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Effects of Roasting Conditions on Chemical Composition, Antioxidants, Volatile Compounds and Sensory Qualities in Arabic Coffee

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Abstract

In this study, the most popular three degrees of roasted Arabic coffee—light (210 ºC; 20 min), medium (230 ºC; 20 min), and dark (240 ºC; 20 min)—were examined for their chemical composition, caffeine content, acrylamide content, phenolic content, antioxidant potential, browning index, and volatile compound separation using GC–MS. The results showed that light-roasted coffee had the lowest levels of ether extract and crude fibre and the highest levels of moisture content and crude protein, both of which were significant ($p < 0.05$). The roasting process, particularly the dark roasting, has reduced the amounts of quercetin, kaempferol, caffeine, trigonelline, and hydroxymethylfurfural, with the exception of quercetin, in both green and roasted coffee samples. Light-roasted coffee had the highest amount of acrylamide (0.47 mg/100 g), while medium-roasted coffee had very low levels (0.38 mg/100 g). The higher the roasting degree, the higher the browning index. The coffee that was light-roasted had the lowest levels of condensed tannins and flavonoid compounds, the highest levels of free total phenolic content, and the lowest levels of DPPH activity. In terms of GC-MS, the dark-roasted coffee included 120 volatile chemicals that were identified and semi-quantified. Overall, this study demonstrated that while intense roasting would decrease the amount of phenolic chemicals in coffee beans, it might preserve or even increase their antioxidant potential. The nutritional value and organoleptic qualities of commercial light-roasted coffee beans are comparatively superior. Our findings may help resolve past disputes and provide useful proof for coffee production in the food sector.

Key words: *Coffea arabica*, GC-MS, phenolic compounds, roasting, antioxidant.

1. Introduction

The most widely consumed beverage in the world, coffee has a number of advantageous economic and health consequences **(Esteban et al., 2020; Wu et al., 2022)**. Millions of people drink it every day because they like its flavour and aroma, as well as its refreshing and energising properties **(Farag et al., 2022)**. Global coffee consumption in the fiscal year 2020–2021 was predicted to be over 1.6 billion cups per day, with over 166 million bags consumed **(Statista, 2022)**. Between 2016–2017 and 2019–2020, the average global demand for coffee increased by 2.2% **(Mas Aparisi, 2021)**. A number of factors could account for the continuous increase in coffee demand, such as the development of speciality coffee shops, the improvement in bean quality, and the proliferation of research linking coffee use to health benefits **(Celli & Camargo, 2019)**.

Coffee consumption reduces the risk of certain health issues, such as type II diabetes, heart disease, liver cirrhosis, obesity, and cancer, according to a number of scientific researches **(Iriondo-dehond et al., 2020; Kusumah & Mejia, 2022)**. The beneficial health effects of coffee are usually attributed to its strong antioxidant activity and bioactive ingredients (**Núñez et al., 2020; Saud & Salamatullah, 2021**). Phenolic acids, mainly chlorogenic acids (CGAs), lactones (CQAs, caffeoylquinic acids, FQAs, feruloylquinic acids, and diCQAs, dicaffeoylquinic acids with at least three isomers per class), methylxanthines (caffeine, theophylline, and theobromine), and diterpenes are among the bioactive compounds found in coffee, both green and roasted. Before and after roasting, certain of these components are essential for determining the coffee's aroma (**Bastian et al., 2021; Haile et al., 2020**).

Caffeine (CAF), CGA, trigonelline (TGA), nicotinic acid, and sucrose are the main components that give coffee its aroma and bioactivity (**Jeszka-skowron et al., 2020; Stefanello et al., 2018**). One of coffee's most distinctive features and the primary element affecting consumers' acceptance and preference is its scent (**Caporaso et al., 2018; Turan et al., 2021**). Coffee's scent is directly influenced by the bean's chemical composition, genetic strain, geographic location, climate, annual rainfall, agricultural practices, and processing method (**Procida et al., 2020**). Variations in coffee species may result in variations in the coffee's chemical composition. 99% of the world's coffee demands are met by just two of the more than 120 coffee species that have been found so far: Coffea arabica (Arabica) and Coffea canephora (Robusta) (**Angeloni et al., 2021; Farag et al., 2022**).

