The potential anticariogenic effect of coffee

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Dental biofilm constitutes an ecosystem of bacteria that produces acids from carbohydrates metabolism resulting in caries disease. This disease is seldom self-limiting and, in the absence of treatment, caries progresses until the tooth is destroyed. An important strategy for the prevention of dental caries is to inhibit or to reduce the biofilm deposition on tooth. Several studies have demonstrated that natural products, particularly those containing polyphenols, offer a certain degree of protection against the growth of cariogenic bacteria and biofilm formation. In addition to being one of the most popular and widely consumed beverages throughout the world, coffee is also rich in polyphenols form the chlorogenic acids family. These substances have been proven to be potential agents in the prevention of oral disease, particularly biofilm-related diseases, suggesting a direct effect against Streptococcus mutans. Additionally, trigonelline, caffeine and specific Maillard reaction products formed during the roasting process contribute to the antibacterial activity of coffee. Despite the above evidences based on in vitro and ex vivo investigations, studies involving human beings are still necessary in order to establish conclusive evidence for the effectiveness of coffee consumption in the prevention of dental caries. These issues will be approached in the present review.

Key words: coffee; phenolic compounds; antimicrobial activity; oral bacteria; dental plaque; dental caries

1. Introduction

Dental caries is the consequence of the interaction among the oral microflora, the diet, the dentition and the oral environment. Bacteria are crucial to the initiation and progression of carious lesions. Without bacteria there are no caries [1]. Among oral pathogens, Streptococcus mutans is generally regarded as the main microbial agent of dental caries although additional acidogenic microorganisms may be involved [2]. The ability to metabolize carbohydrates, to adhere to and form biofilm on tooth surfaces is believed to be associated with the cariogenicity of this pathogen [3].

Many strategies for reducing the accumulation of dental biofilm have been proposed, ranging from the use of sugar restriction and sugar substitutes to the use of vaccination against specific odontopathogenic bacteria and to antimicrobial agents such as antibiotics and antiplaque agents in mouth rinses and toothpastes [4]. In addition to these classical approaches, researchers are increasingly engaged in studying natural products or their components, as an alternative to synthetic agents, to offer a degree of protection against microorganisms involved in caries, and therefore to reduce the prevalence and severity of such pathogenesis. According to Moynihan [5], there are indications that the effects of caries induction by carbohydrates consumption may be increased or reduced by specific components of certain foods in our diet, being the latest commonly called "guardians" due to their inhibiting properties against caries activity.

For example, the preventive action of cheese and yogurt has been reported in experimental and human studies [6-9]. Indeed, the high content of calcium and phosphorus is indicated as the factor responsible for the cariostatic mechanism of these foods [10]. Certain compounds in the lipid fraction of these products also appear to reduce their cariogenicity, but it is not yet clear how and to what extent this is done [11]. According to Kashket et al. [12], the presence of specific components of a food matrix along with the way the food is consumed may modify the effects of sucrose or other sugars on dental caries, by interfering on the formation of extracellular polysaccharides by cariogenic bacteria.

Among additional natural products that exert such antibacterial effect are plant extracts containing phenolic compounds, such as propolis, green tea, cocoa, grapes and coffee [13-17]. Several studies have raised the potential of these agents in the prevention of oral diseases, particularly diseases caused by the presence of biofilm on the tooth surface [3,18-21].

The present review is a compilation of the most important results on the anti-cariogenic properties of coffee in light of the increasing scientific knowledge about the antimicrobial and ant demineralization properties of this natural product.

2. Coffee

Coffee is the dried seed of the fruit originated from a tree of the Coffea genus, Rubiaceae family. Among 80 different species of coffee, the most commercialized are: Coffea arabica, which is considered nobler and has the most renowned taste qualities and Coffea canephora, which although presenting an inferior taste comparing to arabica coffee, is richer
in bioactive compounds [22]. The preparation of the beverage is obtained by aqueous extraction of the roasted and ground seeds, giving the color, texture and flavor widely appreciated by consumers in all parts of the world [23-25].

