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# Effects of roasting and brewing on functional properties of coffee

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**Abstract**

*This study investigated the influence of roasting temperature and brewing method on the antioxidant and antidiabetic properties of coffee beverages. Green coffee beans (Coffea arabica L.) were roasted at temperatures ranging from 160 to 240 °C for 5 and 10 minutes, and two types of coffee brewages, espresso and black, were prepared from each roasted sample. The total polyphenol content (TPC), antioxidant activity (FRAP), and α-amylase inhibitory potential were determined spectrophotometrically. Both TPC and FRAP values increased with roasting temperature up to 220 °C, while their decline at 240 °C indicated thermal degradation of polyphenols. Espresso coffee prepared from beans roasted at 220 °C for 5 minutes had the highest polyphenol content and the highest antioxidant capacity. In contrast, α-amylase inhibition continued to rise with roasting intensity and reached its maximum at 240 °C, suggesting that Maillard reaction products play a key role in enzyme inhibition. Black coffee exhibited significantly higher α-amylase inhibition than espresso. These findings demonstrate that roasting temperature and brewing method jointly determine the functional quality of coffee. Medium-dark roasting (200–220 °C, 10 min) provides a balance between antioxidant activity and α-amylase inhibition. Given that black coffee is typically served in higher volume than espresso (≈80 mL for black and ≈30 mL for espresso coffee), black coffee offers overall stronger functional potential, offering both postprandial glucose regulation and antioxidant activity.*

**Keywords**: *coffee; roasting; polyphenols; antioxidant activity; α-amylase inhibition.*

## INTRODUCTION

Coffee is one of the most widely consumed beverages in the world and represents an integral part of daily habits for many people [1]. In Serbia, the average consumption is estimated at approximately two to four cups of black coffee per day, making this habit highly relevant when considering its potential impact on public health [2]. Studies conducted over the past decades suggest a possible association between regular coffee consumption and a reduced risk of developing type 2 diabetes [3]. This protective effect is most often attributed to the presence of chlorogenic acids, flavonoids, and other bioactive compounds that may influence glucose metabolism and insulin sensitivity [4]. However, the concentration and biological activity of these compounds in coffee beverages depend on several technological factors, primarily the degree of roasting and the method of coffee preparation [5,6]. Although thermal processing is essential for the development of the characteristic aroma and flavour of coffee, it can also result in partial degradation of bioactive compounds [7]. During roasting, coffee beans undergo complex chemical transformations, including caramelization and Maillard reactions, leading to the formation of melanoidins, furans, and numerous volatile compounds that shape the sensory profile of coffee but also influence its antioxidant and potential antidiabetic properties [8].

During light roasting (180–200 °C), the thermal degradation of polyphenols is limited; medium roasting (210-220 °C) enhances flavour development while most bioactive compounds are still preserved, whereas dark roasting (230-250 °C) leads to pronounced thermal degradation of polyphenols and, consequently, to

a reduction in the potential antidiabetic activity [5]. In addition to roasting degree, roasting time plays an important role, since prolonged exposure to higher temperatures accelerates the degradation of polyphenols, promotes the formation of lactone derivatives, and changes the chemical profile of Maillard reaction products. Furthermore, different brewing techniques, such as espresso, black coffee, filter coffee, or cold brew, significantly influence the extraction efficiency of bioactive compounds and, consequently, the functional properties of the resulting beverage [9].

Given the widespread consumption of coffee and its potential relevance to metabolic health, understanding how technological parameters modulate its functional properties is of particular importance. In this context, the present study aimed to investigate the effects of roasting conditions and preparation methods on total phenolic content, antioxidant activity, and α-amylase inhibitory potential of coffee.

## MATERIALS AND METHODS

### Materials

Green coffee beans (*Coffea arabica* L.) originating from Brazil were provided by the local coffee roastery Fuka (Serbia). The Folin–Ciocalteu reagent, TPTZ (2,4,6-tripyridyl-s-triazine), and gallic acid were purchased from Sigma–Aldrich (Steinheim, Switzerland/China). α-Amylase from porcine pancreas was purchased from Sigma-Aldrich (St. Louis, USA). All other chemicals and solvents used in this study were of analytical grade and were purchased from Merck (Darmstadt, Germany) and Lach-Ner (Czech Republic).

