffee production and quality. The Pernambuco Economic Development Agency (ADEPE) established the Coffee Sector Chamber to strengthen the entire coffee production chain in the state. Initiatives such as the creation of the Pernambuco Coffee Route and the expansion of coffee festivals are being discussed to promote local coffee production and consumption [118].

The state of Pernambuco has favorable soil and temperature conditions for Arabica coffee cultivation. However, water shortages occur from September to February, the period of flowering and fruiting. In this region, the climatic conditions, high-altitude crops, and the experience of producers favor the production of coffees that are well-accepted in national and international markets, and the harvest does not coincide with those in the Central-West and Southern regions of Brazil [119].

In addition, the production of specialty coffees has gained prominence, with municipalities such as Taquaritinga do Norte, Garanhuns, and Triunfo being recognized for their sustainable practices and the superior quality of their beans. These coffees have attracted the attention of national and international markets, contributing to the growth and appreciation of Pernambuco's coffee industry. Commercial crops are also cultivated in municipalities in the hinterland, encompassing the agricultural areas of the municipalities of Triunfo, Exu, Santa Cruz da Baixa Verde, and Moreilândia [120]. Among these municipalities in Pernambuco, the most notable in the commercial production of Arabica coffee are Taquaritinga do Norte (agreste) and Triunfo


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(backlands).

Taquaritinga do Norte is a municipality in Pernambuco located in the Agreste region (latitude 07º54'11" S and longitude 36º02'39" W), 165 kilometers from Recife, with the predominant biome being the caatinga. Administratively, the municipality is composed of the district headquarters, Gravatá do Ibiapina and Pão-de-Açúcar, and the villages of Vila do Socorro, Gerimum, Mateus Vieira, and Algodão. It covers an area of 475.183 km2 with a population density of 52.41 inhabitants/km2 [121]. Despite its low latitude, it has a climate with mild temperatures (annual average of 18°C) due to its altitude (785m), contributing to coffee production [122]. According to the BSCA – Brazilian Specialty Coffee Association [123], this mesoregion, known as "highland swamps," is responsible for 92% of the state's coffee cultivation and has had a significant portion of its primitive vegetation replaced by grasses and coffee cultivation.

According to Gois, Corrêa, Monteiro [124], swamps are humid enclaves treated as exceptional areas within an environmental context predominantly characterized by substantial annual water deficits. The distinct physiological conditions, favored by the higher altitude and exposure to humid coastal winds, differentiate these landscapes from their lower-lying surroundings, which are dominated by higher rainfall and milder temperatures, generating sub-humid mesoclimates. In response to the more humid climate, these locations have denser vegetation and more developed soils, which have historically made them prime areas for small-scale subsistence and commercial agriculture.

In Taquaritinga do Norte, the Typica cultivar predominates, considered ancient, rare, and one of the best in the country. Some plantations cultivate the Typica cultivar under shade, resulting in longer cherry ripening times and guaranteeing coffee with a higher sugar concentration (sweeter) and aromatic (floral) intensity, and lower caffeine content (less bitter). In 2014, the Organic Producers Association of Taquaritinga do Norte was founded to promote improvements in coffee production and processing [125]. In 2022, the municipality produced 420 tons of Arabica coffee (processed beans) across 700 hectares, accounting for 70.46% of Pernambuco's total coffee production [126]. The municipality of Triunfo, located in the Pernambuco backlands (latitude 07º50'26"S and longitude 38º06'01"W), occupies an area of 191.5 km2 of the Serra da Baixa Verde, formerly known as Serra Grande do Pajeú [127].

The average altitude is over 1,000 m, making it the highest municipality in the state of Pernambuco. It is also located in a high-altitude marshland region, providing a mild and rainy climate that differentiates it from neighboring cities in the semiarid region [128], with an average productivity of 300 kg/h in 2019 [121]. It is important to emphasize that coffee flowering and fruiting occur from September onwards, which can be affected by the dry season (summer from September to February) [129]. Commercial production of Arabica coffee cv. Typica has shown expansion, generating partnerships between coffee producers and companies. The goal is to improve the quality of coffee beans grown in the region to create a special coffee [130].

