NAUKI INŻYNIERSKIE I TECHNOLOGIE
Journal of Food and Engineering Sciences

Nauki Inżynierskie i Technologie
Journal of Food and Engineering Sciences
Year 2025, Vol. 41
ISSN 2449-9773
journals.ue.wroc.pl/niit

The Effect of Roasting on the Bioactive Properties and Colour of Infusions from *Coffea Arabica* Beans Originating from Central and South America

Karolina Toczek

Wroclaw University of Economics and Business

e-mail: karolina.toczek2905@gmail.com

Quote as: Toczek, K. (2025). The Effect of Roasting on the Bioactive Properties and Colour of Infusions from *Coffea Arabica* Beans Originating from Central and South America. *Nauki Inżynierskie i Technologie. Journal of Food and Engineering Sciences*, *41*, 69-81.

DOI: 10.15611/nit.2025.41.07

JEL: L66, Q01

Abstract

Objective: The aim of the study was to determine the effect of the roasting process on the content of phenolic compounds, antioxidant activity, and colour of infusions prepared from coffee beans (*Coffea arabica*) originating from Central and South America.

Methodology: Green and roasted coffee samples from selected growing regions (Brazil, Nicaragua, and Peru) were used for the study. The total polyphenol content was determined using the Folin-Ciocalteu method, antioxidant activity was determined using the ABTS and FRAP methods, and the colour parameters of the infusions were determined using a colorimeter. The results obtained were subjected to statistical analysis (ANOVA, Duncan's test).

Results: The roasting process significantly affected the polyphenol content, antioxidant activity, and color of coffee brews. The highest values of the analysed parameters were found in medium and dark roasted coffee samples, especially those from Peru and Nicaragua. A positive correlation between polyphenol content and antioxidant activity was shown. The coffee grounds remaining after brewing retained significant amounts of bioactive compounds, indicating their potential for reuse in the context of the circular economy and sustainable development.

Implications and recommendations: The results of the study indicate the need for further analysis of roasting processes in order to develop optimal parameters that allow for the preservation of high levels of bioactive compounds in the brew while maintaining the desired sensory characteristics. Further research should explore the possibility of using coffee grounds as a secondary raw material in the food, cosmetics, and materials industries.

Originality/value: The originality of the work stems from its comprehensive approach to the coffee roasting process, which includes the analysis of both raw and roasted beans, as well as the infusions and grounds prepared from them. This approach allows for a complete understanding of the changes in the chemical composition and bioactive properties of coffee at all stages of its processing, from raw material to final product.

Keywords: coffee, roasting process, antioxidants, phenolic compounds, *Coffea arabica*

1. Introduction

Coffee is one of the most consumed beverages in the world, and its economic, social and cultural importance cannot be overestimated. The cultivation of the coffee tree (*Coffea L.*) covers numerous tropical and subtropical regions, where climatic conditions, soil type and the way the raw material is processed determine the quality of the final product. Among the more than 120 species of the genus *Coffea, Coffea arabica L.* and *Coffea canephora* (robusta) are of the greatest commercial importance, with arabica accounting for about two-thirds of global coffee production (Bilen et al., 2023).

Coffee beans are a rich source of biologically active compounds such as polyphenols, alkaloids (including caffeine), lipids, and volatile compounds, which give the drink its characteristic taste and aroma (Farah & Donangelo, 2006). Chlorogenic acids, which are the dominant phenolic compounds in coffee, have strong antioxidants and anti-inflammatory effects (Tunnicliffe et al., 2011). Thanks to these properties, coffee not only serves as a stimulating drink but is also an important element of the prevention of civilisation diseases, such as type 2 diabetes, cardiovascular diseases and neurodegenerative disorders (Bidel & Tuomilehto, 2013; O'Keefe et al., 2013).

One of the most important stages in coffee processing technology is the roasting process, which has a decisive impact on the chemical composition of beans and infusions. During roasting, a number of physicochemical reactions take place, including primarily the Maillard reaction, which results in the formation of melanoidins, as well as caramelisation and pyrolysis, leading to the formation of furfural and aromatic compounds that define the sensory profile and colour of coffee (Moon & Shibamoto, 2009; Wei & Tanokura, 2015). This process is also responsible for the transformation of bioactive components, which can lead to both the degradation of some phenolic compounds and the formation of new substances with antioxidant activity (Vignoli et al., 2014). Understanding these relationships is crucial not only for producers but also for consumers who care about maintaining a balance between taste and health-promoting value of the infusion.