In the last years, in addition to the popularity inherent to its sensory properties coffee has attracted scientific and popular interest in relation to its therapeutic effects demonstrated in clinical and epidemiological studies, such as anti-inflammatory, antifungal and hypoglycemic properties [26-29]. The in vitro antibacterial activity of coffee against gram-positive and gram-negative bacteria has also been reported [30-34]. This activity seems to change according to coffee’s chemical composition [30, 33] and is influenced by species and processing such as roasting and decaffeination [33].

3. Coffee Chemical Composition and Pharmacological Properties

The chemical composition of green coffee depends on species and other factors such as degree of fruit ripeness, agricultural practices, primary/secondary processing and storage conditions [22]. Green coffee is characterized by being composed of caffeine, chlorogenic acids, trigonelline and the diterpenes cafestol and kahweol. Additional components, common to other plants, are water, carbohydrates (including mono, oligo and polysaccharides), proteins, lipids and minerals [25].

Caffeine is the most known coffee compound, due to its physiological and pharmacological properties. This methylxanthine is heat stable, and its concentration in *Coffea. Canephora* (~2.0g/100g) is approximately twice that found in *Coffea arabica* (~1.0g/100g). Among the physiological effects attributed to caffeine are stimulation of central nervous system, decreasing sleep, and stimulation of the heart muscle [35, 36].

Chlorogenic acids comprise a major class of phenolic compounds commonly responsible for ~ 5.0g/100g of *Coffea arabica* and for ~ 9.0g/100g of *Coffea canephora*. The main subclasses of chlorogenic acids in green coffee are caffeoylequinic acids, dicaffeoylquinic acids, feruloylquinic acids and, less abundantly, *p*-coumaroylquinic acids and caffeoylferuloylquinic acids. Among these classes, caffeoylquinic acids account for approximately 80% of the total chlorogenic acids content. In particular, 5-cafeoylquinic acid accounts for almost 60% and is therefore the most studied isomer and the only one for which a commercial standard is available. For this reason, 5-cafeoylquinic acid is commonly called chlorogenic acid. Besides its contribution to coffee flavor, chlorogenic acids are also bioactive [22]. The dicaffeoylquinic acids present in both coffee and propolis were shown to be potent inhibitors against different types of virus. For an example, in 1996, Robinson *et al.* [37] reported that 3.5-dicaffeoylquinic acid was a potent inhibitor of the human immunodeficiency virus (HIV-1) integrase, an enzyme required for the cell infection. The effect of dicaffeoylquinic acids against influenza and herpes virus has also been studied. Additionally, they presented antibacterial properties in different studies [30,31,33,38]. As other polyphenols, chlorogenic acids are antioxidant compounds. Because of the high chlorogenic acids content in coffee this beverage is known to be the largest contributor to the antioxidant activity of most western diets [22]. Moreover, chlorogenic acids showed inducing effects on replication and mobility of murine macrophages [39], anti-mutagenic properties [40,41] as well as the ability to lower blood glucose through inhibition of glucose-6-phosphatase and other mechanisms [42,43].

Some coffee compounds are poorly studied, despite their importance to human health. Trigonelline is an alkaloid biologically derived from enzymatic methylation of nicotinic acid, which produces during this process a B-complex vitamin also known as niacin. The amount of trigonelline in *Coffea canephora* (~ 0.6g/100g) is approximately two-thirds that found in *Coffea arabica* (~ 2.0g/100g). Considering potential bioactivity, trigonelline has inhibited the invasiveness of cancer cells in vitro [44]. In addition, this compound has been able to regenerate dendrites and axons in animal models, suggesting that it may improve memory [45]. More recently it has been considered an antibacterial compound against *Streptococcus mutans*, a cariogenic bacterium [33].

The coffee compounds cafestol and kahweol are pentacyclic diterpene alcohols. These bioactive compounds and their derivatives, which are mainly salts or esters of saturated fatty acids (predominant) and unsaturated fatty acids represent approximately 20% of the lipid fraction of coffee [22]. Cafestol is the primary constituent of the unsaponifiable fraction of coffee oil, accounting for approximately 0.2% to 0.6% of coffee weight. Kahweol is more sensitive to heat, oxygen, light, and acids and is therefore less abundant [46]. These coffee diterpenes have exhibited anticarcinogenic and hepatoprotective properties in vitro. On the other hand, high consumption of these compounds has been associated with elevated homocysteine and low-density lipoprotein levels in human plasma, which may indirectly increase the risk of cardiovascular diseases [22].