The future of coffee production in Pernambuco points to the consolidation of the state as a regional reference for differentiated-quality coffees. The presence of high-altitude marshlands, combined with the local agricultural tradition, creates favorable conditions for strengthening the production of specialty coffees, a niche market that is growing consistently in Brazil and abroad. The appreciation of the rare and historically relevant Typica cultivar reinforces Pernambuco's potential to offer unique beverages, with sensory profiles recognized and appreciated by demanding consumers [131].

## Coffee Consumption Habits in Brazil

Data from the National Dietary Survey, collected in 2008–9 from a probability sample of 34,003 Brazilians aged 10 and over, revealed that among the five Brazilian regions surveyed, the Northeast had the highest per capita usual coffee intake (175 mL), with the filtered preparation method being the most common [132].

Moderate consumption (an average of four cups per day) makes the brain more alert and capable of performing its intellectual activities, reduces the incidence of apathy and depression, and stimulates memory, attention, and concentration, improving intellectual activity and being suitable for all ages, including children and adolescents. It is important to emphasize that, for producers [133]. Coffee quality varies according to productivity, price, and ease of harvesting, while, for consumers, coffee quality is associated with price, flavor and aroma, health benefits, geographic origin, and environmental and social aspects [134].

Between 2013 and 2019, the global household coffee market showed stability in overall consumption, with Brazil ranking third, with an average annual consumption of over 21,400 60kg bags, ahead of the European Union (>37,590 60kg bags) and the United States of America (>25,162 60kg bags) (USDA, 2019). Global and national coffee consumption has gone through several significant periods since the mid-century, known as "waves." The first wave of coffee consumption began in the 1960s, with exponential growth in consumption primarily focused on the stimulating benefits of caffeine. First-wave coffees were characterized by their low quality, the use of blends with a high percentage of robusta, and highly competitive prices [135-136].

In the second wave of coffee consumption, beginning in the 1990s, the impactful action was the formation of coffee shop chains, primarily Starbucks. Companies introduced specialty coffees to meet consumers' new interest in coffee quality, making coffee a luxury product rather than a commodity [137]. Rethinking mass production, the third wave of coffee began in the 2000s with small roasters, promoting specific regions and new fermentation


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techniques. Coffee is now considered a high-quality artisanal product, and the act of drinking coffee begins to mean more than just consuming a beverage. This act has become associated with pleasure, sensory experience, lifestyle, and social status. Consumer behavior has undergone a significant shift, generating an approach to coffee consumption focused on pleasure, health, and sustainability [138] The third wave of coffee was based on the movement derived from the Alternative Agrifood Networks, with several similar practices and objectives, such as: shortening the supply chain, with a higher level of information about the origins of producers and the characteristics/quality of products; and more direct trade between producers and roasters or coffee shops [139].

The so-called fourth wave of the coffee market in Brazil is known as the concept that consumers want exclusivity in the coffee they consume. Guaranteeing exclusivity depends on reliable information about the entire process: production, transportation, and distribution to the consumer, with traceability of this process being fundamental [140]. Evolving consumer habits contribute to the production of higher-quality coffees, with advantages for producers, as superior coffee can achieve a higher market value than traditional coffee [141]. The appreciation of a differentiated product represents a premium price that the producer receives for greater investment, due to the buyer's perception of the value added to the coffee [142].

Many producers, realizing the good acceptance of their product in the domestic market, have invested in exporting, making it increasingly clear that regions with little tradition in coffee growing, such as the state of Pernambuco, already work with coffee for export and promote specialty coffees with the support of the Pernambuco Specialty Coffee Shops Association Furthermore, regarding the domestic market, it is the responsibility of coffee shops and specialty stores to sell these specialty coffees directly to customers, aiming to reduce dependence on traditional sales channels (supermarkets and hypermarkets) [143].

