

## Effect of microwave roasting on the chemical constituents and antioxidant potentials of coffee beans

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### Abstract

The present work evaluated the effect of microwave roasting on total polyphenol content (TPC), total flavonoid content (TFC), 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity, some selected compounds, and the mineral content of coffee beans. Coffee bean powder was roasted at three microwave power levels (450, 720, and 900 W) and treatment durations (4, 6, and 8 min). The TPC, TFC, and DPPH radical scavenging activity were increased by increasing the microwave power and roasting duration, but detrimental effects were observed at higher power levels and longer treatment durations. The highest TPC, TFC, and DPPH radical scavenging activity were detected for the sample treated at 720 W for 6 min. The mineral content was only increased in the sample treated at 450 W for 4 min; all other treatments decreased the mineral content. Microwave power levels and treatment durations showed a significant increase in the browning intensity of the coffee bean extract. The selected coffee bean compounds as analysed by GC-MS were affected in different ways by microwave treatment. The relative percentage of caffeine was increased from 40.06 to 49.12% when treated at 450 W for 4 min, while *n*-hexadecanoic acid content was decreased from 33.86% in untreated coffee beans to 16.31% when treated at 450 W for 4 min. There was also the formation of new compounds such as octadecanoic acid-methyl ester, vitamin E, and stigmasterol upon microwave roasting of coffee beans. Based on the above results, microwave heating can be used as a roasting method for coffee beans.

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### Introduction

Coffee beans are a rich source of antioxidants such as caffeic acid, chlorogenic acid, ferulic acid, sinapic acid, and many other phenolic compounds, which possess potential health benefits (Jung *et al.*, 2017; Kwak *et al.*, 2017). These phenolic constituents not only affect the bitterness and acidity, but could also prevent many metabolic diseases such as obesity, cardiovascular, diabetes, Alzheimer's, and inflammation (Madhava Naidu *et al.*, 2008; Vignoli *et al.*, 2011; Esquivel and Jiménez, 2012; Jung *et al.*, 2017). Phenolic constituents, which are found abundantly in coffee beans, render coffee as a functional beverage (Esquivel and Jiménez, 2012).

When compared with other species, the consumption of Arabica and Robusta coffee beans is higher; Arabica (70%), Robusta (26%), and other (4%) (USDA, 2012; Diviš *et al.*, 2019). The roasting of coffee beans is considered the main influencer on coffee bean quality, functionality, aroma, flavour, and taste (Schenker *et al.*, 2002). Processing conditions

are not the only factor that could affect the total polyphenol content and DPPH radical scavenging capacity of coffee beans, but agricultural and geographical factors also play important roles (Schenker *et al.*, 2002; Cheong *et al.*, 2013). Apart from roasting, brewing and grinding are the other processing conditions that affect the bioactive compounds present in coffee (Hečimović *et al.*, 2011; Derrosi *et al.*, 2018).

Roasting coffee beans for extended periods leads to an increase in the intensity of roasty flavour. Alstrup *et al.* (2020) reported that a short development time increased the fruity, sweet, and acidic attributes of coffee, whereas a longer development time shifted the balance towards a more bitter, roasty, and nutty profile. For this study, the fast roasting was ended at 204.1°C for 90 s, medium at 201.2°C for 143 s, slow at 198.4°C for 266 s, and baked at 191.1°C for 390 s.

Conventional roasting is done using a frying pan, and since the roasting temperature is not controlled in conventional coffee processing, it can

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cause the distribution of excess heat in the coffee beans, thus rendering the coffee beans to blacken faster. Therefore, the use of tools or machines in coffee roasting can control the temperature and duration, and can maintain the quality of beans (Saloko *et al.*, 2019). Since conventional roasting of coffee beans may reduce the content of phenolic acids, the coffee industry requires an improved roasting method in order to preserve or increase phenolic content in coffee beans. Cheong *et al.* (2013) compared the phenolic constituents and antioxidant capacity of four Asian coffee varieties roasted with a home coffee roaster for 12 min, and then cooled down by blowing in the roaster for 4 min. They reported that the radical scavenging activity was similar between the green and roasted coffee beans, while the Arabica Sidikalang variety exhibited the highest ferric-reducing capacity. Dong *et al.* (2018) used five different microwave power levels (0.3, 0.5, 1.0, 1.5, and 2.0 kW) in their study to explore the drying characteristics of green coffee beans. They found that microwave vacuum drying resulted in a significant increase in TPC and DPPH free radical scavenging activity, and the rate of increase was higher at higher microwave power level. Depending on people's choices, different roasting styles have been created which differ from each other in terms of temperature, duration, and others (Moon *et al.*, 2009). Selection of various factors such as roasting duration, temperature, microwave power, and others significantly impacts the features of the product (Dong *et al.*, 2018; Alkaltham *et al.*, 2020). A decrease in polyphenolic compounds was observed during roasting which was considered to be related to the degradation of chlorogenic, citric, and malic acids, which in turn influenced the total antioxidant capacity (Król *et al.*, 2020).