Central and South American regions such as Brazil, Nicaragua and Peru are among the important *Coffea arabica* growing areas, differing in climatic conditions and bean treatment methods. The microclimatic diversity of individual regions and the varieties of Arabica grown there translate into the unique sensory properties of the beans (Adepoju et al., 2017; Sanz et al., 2002). Brazilian Arabica coffee has a balanced, sweet profile, Nicaraguan coffee has chocolate and rum notes, and Peruvian coffee has a distinct acidity and almond-fruity aroma. The roasting process can emphasise or eliminate these differences by modifying the proportions of bioactive and sensory compounds.

However, there is a lack of clear data on the influence of the degree of roasting and the geographical origin of beans on the content of phenolic compounds, antioxidant activity and colour parameters of Arabica coffee infusions. Most studies focus on one aspect (e.g. comparing light and dark roasts), omitting the analysis of the full cycle from raw beans to the grounds left over from brewing (Dybkowska et al., 2017; Król et al., 2020). This research gap is filled in this article.

2. Literature Review

2.1. Botanical and Geographical Characteristics of the Coffee Tree

The genus *Coffea* includes more than 120 species belonging to the *Rubiaceae* family, among which *Coffea arabica L. and Coffea canephora* (robusta) are the most economically important (Adepoju et al., 2017). *C. arabica* has a mild, complex flavour profile with floral and fruity notes, as well as a lower caffeine content (1-1.5%), while *C. canephora* contains up to 2.7%, which translates into a more bitter, earthy taste (Sanz et al., 2002; Campuzano-Duque et al., 2021).

Arabica beans are grown at altitudes of 600-2000 m above sea level in temperate climates (15-24°C), while robusta grows in lower and warmer zones, making it more resistant to diseases and pests (Bilen et al., 2023).

The largest coffee producers in the world are Brazil, Vietnam and Colombia, which together account for more than half of the global supply (Jaskólska, 2017). Brazil is the world leader in Arabica exports, Colombia is famous for its high-altitude coffees with delicate acidity, while Vietnam dominates the production of robusta. Environmental conditions, soil type, and cultivation methods directly affect the chemical composition and quality of the beans (García et al., 2014).

Sustainable cropping systems, including organic plantations and agroforesters, are increasingly being studied as they increase biodiversity, improve soil structure and reduce greenhouse gas emissions (Giraldi-Díaz et al., 2018; Trinh et al., 2020). Research shows that organic coffee cultivation methods promote higher quality of raw material and a higher content of bioactive compounds in the beans (Król et al., 2020).

2.2. Chemical Composition and Health-Promoting Properties of Coffee

Coffee beans are a complex biological system containing alkaloids, polyphenols, lipids, organic acids, and volatile compounds that determine its sensory and physiological characteristics (Farah & Donangelo, 2006). The most important alkaloid is caffeine, which stimulates the central nervous system, improving concentration and performance of the body (Ashihara & Crozier, 2001).

Particular attention is paid to polyphenols, especially chlorogenic acids, which account for 4-14 % of the dry matter of green beans (Farah & Donangelo, 2006). These compounds have strong antioxidant, anti-inflammatory and antidiabetic effects (Naveed et al., 2018; Tunnicliffe et al., 2011), contributing to reducing the risk of developing cardiovascular diseases, type 2 diabetes and neurodegenerative diseases (Bidel & Tuomilehto, 2013; Nieber, 2017). In addition, coffee contains diterpenes such as cafestol and kahweol, which exhibit anti-cancer potential, however their content in the final beverage depends strongly on the brewing method as paper-filtered coffee retains significantly lower amounts of these compounds. It is also worth noting that excessive intake of diterpenes may increase serum LDL cholesterol levels (Gross et al., 1997).

Regular consumption of moderate amounts of coffee, typically defined as 2 to 4 cups per day, can therefore contribute to improving overall physiological functions, which is confirmed by epidemiological studies (Higdon & Frei, 2006; O'Keefe et al., 2013). At the same time, it is worth emphasising that the method of processing the beans – and especially roasting – significantly shapes the content of bioactive compounds and the antioxidant properties of the infusion.

2.3. The Roasting Process and Its Impact on the Properties of Coffee

The roasting process is a key technological step in coffee processing, in which raw beans are transformed into a product with characteristic characteristics of colour, aroma and chemical composition. Proper management of this process is essential to achieve the desired quality parameters of the brew, and its course depends on factors such as temperature, roasting time and thermal profile.

With the increase in roasting temperature, chlorogenic acids and trigonelline undergo thermal degradation, and trigonelline is converted into small amounts of niacin (vitamin B3), yet the quantities formed are not high enough to have a significant dietary impact. High temperature also leads to the formation of melanoidins with phenolic molecules included, which increases their stability and antioxidant activity (Moreira et al., 2017).

