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POST-HARVEST OF COFFEE: FACTORS THAT INFLUENCE THE FINAL QUALITY OF THE BEVERAGE

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ABSTRACT

Brazil is the world's largest producer and exporter of coffee and the second largest consumer market. Brazil offer differentiated and high quality products to maintain its leading position in coffee production and export. However, Brazilian coffee has suffered some limitations in its commercialization in the international market, due to qualitative aspects. The development of taste and aroma is highly complex, since hundreds of chemical reactions take place at the same time, such as the breakdown of proteins, polysaccharides, trigonelline and chlorogenic acid, mainly in the roasting process. Then, it is necessary that, in addition to pre-harvest management, there are post-harvest practices that meet consumer demands regarding the final quality of the beverage. Studies on physical and chemical changes in the composition of coffee beans must continue to be performed in a comprehensive manner, since factors such as damage to coffee beans, drying methods, processing, storage time, type of packaging and chemical components are directly related to sensorial properties and thus define the quality of the beverage at this point of view. Thus, the objective of this review was to relate the physicochemical, biochemical and physiological characteristics of coffee beans after harvest with the quality of the product after roasting.

Palavras-chave:
Café arábica
Café robusta
Propriedades físico-químicas
Qualidade da bebida

PÓS-COLHEITA DO CAFÉ: FATORES QUE INFLUÊNCIAM NA QUALIDADE FINAL DA BEBIDA

RESUMO

O Brasil é o maior produtor e exportador mundial de café e o segundo maior mercado consumidor. Para manter sua posição de liderança na produção e exportação, o Brasil deve oferecer produtos diferenciados e de alta qualidade. No entanto, o café brasileiro tem sofrido algumas limitações em sua comercialização no mercado internacional, devido a aspectos qualitativos. O desenvolvimento do sabor e aroma é altamente complexo, pois centenas de reações químicas acontecem ao mesmo tempo, como a quebra de proteínas, polissacarídeos, trigonelina e ácido clorogênico, principalmente no processo de torra. É necessário que, além do manejo pré-colheita, existam práticas pós-colheita que atendam às demandas dos consumidores quanto à qualidade final da bebida. Os estudos e pesquisas sobre às alterações físicas e químicas na composição dos grãos devem continuar a ser realizados de forma abrangente, uma vez que fatores como danos aos grãos, métodos de secagem, processamento, tempo de armazenamento, tipo de embalagem e componentes químicos estão diretamente relacionados às propriedades organolépticas e assim definem a qualidade da bebida do ponto de vista sensorial. O objetivo desta revisão foi, portanto, relacionar os aspectos físico-químicos, bioquímicos e fisiológicos que ocorrem após a colheita dos grãos de café com a qualidade do produto após a torrefação.

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INTRODUCTION

According to the Brazilian Coffee Industry Association – ABIC (2009), the coffee sector stood out due to the value of the product by consumers. This recognition is due in large part to the increased awareness of differences in product quality, making the sector produce and sell with greater quality and efficiency.

The acceptance of Brazilian consumers for specialty coffees – of certified origin, gourmet, organic and fair trade – and also by those in single doses, whether espresso or in capsules, is growing (ABIC, 2015). This fact allows that the market cover small productions such as the most important productive agent, especially after the introduction of direct trade, in which the producer and the roaster are directly linked, contrary to the treatment of coffee as a commodity (SAES *et al.*, 2001).

Brazil needs to offer differentiated and high quality products, with unique properties to serve all markets and then to maintain its leading position in coffee production and export. However, Brazilian coffee is subject to marketing restrictions in the international market due to quality aspects. Therefore, innovations and investments in technology and information are required to improve the quality of coffee and not harm its marketing (VERNEQUE, 2016).