Numerous researches have been carried out on coffee beans in the last few decades due to its popularity and high consumption rate. Some of them compared the antioxidant activity between green and roasted coffee beans (Nebesny and Budryn, 2003; Priftis *et al.*, 2015), and some of them are health-related (Ludwig *et al.*, 2014; Li *et al.*, 2016; Poole *et al.*, 2017), but there is hardly any study linking the effect of microwave roasting at different durations and power levels on the chemical constituents and mineral contents. Therefore, the present work aimed to evaluate the effect of microwave roasting on TPC, TFC, antioxidant activity, some selected compounds, and the mineral content in coffee beans.

## Materials and methods

### Materials

*Coffea arabica* (variety; Heirloom) was procured from the Jazan region of Saudi Arabia. Coffee beans were sun-dried until their moisture level reached 11.2% of the dry weight. The samples were then ground and passed through a 60-mesh (250 µm) sieve. The resultant powder was used for the microwave treatment steps.

### Microwave roasting

The reversed coffee roasting process was adopted in the present work (Lee *et al.*, 2017); based on this procedure, grinding preceded roasting. The coffee bean powder was first treated in a household microwave oven (MWL311, Kenwood, China; 900 W and 2450 MHz). Next, 4 g of coffee bean powder were added to a glass beaker, which was then placed in the middle of the microwave oven cavity, and treated at 450 and 720 W for 4 min, respectively, and 900 W for 4, 8, and 6 min, respectively. All the process parameters were selected based on the preliminary trials of TPC, DPPH radical scavenging activity, and the colour of the coffee bean powder. Untreated coffee bean powder served as control. All the samples were placed in airtight plastic bags, and stored at room temperature (23°C) for further analyses.

### Extraction

The slightly modified method of Nebesny and Budryn (2003) was used for the extraction of coffee samples. Coffee bean powder (2 g) was extracted with 20 mL of distilled water at 100°C for 10 min. Then, the mixture was centrifuged at 3,000 g for 10 min at 23°C. The supernatant was then filtered using Whatman filter paper no. 2, and the extract was stored at 4°C prior to the antioxidant assays and mineral content determinations.

For gas chromatography-mass spectrometry (GC-MS) analysis, 1 g of coffee bean powder was extracted with 10 mL of a dichloromethane methanol (2:1, v/v) solution using an ultrasonic device (Wisdom, WUC-D10H, 665 W, 60 Hz; Daihan Scientific Co., Ltd., Wonju-si, Gangwon-do, Korea) at 60°C for 45 min. The extract was filtered, and the filtrate was reduced to half of its original volume under a nitrogen stream prior to the analysis.

### Total polyphenol content

The total polyphenol content (TPC) was measured following the method described by Hayat *et al.* (2011). Briefly, 25 µL of the extract was mixed with 1,500 µL of water. Thereafter, 125 µL of undiluted Folin-Ciocalteu reagent was added to the mixture. After 1 min, 375 µL of 20% sodium carbonate were added, and the final volume of the mixture was made up to 2,500 µL by adding 475 µL of water. The absorbance was measured at 760 nm after 30 min of incubation at 23°C, and TPC was expressed as gallic acid equivalents per gram dry weight of the sample (mg GAE/ g DW).

### Total flavonoid content

The total flavonoid content (TFC) was measured following the method described by Hayat *et al.* (2011). Briefly, extract (250 µL) was mixed with 1,000 µL of water, and then, 75 µL of each NaNO<sub>2</sub> and AlCl<sub>3</sub> were added. The mixture was allowed to stand for 5 min at 23°C, and then, 500 µL of 1 M NaOH and 600 µL of water were added. Absorbance was measured at 510 nm. Blank was prepared without the addition of the extract, and TFC was expressed as catechin equivalents per gram dry weight of the sample (mg CE/g DW).

### DPPH scavenging

The free radical scavenging potential of the samples was determined by DPPH following the method described by Noreen *et al.* (2017), with some modifications. Briefly, the coffee bean extract (130 µL) and 0.1 mM DPPH solution were mixed and kept in the dark for 30 min. Thereafter, absorbance was measured at 510 nm. The control was prepared in the same manner, except that methanol was used instead of the extract. Methanol was used as a blank, and DPPH scavenging percentage was calculated using Eq. 1:

$$\text{DPPH scavenging \%} = [(A_{\text{control}} - A_{\text{sample}}) / A_{\text{control}}] \times 100 \quad (\text{Eq. 1})$$

The results were expressed as 50% inhibitory concentration (IC<sub>50</sub>) of the coffee sample.

### Browning intensity

The browning intensity of coffee bean extracts was measured using a UV-vis spectrophotometer (Jasco V-630, Pfungstadt, Germany) by measuring

the absorbance at 420 nm (A<sub>420</sub>). All the extracts were diluted 15 times before the absorbance measurement.