Vignoli et al. (2014) showed that the intensification of roasting leads to a decrease in the content of polyphenols in Arabica and Robusta beans, but this does not always mean a decrease in the total antioxidant capacity of the infusion, due to the compensatory effect of melanoidins and newly formed phenolic compounds. Similar observations were presented by Odžaković et al. (2016), who noted that light and medium roasting allows to maintain a higher antioxidant potential than heavy roasting.

2.4. Directions of Research on the Influence of the Roasting Process on the Chemical and Biological Properties of Coffee

Earlier studies on the effect of roasting on the chemical and biological properties of coffee showed significant discrepancies, resulting from, among others, differences in methodology, temperature parameters and origin of beans (Król et al., 2020; Várady et al., 2020). In most cases only changes in raw and roasted beans were analysed, leaving out a comprehensive assessment of the entire process, from the bean to the brew to the grounds. The relationships between the colour of the infusion, the content of polyphenols and antioxidant activity, which can be an important indicator of coffee quality, are also not sufficiently understood.

In the context of the growing importance of the circular economy, it is also important to explore the potential of coffee grounds as a source of bioactive compounds that can be used in the food, cosmetics or materials industries (Grigolon et al., 2023).

2.5. Research Purpose

The aim of the study was to evaluate the influence of roasting intensity on selected chemical properties and colour parameters of *Coffea arabica* beans and infusions originating from Peru, Nicaragua and Brazil. The research included the assessment of changes in the content of phenolic compounds in beans and infusions depending on the roasting degree, the analysis of antioxidant activity using the ABTS and FRAP assays, and the evaluation of the relationship between phenolic content and antioxidant potential. Additionally, changes in the colour parameters (L*, a*, b*) of the infusions were analysed as indicators of chemical transformations occurring during heat treatment. The scope of the study was defined based on a literature review and the results of the laboratory analyses conducted within the project.

3. Methodology

Arabica coffee beans from three countries in South and Central America – Brazil (Cerrado de Minas), Nicaragua (El Derrumble) and Peru (Cajamarca) – were analysed to determine the content of phenolic compounds, antioxidant activity and colour parameters. All samples came from *specialty plantations*, differing in the height of the crops (600-2200 m above sea level) and the method of processing. The coffee was roasted in the IKAWA oven under controlled conditions. The beans were divided into portions of 50 g, which were roasted in three degrees of intensity – light, medium and dark. Although the coffees originated from different regions and thus differed in their physical properties such as density and moisture content, all samples were roasted using the same programmed temperature profile in the IKAWA roaster. To account for these intrinsic differences, the onset of the first crack, i.e. the characteristic series of audible cracks accompanying bean expansion, was used as a relative time reference for each batch. From the beginning of the first crack, an identical post-crack development profile was applied, and only the duration of this final phase was varied to obtain light, medium and dark roasts for all coffees.

Table 1. Parameters of the roasting process

Country	Type of roasting	Total Roasting Time (min:s)	Final Temperature (°C)
Brazil	Light	07:09	203
Brazil	Medium	07:54	208
Brazil	Dark	08:39	212
Nicaragua	Light	08:01	209
Nicaragua	Medium	08:46	213
Nicaragua	Dark	09:31	215
Peru	Light	07:05	203
Peru	Medium	07:50	208
Peru	Dark	08:35	212

Source: own study.

Coffee beans from each roasting variant were ground immediately before brewing to a uniform medium-size granulation appropriate for pour-over extraction. For each sample, 22 g of coffee was used and brewed in a paper-filter dripper. The filter was rinsed, the ground coffee was placed inside, and distilled water heated to 97°C was poured according to a three-stage protocol: 60 ml for the preinfusion (30 s), followed by two pours of 120 ml each, delivered in controlled circular motions. After filtration, the infusions and the remaining grounds were collected, cooled, and prepared for chemical and colorimetric analyses.

3.1. Determination of Phenolic Compounds and Antioxidant Activity

For the determination of phenolic compounds and antioxidant activity, ground roasted beans (0.50 g) and coffee grounds remaining after brewing (0.20 g) were placed in 15 ml Falcon tubes and extracted with 80% aqueous methanol acidified with 1% HCl (v/v). Samples were shaken vigorously for 30 s and sonicated for 10 min in an ultrasonic bath without heating. After 24 h refrigeration at 4°C, the samples were sonicated again, centrifuged for 10 min at 10,000 rpm, and the resulting supernatants were stored at 4°C until analysis. Liquid infusions were analysed directly after cooling.

Total phenolic content (TPC) was determined using the Folin–Ciocalteu method according to Gao (2000). Antioxidant activity was evaluated using ABTS radical scavenging and FRAP assays following established procedures described in the literature (Benzie & Strain, 1996; Re, 1999).