During the roasting process, a series of transformations occurs in the chemical composition of the seeds as a consequence of pyrolysis, caramelization, Strecker degradation and Maillard reactions. Thus the contents of thermostable compounds like the chlorogenic acids, trigonelline and diterpenes in roasted coffee are lower than those in green coffee, varying also according to the roasting degree [25]. The free amino acids and peptides and proteins are degraded and react with other compounds, such as reducing sugars in the Maillard reaction, serving as precursors for the formation of volatile compounds such as furans, pyridines, pyrazines, pyrroles, aldehydes, and of melanoids. The melanoids are responsible for coffee’s color and to some extent, its antioxidant activity [22]. The lipid fraction does not appear to be significantly affected by the process, except for the diterpenes which are more sensitive to heat. Sucrose is degraded and consumed by caramelization, pyrolysis and Maillard reactions. Chlorogenic acids are almost
completely degraded when subjected to severe conditions of roasting due to its thermal instability. In the beginning of the process, bioactive lactones are formed reaching peaks in medium roasted seeds and degrading thereafter. Also during roasting a series of volatile compounds are formed and chlorogenic acids are partially incorporated into melanoids’ backbones [22]. Caffeine is not significantly altered during coffee roasting, but small losses may occur due to sublimation. In addition, roasting also degrades trigonelline, producing a variety of compounds including nicotinic acid (3%). In summary, taking into account the roasting process, coffee chemical composition is truly modified, with some beneficial compounds degraded and some created [22].

4. Antibacterial Activity of Coffee

It is generally accepted that antimicrobial agents are the main tools to fight infection diseases. However, the systemic administration of antimicrobial drugs has been identified as the main cause for increasing microorganism’s resistance to the same drugs [47] and is known to produce unbalance in the intestinal microbiota. Therefore natural substances that exert antimicrobial effect against specific pathogens, including coffee, have been recently studied, reinforcing the idea that the development of new therapies with the referred products in the prevention and treatment of diseases, including the oral pathologies, is relevant in the medical field [48].

In this sense, a study by Kashket et al. [12] deserves attention, since the authors observed that coffee compounds may inhibit the formation of glucosyltransferase by cariogenic bacteria. They further speculated that this inhibition probably was due to the action of polyphenols.

Polyphenols constitute one of the most common and widespread groups of substances in flowering plants, occurring in all vegetative organs, as well as in flowers and fruits. They are considered secondary metabolites involved in the chemical defense of plants against predators [49]. Several thousand plant polyphenols are known; however, as mentioned before, coffee is the major source of phenolic compounds in the western diets.

The biological properties of polyphenols include antioxidant [50], anticancer [51], and anti-inflammatory effects [52]. The antimicrobial effects of polyphenols have also been widely reported as their ability to inactivate bacterial toxins [49]. Polyphenols as catechin act on different bacterial strains belonging to various species, such as: Escherichia coli, Bordetella bronchiseptica, Serratia marcescens, Klebsiella pneumoniae, Salmonella choleraesuis, Pseudomonas aeruginosa, Staphilococcus aureus and Bacillus subtilis, by generating hydrogen peroxide and by altering the permeability of the microbial membrane [49]. Caffeic acid and 5-caffeoylquinic, also polyphenols that are found in coffee, have shown activity against the growth of Legionella pneumophila [38], other enterobacteria [32] and Streptococcus mutans [33,53], which is the main bacteria involved in caries disease [11].

In addition to polyphenols, other natural substances such as trigonelline, caffeine and α-dicarbonil compounds have shown antibacterial activity against Streptococcus mutans [31,33,53]. However, the results involving caffeine have been controversial. Antonio et al. [33] did not find antibacterial effect when plain caffeine was tested by susceptibility tests, but the same authors observed that decaffeinated extracts showed lower antibacterial activity against Streptococcus mutans compared to the respective non-decaffeinated extracts. Daglia et al. [31] demonstrated the synergistic effect of caffeine with α-dicarbonil compounds in coffee against the same microorganism. Moreover, according to Almeida et al. [53] caffeine at concentrations found in the beverage (0.5 mg/mL to 1.0 mg/mL) could inhibited S. mutans temporarily (4 h), being necessary higher caffeine concentrations to obtain a stronger and longer lasting inhibition. These authors also observed that when Coffea arabica extracts were supplemented with caffeine, there was improvement of the antibacterial effect of the extract, suggesting a synergistic effect.