The main reasons that determine the chemical composition of coffee are its genetic origin and the environmental conditions to which the plant is exposed, such as altitude, rainfall, light (SCHOLZ *et al*., 2011), soil and climate (MARTINS *et al*., 2015). Altitude affects precipitation and temperature (FRITZSONS *et al.,* 2008). In addition, higher altitudes generate greater accumulation of photoassimilates in leaves and fruits (LAVIOLA *et al*., 2007) and slower maturation, causing greater accumulation of sugars in the coffee beans. High temperatures, on the other hand, anticipate the formation of coffee beans and prevent the complete displacement of the compounds responsible for the aroma and taste properties (DAMATA, 2004). According to Agresti *et al*. (2008), the most important compounds associated with coffee beverage quality are carbohydrates, proteins, lipids, chlorogenic acids, water-soluble tannins, caffeine and trigonelline. However, sucrose, caffeine and trigonelline are genetically controlled and selectable for quality improvement (SCHOLZ *et al*., 2011; KY *et al*., 2001; LEROY *et al*., 2006).

The processes involved in post-harvest, such as processing, drying, storage and roasting, are essential to ensure product quality. These processes reflect on the quality assessment in agronomic, chemical and microbiological aspects. Furthermore, they directly influence the processes that occur with the physicochemical components of the coffee beans, which are the precursors of the aroma and taste properties of the final product (VELMOUROUGANE *et al*., 2011).

Importance of the coffee sector

In Brazil, Arabica coffee occupies 77% of total coffee production, while Robusta coffee occupies 33%. World production is led by Brazil, followed by Vietnam, Colombia and Indonesia. The coffee consumption, on the other hand, is concentrated in the European Union, United States, Brazil and Japan, accounting for 63% of the market (CONAB, 2021). Despite favorable numbers and the good performance of Brazilian coffee production, this chain is still marked by large-scale production, low differentiation, and high market and supply instability (BARRETO & ZUGAIB, 2016; FRANCK *et al*., 2016; MARESCOTTI & BELLETTI , 2016).

C. arabica is characterized by presenting coffee beans with higher added value on the market, for producing a finer and higher quality beverage, more aromatic and tasty. *C. canephora* is intended for the soluble coffee industry and also for blends with *C. arabica* to reduce its acidity and promote a fuller-bodied beverage. Furthermore, blends reduce the cost of the final product (ABIC, 2009).

Brazil, due to its vast territory, which includes different climates, soils and reliefs, has a wide variety of coffees in terms of quality its beans and, consequently, of its beverages, which leads to the development of different blends through natural coffee or coffee yard, pulped, and peeled. Then, a soft drink, full-bodied, acidic, aromatic, special and with different properties can be obtained (MATIELLO *et al*., 2005). These factors make it possible for Brazilian coffee to meet various world demands, both in terms of price and flavor diversification (MACHADO *et al*., 2020). In addition to edaphoclimatic influences, different management systems are applied to its cultivation (ABIC, 2009).

As the quality standard generates a high level of competitiveness, producing countries must invest in resources that provide differentiated quality to their products. According to Ormond *et al.* (1999), in some countries, mainly in Colombia, there is a selective harvesting method, in which only ripe coffee beans (cherries) are harvested. This harvest takes place two to three times a year to ensure greater homogeneity and quality of the coffee. In Brazil, harvesting is performed manually by stripping or mechanized in order to reduce costs, since selective manual harvesting increases the cost of the operation due to the need for more labor. However, for the production of specialty coffees, it becomes essential to avoid green or dried fruits that would cause a loss of quality in the beverage (MATIELLO, 2021).

According to Saes *et al.* (2001), Brazil has invested in qualification strategies since the 1990s, allowing sectors of the coffee agroindustry to follow trends in the evaluation of products with differentiated quality characteristics to maintain competitiveness. Therefore, the specialty coffees segment was created, which connects coffees with tangible characteristics, such as physical, sensory and locational properties, and intangible values, which are represented by attributes that differentiate the product to the consumer, such as technological, ecological and social aspects of production. Small producers, in order to remain in the market competitively, can invest in niches targeted at products based on differentiation (CLAY *et al*., 2018; MARESCOTTI & BELLETTI, 2016). Among these products, the specialty coffees stand out for having higher quality, safety (MARESCOTTI & BELLETTI, 2016).