### Preparation of the coffee beverages

Green coffee beans were roasted in a household oven with temperature control at five temperatures (160, 180, 200, 220 and 240 °C) for 5 and 10 minutes. Roasting was performed in small batches (33 g per batch) to ensure uniform heat treatment. After roasting, the beans were cooled to room temperature and ground using a laboratory mill.

Two coffee beverages were prepared from each roasted sample. Espresso was prepared using 18 g of ground coffee extracted with 126 mL of distilled water, while black coffee was prepared by adding 10 g of ground coffee to 70 mL of boiling water; the mixture was briefly brought to the boil and then allowed to settle. In both cases, solid residues were removed by vacuum filtration, and the extracts were stored at 4 °C until further analysis [10,11].

### Determination of total polyphenol content (TPC)

Total polyphenol content in coffee extracts was determined using previously described Folin–Ciocalteu method [12]. An aliquot of 50 µL of coffee extract was mixed with 250 µL of Folin–Ciocalteu reagent and 3.7 mL of distilled water. After thorough mixing, 1.0 mL of sodium carbonate solution (20%) was added. The reaction mixture was incubated for 2 h in the dark at room temperature to allow complete colour development. After incubation, absorbance was measured at 750 nm against a blank. Gallic acid was used as the calibration standard in the concentration range of 0.02–1.5 mg/mL. Total polyphenol content was calculated from the calibration curve and expressed as gallic acid equivalents per millilitre.

### Ferric ion reducing antioxidant power (FRAP)

The antioxidant activity of coffee extracts was determined using the FRAP assay, which is based on the reduction of the $Fe^{3+}$–TPTZ (iron(III)–tripyridyltriazine) complex to the blue-coloured $Fe^{2+}$–TPTZ (iron(II)–tripyridyltriazine) complex under acidic conditions [13]. The FRAP reagent was freshly prepared by mixing 0.3 M acetate buffer (pH 3.6), 10 mM TPTZ solution in 40 mM HCl, and 20 mM $FeCl_3 \cdot 6H_2O$ in a volume ratio of 10:1:1. For the assay, 50 µL of coffee extract was added to 1.5 mL of FRAP reagent. The mixture was vortexed and incubated for 5 min in the dark at room temperature. After incubation, absorbance was measured at 593 nm against a blank. Calibration was performed using $FeSO_4 \cdot 7H_2O$ standard solutions in the concentration range of 0.2–1.0 mmol/L. Antioxidant activity was calculated from the calibration curve and expressed as mmol $Fe^{2+}$ equivalents per liter.

### Determination of inhibitory effect on α-amylase activity

The inhibitory effect of coffee extracts on α-amylase activity was determined using the DNS (3,5-dinitrosalicylic acid) method, based on the quantification of reducing sugars released from starch during enzymatic hydrolysis [14]. The method relies on the reduction of DNS by reducing sugars, resulting in the formation of a coloured product whose absorbance is measured at 540 nm. The reaction mixture consisted of 20 µL of coffee extract, 20 µL of α-amylase solution (2.5 mg/mL), and 160 µL of sodium phosphate buffer (pH 6.9). After pre-incubation for 5 min at 37 °C, the reaction was initiated by the addition of 200 µL of 1% starch solution and further incubated for 5 min at 37 °C. The reaction was terminated by adding 400 µL of DNS reagent, followed by heating in a boiling water bath for 5 min to develop the colour. After cooling, the reaction mixtures were diluted with 3 mL of distilled water, and absorbance was measured at 540 nm against a blank. Control samples without enzyme and with coffee extract were prepared to account for non-enzymatic starch hydrolysis, while control samples with enzyme and without

coffee extract were prepared to account for uninhibited enzymatic starch hydrolysis. The percentage of α-amylase inhibition was calculated by comparing the amount of reducing sugars released due to enzymatic hydrolysis in the presence of coffee extract with that released by the enzyme control (without extract), which was defined as 100% enzyme activity.