Robusta and Arabica beans have varied flavour characteristics because of their different chemical compositions. Compared to Robusta beans, Arabica beans provide a more complex and flavourful cup. However, Robusta frequently yields a more bitter, musty-tasting beverage with more body (**Ogutu et al., 2022**). Customers' preferences, emotions, or attitudes towards coffee intake may be influenced by the variations in sensory attributes (**Seninde & Chambers, 2020**). Consumers are becoming more concerned about their diet and overall health these days. Consumer perceptions of coffee's health benefits are yet unknown, though. Sixty-six percent of Americans limit their caffeine intake, while only sixteen percent of coffee drinkers are aware of the health benefits of coffee. Given that 49% of European consumers think coffee has an impact on their health, many are confused about this (**Samoggia & Riedel, 2019**).

The roasting temperature and roasting time affect the coffee's degree of roasting, and these two factors determine whether the coffee is light, medium, or dark roasted (**Somporn et al., 2011**). The coffee's chemical composition and biological activity can be significantly altered by roasting. For instance, certain components, like natural phenolic compounds, may be lost, while other components, such antioxidant chemicals, including results of the Maillard process, may be created. As a result, antioxidant activity may be preserved or even raised (**Wang et al., 2011**). Coffee's antioxidant activity and caffeine concentration decrease as roasting intensity increases (**Alqarni et al., 2018; Cho et al., 2014**). Coffee that has been light-roasted has a higher antioxidant capacity than coffee that has been hard-roasted because of its high polyphenol content (**Vignoli et al., 2014**). According to the literature, no thorough investigation has investigated how roasting level affects the chemical composition, antioxidant activity, and volatile chemicals that give Arabica coffee its scent. In order to facilitate the performance of a biological investigation in the nest stage, the current study compares the differences in chemical composition, antioxidant activity, colour qualities, and fragrance volatile chemicals in Arabica coffee at three different roasting degrees.

2. Materials and methods

Chemical and reagents

The deionised Milli-Q water used in all experiments was acquired using the Millipore Milli-Q Gradient Water Purification System (Darmstadt, Germany). Gallic acid and quercetin were the standards for the antioxidant assay, and Sigma-Aldrich (St. Louis, MO, USA) provided the remaining chemicals, which included the Folin–Ciocalteu reagent, sodium carbonate anhydrous, hydrated sodium acetate, hexahydrate aluminium chloride, vanillin, and 2,2'-diphenyl-1-picrylhydrazyl (DPPH).

Plant material

Green coffee beans (Arabica coffee (Brazil)) were purchased from a commercial market in Cairo, Egypt. Beans that were uniform in size and defect-free were roasted.

Roasting conditions

A laboratory-scale electric rotary drum roaster with a 100 g capacity (PRE 1Z; Probat-Werke von Gimbom Maschinenfabrik GmbH, Germany) was used to roast 50 g of coffee beans in its roasting drum. The roasting time was set at 20 minutes and the conditions chosen for each experiment were 210, 230, and 240 degrees Celsius. The roasted coffee was well ground in a coffee grinder (model GVX212, Krupps, Essen, Germany) with a 0.30 mm screen size and kept in the refrigerator in an airtight jar until analysis. Temperature changes in the roasting drum were noted while the coffee was being roasted.

Chemical analysis

Using **AOAC (2010)** methodologies, a proximate chemical analysis of roasted coffee powder was conducted to determine its moisture content, ether extract, crude protein, crude fibre, and ash content. By subtracting the total percentages of crude protein, ether extract, crude fibre, and ash content from 100, the nitrogen-free extract was calculated.

Determination of acrylamide

According to **Wendie et al. (2005),** acrylamide was measured at 260 oC using a gas chromatograph equipped with a flame ionisation detector. An RTX-5 column (30 m long 0.2 5 mm I.D. 0.25 m film thickness) was used, along with an injector temperature of 260 oC, helium gas as a carrier gas at constant pressure, and an oven temperature that ranged from 100 oC (kept for 0.5 minutes) to 200 ºC at a rate of 15 ºC per minute.