### Mineral content

The selected minerals namely calcium, magnesium, manganese, iron, copper, and zinc in the coffee bean samples were analysed using an inductively coupled plasma-optical emission spectrometer (ICP-OES) (PerkinElmer Optima 4300 DV, USA). Briefly, the calibration curves of all the aforementioned metals were obtained by running their respective standards on the ICP-OES, and the concentrations of the metals in the samples were calculated. The experimental conditions were as follows: sample uptake rate, 1.5 mL/min; plasma flow, 15 L/min; nebuliser flow, 0.8 L/min; auxiliary flow, 0.2 L/min; RF power, 1300 W; and pump rate, 15 rpm.

### GC-MS analysis

GC-MS analysis of the coffee bean samples was performed using an Agilent 7890A gas chromatograph coupled with a 5975C mass selective detector. The column used was the HP-5MS (Agilent; 30 m × 250 µm, 0.25 µm), while helium was applied as the carrier gas at a flow rate of 1 mL/min. The GC temperature was programmed from 60°C with an initial time of 2 min, to 300°C at a rate of 6°C/min, and then kept under isothermal conditions for a total run time of 57 min. The injection volume was 2 µL performed using the splitless mode. The mass spectrometric detector was operated in the electron impact mode with a 70-eV ion source. The compounds were identified based on their mass fragment patterns using the mass spectral library of GC-MS or from the literature on mass spectra.

### Statistical analysis

All the experiments, except GC analysis, were performed in triplicate. The results were expressed as mean ± SD (standard deviation). One-way analysis of variance (ANOVA) was applied to groups, and significant differences among the parameters were determined using Duncan's multiple range test using SAS statistical software (Version 9.2, 2000-2008; SAS Institute Inc., Cary, NC, USA).

## Results and discussion

*Effect of microwave roasting on TPC, TFC, and DPPH scavenging of coffee beans*

The coffee beans were roasted at three different power levels of 450, 720, and 900 W for 4 min, and compared against control. The effect of microwave roasting on TPC, TFC, and DPPH scavenging of coffee beans is given in Table 1.

It was apparent that the microwave power significantly affected the TPC of coffee beans. As compared to control, the coffee beans heated at 720 W revealed a significantly ( $p < 0.05$ ) higher TPC and TFC values. For example, the TPC of control was 30.93 mg GAE/g DW, which was increased to 35.60 mg GAE/g DW when the coffee beans were treated at 720 W for 4 min. The  $IC_{50}$  is a concentration of any substance inhibiting the half maximal activity of any biological or chemical function; the lower the  $IC_{50}$ , the higher the potency of a substance and *vice versa*. A significantly lower  $IC_{50}$  (1.14 mg/mL) was observed for the sample treated at 720 W as compared to those roasted at 450 W (1.24 mg/mL), 900 W (1.30 mg/mL), and control (1.26 mg/mL), respectively. Statistically, the results of control and the sample treated at 450 W were similar to each other; however, the 720 W sample showed a significant increase in TPC, TFC, and DPPH scavenging capacity in the samples. Though a little increase in microwave power showed a positive effect, the higher microwave power level of 900 W exerted a detrimental effect on TPC, TFC, and DPPH scavenging capacity of the samples. The TFC of control was 41 mg CE/g DW, and decreased to 32.6 mg CE/g DW upon treatment at 900 W. Al-Juhaimi *et al.* (2018) reported similar results that TPC, TFC, and antioxidant activity of apricot kernels were increased by 320 and 540 W microwave treatments, but decreased when the power was increased to 720 W. The degradation, polymerisation, and auto-oxidation of the phenolic compounds during roasting might be the cause of a decrease in their content (Wongsa *et al.*, 2019). The antioxidant activity of some plant materials like citrus peels was increased by increasing the microwave power levels (Hayat *et al.*, 2010). Ludwig *et al.* (2013) added sugar

to coffee bean samples during roasting, and found that there was no effect on the phenolic compounds, but the DPPH quenching activity of the roasted coffee was increased. The microwaving process can disrupt the cell wall of the plant materials and assist the phytochemicals to be released from the plant matrix more easily, thus causing an increase in the amount of available bioactive constituents, and in turn the enhancement in antioxidant potential of plant food materials (Hayat *et al.*, 2019; Uslu and Özcan, 2019; Hayat, 2020; Karrar *et al.*, 2020). However, our findings are contrary to the study of Nebesny and Budryn (2003) which reported that green coffee exhibited a higher antioxidant activity as compared to the conventional and microwave-roasted samples; however, as compared to oven roasting, microwave roasting better protected its antioxidant characteristics. On the other hand, the same research reported that the pre-dried microwave-roasted (750 W for 7.42 min) coffee beans showed a higher TPC and antioxidant activities as compared to the pre-dried convective-roasted (230°C for 3.78 min) coffee beans (Nebesny and Budryn, 2003). The complexity of the chemical reactions during roasting can lead to the reported discrepancy. During roasting, the degradation of some compounds like chlorogenic acids may cause the decrease in the antioxidant potential of the coffee beans (Perrone *et al.*, 2012), while some other bioactive compounds like hydroxycinnamates and quinic acid may also be released due to such degradation (Wei and Tanokura, 2015). Moreover, the Maillard reaction might take place due to high temperature during roasting, thus generating a number of compounds which can contribute to the antioxidant potential of the product (Pastoriza and Rufián-Henares, 2014). Consequently, all of the substances appearing during roasting can either compensate for the loss of some compounds or even contribute towards the enhancement in the antioxidant potential (Ludwig *et al.*, 2013).