In this context, due to production strategies, such as the mechanization of crops and infrastructure in the field, beyond the adoption of quality programs, Brazil is considered to have favorable expectations for the coffee agribusiness. Thus, Brazil has suitable climate and soil conditions to produce different products that encompass different markets (AGNOLETTI *et al*., 2020), both for export and for domestic consumption.

Coffee Quality

In order to remain as the world's largest producer and exporter of coffee, Brazil has sought to meet market demands, investing in the use of the most modern technologies to meet the required quality and socio-environmental aspects. The development of more sustainable cultivation practices is becoming increasingly important so that the coffee obtained has greater added value, increasing the income of producers and valuing the culture (ALMEIDA & ZYLBERSZTAJN, 2017). Furthermore, market segmentation, generated by the increased consumption of high-quality coffees, creates new opportunities for producing countries (TOLESSA *et al*., 2017). Physical and chemical aspects of the coffee beans and its beverage are considered to measure the coffee quality (CHENG *et al*., 2016).

According to Kader (2006), quality "is a combination of attributes, properties or characteristics that give value to the product". Moreno *et al*. (1995) emphasize that the quality of the coffee beverage depends on several factors, such as the variety or species cultivated, environmental factors, agricultural practices, processing systems, storage conditions, industrial processes, preparation of the beverage and consumer taste.

Researches on coffee quality were exclusively focused on varietal, environmental and roasting process issues. Currently, these researches have started to incorporate post-harvest techniques as an important factor in determining the quality of the beverage, with an emphasis on harvesting of ripe fruits and coffee beans drying methods (PEREIRA *et al*., 2020).

Cherry coffee, when still on the plant, has ideal properties for obtaining high quality coffee, as the endosperm and chemical precursors are fully formed (GIOMO, 2012). Therefore, for these properties to be preserved, special care is required in harvesting and handling the coffee beans (MOURA *et al*., 2007). Therefore, determining the ideal harvest time and performing a perfect drying, avoiding fermentation processes, chemical decomposition and undesirable biochemical alterations, are fundamental factors for the production of a coffee beverage with superior quality (PIMENTA, 2003).

Giomo (2012) states that the presence of green coffee beans is responsible for several damages to the quality of the beverage. This presence can occurs due to the lack of uniformity in the coffee flowering and the non-selective harvesting of coffee beans (CUSTÓDIO *et al*., 2012; CALDEIRA *et al*., 2017).

Bytof *et al.* (2000) found that metabolic reactions in postharvest processes are largely determined by coffee beans treatment. This treatment includes factors such as the dry or wet process for removing pulp and mucilage, drying, storage, transport and roasting.

In general, the post-harvest factors that most influence coffee quality are fruit selection, processing, occurrence of enzymatic and microbial fermentation, drying, storage conditions and the degree of roasting of the coffee beans (CLEMENTE *et al*., 2015; PEREIRA *et al*., 2020). Fruits picked manually, selectively, ripe, dried and stored in a cool and moisture-free place usually produce beverage with a high degree of quality. The type of processing (dry or wet) to which the coffee is submitted can change its final characteristics, through several biochemical reactions that occur in the fruits after harvesting and the diversity of microorganisms that develop and infect the coffee beans (SAMPAIO, 1993). In addition, the action of microorganisms in the mucilage of coffee beans alters its composition through the fermentation of sugars producing alcohol and the action on alcohol generating different acids, which can improve or harm the quality of the coffee (SAMPAIO, 1993). The drying process, on the other hand, aims to reduce the water content of the coffee beans, reducing the risk of fermentation and the development of fungi and bacteria (WINTGENS, 2004), which are responsible for undesirable physical, chemical and sensory changes if the correct technique is not used (BORÉM *et al*., 2008c).

The incidence of bleaching of the coffee beans is the main problem during storage. This process occurs due to the damage generated during processing and it is aggravated by the relative humidity of the air. This factor favors the breakdown of the cell membrane and the occurrence of oxidative reactions, responsible for the bleaching, which depreciates the coffee beans quality and decreases its commercial value (SAMPAIO, 1993). The roasting step is responsible for the coffee characteristics such as taste and aroma, determining physical and chemical properties, creating new flavors and texture, making the coffee suitable for extraction and consumption (SCHENKER & ROTHGEB, 2017).