Colour measurements of the coffee infusions were performed in the CIE L*a*b* colour space using a colorimeter (CR-400, Konica Minolta, Japan). Colour was included in the analysis because it is one of the most sensitive indicators of chemical transformations occurring during roasting and is widely used in the coffee industry as a rapid proxy for roasting degree and melanoidin formation. This analysis enabled the evaluation of visual changes in the infusions and their relationship with chemical transformations during roasting.

Statistical analyses were conducted using one-way ANOVA with Duncan's test at a significance level of $p < 0.05$. The computations were performed in Statistica PL 13.3.

4. Research Results

4.1. Phenolic Compound Content in Beans, Infusions and Grounds

The results of the study indicate that both the origin of the beans and the degree of roasting had a significant effect ($p < 0.05$) on the content of phenolic compounds in the analysed coffee samples. The highest content of total polyphenols in dry beans was recorded in samples from Nicaragua and Peru, especially for medium and dark roasts.

Analysing the results within individual countries, it was found that in the case of Brazilian coffee, the highest content of phenolic compounds was shown by medium-roasted samples (approximately 3041 mg GAE/100 g d.m.), slightly lower – dark roasted (approximately 2980 mg GAE/100 g d.m.), and the lowest – unroasted (2178.98 mg GAE/100 g d.m.). In the case of Nicaraguan coffee, a clear increase in the content of phenolic compounds was observed with an increase in roasting intensity – from approximately 2890 mg GAE/100 g d.m. in unroasted coffee to 3613.47 mg GAE/100 g d.m. in medium roast, with a slight decrease for dark roast coffee (approximately 3470 mg GAE/100 g d.m.). For Peruvian coffee, a systematic increase in the content of polyphenols was recorded with the intensity of roasting – from approximately 2780 mg GAE/100 g d.m. in unroasted coffee, through 3195 mg GAE/100 g d.m. in medium roast, up to 3438.17 mg GAE/100 g d.m. in dark roast.

Similar trends were observed in the case of infusions. The highest values were recorded for coffee originating from Peru (216.77-230.86 mg GAE/100 ml of infusion), slightly lower for coffees from Nicaragua (203.02-211.21 mg GAE/100 ml of infusion), and the lowest for Brazilian samples (119.85-202.37 mg GAE/100 ml of infusion).

Coffee residues had a lower phenolic content than dry beans, but the amount was still significant. The highest content of polyphenols was found in coffee grounds from unroasted coffees from Nicaragua (2038.32 mg GAE/100 g d.m.), while the lowest in dark roast samples from Peru (1335.55 mg GAE/100 g d.m.).

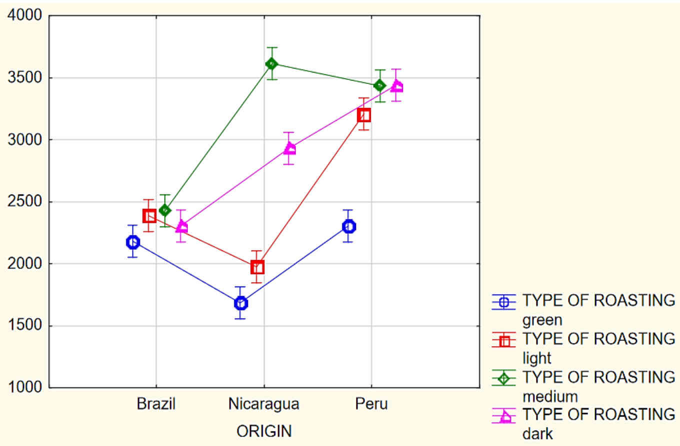

Fig. 1. The relationship between the origin and type of coffee roasting on the content of polyphenolic compounds in dry beans [mg GAE/100 g d.m.]

Source: own study using Statistica v.13.3 (StatSoft, USA).

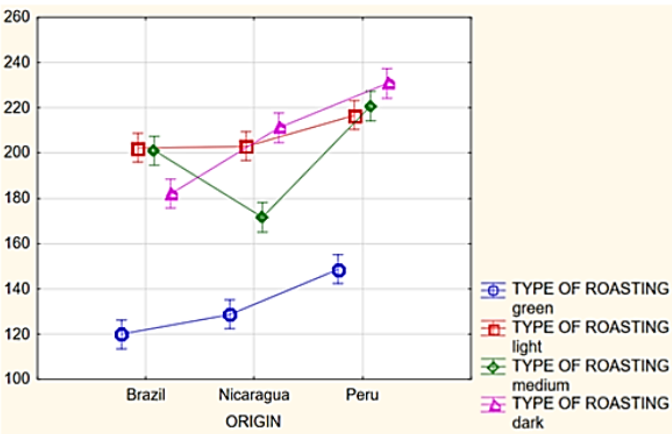

Fig. 2. The relationship between the origin and type of coffee roasting on the content of polyphenolic compounds in the infusion [mg GAE/100 ml of infusion]

Source: own study using Statistica v.13.3 (StatSoft, USA).