**Table 1.** Effect of microwave roasting at different microwave power levels (450, 720, and 900 W) and treatment durations (4, 6, and 8 min) on TPC, TFC, and DPPH scavenging of coffee beans.

Parameter	Untreated	450 W - 4 min	720 W - 4 min	720 W - 6 min	720 W - 8 min	900 W - 4 min
TPC	30.93 ± 2.89 <sup>cd</sup>	32.47 ± 0.97 <sup>c</sup>	35.60 ± 0.87 <sup>b</sup>	40.06 ± 0.23 <sup>a</sup>	23.73 ± 0.42 <sup>e</sup>	29.07 ± 2.39 <sup>d</sup>
TFC	41.00 ± 0.53 <sup>c</sup>	41.40 ± 0.20 <sup>c</sup>	43.07 ± 1.10 <sup>b</sup>	44.40 ± 0.40 <sup>a</sup>	24.73 ± 0.12 <sup>e</sup>	32.60 ± 0.60 <sup>d</sup>
DPPH	1.26 ± 0.01 <sup>bc</sup>	1.24 ± 0.03 <sup>c</sup>	1.14 ± 0.05 <sup>d</sup>	1.01 ± 0.03 <sup>e</sup>	1.59 ± 0.02 <sup>a</sup>	1.30 ± 0.03 <sup>b</sup>

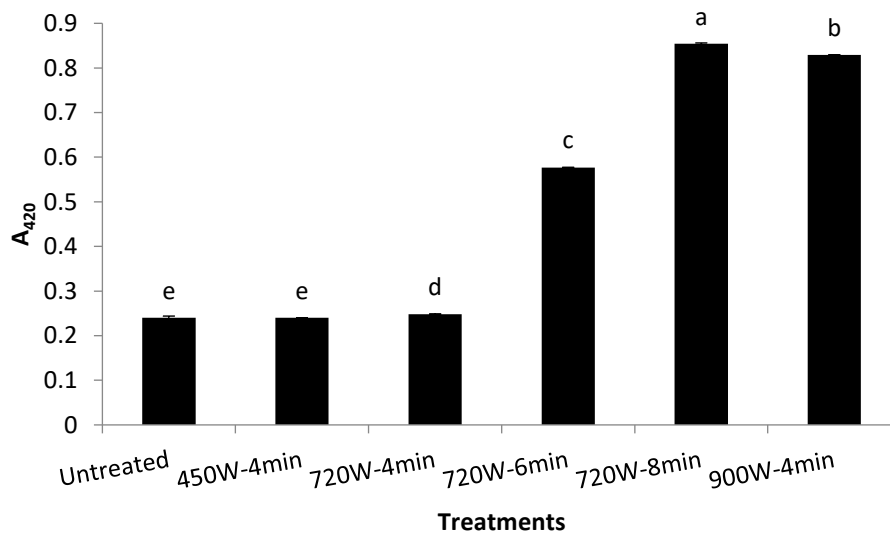
Values are mean of triplicates ( $n = 3$ ) ± standard deviation. Means followed by different lowercase superscripts in the same row are significantly different at  $p < 0.05$ .

### Effect of microwave durations

The coffee bean powder was treated at 720 W for 4, 6, and 8 min, and the results are shown in Table 1. The effect of microwave treatment durations showed a significant increase in TPC, TFC, and DPPH radical scavenging capacity as compared to the effect of the microwave power levels. A significantly ( $p < 0.05$ ) highest TPC and TFC, and the lowest  $IC_{50}$  for DPPH scavenging was achieved when the coffee bean sample was roasted for 6 min at 720 W. The longer roasting duration of 8 min showed an adverse effect on TPC, TFC, and DPPH scavenging capacity. The  $IC_{50}$  values of control and samples treated at 720 W for 4, 6, and 8 min were 1.26, 1.14, 1.01, and 1.59 mg/mL, respectively. These results are in agreement with the findings of previous studies (Hayat *et al.*, 2010; 2019).

