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Influence of the roasting process on total polyphenols, antioxidant capacity and PAH in coffee

[1]Oana Pece, [2]Anca Becze, [1]Corina Hărșan, [1]Adina L. Longodor, [1]Aurelia Coroian

[1] University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Cluj-Napoca, Romania; [2] Research Institute for Analytical Instrumentation, Cluj-Napoca, Romania. Corresponding author: A. Coroian, aurelia.coroian@usamvcluj.ro

Abstract. Green coffee brings many benefits to the human body, due to its biologically active compounds, antioxidant capacity and total polyphenol content. By applying coffee roasting, in addition to improving sensory characteristics, it also determines the development of potentially toxic compounds such as PAH. Total polyphenols, antioxidant capacity, PAH in green coffee and roasted coffee were analyzed. Among the polycyclic aromatic hydrocarbons analyzed, the highest value was 30.74 ng g^{-1}, in the case of phenanthrene in roasted coffee. PAHs: Acenaphthene, fluorene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene were <0.05 in both green and roasted coffee.
Key Words: green coffee, roasting, total polyphenols, antioxidant capacity, PAH, aflatoxin B1, HPLC.

Introduction. Coffee contains antioxidants and other pharmacologically active substances. Many of the health benefits associated with green coffee are largely due to chlorogenic acids and, to a lesser extent, caffeine (Eldin et al 2021; Jeszka-Skowron et al 2016). The effect of green coffee bean extract on hypertension was observed when it was administered dissolved in water. Ferulic acid, the active metabolite of chlorogenic acid, was found to lower blood pressure in hypertensive mice (Kozuma et al 2005). The antioxidant capacity of chlorogenic acid and its metabolites, similar to ascorbic acid, has positive effects on endothelial dysfunction and may reduce blood pressure (Kozuma et al 2005). Green coffee has many benefits, but roasting produces potentially toxic compounds, such as polycyclic aromatic hydrocarbons (PAHs). Their content in coffee depends greatly on the duration and temperature of roasting (Coroian 2021). PAHs are known to be mutagenic, teratogenic and carcinogenic, and many PAHs pose significant risks to human health and well-being (Kim et al 2013). Other sources of PAHs include the burning of waste, wood and coal (Patel et al 2020). Food processing and cooking at high temperatures, as well as smoking, frying and baking, are major sources of PAH contamination (Abdel-Shafy & Mansour 2016). PAHs can affect human health. A study of road workers showed that these toxic agents increased serum immunoglobulins and monocytes (Karakaya et al 1999). Harvesting, storage, handling, humidity, temperature and hygiene conditions can lead to the development of mycotoxins (Mastan et al 2024). Green coffee, roasted coffee, instant coffee and derived products can contain mycotoxins, making them important for analysis and regulation regarding mycotoxin contamination (Vieira et al 2015). Aflatoxin B1 is known to be a hepatotoxin and a potential carcinogen (Abrar et al 2013). After ingestion, aflatoxins are rapidly absorbed and transmitted to pregnant women, allowing them to cross the placental barrier and affect fetal growth and development (Ismail et al 2021). Due to the risk that aflatoxins pose to the human body, they must be monitored and quality standards must be implemented throughout the entire technological flow of coffee production. The aim of this study was to evaluate the influence of the roasting process on total polyphenols, antioxidant capacity and PAH in coffee.

Material and Method. For this study, we considered green coffee beans, originating from Ethiopia. The samples to be analyzed were subjected to the roasting process in a circulating air oven, at 220°C, for 8 minutes. After roasting, the coffee beans lost approximately 10% in weight, but increased in volume. After the heat treatment, the samples were ground with an electric grinder and placed in clean, hermetically sealed containers, and stored until the time of analysis.

Extraction step. 0.5 g of sample was used and extracted with 1 mL of methanol for 20 minutes at room temperature in an ultrasonic bath. The samples were centrifuged at 11000 rpm for 2 minutes and the supernatant was filtered through a 0.45 μm cellulose filter.