### Statistical analysis

All data are expressed as mean ± standard deviation (SD) of three independent measurements. The effects of roasting time (5 vs. 10 min) and brewing method (espresso vs. black coffee) were evaluated using a paired Student's t-test, with statistical significance set at $p < 0.05$.

## RESULTS

### Total polyphenol content (TPC)

Total polyphenol content (TPC) varied substantially among the analysed coffee samples and was strongly influenced by both roasting conditions and brewing method (**Tables 1** and **2**). In black coffee, TPC values increased progressively with increasing roasting temperature from 160 to 220 °C. The highest TPC was recorded at 220 °C after 10 min of roasting (4.85 mg GAE/mL). Further increasing the roasting temperature to 240 °C resulted in a decrease in TPC at both roasting times, indicating thermal degradation of polyphenolic compounds at higher temperatures.

In espresso coffee, TPC increased markedly at roasting temperatures of 200 and 220 °C (**Table 2**). The highest TPC value observed in the entire experiment was obtained at 220 °C after 5 min of roasting (12.77 mg GAE/mL), while a slightly lower value was recorded at the same temperature after 10 min (11.39 mg GAE/mL). At 240 °C, a pronounced decline in TPC was evident, irrespective of roasting duration, indicating substantial thermal degradation of polyphenols at the highest temperature.

Overall, espresso coffee contained significantly higher polyphenol levels than black coffee ($p = 0.023$). While prolonged roasting at lower temperatures led to an increase in TPC, the opposite trend was observed at higher temperatures. As a result, roasting time (5 vs. 10 min) did not exert a statistically significant overall effect on TPC.

### Antioxidant activity

The antioxidant activity of black and espresso coffee, expressed as FRAP values, followed trends similar to those observed for TPC (**Tables 1** and **2**). In black coffee, FRAP values increased steadily with the increase of roasting temperature reaching maximum of 34.88 mmol $Fe^{2+}$/L at 220 °C after 10 min of roasting. Espresso coffee exhibited considerably higher FRAP values overall, with the highest activity of 68.86 mmol $Fe^{2+}$/L observed at 220 °C after 10 min of roasting. A decrease at 240 °C was observed in both coffee types, suggesting that excessive roasting promotes the breakdown of antioxidant compounds and reduces the redox potential. The strong correlation between TPC and FRAP ($R = 0.971$) indicates that polyphenols are the dominant contributors to the antioxidant capacity of coffee under these conditions.

In line with TPC, espresso coffee exhibited significantly higher FRAP values than black coffee under comparable roasting conditions ($p = 0.011$), indicating a consistent influence of the brewing method on both antioxidant capacity and polyphenol content.

**Table 1.** TPC and FRAP results of black coffee.

| Temperature, °C | Time, min | TPC, mg GAE/mL | FRAP, mmol $Fe^{2+}$/L |
|---|---|---|---|
| 160 | 5 | 3.64 ± 0.60 | 28.20 ± 0.08 |
| 180 | 5 | 4.00 ± 0.52 | 29.71 ± 0.09 |
| 200 | 5 | 4.06 ± 0.43 | 30.56 ± 0.06 |
| 220 | 5 | 4.27 ± 0.23 | 32.69 ± 0.06 |
| 240 | 5 | 4.16 ± 0.35 | 30.96 ± 0.07 |
| 160 | 10 | 4.35 ± 0.39 | 31.65 ± 0.10 |
| 180 | 10 | 4.72 ± 0.26 | 32.27 ± 0.14 |
| 200 | 10 | 4.77 ± 0.25 | 33.55 ± 0.04 |
| 220 | 10 | 4.85 ± 0.54 | 34.88 ± 0.08 |
| 240 | 10 | 4.08 ± 0.11 | 28.17 ± 0.13 |

Data are expressed as mean ± standard deviation.