### Effect of microwave roasting on the browning intensity of coffee bean extract

The browning intensity of coffee bean water extract was measured by recording the absorbance at 420 nm ( $A_{420}$ ). Browning is an index which determines the degree of roasting, and it plays an important role in the overall acceptability of the coffee beverage. As can be seen in Figure 1, the highest browning intensity was exhibited by coffee bean powder extract that was roasted at 720 W for 8 min. The browning intensity of the samples was increased significantly ( $p < 0.05$ ), both by increasing the microwave power and roasting duration. These results are aligned with the findings of other researchers who reported an increase in the browning degree of the coffee beans when the roasting duration was increased (Nicoli *et al.*, 1997; Doğan *et al.*, 2019). These results showed that microwave roasting changed the physical characteristics of the samples, and might also generate colour-forming compounds during the roasting process.



**Figure 1.** Effect of microwave roasting at different microwave power levels (450, 720, and 900 W) and treatment durations (4, 6, and 8 min) on the colour of coffee bean extract.

### Effect of microwave roasting on the mineral content of coffee beans

Table 2 shows the content of the studied minerals of the coffee beans as affected by microwave roasting. As can be seen from the Table, the mineral content was increased upon microwave roasting, but the microwave power level and roasting duration had varying effects. The mineral content was increased at low power levels but was decreased with an increase in microwave power. For example, the Ca content of control was increased from 719.53 to

748.98 mg/kg DW when treated at 450 W for 4 min, but was decreased to 495.87 and 415.67 mg/kg DW when the power was increased to 720 and 900 W for 4 min, respectively. On the other hand, roasting duration negatively affected the mineral content. For example, the Mg content of the samples treated at 720 W for 4, 6, and 8 min was 876.48, 830.88, and 714.83 mg/kg DW, respectively, while the Mg content was 1,096.44 mg/kg DW for control. Gogoasa *et al.* (2013) reported a similar Mg content (1,050 mg/kg DW) but a different Ca content (1,270 mg/kg DW) in

Jacobs Aroma coffee. Hayat *et al.* (2019) described that the mineral content of fennel seeds was decreased upon microwave roasting, and both the microwave power and roasting duration negatively affected the mineral content. Ghafoor *et al.* (2018) also reported a decrease in the mineral content of oven-roasted chia seeds. The materials respond to the microwave energy depending on their dielectric permittivity, and the loss factor. There is the potential of a material absorbing the electromagnetic energy as its dielectric permittivity while transforming the stored energy into heat, and it is called the loss factor of a material. The higher the applied power, the faster the material will be heated due to the increase in the electric field

(Shang *et al.*, 2006). The minerals investigated in the present work might have high loss factor, thus resulting in high internal temperature and consequently a decrease in their content. Moreover, the decrease in mineral content might also be ascribed to the evaporative loss of dielectric species from the coffee during microwave heating (Hayat *et al.*, 2010). Measuring the dielectric properties of the studied minerals may give further insights into the exact mechanisms of their varying contents. Extensive modifications to the microwave apparatus are needed to make these measurements, and this will form the basis of future research.

**Table 2.** Effect of microwave roasting at different microwave power levels (450, 720, and 900 W) and treatment durations (4, 6, and 8 min) on the mineral content (mg/kg DW) in coffee beans.

Mineral	Untreated	450 W - 4 min	720 W - 4 min	720 W - 6 min	720 W - 8 min	900 W - 4 min
Ca	719.53 ± 2.16 <sup>b</sup>	748.98 ± 5.62 <sup>a</sup>	495.87 ± 4.42 <sup>c</sup>	412.54 ± 3.60 <sup>d</sup>	274.80 ± 4.49 <sup>e</sup>	415.67 ± 2.36 <sup>d</sup>
Mg	1096.44 ± 8.93 <sup>b</sup>	1206.93 ± 9.79 <sup>a</sup>	876.48 ± 3.57 <sup>d</sup>	830.88 ± 8.02 <sup>e</sup>	714.83 ± 2.58 <sup>f</sup>	932.50 ± 3.54 <sup>c</sup>
Mn	1.30 ± 0.07 <sup>c</sup>	2.32 ± 0.03 <sup>a</sup>	2.03 ± 0.03 <sup>b</sup>	1.37 ± 0.04 <sup>c</sup>	0.20 ± 0.02 <sup>e</sup>	0.87 ± 0.04 <sup>d</sup>
Fe	1.29 ± 0.06 <sup>c</sup>	1.50 ± 0.08 <sup>b</sup>	2.02 ± 0.02 <sup>a</sup>	0.76 ± 0.00 <sup>d</sup>	0.86 ± 0.04 <sup>d</sup>	0.82 ± 0.02 <sup>d</sup>
Cu	6.71 ± 0.13 <sup>b</sup>	9.19 ± 0.05 <sup>a</sup>	4.37 ± 1.00 <sup>d</sup>	3.48 ± 0.05 <sup>e</sup>	2.78 ± 0.06 <sup>f</sup>	4.73 ± 0.04 <sup>c</sup>
Zn	0.04 ± 0.02 <sup>c</sup>	0.92 ± 0.04 <sup>a</sup>	0.21 ± 0.03 <sup>b</sup>	nd	nd	nd

Values are mean of triplicates ( $n = 3$ ) ± standard deviation. Means followed by different lowercase superscripts in the same row are significantly different at  $p < 0.05$ . nd: not detected.