Determination of total polyphenols. 5 mL of distilled water, 1.5 mL of sodium carbonate solution (10%), 0.5 mL of extract and 0.5 mL of Folin-Ciocalteu solution were pipetted into a 15 mL Erlenmeyer flask. The solution was left for 45 minutes at room temperature, then measured at a wavelength of 764 nm against a blank solution. Measurements were compared to a gallic acid calibration curve (25, 50, 100, 250 ppm) and the results are expressed in gallic acid equivalents.

Total antioxidant capacity. After the sample was prepared, it was introduced into the PHOTOCHEM apparatus. The sample was exposed to a specific wavelength of UV light. The purpose of this step was to generate free radicals in the sample. The results are expressed in ascorbic acid equivalents. For solid samples (coffee) the following calculation formula was applied:

$$Concentration\left[\frac{\mu g}{mg}\right] = \frac{Q \times D \times M \times V}{PV \times Mp}$$

Where:
Q-nmol of ascorbic acid or trolox read on the machine;
D-the dilution factor;
M-molecular mass (trolox=250.3 ng $nmoL^{-1}$);
V-extraction volume in mL;
PV-volume pipetted into the test tube;
Mp-sample mass in g.

Determination of polycyclic aromatic hydrocarbons (PAHs). High-performance liquid chromatography (HPLC) with fluorescence detection after solid-liquid extraction was used to analyze the 13 PAHs in green and roasted coffee. 10 g of ground and homogenized coffee were used. The samples were extracted with 25 mL of hexane in an ultrasonic bath for 20 min. After evaporation to dryness on a rotary evaporator, the green and roasted coffee samples were spiked with 1 mL of acetonitrile and injected into the HPLC. A gradient program and wavelengths were used to identify the 13 polycyclic aromatic hydrocarbons.

Results and Discussion

Total polyphenols. Following the analysis of total polyphenols, in green coffee their value is 10245 mg kg^{-1}. After its thermal processing, the content in total polyphenols decreased to 7785 mg kg^{-1}. In the study by Król et al (2020), total polyphenol content was significantly affected by thermal processing. Thus, green coffee beans were the richest in total polyphenols (8.74 mg g^{-1}), roasted coffee recording a significantly lower value (7.95 mg g^{-1}). Table 1 shows the values obtained for total polyphenols in green coffee and roasted coffee.

Table 1

Total polyphenols, antioxidant capacity and aflatoxin B1 in green and roasted coffee

Parameter	*Green coffee*	*Roasted coffee*
Total polyphenols mg kg^{-1} GAE equivalent	10245	7785
Antioxidant capacity μg mg^{-1} Trolox	20.34	16.78
Aflatoxin B1 μg kg^{-1}	<0.05	<0.05

The main phenolic compound contained in coffee extracts is chlorogenic acid, responsible for the beneficial effects of coffee consumption on the body. This compound degrades as roasting time increases, thus the concentration of phenolic acids influences the quality and nutritional value of roasted coffee (Cho et al 2014).

Cho et al (2014) studied two representative parameters, total polyphenol content and total flavonoid content in green coffee and roasted coffee at 4 different levels. The most abundant in total polyphenols was lightly roasted coffee with 55 mg g^{-1} total polyphenols. Following the results obtained, they concluded that minimal roasting of green coffee beans positively influenced the content in total polyphenols, the values decreasing as the processing time increases. Following the analysis of the antioxidant capacity, green coffee recorded a value of 20.34 μg mg^{-1}, this decreases after roasting to 16.78 μg mg^{-1}. The type of coffee with the highest values for antioxidant capacity is 100% Arabica green coffee. This type of coffee also presented the highest content in total polyphenols and flavonoids. Roasted 100% Arabica coffee recorded a lower value, but comparable to the green one (Hudáková et al 2016). The data obtained from the analyses performed, as well as those reported in the specialized literature, suggest that minimal roasting is an important process that ensures product preservation, but that long duration and high temperature can significantly influence the chemical composition (Mastan et al 2023, 2024; Coroian 2021). Coffee beans are a rich source of phytocompounds with significant antioxidant potential. Furthermore, they contain phenolic substances, such as chlorogenic acids, which have been shown to have a variety of benefits, such as anti-obesity, anti-diabetic, anti-hypertensive, antioxidant, anti-inflammatory, antimicrobial and neuroprotective effects (Eldin 2021).