**Table 2.** TPC and FRAP results of espresso coffee.

| Temperature, °C | Time, min | TPC, mg GAE/mL | FRAP, mmol $Fe^{2+}$/L |
|---|---|---|---|
| 160 | 5 | 3.40 ± 0.18 | 25.14 ± 0.04 |
| 180 | 5 | 3.70 ± 0.28 | 27.79 ± 0.12 |
| 200 | 5 | 9.20 ± 0.32 | 65.55 ± 0.04 |
| 220 | 5 | 12.77 ± 0.51 | 68.86 ± 0.06 |
| 240 | 5 | 4.63 ± 0.23 | 39.28 ± 0.08 |
| 160 | 10 | 4.97 ± 0.44 | 37.99 ± 0.26 |
| 180 | 10 | 6.40 ± 0.34 | 40.01 ± 0.32 |
| 200 | 10 | 10.60 ± 0.26 | 67.51 ± 0.14 |
| 220 | 10 | 11.39 ± 0.36 | 63.04 ± 0.16 |
| 240 | 10 | 4.29 ± 0.18 | 35.12 ± 0.14 |

Data are expressed as mean ± standard deviation.

### Antidiabetic activity

The antidiabetic potential of coffee extracts was assessed by measuring their inhibitory effect on α-amylase activity. Overall, α-amylase inhibition differed markedly between beverage types and increased progressively with roasting temperature in both black and espresso coffee (**Figure 1**).

In black coffee, α-amylase inhibition increased steadily with rising roasting temperature, reaching the highest values at 240 °C (62.88% after 5 min and 68.07% after 10 min of roasting). A similar temperature-dependent trend was observed for espresso coffee; however, the overall inhibition levels were substantially lower than those recorded for black coffee. The maximum inhibition in espresso coffee was also observed at 240 °C, amounting to 35.26% after 5 min and 36.98% after 10 min of roasting.

α-amylase inhibition tended to be higher at shorter roasting times at lower temperatures, while the opposite trend was observed at roasting temperatures of 200 °C and above. Consequently, the overall effect of roasting time was not statistically significant ($p = 0.3487$). In contrast, a significant difference was observed between black and espresso coffee, with black coffee exhibiting higher inhibitory activity ($p = 0.003$).

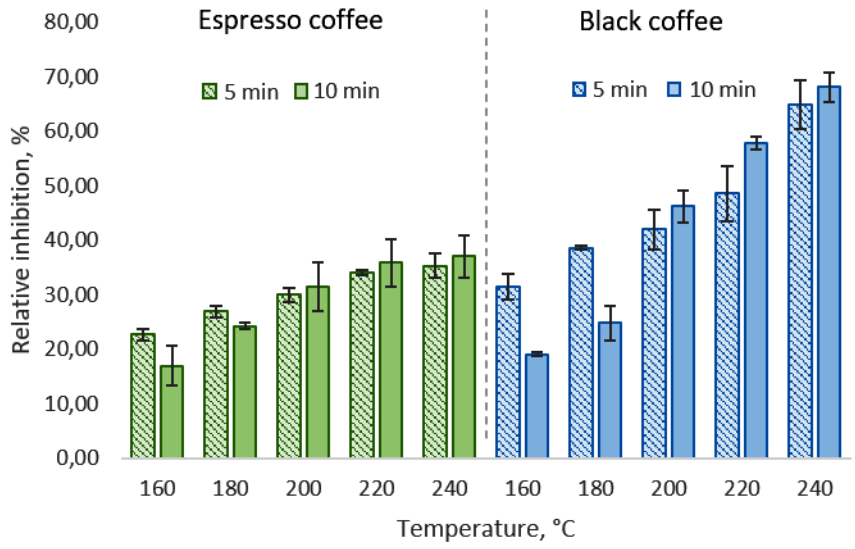


**Figure 1.** Influence of roasting temperature (160–240 °C) and duration (5 and 10 min) on α-amylase inhibition in espresso and black coffee.

## DISCUSSION

This study examined how roasting conditions and brewing method jointly influence the functional properties of coffee, with particular emphasis on polyphenol content, antioxidant capacity, and α-amylase inhibitory activity. By comparing black and espresso coffee prepared from beans roasted at different temperatures and durations, we aimed to disentangle the relative contributions of thermal processing and extraction conditions to these bioactivities. The results demonstrate that roasting temperature is a key determinant of polyphenol retention and antioxidant potential, whereas enzyme inhibitory activity follows a distinct pattern, highlighting the complex and sometimes opposing effects of roasting intensity and brewing technique on coffee functionality.