Browning index

According to **Chung et al. (2013),** a spectrophotometer UV–Vis (Labomed Inc., USA) was used to measure the absorption of the five-fold diluted coffee brew solution at 420 nm. Melanoidins and other brown chemicals produced during caramelisation and Maillard processes are measured by this index.

Color measurements

To assess the colour computation for roasted coffee, a chromameter (CR 400) was utilised. According to the International Commission of Illumination (CIE), the data were displayed as L*, a*, and b*, which stand for reflected light and coordinated chromatic, respectively, red–green and yellow–blue axes.

Determination of phytochemicals

Extraction of free and bound phenolic Compounds

With a few adjustments, the procedures outlined by **Peng et al. (2019)** were used to extract free phenolic components from coffee samples. After thoroughly mixing coffee powder with 70% ethanol at a ratio of 1:10 (w:w), the Ultra-Turrax T25 Homogeniser (IKA, Staufen, Germany) homogenised the mixture for 30 seconds at 10,000 rpm. It was then incubated for 12 hours at 120 rpm at 4°C in a shaking incubator (ZWYR-240 incubator shaker, Labwit, Ashwood, VIC, Australia). The mixture was then centrifuged using a Hettich Refrigerated Centrifuge (ROTINA380R, Tuttlingen, BadenWürttemberg, Germany) for 15 minutes at 5000 rpm and 4°C. Free phenolic extracts were obtained from the supernatant fluid after it was filtered using a 0.45 µm syringe filter (Thermo Fisher Scientific Inc., Waltham, MA, USA).. Samples' bound phenolic chemicals were extracted using a modified version of **Phan et al, (2019)** methodology. After adding 2 M NaOH and incubating for one hour at 200 rpm in the shaking incubator, the sediment underwent alkaline hydrolysis. After adjusting pH 2.0 for acid hydrolysis with concentrated HCl, pH was recovered to 7.0 using 2 M NaOH. In order to dissolve the released bound phenolic chemicals into the organic solvent phase, the samples were then combined with 70% ethanol and incubated for 60 minutes. The mixture was centrifuged at 8000 rpm for 20 minutes at 4°C. As bound phenolic extracts, the supernatant fluid was gathered and filtered using a syringe filter. Phenolic extracts, both bound and free, were kept at -20°C until they were ready for additional examination.

Quantification of phenolic compounds and antioxidant assays Sample preparation

According to **Suleria et al. (2020)** and **Ali et al. (2021),** all estimated analyses for phenolic compounds (TPC, TFC, and TCT) and the determination of total antioxidant capacity (DPPH, ABTS, FRAP, •OH-RSA, FICA, and RPA) were adjusted to fit the 96-well plate (Costar, Corning, NY, USA) and spectrophotometer (Multiskan® Go microplate photometer) (Thermo Fisher Scientific, Waltham, MA, USA).

Determination of total phenolic content (TPC)

With certain adjustments based on **Mussatto et al. (2011),** the Folin–Ciocalteu technique was used to quantify the total concentration of phenolic compounds in coffee beans. In short, 200 µl of water, 25 µl of Folin-Ciocalteu reagent solutions, and 25 µl of sample extract or standard were applied to a plate, and the plate was then incubated for 5 minutes at 25°C. 25 µl of 10% (w/w) sodium carbonate was then added, and the mixture was incubated for one hour under the same conditions. Water served as the blank and gallic acid (0–200 µg/ml) as the calibration curve. The results were reported as mg gallic acid equivalents (GAE) per (mg GAE/g) ± standard deviation (SD), with absorbance measured at 765 nm.

Determination of total flavonoid compounds (TFC)

Ali et al. (2021) measured the total flavonoid content of roasted coffee beans. In short, a plate was filled with 80 µl of sample extract, 80 µl of 2% aluminium chloride, and 120 µl of 50 g/L sodium acetate solution. The plate was then incubated for 2.5 hours at 25°C in the dark. Water was utilised as the blank and quercetin (0–50 µg/ml) as the standard curve. The final flavonoid content of the samples was represented as mg quercetin equivalents (QE) per g (mg QE/g) ± SD, and absorbance was measured at 440 nm.