## Sensory Aspects of Coffee

The distinctive sensory qualities of coffee vary throughout the world due to the influences of genetics, geographic location, unique climates, different agricultural practices, and variations in post-harvest processing methods. The chemical composition, volatile and non-volatile compounds, are responsible for the aroma and flavor that coffee presents during tasting [144].

The most widely cultivated coffee species (*Coffea arabica* and *Coffea canephora*) have distinct physical and chemical characteristics, producing beverages with distinct and specific sensory characteristics. The Arabica species has the highest commercial value due to its superior sensory characteristics in terms of aroma and taste, and represents over 60% of global coffee production [145-146] Robusta coffee has a higher soluble solids content and produces higher yields after the roasting process [147]. In addition to the species, the final volatile compounds responsible for the aroma and flavor that characterize the beverage are produced during the roasting of green coffee. Green coffee contains aromatic precursors and methoxypyrazines that provide its characteristic aroma, but these are degraded during the roasting process. The volatile compounds characteristic of roasted coffee are not typically present in the original matrix, but are produced during the technological process [148].

Flavor is formed during the roasting process, when approximately three hundred compounds present in the raw bean give rise to almost a thousand volatile constituents, including the following classes and approximate number of compounds: furans (150), pyrazines (100), phenols and ketones (90 in each class), pyrroles (80), hydrocarbons (76), carboxylic acids (60), esters (55), alcohols (50), and aldehydes (45) [149][147]. However, only about 5% of these compounds can be responsible for coffee's aroma, comprising approximately 50 compounds, such as pyrazines, furans, aldehydes, ketones, phenols, and sulfur compounds Toci & Boldrin [147].

Thus, the aromatic perception of coffee forms a complex mixture of these volatile compounds, which present different qualities, intensities, and concentrations, in addition to synergistic and antagonistic interactions between these different compounds. Notably, although some volatiles have low odor and concentration thresholds, they can contribute significantly to coffee flavor [150].

Since the 1980s, numerous studies [151-156] have been published related to the characterization of key aroma compounds, primarily in roasted coffees. These results differ among studies, depending on the type and preparation of the coffee evaluated, and the industrial processes used to produce the coffee [157].

Another aspect of the production process that allows for sensory variations in coffee is the degree of grinding. Some studies [158-159] state that the finer the grind, the greater the extraction of soluble and volatile compounds, implying that there is a relationship between the extraction rate of aromatic compounds and the particle size. According to Normative Instruction No. 8 of June 11, 2003, created by the Ministry of Agriculture, Livestock, and Supply [160], coffee is classified based on aroma and flavor. Raw coffee beans are classified into two groups, determined by the cup test: Group I (Arabica) and Group II (Robusta), and can then be further classified into subgroups.

Beans can be classified by color, which varies depending on the drying process, exposure to air, storage, and damage suffered during pulping and processing, as bluish-green, green, yellowish (indicating signs of aging), yellow, brown, leaden, whitish, and mixed (presence of different colors). Blue-green, green, greenish, whitish, yellowish, and yellow coffees are considered the highest quality and the only ones accepted for export [161]. Another quality differentiator is the beverage extraction technique, which intensifies or minimizes sensory characteristics that differentiate


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the coffee. Furthermore, consumer preferences regarding the type of extraction are influenced by the geographic, cultural, and social environment, as well as personal preferences [162-163].

In the coffee trade, cupping procedures are used to negotiate the commodity, based on the quality of the beverage, which is evaluated by tasters or Q-graders, based on personal opinion and accumulated tasting experience. Although this process is widely used, it presents serious flaws when used as a method for characterizing coffee quality [164].

In the coffee market, sensory analysis procedures and the descriptions of specialized tasters are used as negotiation arguments, based on the quality of the beverage. This technique is costly and requires extensive training to achieve agreement among tasters on the interpretations of the terms to be used [165-166]. The Specialty Coffee Association (SCA) international method is one of the most widely used in Brazil for the sensory classification of coffees, especially when it comes to specialty coffees. The fact that its classification is done through scores provides greater consistency in discriminating the quality of the beverage when compared to Normative Instruction No. 8. The SCA evaluation form includes 11 factors that are individually evaluated for greater scoring accuracy (0 to 6 points).