In both black and espresso coffee, TPC increased with rising roasting temperature and reached its highest values at 220 °C, after which

it declined at 240 °C (**Tables 1** and **2**). This trend was consistent at both roasting times (5 and 10 min), suggesting that temperature had a stronger influence on TPC than heating duration. Similar findings have been reported previously, where moderate roasting enhances the release or extractability of polyphenolic compounds, while darker roasting leads to a progressive loss due to thermal degradation [15,16]. Additionally, Várady *et al.* [17] reported the highest TPC in beans roasted at 215 °C, further indicating that the optimal TPC is achieved under moderate roasting conditions, after which degradation becomes dominant.

During coffee roasting, Maillard reactions occur between reducing sugars and amino acids, leading to the formation of brown, high-molecular-weight compounds known as melanoidins [18,19]. As roasting advances, some polyphenol compounds, particularly chlorogenic acid, can become incorporated into these melanoidin polymers. This structural integration reduces their free form but preserves their contribution to the overall biological potential of the beverage. In addition, melanoidin can react with the Folin–Ciocalteu reagent, contributing to the measured TPC [20]. This explains why TPC continued to increase at moderate roasting temperatures (200–220 °C) despite the onset of phenolic degradation. However, at higher temperatures (240 °C), the degradation of polyphenolic compounds and excessive polymerization lead to a noticeable decline in TPC [15].

A comparable pattern was observed for antioxidant activity measured by the FRAP assay. FRAP values increased with roasting temperature and reached a maximum at 220 °C, followed by a decline at 240 °C, following the behaviour of TPC. The strong positive correlation between TPC and FRAP in our study ($R = 0.971$) suggests that polyphenols play a major role in determining the reducing capacity of the samples. This is in line with the findings that polyphenol acids account for a substantial proportion of the total antioxidant activity in coffee [15]. Additionally, at moderate roasting levels, both residual free polyphenols and newly formed Maillard reaction products likely contribute to increased FRAP values [20]. Melanoidin structures formed during intermediate stages of roasting retain significant reducing activity, and together with enhanced extractability of polyphenols, they could contribute to the higher FRAP values at 220 °C [21]. However, at higher temperatures, thermal degradation affects both polyphenols and Maillard products, resulting in the decrease in antioxidant activity observed at 240 °C [15].

While roasting conditions clearly influenced the concentration and activity of bioactive compounds in coffee beans, the final functional properties of the beverage are also strongly determined by the brewing method. Our results showed a statistically significant difference in both TPC and antioxidant activity between black and espresso coffee, with espresso consistently exhibiting higher values ($p = 0.023$ and $p = 0.011$). Previous studies have demonstrated that the brewing method significantly affects polyphenol extraction and antioxidant activity in coffee [22]. Chavez *et al.* [23] found that espresso infusions exhibited higher TPC and stronger antioxidant activity compared with other brewing techniques.

When antidiabetic activity was considered, however, a distinctly different roasting-dependent pattern emerged. In contrast to TPC and FRAP, which reached their maximum at moderate roasting levels, α-amylase inhibition increased progressively with roasting intensity and was highest at 240 °C. This indicates that the compounds responsible for enzyme inhibition differ from those contributing to the antioxidant capacity. This effect may be explained by the formation of late-stage Maillard reaction products and high-molecular-weight melanoidins at higher roasting intensities, which have been shown to interact with digestive enzymes and reduce their activity [24].

A consistent difference between brewing methods was also observed, with black coffee exhibiting significantly higher α-amylase inhibition than espresso across all roasting conditions ($p = 0.003$). This effect is likely related to the technological characteristics of black coffee preparation, including prolonged contact between hot water and coffee grounds and the presence of suspended solids in the final beverage, both of which can enhance the extraction of melanoidins and other roasting-derived components with potential enzyme inhibitory activity.