Determination of total condensed tannins (TCT)

Ali et al. (2021) used the vanillin sulphuric acid method to quantify the total amount of condensed tannins in coffee beans. In short, a plate was filled with 25 µl sample extract, 150 µl vanillin solution, and 25 µl 32% sulphuric acid. The plate was then incubated for 15 minutes at 25°C in the dark. Water and catechin (0–1 mg/ml) were utilised for the blank and standard curve, respectively. The ultimate concentration of condensed tannins in coffee beans was calculated as mg catechin equivalents (CE) per g (mg CE/g) ± SD using the absorbance, which was measured at 500 nm.

DPPH antioxidant assay

The modified DPPH assay, which was based on **Nebesny and Budryn's (2003)** approach, was employed as a preliminary test to assess the coffee beans' ability to scavenge free radicals by changing their colour from purplish to yellowish. In short, 260 µl of 0.1 mM DPPH solution and 40 µl of sample extract or standard were applied to a plate, and the plate was then incubated for 30 minutes at 25°C. For the standard curve and blank, respectively, trolox (0–200 µg/ml) and water were utilised. The data were presented as mg Trolox equivalents (TE) per dry weight (mg TE/g) ± SD, with the absorbance measured at 517 nm.

Estimation of Flavonols (Quercetin and Kaempferol)

Sample Preparation

A 250 mL flask with a round bottom was filled with 1 g of finely ground tea leaf sample. 5 mL of 6M hydrochloric acid (HCL) was added after 40 mL of 60% aqueous methanol. Before being filtered in a 50 mL volumetric flask, the mixture was refluxed for two hours at the boiling temperature. The filtrate was marked with 60% methanol in water after cooling. Prior to being injected into the HPLC, the sample was filtered using a 0.45 µ membrane filter (**Kingori et al, 2021**).

Standards Preparation

Myricetin, quercetin, and kaempferol stock solutions containing 200 µg/mL each were made in ethanol at room temperature (20˚C to 25˚C). Before being injected into the HPLC, working standard solutions for each individual standard were diluted between 0 and 100 µg/mL and run through a 0.45 µ filter membrane.

HPLC Instrumentation and Conditions

The Shimadzu Corporation in Kyoto, Japan, manufactured the Shimadzu LC 20 A series of HPLC systems, which included a binary pump with vacuum degasser (DGU-20A5R), thermostated column compartment (CTO-10AS vp), auto sampler (SIL 20 ATHT), and photo diode array detector (SPD-20MA). The temperature of the C18-phenyl reversed-phase column, which measured 4.6 × 250 mm and 5 µ, was kept at 25˚C. Acetonitrile of HPLC grade was used as mobile phase B, and 0.1% aqueous acetic acid was used as mobile phase A. At 0.01 minutes, 10% B; 30 minutes, 55% B; 35 minutes, 50% B; and 38 to 40 minutes, 10% B, a gradient elution system was operated. The injection volume was 20 µL, and the mobile phase flow rate was 1.0 mL/min. At 370 nm, the eluents were found and examined.

Analysis of caffeine, trigonelline, and furfural contents in roasted and ground coffee

Roasted coffee samples were tested for caffeine, trigonelline, and hydroxymethylfurfural using the approach modified by **Vignoli et al. (2014).** Using a Thermo Scientific Accela LC system (diode array detector (DAD), autoinjector, and Accela pump) (Thermo Fisher Scientific, Austin, TX), high performance liquid chromatography (HPLC) was used to conduct the analyses. The reverse phase Lichrospher 100 RP-18 (250 × 4.6 mm, particle size of 5 µm, pore size 10 nm) (Merck, Germany) was the column utilised for the separation. Water (A) and methanol (B) made up the mobile phase. The elution took place in the following intervals: 0–6 min (90% A and 10% B), 6–7 min (90–80% A and 10–20% B), 7–23 min (80% A and 20%), 23–24 min (80–0% A and 20–100% B), 24–25 min (0–90% A and 100–10% B), and finally, 25–26 min (90–80% A and 10% B). The injection volume was 1 µL (partial loop), the flow was 1 mL/min, and the injector and column were at 25 ◦C and 40 ◦C, respectively. Peaks were found at 272 nm wavelengths. Using a calibration curve and standard injection, caffeine, trigonelline, and HMF were discovered.