From a biochemical point of view, the development of taste and aroma is extremely complex, considering that hundreds of chemical reactions occur at the same time, such as the breakdown of proteins, polysaccharides, trigonelline and chlorogenic acid (DE MARIA *et al*., 1996). More than 800 volatile and non-volatile components have already been identified in coffee. However, research is still ongoing in order to identify the most relevant components for the decline in the quality of the beverage (FARAH & DONANGELO, 2006).

Coffee Processing

The coffee manual sieving must be performed in order to remove larger impurities from the crops. Then, the coffee must be taken quickly to the preparation site, preventing it from being piled up next to the crops or preventing it from passing for long periods on the transport carts or in sacks, in order to avoid fermentation processes (CHALFOUN *et al.*, 2016).

There are two methods of coffee processing, one for each market segment. When the coffee is dry processed, the beverage is more "full-bodied", astringent and less acidic. However, wet-processed coffees are less "full-bodied", have a smoother flavor and high acidity (FERNANDES & CHALFOUN, 2013).

At the beginning of processing, all material goes through a washer that also acts as a hydraulic separator based on the difference in density between the fruits. In addition, the coffee washing provides pre-cleaning of the product, as it separates impurities and, therefore, increases the useful life of dryers and processing machines (CHALFOUN *et al*., 2016).

In dry processing, all the material brought from the field passes through the hydraulic separator, obtaining parcels of cherries and green fruits and also floating coffees (fruits that are less dense as they contain anomalies in the formation or pests attack). Each one of these parcels must be dried, processed and sold separately. Despite having the lowest operating costs during drying, especially in equatorial regions, where there is continuous rainfall during the harvest period, and in places with changing climatic conditions, the dry processing can negatively affect the quality of the product as a result of undesirable fermentations (MALTA *et al*., 2013).

In wet coffee processing, most of the unripe fruits are separated together with the floats by the hydraulic separator. The separation of ripe and partially ripe fruit is done using a mechanical peeler (SILVA *et al*., 2013). This separation into lots allows the use of unripe fruits and adds value to them, as they can be peeled after being stored in water. Thus, they can be marketed as parchment coffee, beyond optimize the time and space needed for drying (COELHO *et al*., 2020).

After going through the huller, the hulled cherry coffee beans still retain much of the mucilage adhered to the endocarp, also known as parchment. The maintenance of mucilage is difficult to manage in the yard and can be a problem because it is an excellent substrate for the microorganisms growth. Therefore, one more step can be performed aiming at the removal of the mucilage, which can be removed mechanically (demucilled coffee) or even biologically (pulped coffee), using fermentation tanks. Before proceeding to drying, the coffee beans must be washed in order to remove the mucilage residues. The coffee produced by this process is also called washed coffee (GIOMO, 2012; SILVA *et al*., 2013). Among the main pulping advantages are the reduction of undesirable microbial fermentations, the reduction of the volume to be handled and, consequently, the space and time spent in the following steps (CHALFOUN *et al*., 2016).

This type of processing requires stricter control of the ripening stage of the fruit, which allows to obtain higher quality coffees (FERNANDES & CHALFOUN, 2013; SILVA *et al*., 2013). If the processing is performed properly, there is great possibility of obtaining a final product with preserved qualitative characteristics, capable of satisfying different markets (CHALFOUN *et al*., 2016; SILVA *et al*., 2013).

According to Chalfoun *et al*. (2016), the choice of the method to be used is fundamental for the producer's final profitability and depends on some aspects, such as the relationship between costs and benefits. It is necessary to take into account the available capital, technologies and equipment, compliance with environmental legislation for the use of water and effluent treatment, as well as the quality standard required by the consumer market.

In recent years, the action of microorganisms present in coffee processing and post-harvesting has been studied in order to understand the effect of metabolic processes generated by them, especially those related to fermentation. Therefore, maybe it can be possible to optimize processing and enhance the quality of coffee through of induced fermentation (LEE *et al*., 2015).