#### *Effect of microwave roasting on selected compounds of coffee beans as analysed by GC-MS*

The effect of microwave roasting on the selected compounds that were analysed by GC-MS is given in Table 3. The compounds, which are either the main compounds of coffee or contribute to its antioxidant capacity, like caffeine, beta-tocopherol, vitamin E, stigmaterol, and beta-sitosterol were selected for this experiment. Microwave roasting exerted a mixed effect on the compounds of coffee beans; for example, the relative percentage of caffeine increased from 40.064 to 49.125% when treated at 450 W for 4 min. However, when the microwave power was further increased to 720 and 900 W, the relative percentage of caffeine was decreased to 46.019 and 27.098%, respectively. On the other hand, *n*-hexadecanoic acid content was found to be 33.862% in control, and was decreased to 16.311% when treated at 450 W for 4 min, and was even not detected in coffee bean samples treated at all other microwave power levels and roasting durations. New compounds were also formed in the treated samples that were not detected in control. For

example, octadecanoic acid, methyl ester was not detected in control but was found in the samples treated at 720 W for 8 min and 900 W for 4 min, respectively. It could be due to the fact that some alcohols were formed during microwave roasting, and reacted with acids, and formed ester compounds. Vitamin E and stigmaterol were also not detected in control but were found in microwave-roasted samples. This could be attributed to the fact that these compounds were present in the bound state, and liberated upon microwave roasting (Xu *et al.*, 2007; Hayat *et al.*, 2010).

#### **Conclusion**

The effect of microwave roasting on TPC, TFC, DPPH scavenging capacity, mineral content, colour, and content of selected compounds in coffee beans was investigated. It was found that TPC, TFC, and antioxidant activity of the coffee bean extract was increased with increasing microwave power and roasting duration; however, too high microwave power levels and roasting durations had a detrimental

**Table 3.** Effect of microwave roasting at different microwave power levels (450, 720, and 900 W) and treatment durations (4, 6, and 8 min) on selected compounds as analysed by GC-MS.

No.	Retention Time	Compound	Peak Area Abundance (%)					
			Untreated	450 W - 4 min	720 W - 4 min	720 W - 6 min	720 W - 8 min	900 W - 4 min
1	24.398	Caffeine	40.064	49.125	46.019	37.039	25.829	27.098
2	25.336	Hexadecanoic acid, methyl ester	2.172	-	-	-	3.806	3.986
3	26.452	<i>n</i> -Hexadecanoic acid	33.862	16.311	-	-	-	-
4	27.997	9,12-Octadecadienoic acid (Z,Z)-, methyl ester	1.250	2.244	3.376	3.198	3.283	3.621
5	28.443	Octadecanoic acid, methyl ester	-	-	-	-	0.858	0.961
6	32.689	Phenol, 2,2'-methylenebis[6-(1,1-dimethylethyl)-4-methyl-2,6,10,14,18,22-tetracosahexaene, 2,6,10,15,19,23-hexamethyl-, (all-E)-	1.465	2.616	1.890	1.936	3.556	2.401
7	37.661	Tetracosahexaene, 2,6,10,15,19,23-hexamethyl-, (all-E)-	0.992	1.315	1.954	2.105	1.067	1.078
8	40.042	Beta-tocopherol	0.858	1.743	3.501	2.850	1.345	1.414
9	41.077	Vitamin E	-	0.648	1.285	1.102	0.553	0.544
10	42.628	Stigmasterol	-	-	-	3.071	1.666	1.836
11	43.337	Beta-sitosterol	1.648	3.231	6.546	4.324	2.304	2.295

effect. Therefore, it could be concluded that moderate microwave heating either released the bound phenolic compounds or generated some new compounds, but roasting for longer duration or at higher microwave power levels caused their degradation. The browning intensity of the coffee extract was increased both with microwave power and roasting duration. The mineral content of the coffee beans was increased at low microwave power levels and short roasting durations, but all other treatments showed an adverse effect on the mineral content. Microwave roasting had a mixed effect on the coffee bean compounds as analysed by GC-MS. The results of the present work suggest that moderate microwave roasting condition could be beneficial for coffee beans in terms of its effect on TPC, TFC, DPPH scavenging capacity, mineral content, and colour.

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#### References

- Al-Juhaimi, F., Musa Özcan, M., Ghafoor, K. and Babiker, E. E. 2018. The effect of microwave roasting on bioactive compounds, antioxidant activity and fatty acid composition of apricot kernel and oils. *Food Chemistry* 243: 414-419.
- Alkaltham, M. S., Salamatullah, A. and Hayat, K. 2020. Determination of coffee fruit antioxidants cultivated in Saudi Arabia under different drying conditions. *Journal of Food Measurement and Characterization* 14: 1306-1313.
- Alstrup, J., Petersen, M. A., Larsen, F. H. and Münchow, M. 2020. The effect of roast development time modulations on the sensory profile and chemical composition of the coffee brew as measured by NMR and DHS-GC-MS. *Beverages* 6: article no. 70.
- Cheong, M. W., Tong, K. H., Ong, J. J. M., Liu, S. Q., Curran, P. and Yu, B. 2013. Volatile composition and antioxidant capacity of Arabica coffee. *Food Research International* 51(1): 388-396.