Estimation of volatiles compounds

Gas chromatography mass spectrometry (Hewlett-Packard 6890 GC/HP 5973 MS Agilent Technologies) was used to separate volatile compounds. Helium was the carrier gas, and the oven program was raised from 40 to 200 ˚C with an initial and holding time of 5 ºC min_1 at 5 and 45 minutes, respectively. The GC–MS conditions were stated by **Buffo & Cardelli-Freire, (2004)**. The column gas flow rate was 1 mL min_1, as defined in the GC–MS conditions. The parameters were as follows: ionising force of 70 eV, mass range of 30–330 amu, interface temperature of 280 ºC, and scanning rate of 2.2 scan sec-1. In split-less mode, 1 µL of injection was used. Comparing mass spectra to known volatile chemicals using the WILEY and NIST mass spectral (MS) libraries.

Sensory analysis.

The Speciality Coffee Association's approach (**Speciality Coffee Association of America, 2015**) was followed in the preparation of the samples. A cup holding 8.25 grammes of coffee powder was filled with 150 millilitres of hot water to begin the coffee brewing process. The samples were assessed by a group of five qualified coffee experts who held Q-Grader Coffee Certificates. SCA standards, which evaluate ten sensory attributes—fragrance, flavour, aftertaste, acidity, body, uniformity, balance, sweetness, cleanliness, and overall—were followed in the methods used to evaluate the coffees. With the exception of the sensory analysis (quintuplicates) and the instrumental colour examination of the beans (10 repetitions), every decision was made in triplicate.

Statistical analysis

According to **McClave and Benson (1991),** analysis of variance was used to statistically examine the collected data. Software for one-way analysis of variance (ANOVA) was applied to all of the data. Duncan's new multiple range tests were used to differentiate significant treatment means. At $p < 0.05$, differences were deemed significant.

3. Results and discussion

Proximate chemical composition

Table 1 shows the approximate chemical composition content of various coffee roasting grades. According to the data, light-roasted coffee has the lowest levels of crude fibre (25.30%) and ethyl ether extract (10.42%) and the highest levels of moisture content (3.50%) and crude protein (13.14%). Dark-roasted coffee samples contain the lowest moisture content (2.60%), the lowest crude protein (11.60%), and the highest ether extract (10.72%), crude fibre (27.80%), and ash content (4.52%). These values are statistically different ($p < 0.05$). A large percentage of dry matter causes the moisture content to drop as the roasting temperature rises. Its relative thermal stability allowed for a small rise in ether extract. A portion of the coffee protein is broken down into free amino acids and peptides during roasting, which are then absorbed by Strecker reactions and cause the protein concentration to drop. Except for moisture levels (1.5%), which may be the result of variable roasting conditions, these data are consistent with those published by **Oliveira (2006)** and **Hadipernata & Nugraha (2018)** for roasted coffee. In accordance with our results, **Nogaim and Gowri (2013)** discovered that the average amounts of moisture, crude proteins, total lipids, carbs, and ash in Arabic coffee were 6.99, 10.95, 6.13, 22.12, and 4.16%, respectively. Furthermore, **Vasconcelos et al. (2007)** found that protein concentrations remained constant across roasting levels, whereas ash content decreased and oil content slightly increased following roasting, most likely as a result of variations in variety and growing conditions.