Among them are fragrance/aroma, flavor, acidity, aftertaste, and body, as well as balance, uniformity, clean cup, and sweetness. To be considered specialty coffees, the final score must be above 80 points [167]. However, according to Dzung [168], one of the main problems with using specialized tasters in sensory evaluation is that the qualifications for these experts are not well defined. According to the ISO 856-2 [169] standard, experience is not the only criterion for a specialist, as they must be trained and have high sensory sensitivity.

Due to these issues, sensory analysis has been a very important tool for evaluating the characteristics and quality parameters of foods and beverages, including coffee [170-171]. The characterization of the different attributes of beverages in the coffee chain can be performed through discriminative, descriptive, and affective tests, with trained and untrained judges, conducted according to pre-established standards [172].

## Sensory Analysis of Food and Beverages

Sensory analysis is a widely used tool in the food industry, and it has evolved over time, going from tasting by business owners to standardizing different tests with the application of statistical tests for validation and comparison of responses. According to several authors, this evolution occurred in four distinct phases [173-175]. Before 1940 - sensory analysis was centered on a single person ("quality arbiter") and focused solely on wines, with individual tasters who, after tasting, set a fair price for the wine based on its quality.

Between 1940 and 1950 - new concepts of quality, such as the importance of monitoring the production process. Analysis gained greater importance after supporting research into food acceptance for the American armed forces, as adequate nutrition did not guarantee food acceptance, as reported by the US Quartermaster Food and Container Institute. This highlighted the importance of flavor and the degree of acceptability of products, assessed through sensory analysis.

Between 1950 and 1970, the food industry began to understand the importance of developing tests to aid in product evaluation and improvement. This awareness led to studies on the primary attributes responsible for the sensory quality of foods, as well as the correct use of human sensory organs. Standards for sensory analysis and the conditions for its performance were also defined, including the use of appropriate statistical procedures for analyzing data obtained from tests.

After 1970, sensory panels began to be used, consisting of trained or untrained tasters (consumers), as well as the choice of sensory evaluation method, depending on the objective of the study. The concept of sensory quality of a food was recognized and began to be seen as the result of the interaction between food and human beings.

According to ISO 5492:2008, sensory analysis is the science related to the evaluation of a product's sensory attributes through the senses. Sensory analysis encompasses a set of techniques that measure human reactions to food and other products, providing useful information for product developers [174]. There are numerous factors that determine a consumer's choice of a food product, but the most important is undoubtedly human sense perception [176].

Understanding consumers' food choices and the psychological processes involved in their preferences is crucial to promoting more informed food regulation and guiding food design The methods for performing sensory analysis are divided into three major groups and can be used alone or in combination, depending on the objectives and expected results. Discriminative methods determine qualitative and/or quantitative differences between samples; descriptive methods identify and describe samples qualitatively and quantitatively; and subjective and affective factors subjectively assess the consumer's acceptance and/or preference for the product [173][175]. In product research and development, it is important to understand the parameters that influence the sensory characteristics of products and how they contribute to maintaining quality and market acceptance or rejection [163] [177-179].

In the description of characteristics, Quantitative Descriptive Analysis (QDA) is the most widely used sensory description technique in the food industry, as it allows the collection, description, and quantification of detectable sensory attributes in the product, using highly trained evaluators and robust statistical analysis of the data [173].


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The main advantage of QDA is the type of information obtained, i.e., a comprehensive sensory description of the product with the possibility of comparing multiple sensory characteristics. However, this method can be more time-consuming and costly than other descriptive methods due to the need for intensive training of the evaluators [180].

In addition to QDA, new descriptive methods began to be used with untrained groups, reducing costs and time in descriptive analysis. These rapid techniques, with a large number of modifications and variations [180], are capable of determining aromatic and flavor profiles, including rapid descriptive methods (Check All That Apply – CATA, Sorting, Naping, etc.) and temporal descriptive tests (Time-Intensity - TD and Temporal Dominance of Sensations - TDS) [181].