Polycyclic aromatic hydrocarbons. Following the analysis of the content of PAHs in green coffee, a significant variation was found, between 0.05 and 20.34 ng g^{-1}. Of these, phenanthrene stands out as the most representative, with an average value of 20.34 ng g^{-1}, followed by naphthalene, which records an average level of 8.65 ng g^{-1}. In smaller quantities, fluoranthene 1.02 ng g^{-1}, benzo(a)pyrene 0.84 ng g^{-1} and chrysene 0.15 ng g^{-1} (Figure 1).

It is important to mention the other PAHs, which, despite their presence, register values below the detection limits. (Orecchio et al 2009). As in the case of green coffee, in roasted coffee, it is observed that phenanthrene predominates, with a considerable value of 30.74 ng g^{-1}, followed by naphthalene with 9.57 ng g^{-1}. The presence of fluoranthene, with 1.81 ng g^{-1}, and benzo(a)pyrene with 1.36 ng g^{-1} is also noted. Values for anthracene, chrysene, pyrene and benzo(a)anthracene are the following: 0.57, 0.25, 0.13, and 0.10 ng g^{-1}, respectively. These results suggest that the coffee roasting process influences the composition and content of polycyclic aromatic hydrocarbons, generating different concentrations of these in roasted coffee compared to green coffee. It is important to consider these aspects in terms of the potential impact on the quality and safety of coffee consumption. The presence of high molecular weight hydrocarbons, for example benzo(a)pyrene, in coffee samples indicates contamination resulting from thermal processing. The most carcinogenic polycyclic aromatic hydrocarbons are part of the group of substances with high molecular mass, including benzo(a)pyrene (Pînzaru et al 2014). According to a report given by the European Commission, the daily intake of polycyclic aromatic hydrocarbons, more precisely benzo(a)pyrene, was estimated between 0.05 and 0.29 μg day^{-1}. Higher values were recorded in certain areas such as southern Italy (0.32 μg day^{-1}). Also, values up to 0.36 μg day^{-1} were calculated in the case of specific diets, and in the case of the consumption of foods with a high content of PAHs, the values rose to 0.42 μg day^{-1} (European Commission 2002).

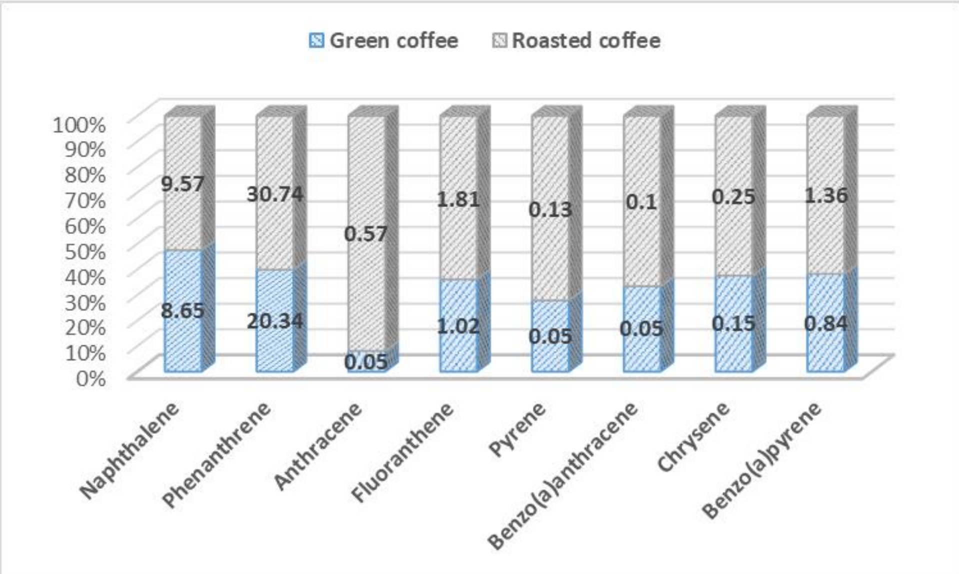

Figure 1. Polycyclic aromatic hydrocarbons in green coffee and roasted coffee.