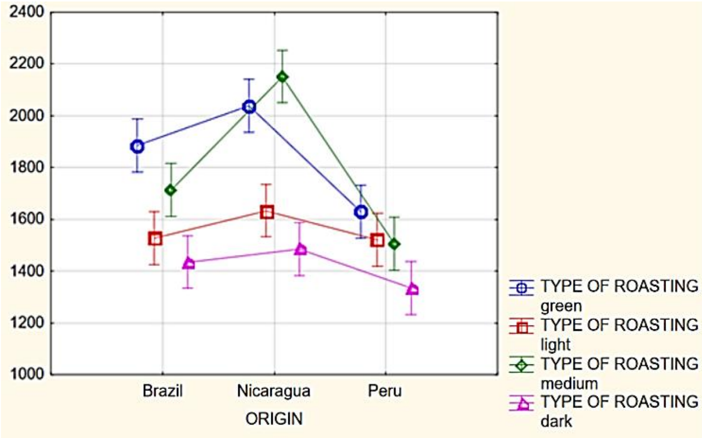

Fig. 3. The relationship between the origin and type of coffee roasting on the content of polyphenolic compounds in coffee grounds [mg GAE/100 g d.m.]

Source: own study using Statistica v.13.3 (StatSoft, USA).

4.2. Antioxidant Activity of Coffee (ABTS and FRAP)

In the ABTS test, medium and dark roast coffees from Peru and Nicaragua showed the highest activity. For beans, the values reached 2.15 mmol TE/100 g d.m. (Peru – dark roasting) and 2.09 mmol TE/100 g d.m. (Nicaragua – medium roasting). The lowest activity was recorded in unroasted Brazilian beans (0.60 mmol TE/100 g d.m.).

In infusions, antioxidant activity increased with the intensity of roasting – from 0.047 mmol TE/100 ml of infusion (Brazil – unroasted) to 0.147 mmol TE/100 ml of infusion (Peru – dark). In the grounds, the values were lower, but still significant, whereas the highest activity was recorded for unroasted coffee beans from Nicaragua (0.57 mmol TE/100 g d.m.).

The FRAP method confirmed similar trends. The highest reduction capacity was shown by samples of medium-roasted coffee from Nicaragua (26.68 mmol TE/100 g d.m.) and dark roasted Peruvian coffee (24.10 mmol TE/100 g d.m.). For infusions, the maximum values reached 1.75 mmol TE/100 ml of infusion (Peru – dark roasting), while for coffee grounds 9.85 mmol TE/100 g d.m. (Nicaragua – unroasted).

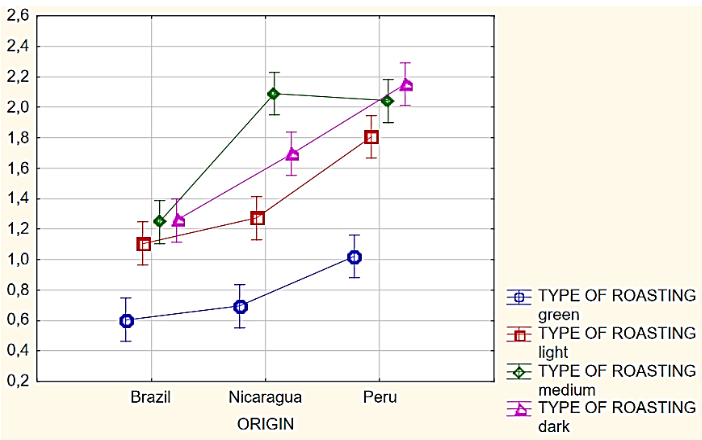

Fig. 4. The relationship between the origin and type of coffee roasting on its antioxidant capacity – variable ABTS; dry beans [mmol TE/ 100 g d.m.]

Source: own study using Statistica v.13.3 (StatSoft, USA).