Descriptive methodologies then began to be divided into classical and alternative methods. Classical descriptive methodologies require long analysis times, due to intense training for a complete qualitative and quantitative description of a food's sensory characteristics [182-183]. Alternative methods, in turn, were proposed to reduce analysis time, using panelists with less training, or no training at all (consumers) [184].

Among the alternative methods, those that use consumers as untrained panelists have been developed and applied [185]. These methods have two main advantages over classical quantitative descriptive analysis: less time and resources, and consideration of the consumer's sensory perception [182].

## Check All That Apply (CATA)

In the 2010s, one of the central tenets of sensory evaluation was successfully challenged, and it is now generally accepted that analytical sensory tests can be conducted with consumers, which have been shown to provide accurate and reliable information related to descriptive and hedonic tests. Conducting analytical tests with consumers requires the use of appropriate methods that take into account lack of training, colloquial language, the number of descriptors, and the testing environment and time [186]. The use of Check-All-That-Apply (CATA) questions in consumer research focused on food and beverages is now common, and the method is known to provide valid sensory characterizations of products [187].

The consumer descriptive method, CATA, consists of presenting a list compiled and in accessible language of the attributes of the product being evaluated by consumers and asking them to mark the attributes they consider appropriate to describe the sample. Several studies on food and beverages have compared CATA to QDA, that is, consumer descriptions by trained judges [181] [188-190]. Studies have shown that sensory characterization performed by trained evaluators and consumers using CATA questions yielded very similar results [191-195]. Specifically, the minimum recommendation for CATA is a number of consumers between 60 and 80 [196]. This large number of participants is not only a characteristic of CATA, but a requirement for all consumer-based methods to ensure validity, due to inconsistencies in measurements resulting, among other reasons, from a lack of training, which can lead to divergent responses [194].

In a recent study published by Jaeger et al. [201] using open-ended questions, participants were asked to describe how they perceived a pair of samples with respect to an attribute and link it to the selection of CATA terms.

It was found that: most consumers accurately used CATA terms to describe the sensory characteristics they perceived in the sample. Failure to select a descriptor for the samples leads most consumers to indicate that the corresponding sensory attribute was not perceived. Failure to select a descriptor for only one sample leads consumers to report perceiving a difference in the intensity of the attribute between the samples.

In another study, Nascimento and colleagues [198] demonstrate the plurality of CATA applications by evaluating sixteen mixed juices in different cities, demonstrating differences in characterization between the South and Northeast regions. Through correspondence analysis, consumers in Porto Alegre, Rio Grande do Sul, perceived different attributes than those in Salvador, Bahia. This study suggests that the data are valid in characterizing the sensory parameters of mixed juices, but that familiarity with the fruit flavors influences acceptance.

Examples of CATA Studies Applied to Coffee:

Evaluation of the Impact of Different Roasting Methods on the Perceived Sensory Profile:

- The CATA method has been used to understand how varying roast levels (light, medium, dark) influence consumers' sensory perception of coffee. Attributes such as aroma (fruity, caramelized), taste (bitter, sweet), body, and intensity are identified by consumers through attribute selection. This data helps map consumer preferences for each roast type [199].

- Comparison Between Specialty and Commercial Coffees Regarding Consumer-Selected Attributes:

- CATA studies compare different coffee categories (specialty vs. commercial) to evaluate how consumers perceive sensory attributes and which characteristics correlate with quality and acceptance. This approach identifies attributes valued in specialty coffees, such as fruity notes, balanced acidity, and smooth body [200].

- Identification of Sensory Defects in Coffee Through Consumer Perception:

- CATA is also applied to detect sensory defects in coffee, such as moldy, fermented, or burnt flavors, based on consumers' selection of defect-related terms. This provides a rapid, effective quality evaluation tool and aids producers in monitoring faults in processing and storage [201] highlighted the ability of CATA to


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identify negative sensory characteristics related to coffee defects alongside consumer preference segmentation.