- Derrosi A., Ricci, I., Caporizzi, R., Fiore, A. and Severini, C. 2018. How grinding level and brewing method (Espresso, American, Turkish) could affect the antioxidant activity and bioactive compounds in a coffee cup. *Journal of the Science of Food and Agriculture* 98: 3198-3207.
- Diviš, P., Pořízka, J. and Křikala, J. 2019. The effect of coffee beans roasting on its chemical composition. *Potravinárstvo* 13(1): 344-350.
- Doğan, M., Aslan, D., Gürmeriç, V., Özgür, A. and Saraç, M. G. 2019. Powder caking and cohesion behaviours of coffee powders as affected by roasting and particle sizes: principal component analyses (PCA) for flow and bioactive properties. *Powder Technology* 344: 222-232.
- Dong, W., Cheng, K., Hu, R., Chu, Z., Zhao, J. and Long, L. 2018. Effect of microwave vacuum drying on the drying characteristics, color, microstructure, and antioxidant activity of green coffee beans. *Molecules* 23(5): article no. 1146.
- Esquivel, P. and Jiménez, V. M. 2012. Functional properties of coffee and coffee by-products. *Food Research International* 46(2): 488-495.
- Ghafoor, K., Aljuhaimi, F., Özcan, M. M., Uslu, N., Hussain, S., Babiker, E. E. and Fadimu, G. 2018. Effects of roasting on bioactive compounds, fatty acid, and mineral composition of chia seed and oil. *Journal of Food Processing and Preservation* 42(10): article ID e13710.
- Gogoasa, I., Pirvu, A., Alda Liana, M., Velciov, A., Rada, M., Bordean Despina, M., ... and Gergen, I. 2013. The mineral content of different coffee brands. *Journal of Horticulture, Forestry and Biotechnology* 17(4): 68-71.
- Hayat, K. 2020. Impact of drying methods on the functional properties of peppermint (*Mentha piperita* L.) leaves. *Science Letters* 8(1): 36-42.
- Hayat, K., Abbas, S., Hussain, S., Shahzad, S. A. and Tahir, M. U. 2019. Effect of microwave and conventional oven heating on phenolic constituents, fatty acids, minerals and antioxidant potential of fennel seed. *Industrial Crops and Products* 140: article ID 111610.
- Hayat, K., Abbas, S., Jia, C., Xia, S. and Zhang, X. 2011. Comparative study on phenolic compounds and antioxidant activity of Feutrell's Early and Kinnow peel extracts. *Journal of Food Biochemistry* 35(2): 454-471.
- Hayat, K., Zhang, X., Chen, H., Xia, S., Jia, C. and Zhong, F. 2010. Liberation and separation of phenolic compounds from citrus mandarin peels by microwave heating and its effect on antioxidant activity. *Separation and Purification Technology* 73(3): 371-376.
- Hećimović, I., Belščak-Cvitanović, A., Horžić, D. and Komes, D. 2011. Comparative study of polyphenols and caffeine in different coffee varieties affected by the degree of roasting. *Food Chemistry* 129: 991-1000.
- Jung, S., Kim, M. H., Park, J. H., Jeong, Y. and Ko, K. S. 2017. Cellular antioxidant and anti-inflammatory effects of coffee extracts with different roasting levels. *Journal of Medicinal Food* 20(6): 626-635.
- Karrar, E., Sheth, S., Wei, W. and Wang, X. 2020. Effect of microwave heating on lipid composition, oxidative stability, color value, chemical properties, and antioxidant activity of gurum (*Citrulluslanatus* var. *Colocynthoide*) seed oil. *Biocatalysis and Agricultural Biotechnology* 23: article ID 101504.
- Król, K., Gantner, M., Tatarak, A. and Hallmann, E. 2020. The content of polyphenols in coffee beans as roasting, origin and storage effect. *European Food Research and Technology* 246: 33-39.
- Kwak, H. S., Ji, S. and Jeong, Y. 2017. The effect of air flow in coffee roasting for antioxidant activity and total polyphenol content. *Food Control* 71: 210-216.
- Lee, S. J., Kim, M. K. and Lee, K.-G. 2017. Effect of reversed coffee grinding and roasting process on physicochemical properties including volatile compound profiles. *Innovative Food Science and Emerging Technologies* 44: 97-102.
- Li, Y. M., Peng, J. and Li, L. Z. 2016. Coffee consumption associated with reduced risk of oral cancer: a meta-analysis. *Oral Surgery, Oral Medicine, Oral Pathology, and Oral Radiology* 121(4): 381-389.
- Ludwig, I. A., Bravo, J., De Peña, M. P. and Cid, C. 2013. Effect of sugar addition (torrefacto) during roasting process on antioxidant capacity and phenolics of coffee. *LWT - Food Science and Technology* 51(2): 553-559.