Mycotoxins. The analyzes carried out to determine the amount of aflatoxin B1 in green and thermally processed coffee beans highlighted the fact that hygiene and food safety conditions were respected, as the recorded values were below the detection limit (<0.05 μg kg^{-1}) (Table 1). The International Organization for Standardization (ISO) defines quality as the ability of a set of properties of a product, system or process to satisfy consumer needs. Coffee quality standards include a variety of details, from the geographical region of origin to specific characteristics such as moisture content inside the beans, their size and the proportion of damaged beans. Factors that influence the quality of coffee beans and the possibility of their contamination are climatic conditions, agronomic practices, harvesting and post-harvest procedures, storage, packaging and transport of the beans. A significant impact on coffee contamination is given by storage conditions. The development of mycotoxins is influenced by humidity and temperature, but also by the presence of microorganisms. It is very important to comply with hygiene and food safety standards, as well as constant monitoring of these indicators during storage (Mastan et al 2024; Lazar et al 2024). According to European Commission Regulation No. 1881/2006, the maximum level of mycotoxins (ochratoxin A) in both roasted beans and ground coffee is 5 μg kg^{-1} (European Commission 2006). Batista et al (2003) examined green coffee from several areas in Brazil, found that 58% of the samples were contaminated with potentially ochratoxigenic fungi, and 22% of the samples were identified with ochratoxin A. Soliman et al (2002) studied the effect of roasting methods on the level of aflatoxins in green coffee. They used green coffee beans naturally contaminated with aflatoxins, of which aflatoxin B1 was in the amount of 6 μg kg^{-1}. The thermal processing methods used were: traditional frying at 180°C for 10 minutes, in the oven at 150°C for 15 minutes and in the microwave oven for 4 minutes. All 3 methods resulted in the destruction of aflatoxins, with traditional roasting being the most effective with a 55.9% reduction in total aflatoxins. Mycotoxin contamination poses a real threat to consumer health, hinders trade and results in significant economic losses for producing countries (Vieira et al 2015).

Conclusions. Total polyphenols and antioxidant capacity showed changes in the roasting process, being in lower quantities in roasted coffee compared to green coffee. In the case of mycotoxins, aflatoxin B1 is below the detection limit, which confirms compliance with sanitary conditions and good practices, implementation and compliance with quality standards. After roasting, anthracene, fluorene and acenaphthene were below the detection limit. The hydrocarbons identified in the highest quantity were: phenanthrene, naphthalene and benzo(a)pyrene.

Conflict of interest. The authors declare no conflict of interest.

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Authors:
Oana Pece, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Mănăştur Str. 3-5, 400272 Cluj-Napoca, Romania, e-mail: oanamastan@yahoo.com
Anca Becze, Research Institute for Analytical Instrumentation, INCDO-INOE 2000, 67 Donath Street, 400293 Cluj-Napoca, Romania, e-mail: anca.naghiu@icia.ro
Corina Hărșan, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Mănăştur Str. 3-5, 400272 Cluj-Napoca, Romania, e-mail: corina.harsan@yahoo.com
Adina Lia Longodor, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Mănăştur Str. 3-5, 400272 Cluj-Napoca, Romania, e-mail: lia_adina@yahoo.com
Aurelia Coroian, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Mănăştur Str. 3-5, 400272 Cluj-Napoca, Romania, e-mail: aurelia.coroian@usamvcluj.ro

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