The CATA test has proven to be an important research tool in the field of sensory analysis. The CATA methodology is described as efficient for describing and discriminating products, with its main advantages being its simplicity and the speed with which analyses are performed [182].

## Coffee And Food Pairing

Coffee and food pairing has become an increasingly relevant practice in the fields of gastronomy and sensory analysis, aiming to enhance the organoleptic characteristics of both the beverage and the accompanying foods. Similar to wine pairing, coffee pairing is based on the balanced combination of sensory attributes such as acidity, bitterness, body, sweetness, and aroma, in order to create more complex and pleasurable taste experiences [202-203].

The chemical composition of coffee shaped by factors such as geographic origin, botanical variety, processing method, and roasting degree determines its sensory profile and, consequently, the type of food with which it best pairs. Light roast coffees, for instance, tend to display higher acidity and fruity notes, pairing well with light desserts and citrus fruits. In contrast, dark roast coffees, with their intense body and bitter or chocolaty notes, harmonize better with chocolates, nuts, and desserts based on caramel or spices [204]. Pairing can be explored through two main approaches: pairing by similarity and pairing by contrast. In the first, foods with sensory profiles similar to those of coffee are combined, reinforcing certain flavor notes (e.g., coffees with cocoa notes paired with chocolate desserts). In the second, the goal is to achieve balance between opposing characteristics, such as pairing acidic coffees with sweet foods, thus softening extreme perceptions and promoting gustatory balance [205].

From a scientific perspective, recent studies have applied both descriptive and affective sensory methodologies to assess consumer acceptance and perception of coffee–food combinations. Findings indicate that attributes such as aromatic intensity, flavor persistence, and food texture are key determinants of successful pairings [206]. Moreover, serving temperature and coffee brewing method (espresso, filter, French press, among others) significantly influence sensory perception and the choice of suitable food combinations.

Coffee and food pairing has proven to be not only a strategy for product appreciation but also a valuable tool for sensory education and value addition within the coffee sector. In coffee shops and tasting events, pairing is used to engage consumers with the world of specialty coffee, broadening their sensory repertoire and promoting a more conscious and appreciative coffee culture [207] [208-211].

## Conclusion

This review highlights the complexity of the coffee production chain, spanning from plant cultivation to the consumer's final sensory experience. Each stage, including cultivar selection, agricultural management, harvesting, post-harvest processing, roasting, grinding, and beverage preparation, directly influences the physicochemical and sensory characteristics of the product. Proper agricultural practices, such as soil management, pest control, irrigation, and fertilization, are essential to ensure bean quality and consistency in the final coffee.

Processing, particularly roasting and grinding, plays a decisive role in defining the beverage's aromatic profile, flavor, and body. Decisions made at these stages can enhance desirable attributes or compromise sensory quality. Sensory evaluation, combined with chemical analyses and statistical methods, is fundamental for characterizing coffee, guiding bean selection, and understanding consumer preferences. Furthermore, food pairing practices have shown promise in expanding sensory experiences and offering opportunities for product innovation and value addition.

The study also points out that coffee cultivation faces significant challenges, including climate change, international market price fluctuations, and the need for environmental sustainability. In this context, technologies for crop monitoring, digital management, and intelligent bean processing emerge as strategies to increase productivity, reduce environmental impact, and ensure consistent quality. At the same time, the development of advanced sensory analysis methods, including descriptive analysis and consumer insights, allows for a better understanding of consumer preferences and expectations, creating opportunities for product diversification and unique consumption experiences.

Moreover, coffee valorization extends beyond the final product, involving origin certifications, fair trade practices, and sensory marketing, which add value and strengthen global competitiveness. Therefore, the future of Brazilian coffee depends on an integrated approach that considers sustainability, technology, sensory science, and producer education, ensuring excellence in production and meeting the demands of increasingly discerning consumers. Thus, the coffee chain represents a rich field for research and innovation, and it is crucial to continue investing in studies that correlate production practices, processing, and sensory evaluation, promoting Brazil's consolidation as a global reference for high-quality coffees and unique sensory experiences.

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