Reinforcing the theory of antibacterial activity of coffee, Daglia et al. [54] suggested that coffee active molecules may adsorb to host surfaces, preventing the tooth receptor from interacting with bacterial adhesions and preventing both reversible and irreversible Streptococcus mutans adherence to tooth surfaces.

Taking into account the results of the studies referred above, coffee has consistently antibacterial properties against Streptococcus mutans, which represents an anti-caries effect. The anti-caries effect of a substance has been related not only to its antibacterial effects, by inhibiting the critical metabolic processes of mutans streptococci, but also by its physicochemical effects, by inhibiting demineralization and enhancing remineralization processes [34] which will be approached in the following segment.

5. Pathogenesis of Dental Caries and the Anticariogenic Action of Coffee

Dental caries is the most prevalent and costly oral infectious disease worldwide. Virulent biofilms firmly attached to tooth surfaces are the prime biological factors associated with this condition [55]. However, dental caries is a multifactorial infectious disease, arising from the interplay between oral flora, the teeth and dietary factors. Dietary carbohydrates, mainly mono- and disaccharides, are absorbed into dental biofilm and broken down into organic acids by the micro-organisms present in dense concentrations. In particular, the acid production resulting from carbohydrate metabolism by cariogenic bacteria and the subsequent decrease in environmental pH are responsible for the demineralization of tooth surfaces [56]. Specifically, a tooth is in a constant state of back-and-forth demineralization...
and remineralization between the tooth and surrounding saliva. When the pH at the surface of the tooth drops below 5.5, demineralization proceeds faster than remineralization [49].

This process of enamel demineralization involves the dissolution of enamel apatite crystals, and the diffusion of ions, such as calcium, phosphate, and hydrogen, into and out of the enamel microstructures, resulting in decay. It has been suggested that the ion diffusion pathway in enamel is controlled by the organic matrix network, which occupies the enamel tissue. The changes on enamel organic matrix can affect the demineralization process through the control of the diffusion pathway in tooth structures. Antonio et al. [34] suggested that a light roasted Coffea canephora extract may interact with the enamel organic matrix through its mineral contents, inhibiting the decomposition of the organic matrix during the acid attack by the micro-organisms. These authors affirmed it after chemical analyses of the studied coffee extract, which showed a large amount of calcium and phosphorus.

Zhang et al. [57] avowed that interactions between polyphenols and organic matrixes seem to also inhibit the demineralization process. According to them, the referred interaction involves covalent, ionic, hydrogen bonding or hydrophobic processes, which induces the metamorphism of enamel organic matrix. The metamorphic organic matrix is precipitated in the enamel, resulting in a slowdown of the speed of mineral ions loss, and consequently, enamel demineralization is inhibited. Coffee extracts are extremely rich in polyphenols, which suggest that they can inhibit the tooth demineralization process. The inhibition of tooth demineralization after the biofilm formed on dental fragments was observed by Antonio et al. [34].

Furthermore, in an epidemiological study comparing regular coffee consumers and non-consumers, Anila-ambodiripad and Kori [58] reported the beneficial effect of coffee against the development of caries disease in the Indian population, which consumes a sugar-rich diet. Nevertheless, research with coffee in the field of dental caries is still scarce.

7. Conclusions

The studies carried out in recent decades have shown the antibacterial role of coffee: coffee compounds may reduce bacterial growth rate and adherence to tooth surface. It can also perform antidemineralization effects on the teeth surface. Moreover, coffee opens a promising avenue of applications, since it is relatively safe and its taste and aroma are largely appreciated in all parts of the world. Thus, this product seems to be particularly promising anticariogenic food product for consumption, but in vivo studies on the effect of coffee on saliva and dental biofilm are still required.

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References