Table 1. Proximate chemical composition (% in dry matter) content in light, medium, and dark coffee

Components %	Light coffee (210 ºC)	Medium coffee (230 ºC)	Dark coffee (240 ºC)
Moisture	$3.50{\pm}0.22^{a}$	$3.02{\pm}0.28^{b}$	$2.60{\pm}0.30^{c}$
Ether extract	$10.42{\pm}0.14^{c}$	$10.55{\pm}0.18^{b}$	$10.72{\pm}0.12^{a}$
Crude protein	$13.14{\pm}0.45^{a}$	$12.50{\pm}0.33^{b}$	$11.60{\pm}0.46^{c}$
Crude fiber	$25.30{\pm}0.52^{c}$	$27.20{\pm}0.36^{b}$	$27.80{\pm}0.41^{a}$
Ash	$4.16{\pm}0.05^{c}$	$4.30{\pm}0.04^{b}$	$4.52{\pm}0.06^{a}$
Nitrogen free extract	$56.98{\pm}1.2^{b}$	$45.45{\pm}1.8^{a}$	$45.36{\pm}2.2^{a}$

Values (means ± SD) with different superscript letters are statistically significantly different ($p \leq 0.05$).

Acrylamide content, Browning index and color characteristics in light, medium, and dark coffee

The acrylamide content, browning index, and colour features at different roasting levels are displayed in Table 2. Light-roasted coffee had the greatest levels of acrylamide (0.45 mg/100 g), while medium-roasted coffee had very low levels (0.38 mg/100 g). According to **Adimas et al. (2024),** roasting produces harmful substances including acrylamide. Acrylamide is typically produced during high-temperature cooking, such as baking, roasting, and frying, when the amino group in asparagine and the carbonyl source undergo a Maillard reaction. It is important to note that the acrylamide level surpasses maximum values at a light roast and then falls as the roasting temperature rises. This outcome aligns with the notion of formation during the early stages of the Maillard process. Acrylamide levels in coffee (powder, instant, and ground) ranged from 150 to 327 µg/kg, according to **Bortolomeazzi et al. (2012).** Acrylamide may be carcinogenic to humans because it has been shown in numerous studies and by the International Agency for Research on Cancer to have a mutagenic effect on lab animals. More research is required to identify the permissible level of acrylamide in coffee products. In this regard, the Food and Drug Administration declared that 0.077 mg/kg is the permissible intake in fries. **Granby & Fagt (2004)** found that medium-roasted coffee had 1 g/100 g of acrylamide, while dark-roasted coffee had 0.5 g/100 g. Additionally; **Alves et al. (2010)** noted that the amount of acrylamide in medium-roasted espresso was almost 25% lower than that of dark-roasted coffee. According to **Soares et al. (2009),** coffee that has been slow-roasted—that is, roasted at low temperatures for an extended period of time—had less acrylamide than coffee that has been roasted at high temperatures for a brief period of time. According to **Ku Madihah et al. (2013)**, roasting Arabic coffee at 180 ºC for 26 minutes yields the lowest levels of acrylamide (0.23 mg/100 g).

Table 2 displays the variations in the browning index, L*, a*, and b* values when the roasting temperature was raised simultaneously (20 minutes). Light-roasted coffee had the lowest browning index (0.52), while dark-roasted coffee had the highest (1.74). As the roasting temperature is raised, the whiteness of the coffee (measured by the L* value) tends to drop significantly ($p < 0.05$). The value a*, which tends to rise during the roasting process, represents the redness of roasted coffee. At lower roasting temperatures (210 ºC; 20 min), the roasted coffee's b* value (degree of yellowness) rose; but, at higher roasting temperatures (240 ºC; 20 min), it sharply declined. One of the elements that is frequently used to gauge the degree of roasting and one indicator of the quality of the finished product is colour development (**Shan et al., 2016**). During roasting, a number of events take place, but the Maillard reaction and oxidative polymerisation or degradation of phenolic chemicals are the primary reactions that produce colour and brown compounds. Since both enzymatic and non-enzymatic browning happen during roasting, the browning index gauges the purity of the browning. In a similar **vein, Yen et al. (2005)** discovered that aqueous extracts of soluble wasted coffee grounds had a lower browning index than roasted coffee. The whiteness of roasted coffee is indicated by the L* value. With higher roasting temperatures, the L* value tends to drop significantly ($p < 0.05$); this could be because non-enzymatic browning produces brown chemicals (**Wang et al., 2011; Shan et al., 2016**). Throughout the roasting temperature, the roasted coffee's redness (a* value) tended to rise. **Gökmen & Senyuva (2006)** found a correlation between the amount of acrylamide in coffee and the CIE a* colour value. According to **Alves et al. (2010),** dark and medium-roasted coffee had lower levels of acrylamide than light coffee. Roasted coffee's b*value, or degree of yellowness, rose at the lower roasting grade (210 ºC; 20 min) but sharply dropped at the higher roasting grade (240 ºC; 20 min). **Afoakwa et al. (2014)** claim that the thermal oxidation of polyphenols and the creation of Maillard products result in an increase in the b-value as roasting duration increases.