Based on the obtained results, espresso coffee may be considered more favourable in terms of antioxidant activity, while black coffee shows a greater potential with respect to α-amylase inhibition. However, interpretation of these concentration-based differences requires consideration of typical consumption volumes, as black coffee is generally consumed in substantially larger servings than espresso. When expressed per typical serving size (approximately 80 mL for black coffee and approximately 30 mL for espresso), black coffee yields higher FRAP values and stronger α-amylase inhibition, despite espresso containing higher concentrations of polyphenols when calculated per millilitre. Although the highest enzyme inhibition occurred at 240 °C, this very dark roast was accompanied by lower TPC and FRAP values compared to the 200–220 °C range. Roasting at 200–220 °C for 10 minutes therefore represents a more favourable balance, maintaining high α-amylase inhibition while preserving most of the antioxidant capacity. Our findings indicate that darker roasting enhances enzyme inhibition, whereas medium–dark roasting better preserves polyphenols and antioxidant activity. Within this balance, black coffee, prepared from medium–dark roasted beans, appears to provide the most balanced combination of functional properties per serving.

## CONCLUSION

The results of this study demonstrate that both the roasting temperature and the brewing method significantly influence the functional properties of coffee. The TPC and antioxidant activity increased with roasting temperature up to 220 °C, followed by a decline at 240 °C, indicating the onset of polyphenol degradation. In contrast, the inhibition of α-amylase continued to rise with roasting intensity, suggesting that Maillard reaction products play a key role in this bioactivity.

Black coffee exhibited significantly higher α-amylase inhibition than espresso, while espresso contained higher levels of polyphenols per millilitre. When expressed per serving (≈80 mL for black coffee and ≈30 mL for espresso), black coffee exhibited higher overall antioxidant and enzyme-inhibitory potential than espresso. Coffee prepared from medium-dark roasted beans, particularly black coffee, may therefore offer enhanced health-related benefits associated with postprandial glucose regulation and antioxidant protection. Further studies are needed to confirm these effects *in vivo* and to better characterize the compounds responsible for the observed activities.

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# Uticaj prženja i načina pripreme na funkcionalna svojstva kafe

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**Kratak sadržaj**

*U ovom radu ispitivan je uticaj temperature pečenja i načina pripreme napitka od kafe na njena antioksidativna i antidijabetska svojstva. Zelena zrna kafe (Coffea arabica L.) pečena su na temperaturama od 160 do 240 °C tokom 5 i 10 minuta, a iz svakog uzorka pripremljena su dva tipa napitaka – espresso i crna kafa. Ukupan sadržaj polifenola, antioksidativna aktivnost i sposobnost inhibicije enzima α-amilaze određeni su spektrofotometrijski. Sadržaj ukupnih polifenola i antioksidativna aktivnost rasle su sa povećanjem temperature pečenja do 220 °C, nakon čega je zabeležen pad na 240 °C, što ukazuje na termičku razgradnju polifenolnih jedinjenja. Najviši sadržaj polifenola i antioksidativna aktivnost su utvrđeni kod espresso kafe pečene na 220 °C tokom 5 minuta. Nasuprot tome, sposobnost inhibicije α-amilaze nastavila je da raste sa intenzitetom pečenja i dostigla maksimum pri 240 °C, što ukazuje da proizvodi Majloardove reakcije učestvuju u inhibiciji α-amilaze. Crna kafa pokazala je znatno veću inhibiciju α-amilaze u odnosu na espresso, dok je espresso kafa sadržala više polifenola po mililitru napitka. Kada se rezultati izraze po šoljici kafe (≈80 mL za crnu i ≈30 mL za espreso kafu), crna kafa je ispoljila veću ukupnu antioksidativnu aktivnost, inhibiciju α-amilaze i veći ukupni sadržaj polifenola. Rezultati ukazuju da temperatura pečenja i način pripreme zajedno određuju funkcionalni kvalitet kafe. Srednje tamno prženje (200–220 °C, 10 min) predstavlja optimalan odnos između antioksidativne aktivnosti i inhibicije α-amilaze, što sugeriše da crna kafa pripremljena od srednje tamno prženih zrna može imati povoljnije dejstvo na regulaciju postprandijalne glikemije.*

**Ključne reči:** *kafa; pečenje kafe; polifenoli; antioksidativna aktivnost; inhibicija α-amilaze.*