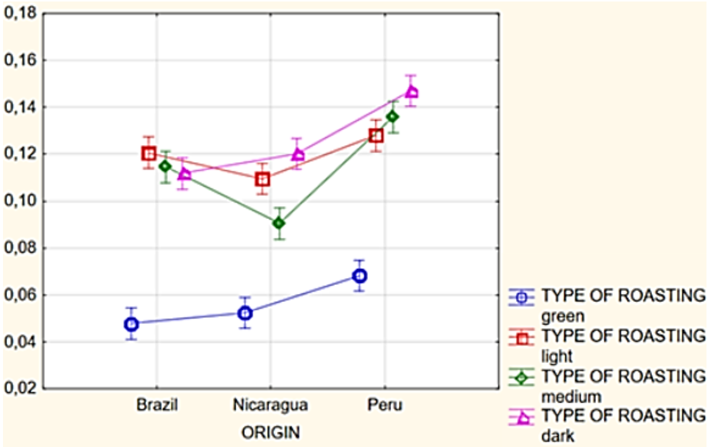

Fig. 5. The relationship between the origin and type of coffee roasting on its antioxidant capacity – ABTS variable; infusion [mmol TE/ 100 ml of infusion]

Source: own study using Statistica v.13.3 (StatSoft, USA).

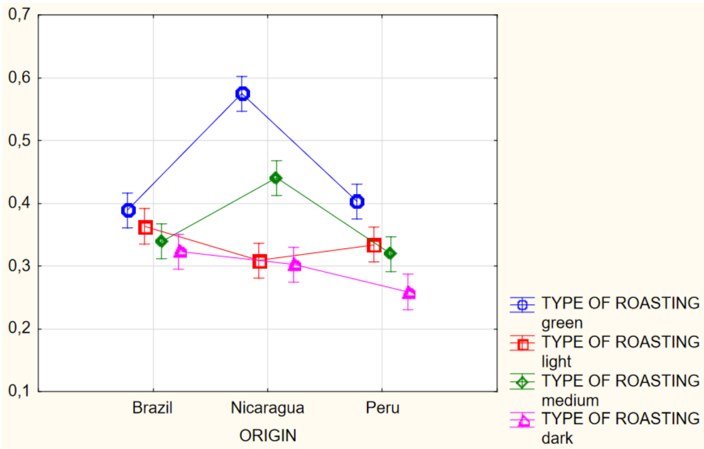

Fig. 6. The relationship between the origin and type of coffee roasting on its antioxidant capacity – variable ABTS; grounds [mmol TE/ 100 g d.m.]

Source: own study using Statistica v.13.3 (StatSoft, USA)

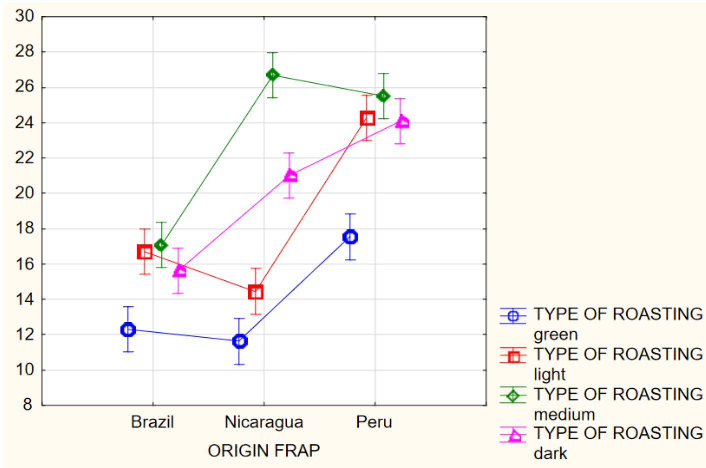

Fig. 7. The relationship between the origin and type of coffee roasting on its ability to reduce iron ions – dry beans [mmol TE/100 g d.m.]

Source: own study using Statistica v.13.3 (StatSoft, USA).

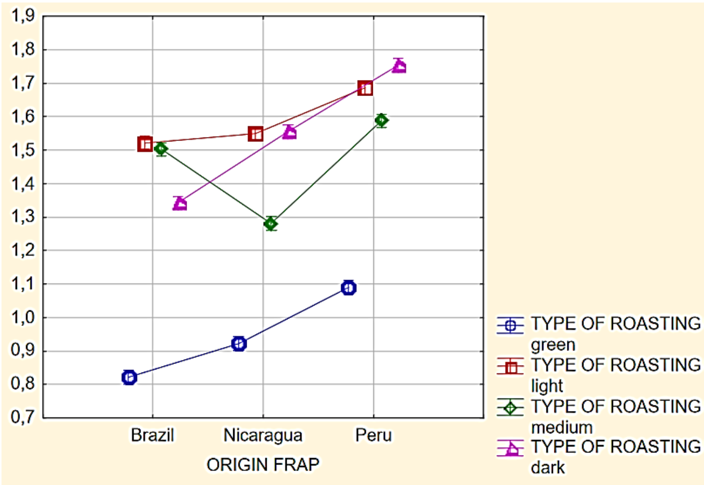

Fig. 8. The relationship between the origin and type of coffee roasting on its ability to reduce iron ions – infusion [mmol TE/ 100 ml of infusion]

Source: own study using Statistica v.13.3 (StatSoft, USA).