The function of fermentation, in general, is conditioned only to the purpose of degrading the mucilage and facilitating the drying of coffee, both in wet and dry processing. However, researches to understand the metabolic processes that occur in coffee beans during processing indicate that fermentations can provide extremely exotic coffees, with floral and citrus notes and intense acidity or with denser notes of cereals, herbs and chocolate, depending on the spontaneity of the fermentation process (PEREIRA *et al*., 2019).

According to Schwan and Fleet (2015), coffee beans are viable organisms, whose physiological state interferes in the potential for quality improvement. Therefore, through technology, the controlled fermentation of coffee can increase the curve of special aromas and tastes, giving sensory notes of sweets, citrus and floral fruits. Therefore, when roasted, the coffee adds value and quality, but if this process is not well controlled, it can lead to quality losses (LIN, 2010).

Drying process

Drying process is one of the most critical points in coffee post-harvest. The quality of the coffee is closely related to the efficiency of this process, since the coffee beans undergo several physicochemical changes until its moisture is reduced to ideal levels (GIOMO, 2012).

The drying process consists of reducing the initial moisture content of the fruit to about 11%-13%. When this process is performed carefully and in a controlled manner, this reduction of moisture is essential for the preservation of the product, since it reduces the metabolic activity of the coffee beans and inhibits the microorganisms action. Furthermore, the physical integrity and the chemical components of the coffee beans are preserved – essential characteristics for the development of the sensorial properties of the final product. This type of procedure can be performed in three ways: exclusively on terraces, exclusively in mechanical dryers or in a combination between the first two ways. In all of them, it is important to work with homogeneous lots, considering that cherry fruits have 60%-70% moisture, green ones 45%-55% moisture and the floating portion 20%-30% moisture. Therefore, fruits at different maturity stages will have different drying times (CHALFOUN *et al*., 2016; GIOMO, 2012).

Drying on terraces has the advantage of saving energy, since only the solar energy is used for drying. On the other hand, it has several disadvantages, such as: the coffee beans or fruits are exposed to environmental conditions which, if unfavorable, lead to loss of the final weight of the coffee beans, stains, loss of color and infestation of the product by microorganisms. These factors are responsible for the loss of quality and depreciation of the product. This drying requires special care, such as handling the thickness of the layer of fruits or coffee beans and its stirring. The higher the coffee's moisture content, the thinner the layer should be. In the initial drying stage, the average thickness should be kept from 3 to 5 cm and it should be gradually increased up to 10 cm, as the moisture decreases. The presence of green fruits requires a thicker layer, since the moisture content in these fruits is lower.

Regarding the drying in terraces, the use of mechanical dryers has as advantages: to reduce drying time, to allow drying in humid regions, to prevent coffee quality from being affected by climatic factors and to reduce the area of terraces and the hand-labor required for management (CHALFOUN *et al*., 2016). On the other hand, due to the expenditure of energy to move the coffee and heat and move the air, it entails higher costs (REINATO *et al*., 2002).

According to the literature, beyond the sensory variables, there are correlations between physiological and drying kinetics variables, such as electrical conductivity, germination percentage and drying time and rate (ALVES *et al*., 2017). These authors also found a greater sensitivity of dry processed coffees to mechanical drying, presenting the worst physiological performances. In that study, airflow did not interfere with physiological quality. However, the rise in temperature from 40°C to 45°C, in wet processed coffees, provided a decrease in physiological quality and the increase in the drying rate, by increasing the drying air flow to a temperature of 40°C. This change had a negative effect on the sensory quality of the pulped coffee.

Storage and Processing

Coffee storage under inadequate conditions can be a decisive factor for qualitative and quantitative losses of the product. Therefore, care must be taken regarding the migration of moisture, vapor condensation and attack by insects or fungi to avoid these losses (NOGUEIRA *et al*., 2007). Thus, providing an environment in which local conditions favor the reduction of the respiratory rate of the coffee beans, ensuring the preservation of the initial quantitative and qualitative composition of the chemical compounds is very important (ABREU *et al*., 2017).