- Ludwig, I. A., Clifford, M. N., Lean, M. E. J., Ashihara, H. and Crozier, A. 2014. Coffee: biochemistry and potential impact on health. *Food and Function* 5(8): 1695-1717.
- Madhava Naidu, M., Sulochanamma, G., Sampathu, S. R. and Srinivas, P. 2008. Studies on extraction and antioxidant potential of green coffee. *Food Chemistry* 107(1): 377-384.
- Moon, J. K., Yoo, H. S. and Shibamoto, T. 2009. Role of roasting conditions in the level of chlorogenic acid content in coffee beans: correlation with coffee acidity. *Journal Agricultural and Food Chemistry* 57(12): 5365-5369.
- Nebesny, E. and Budryn, G. 2003. Antioxidative activity of green and roasted coffee beans as influenced by convection and microwave roasting methods and content of certain compounds. *European Food Research and Technology* 217(2): 157-163.
- Nicoli, M. C., Anese, M., Manzocco, L. and Lerici, C. R. 1997. Antioxidant properties of coffee brews in relation to the roasting degree. *LWT - Food Science and Technology* 30(3): 292-297.
- Noreen, H., Semmar, N., Farman, M. and McCullagh, J. S. O. 2017. Measurement of total phenolic content and antioxidant activity of aerial parts of medicinal plant *Coronopus didymus*. *Asian Pacific Journal of Tropical Medicine* 10(8): 792-801.
- Pastoriza, S. and Rufián-Henares, J. A. 2014. Contribution of melanoidins to the antioxidant capacity of the Spanish diet. *Food Chemistry* 164: 438-445.
- Perrone, D., Farah, A. and Donangelo, C. M. 2012. Influence of coffee roasting on the incorporation of phenolic compounds into melanoidins and their relationship with antioxidant activity of the brew. *Journal of Agricultural and Food Chemistry* 60: 4265-4275.
- Poole, R., Kennedy, O. J., Roderick, P., Fallowfield, J. A., Hayes, P. C. and Parkes, J. 2017. Coffee consumption and health: umbrella review of meta-analyses of multiple health outcomes. *British Medical Journal* 359: article ID j5024.
- Priftis, A., Stagos, D., Konstantinopoulos, K., Tsitsimpikou, C., Spandidos, D. A., Tsatsakis, A. M., ... and Kouretas, D. 2015. Comparison of antioxidant activity between green and roasted coffee beans using molecular methods. *Molecular Medicine Reports* 12(5): 7293-7302.
- Saloko, S., Sulastri, Y., Murad, M. and Rinjani, M. 2019. The effects of temperature and roasting time on the quality of ground Robusta coffee (*Coffea robusta*) using *Gene Café* roaster. *AIP Conference Proceedings* 2199: article ID 060001.
- Schenker, S., Heinemann, C., Huber, M., Pompizzi, R., Perren, R. and Escher, R. 2002. Impact of roasting conditions on the formation of aroma compounds in coffee beans. *Journal of Food Science* 67(1): 60-66.
- Shang, H., Snape, C. E., Kingman, S. W. and Robinson, J. P. 2006. Microwave treatment of oil-contaminated North Sea drill cuttings in a high power multimode cavity. *Separation and Purification Technology* 49: 84-90.
- United States Department of Agriculture (USDA). 2012. Product, supply and distribution (PSD) online. Retrieved from USDA website: <https://apps.fas.usda.gov/psdonline/app/index.html#/app/home>
- Uslu, N. and Özcan, M. M. 2019. Effect of microwave heating on phenolic compounds and fatty acid composition of cashew (*Anacardium occidentale*) nut and oil. *Journal of the Saudi Society of Agricultural Sciences* 18(3): 344-347.
- Vignoli, J. A., Bassoli, D. G. and Benassi, M. T. 2011. Antioxidant activity, polyphenols, caffeine and melanoidins in soluble coffee: the influence of processing conditions and raw material. *Food Chemistry* 124(3): 863-868.
- Wei, F. and Tanokura, M. 2015. Chemical changes in the components of coffee beans during roasting. In Preedy, V. R. (ed). *Coffee in Health and Disease Prevention*, p. 83-91. United States: Elsevier.
- Wongsa, P., Khampa, N., Horadee, S., Chaiwarith, J. and Rattanapanone, N. 2019. Quality and bioactive compounds of blends of Arabica and Robusta spray dried coffee. *Food Chemistry* 283: 579-587.
- Xu, G., Ye, X., Chen, J. and Liu, D. 2007. Effect of heat treatment on the phenolic compounds and antioxidant capacity of citrus peel extract. *Journal of Agricultural and Food Chemistry* 55(2): 330-335.