Table 2. Acrylamide content, Browning index and color characteristics in light, medium, and dark coffee

Items		Light coffee (210 ºC)	Medium coffee (230 ºC)	Dark coffee (240 ºC)
Acrylamide(mg/100 g)		$0.47{\pm}0.02^{a}$	$0.38{\pm}0.04^{c}$	$0.42{\pm}0.01^{b}$
Browning index (420 nm)		$0.52{\pm}0.01^{c}$	$0.94{\pm}0.03^{b}$	$1.74{\pm}0.02^{a}$
Color	L*	$54.20{\pm}1.3^{a}$	$46.50{\pm}1.7^{b}$	38.40±2.02c
	a*	$10.25{\pm}0.85^{c}$	$14.72{\pm}0.72^{b}$	$14.96{\pm}0.88^{b}$
	b*	$30.82{\pm}0.54^{a}$	$29.50{\pm}0.65^{b}$	$28.44{\pm}0.72^{c}$

Values (means ± SD) with different superscript letters are statistically significantly different ($p \leq 0.05$).

Phenolic content (TPC, TFC, and tannins content)

Table 3 displays the analysis of the TPC, TFC, and TCT data for estimating the phenolic content in the coffee beans. With the exception of TCT, all values of the free phenolic compounds were higher than those of the bound. The phenolic content of coffee beans with varying levels of roasting showed significant variances ($p < .05$). The coffee beans that were light-roasted had the greatest TPC value (28.30 mg G AE/g), followed by medium-roasted (26.50 mg GAE/g) and dark-roasted (23.90 mg GAE/g). According to earlier studies, roasting intensifies the tendency for the total quantity of phenolic compounds to decline (**Cho et al., 2014; Król et al., 2020**). After intense roasting, polyphenolic chemicals, particularly the chlorogenic acids in coffee beans, which exhibit high thermal instability, can breakdown directly at temperatures above 80°C, resulting in a decrease in TPC (**Hecimovic et al., 2011; Król et al., 2020**). When cellulose constituents are broken down during heat processing, partially bound phenolic chemicals that are present in the plant matrix may be released (**Cho et al., 2014; Mehari et al., 2020**). It contributes to the accumulation of free phenolic compounds, which prevents the significant decline but results in a comparatively greater level of free TPC values when compared to bound TPC values. Additionally, a similar pattern and notable variations were observed in the bound TPC value, which showed that as the roasting degree increased, the total bound phenolic compounds dropped from 24.5 mg GAE/g to 18.20 mg GAE/g. However, owing of their interaction with the Folin-Ciocalteu reagent, the presence of Maillard reaction products—particularly melanoidins—must be taken into account as they may somewhat raise the value of total phenols (TPC) (**Pérez-Hernández et al., 2012**). To evaluate the characteristics, cross-analysis using other antioxidant assays is required.