Most of the coffee in Brazil is stored in jute bags. In this type of storage, the product is subject to loss of quality, since it is not isolated from external environmental conditions. This type of packaging is still widely used due to its ease of handling as a storage unit, satisfying the retail trade. However, barrier-free packagings, such as a jute bag, are not suitable for storing specialty coffees (ABREU *et al*., 2015). Therefore, there are many details that must be taken into account in the construction of warehouses, such as, for example, the waterproofing of the floors, the height of the ceiling height, together with the installation of skylights, aiming at greater air circulation, and avoiding the direct contact of the bag with the floor (NOGUEIRA *et al*., 2007).

In addition to jute bags, packagings called big-bags, with a capacity of up to 1,200 kg, have been used due to their easy mechanized handling and the consequent reduction in the use of labor. On the other hand, they present a reduction in the static capacity of the warehouse, as the maximum stacking height is limited (BORÉM, 2008a).

The plastic bags impermeable to CO_2, called GrainProTM, which coat the jute bags, emerged as a more viable alternative to the storage of coffee beans (TRUBEY *et al*., 2005). Waterproof packaging (nylon bags and vacuum aluminized bags) can also be used, which are able of preserving the quality of the hulled cherry coffee for about 360 days (BORÉM *et al*., 2008b). Brazilian coffee exporting companies are already using hypobaric packaging to preserve the quality of the coffee beans. However, the high cost of this process makes the use of these methods unfeasible for most producers. Another option for differentiated coffees of high quality and greater added value is storage in a hermetic system, which allows the control or modification of the atmosphere, which is an alternative for producers in this market niche (BORÉM *et al*., 2008b; NOBRE *et al*., 2007).

Coffee processing is a post-harvest process aimed at obtaining homogeneous lots that meet the needs of industry and commerce. Then, the coffee fruits in coconut must be cleaned and peeled and, as well as the parchment beans, classified, observing qualitative parameters, such as the color of the coffee beans, the shape and the number of defects (SILVA *et al.,* 2015). This process must be performed as close as possible to commercialization, aiming to preserve the original characteristics of the product (SILVA *et al*., 2005).

Physicochemical, biochemical and physiological aspects of coffee

The chemical composition of the coffee bean changes according to the cultivated coffee species. This heterogeneity contributes to the fact that, after undergoing heat treatments, the coffee beans provide beverages with different sensory characteristics (MONTEIRO & TRUGO, 2005). The genetic variety, environmental conditions and all post-harvest processing influence the chemical composition of the coffee bean (DURÁN *et al*., 2017). Several volatile and non-volatile chemical compounds are present in coffee beans, in different proportions, such as: acids, aldehydes, ketones, sugars, proteins, amino acids, fatty acids, carbohydrates, trigonelline, phenolic compounds, especially chlorogenic acids, caffeine, between others.

The volatile compounds in coffee are extremely responsible for the aroma. Desirable taste and aroma are mainly developed during roasting. Roasted coffee contains more than 800 volatile components. Its main precursors are amino acids, sugars and chlorogenic acids (RAMALAKSHMI & RAGHAVAN, 2003). Furans are the predominant volatile constituents in roasted coffee, followed by pyrazines, ketones, pyrroles, phenols and hydrocarbons (FLAMENT, 2002).

Volatile phenolic compounds have distinct sensory properties, being responsible for the odor of burning matter, spices, cloves, smoke and also for the astringency and bitterness sensation found in coffee (DART & NURSTEN, 1985).

Chlorogenic acids (CGA) represent from 5.5% to 10% of the coffee composition. Most CGAs comprise the following groups: caffeoylquinic acids (3-, 4- and 5-CQA), dicaffeoylquinic (3,4-DiCQA, 3,5-DiCQA and 4,5-DiCQA), feruloylquinic (3-, 4 - and 5-FQA). Other compounds such as p-coumaroylquinic, diferuloylquinic, caffeoylferuloylquinic, p-coumaroylcaffeoylquinic and pcoumaroylferuloylquinic acids can also be found. Some studies indicate that the beverage's astringent and musty taste and bitterness are due to the concentration of chlorogenic acid and the proportions of several compounds present in the raw coffee bean. In general, the presence of these acids indicates low product quality, however, during roasting, their levels are extremely low, occurring reactions that produce acidic compounds and other phenolic derivatives that contribute to the coffee aroma (RAMALAKSHMI & RAGHAVAN, 2003; SALVA & LIMA, 2007).