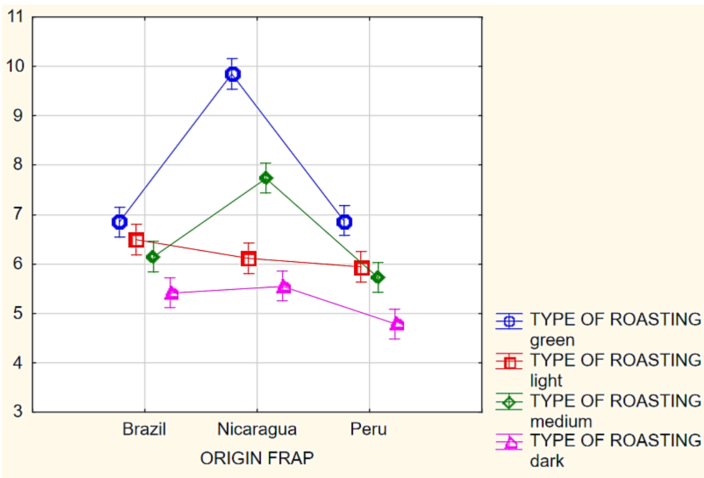

Fig. 9. The relationship between the origin and type of coffee roasting on its ability to reduce iron ions – grounds [mmol TE/100 g d.m.]

Source: own study using Statistica v.13.3 (StatSoft, USA).

4.3. Colour Analysis of Infusions

Colorimetric analysis of coffee brews carried out in the CIE Lab system showed significant differences in colour depending on the degree of roasting and the origin of the samples. With the increase in the intensity of roasting, the values of the L* coefficient (brightness) steadily decreased, while the coefficients a* (red colour content) and b* (yellow colour content) increased, which indicates the appearance of warmer colour tones of the infusion.

For Brazilian coffee infusions, the brightness (L*) decreased from 84.48 for unroasted coffee (light yellow) to 61.95 for dark roast (brown-amber), while the coefficients a* and b* increased from -2.05 and 9.06 respectively to 14.60 and 66.29.

Nicaraguan and Peruvian coffee brews showed similar trends, reaching the lowest L* values (approximately 52-54) with the highest a* (18-22) and b* (58-62) highs. Such values correspond to the intense colour of dark amber with a strong saturation of red-gold shades, typical of strongly roasted coffees.

4.4. Summary of the Results

1. The degree of roasting and the origin of the raw material significantly differentiated the content of phenolic compounds and antioxidant activity.
2. Higher levels of polyphenols were observed in infusions from Peru and Nicaragua than in samples from Brazil.
3. Coffee grounds retained significant amounts of phenolic compounds.
4. The parameters L*, a*, b* systematically changed with the intensity of roasting.

5. Discussion and Conclusions

The results of the conducted research confirm that the roasting process is a key stage of coffee technology, significantly shaping both its chemical composition and bioactive and sensory properties.

With the increase in roasting intensity there were changes in the content of phenolic compounds, antioxidant activity and the colour of infusions of Coffea arabica varieties grown in Peru, Nicaragua, and Brazil. Based on the comparison, it was shown that coffee from Peru and Nicaragua was characterised by a higher content of polyphenols and a higher antioxidant potential than coffee from Brazil, which can be associated with differences in climate and altitude of cultivation areas (1100-2200 m above sea level).

The results are consistent with Adepoju et al. (2017) and Ceballos-Sierra & Dall'erba (2021), indicating that environmental conditions have a significant impact on the biosynthesis of phenolic compounds in coffee beans.

Colour analysis confirmed that L*, a* and b* parameters can be a useful tool in assessing coffee quality. The decrease in brightness and increase in red and yellow as roasting intensity increases reflects the chemical changes that occur during the Maillard reaction and the formation of melanoidins (Wang & Lim, 2015; Yeager et al., 2022).

During coffee roasting, melanoidins are formed mainly in the advanced stages of the Maillard reaction, where reduced sugars react with amino compounds and undergo subsequent dehydration, fragmentation, condensation and polymerisation, leading to high-molecular-weight brown nitrogenous polymers. Their formation intensifies with increasing roasting degree and contributes markedly to the development of colour and sensory attributes of roasted coffee. Importantly, coffee melanoidins can incorporate phenolic structures and other low-molecular-weight compounds, which may partially explain their antioxidant potential even when some native antioxidants are degraded during thermal processing (Iriondo-DeHond et al., 2021). Therefore, although melanoidins were not quantified in this study, they represent a plausible mechanism linking roasting-induced transformations with the observed changes in colour and antioxidant-related parameters.