During coffee processing, chlorogenic acids can be partially isomerized, hydrolyzed or degraded to low molecular weight compounds. In the roasting process, high temperatures produce lactones and promote the polymerization of CGAs with other coffee components to form melanoidins, which are brown colored compounds that contribute to the color and aroma of the coffee, besides having antioxidant activity. Genetic factors, the degree of maturation, cultural practices and environmental conditions are determining factors for the composition of CGA in raw coffee bean and will also affect the final quality of the beverage (FARAH & DONANGELO, 2006).

Trigonelline, on the other hand, is a nitrogenous compound, found in large amounts in unripe fruits, being important for the taste and aroma of coffee. In roasting process, it can be reduced by up to 70%, reacting and forming volatile products, such as pyridines and pyrroles. Through this process, trigonelline can also be transformed into nicotinic acid and nicotinamide, which are two forms of Vitamin B3 (MONTEIRO & TRUGO, 2005).

Caffeine, the best known constituent of coffee, was the first to be discovered and has been industrially studied and explored for the longest time. In raw and roasted coffee bean, the caffeine content varies according to the species, wherein *C. canephora* has about twice the amount of caffeine as *C. arabica*. Despite its reduced content when subjected to the roasting process, the caffeine has high thermal stability during this process (RAMALAKSHMI & RAGHAVAN, 2003). Belonging to the group of xanthines, this compound is a pharmacologically active, odorless alkaloid, besides having a characteristic bitter taste, contributing with an important note of bitterness to the taste and aroma of the coffee beverage (TRUGO, 1984).

Researches performed by the OIC (1991) found that the beverage's desirable acidity is attributed to malic and citric acids, while the undesirable acidity is probably the result of excessively fermented fruits. According to Pimenta (2001), the titratable acidity can vary depending on the stage of ripening of the fruits, the level of fermentation and the defects that occur in them, which can serve as an important attribute for the sensory analysis of the product.

According to Carvalho and Chalfoun (1985), the coffee maturation process begins with an increase in respiratory activity and ethylene synthesis, accompanied by the metabolism of sugars and acids. Associated with these processes, the degradation of chlorophyll occurs, starting the synthesis of pigments responsible for the change in the color of the husk, which changes from green to cherry-red or yellow. In addition, there is a decrease in phenolic compounds, responsible for astringency, and also occurs the synthesis of volatile compounds, such as esters, aldehydes and alcohols, which characterize the aroma of the ripe fruit.

Pimenta and Vilela (2002) emphasize that fruits harvested at the cherry stage have higher polyphenoloxidase activity, higher coffee bean weight, higher sugar content and lower total phenolics, caffeine and potassium leaching. Green coffee fruits, on the other hand, have coffee beans with a high content of total phenolics (greater astringency), caffeine, protein and crude fiber, high potassium leaching and higher pectinmethylesterase activity. Also according to the authors, the coffee beans that dry on the plant have lower weight, lower lipid contents, high polygalactunorase activity and high potassium leaching index.

The roasted coffee

The coffee roasting process is a crucial part of its processing, considering that the taste and aroma that characterize the coffee beverage are the result of reactions that occur during roasting (SCHENKER & ROTHGEB, 2017). The roasting point is important due to its influence on the final attributes of the beverage, and can be divided into light roasting, medium roasting and dark roasting (SERVIÇO NACIONAL DE APRENDIZAGEM RURAL, 2017). This process alters physically and chemically the coffee bean, modifying its sensory properties. The degree of roasting directly influences the coffee flavor and is directly related to the color of the roasted coffee bean. Roasting is the result of the transfer of energy from the roaster to the raw coffee bean. The amount of heat that is transferred to the coffee beans is controlled through time and temperature, usually visually monitored by the roaster (DURÁN *et al*., 2017).

In the first stage of roasting, an endothermic process occurs in which the coffee beans are heated and release water vapor (coffee bean temperature below 160ºC). As the temperature rises, the exothermic phase begins, in which the coffee beans release CO_2 and volatile compounds (coffee beans temperature between 160ºC and 260ºC). At this stage, the formation of these gases inside the coffee beans significantly increase their volume, reducing its density; then the typical porous structure of roasted coffee appears (PITTIA *et al.*, 2001). Maillard and caramelization reactions occur between 170ºC and 220ºC and pyrolytic reactions predominate at temperatures above 230ºC (FARAH, 2019; SCHENKER & ROTHGEB, 2017; POISSON *et al.*, 2017). Pyrolytic reactions cause oxidation, reduction, hydrolysis, polymerization, decarboxylation and several other chemical changes that lead to the formation of substances that are fundamental for the formation of the sensory quality of the product (HERNANDÉZ *et al.*, 2007). The chemical changes involve caramelized sugars, carbohydrates, aldehydes, acetic acid, ketones, furfural, esters, fatty acids, carbon dioxide and sulfides. These compounds are formed depending on the degree of roasting and directly influence the coffee flavor. In general, between 50°C and 100°C there is evaporation of water and protein denaturation, whereas from 100°C to 180°C, browning of the coffee bean is observed due to thermal degradation of organic compounds, and between 180°C and 200°C there is the development of aromas. Above 200°C, total roasting occurs (CIÊNCIA VIVA, 2021).

Most of mono and disaccharides and some polysaccharides in raw coffee bean are degraded during roasting, originating the volatile compounds responsible for the sweet and caramel flavor. The roasting process interferes with the phenolic compounds through the Maillard reaction. Such compounds are formed by the thermal degradation of carbohydrates, chlorogenic acid and lignins, and both the time and the roasting temperature interfere in the final composition of the coffee beans (ARAÚJO, 2019).

The greater the roasting degree, the greater the loss of coffee bean mass, varying according to the quality of the coffee bean used, which may correspond to 20% loss in relation to the initial mass (MUINHOS, 2017). Color change is one of the most obvious characteristics of the roasting steps. Coffee beans change from greenish-gray blue (green coffee bean color) to yellow, orange, brown, dark brown and finally almost black (POISSON *et al.*, 2017).

The quality of the beverage can be related to the roasting degree, being evaluated through three characteristics: acidity, aroma and body. According to Melo (2004), acidity is characteristic of lighter roasts, while in intermediate roasts, the aroma and body become more accentuated and as the coffee bean becomes darker, some components are carbonized, prevailing a burnt flavor.

CONCLUSIONS

- To eliminate restrictions of Brazilian coffee in relation to the international market, producers need to be aware of the processes that affect coffee quality. Therefore, it is necessary, beyond the pre-harvest management, post-harvest practices that meet consumer demands for high quality of the final beverage. Thus, the producers must seek measures aimed at obtaining uniformity of the fruits at harvest, the correct application of processing methods (taking into account aspects such as availability of capital, environmental legislation and market requirements), the definition of the correct drying method to be used (considering the environmental conditions and availability of capital) and the definition of the adequate storage conditions.
- In addition, it is essential that the roasting industry performs the roasting process correctly, since many biochemical reactions occur in this process, being responsible for generating the taste and aroma that characterize the coffee beverage. Thus, different coffee beverages can be developed with high quality in order to meet different market niches.
- Producers and industry must work together, considering that coffee produces, beyond the beverages, by-products that, if handled correctly, can reduce the cost of production.
- Finally, studies and researches on physicochemical changes in the composition of the coffee bean must be deepened to identify the most relevant components to increase and

decrease the quality of the beverage, since the chemical components are directly related to the sensory properties and determine the quality of the beverage in this perspective.

AUTHORSHIP CONTRIBUTION STATEMENT

SILVA, C.A.: Conceptualization, Investigation, Methodology, Validation, Writing – original draft; **COELHO, A.P.F.:** Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing; **LISBOA, C.F.:** Methodology, Supervision, Writing – original draft, Writing – review & editing; **VIEIRA, G.:** Methodology, Supervision, Writing – original draft; **TELES, M.C.A.:** Investigation, Methodology, Writing – original draft.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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