An important aspect is also the residual antioxidant activity of coffee grounds, retaining significant amounts of phenolic compounds, which indicates their potential in the context of a circular economy. The recovery of these raw materials can be used in the food, cosmetics and materials industries (Grigolon et al., 2023).

The results obtained can be the basis for optimising roasting parameters to balance desirable sensory attributes with the preservation of high levels of bioactive compounds. Choosing the optimal degree of roasting, especially medium, allows to maintain a balance between the taste and biological activity of the infusion.

5.1. Implications for Science and Practice and Directions for Further Work

The analysis indicates that the colour parameters can be used as a quick indicator of the chemical quality of the brew, useful in the control of technological processes in roasters. The continued antioxidant activity of coffee grounds opens new possibilities for their secondary use.

The research included samples from a limited number of regions and one species of coffee (*C. arabica*). In the future it is advisable to expand the analyses to other species, e.g. *C. canephora* (robusta), as well as to various roasting, brewing and grinding techniques. It is worth using chromatographic techniques (HPLC, LC-MS), which will allow for the detailed identification of phenols and tracking their transformations during heat treatment.

Further studies should include sensory analyses of the infusions in correlation with the chemical profile and assessment of the stability of bioactive compounds during storage. A combination of chemical, colour and sensory analyses will enable the creation of a comprehensive model of coffee quality.

The methods used (Folin–Ciocalteu, ABTS, FRAP and CIE Lab colour analysis) proved to be effective in assessing the bioactive and visual properties of coffee. Their use in further research can promote the standardisation of measurements and the comparability of results between different coffee grades and processing technologies.

5.2. Final Conclusions

1. The degree of roasting of coffee significantly affects the content of phenolic compounds, antioxidant activity and colour parameters of brews.
2. Coffee grounds retain significant amounts of bioactive compounds, which justifies their potential use in the circular economy.

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Wpływ procesu palenia na wybrane parametry jakości ziarna kawowca (*Coffea L.*) z obszaru Ameryki Środkowej i Południowej oraz napojów z niego otrzymanych

Streszczenie

Cel: Celem badania było określenie wpływu procesu palenia na zawartość związków fenolowych, aktywność przeciwutleniającą i barwę naparów przygotowanych z ziaren kawy (*Coffea arabica*) pochodzących z Ameryki Środkowej i Południowej.

Metodyka: Do badania wykorzystano próbki zielonej i palonej kawy z wybranych regionów uprawy (Brazylia, Nikaragua i Peru). Całkowitą zawartość polifenoli określono metodą Folina-Ciocalteu, aktywność przeciwutleniającą metodami ABTS i FRAP, a parametry barwy naparów za pomocą kolorymetru. Uzyskane wyniki poddano analizie statystycznej (ANOVA, test Duncana).

Wyniki: Proces palenia miał znaczący wpływ na zawartość polifenoli, aktywność przeciwutleniającą i barwę naparów kawowych. Najwyższe wartości analizowanych parametrów stwierdzono w próbkach kawy palonej średnio i ciemno, zwłaszcza pochodzących z Peru i Nikaragui. Wykazano dodatnią korelację między zawartością polifenoli a aktywnością przeciwutleniającą. Fusy pozostałe po zaparzeniu zachowały znaczne ilości związków bioaktywnych, co wskazuje na możliwość ich ponownego wykorzystania w kontekście gospodarki o obiegu zamkniętym i zrównoważonego rozwoju.

Implikacje i rekomendacje: Wyniki badania wskazują na potrzebę dalszej analizy procesów palenia w celu opracowania optymalnych parametrów, które pozwolą zachować wysoki poziom związków bioaktywnych w naparze przy jednoczesnym zachowaniu pożądanych właściwości sensorycznych. Dalsze badania powinny skupić się na możliwości wykorzystania fusów z kawy jako surowca wtórnego w przemyśle spożywczym, kosmetycznym i materiałowym.

Oryginalność/wartość: Oryginalność pracy wynika z kompleksowego podejścia do procesu palenia kawy, które obejmuje analizę zarówno surowych, jak i palonych ziaren, a także przygotowanych z nich naparów i fusów. Podejście to pozwala na pełne zrozumienie zmian w składzie chemicznym i właściwościach bioaktywnych kawy na wszystkich etapach jej przetwarzania, od surowca do produktu końcowego.

Słowa kluczowe: kawa, proces palenia, przeciwutleniacze, związki fenolowe, *Coffea arabica*