The results of free phenolic compounds showed a reversal trend as compared to bound phenolic, with the free TFC and TCT values increasing from 1.04 mg QE/g and 2.02 mg CE/g to 1.22 mg Q E/g and 6.30 mg CE/g. These differences were significant as the roasting degree increased. According to similar findings, the degree of roasting had a direct correlation with the amount of total flavonoids and tannins (**Hecimovic et al., 2011; Odzakovic et al., 2016; Król et al., 2020**). As the roasting temperature increased, more and more bound phenolic compounds were released, improving the free TFC and TCT while decreasing the bound phenolic compounds in a reasonable way. Condensed tannins may be broken down by proper roasting into flavonoids with lower molecular masses, including anthocyanin, which may somewhat increase the free TFC value. However, at temperatures below 210°C, the tannins' great heat resistance may be somewhat diminished (**Ahmad et al., 2018; Van Cuong et al., 2014**). Gallic acid is a component of hydrolysable tannins that belong to nonflavonoids, while flavan-3-ol is the monomer of condensed tannins that belong to flavonoids (**Mehari et al, 2020**). Thus, the isomerisation and polymerisation of polyphenolic compounds, as well as interactions with proteins and sugars during thermal processing, could result in the formation of a variety of compounds, such as flavan-3-ols complexes, quinolactones, and gallic acid complexes, which could raise TPC and TCT (**Kim et al., 2011; Król et al., 2020**).

In accordance with **Herawati et al. (2019),** it is evident that the DPPH radical scavenger activities dramatically declined as the roasting level rose. Meanwhile, **Del Castillo et al. (2002)** found that Colombian Arabica coffee beans with medium roast (233 ºC/3 min) had the highest antioxidant activity, whereas dark coffee (240 ºC/3 min) had the lowest. Reducing antioxidant compounds is consistent with a more intense roasting process where the antioxidants are destroyed during heating, as determined by **Giuffrè et al. (2018).** This is because antioxidant compounds are thermally unstable, which is consistent with the degradation of the bioactive compounds during roasting (**Vignoli et al., 2014**). To improve the overall antioxidant qualities and help make up for phenolic losses in antioxidant activity, however, significant amounts of Maillard and Strecker reaction products are created as the roasting grade rises (**Ludwig et al., 2014**).

Table 3. Phenolic content in coffee beans with three roasting degrees and their antioxidant activity

Antioxidant assays	Light coffee (210 ºC)	Medium coffee (230 ºC)	Dark coffee (240 ºC)
Free Phenolic			
TPC (mg GAE/g)	28.30±0.55^{a}	26.50±0.62^{b}	23.90±0.78^{c}
TFC (mg QE/g)	1.04±0.04^{b}	0.95±0.05^{c}	1.22±0.03^{a}
TCT (mg CE/g)	2.02±0.12^{c}	4.12±0.18^{b}	6.30±0.16^{a}
DPPH (mg TE/g)	154.20±1.4^{a}	151.60±1.6^{b}	146.80±1.9^{c}
Bound Phenolic			
TPC (mg GAE/g)	24.50±0.65^{a}	21.70±0.80^{b}	18.20±0.92^{c}
TFC (mg QE/g)	0.98±0.06^{a}	0.84±0.04^{c}	0.90±0.08^{b}

TCT (mg CE/g)	11.55±0.22^{a}	5.94±0.35^{b}	3.12±0.46^{c}
DPPH (mg TE/g)	71.40±1.04^{c}	78.30±0.98^{b}	80.50±1.02^{a}

Values (means ± SD) with different superscript letters are statistically significantly different ($p \leq 0.05$).

Quantitative levels of quercetin, kaempferol caffeine, trigonelline, and HMF in green, and dark coffee

Table 4 displays the amounts of quercetin and kaempferol in light, medium, dark, and green coffee. Under the study's chromatographic settings, quercetin (27.50 mg/g) and kaempferol (29.60 mg/g) were the two main flavonols found in green coffee. By examining how roasting at 240°C for 20 minutes affected these two compounds, it was found that the quercetin content increased to 42.20 mg/g. Additionally, the roasted samples showed no kaempferol, indicating that quercetin was the more prevalent of the two biomolecules. Given that epidemiological studies have suggested a potential link between kaempferol-containing foods and a lower chance of acquiring a number of illnesses, such as cancer and cardiovascular diseases, this finding raises a lot of interest for further research (**Kolb et al, 2020**). These findings are in good agreement with those found for the flavonoid content of roasted and green coffee (**Król et al., 2020**).

The analysis was performed in HPLC with the goal of determining whether the applied roasting procedure had an impact on the concentrations of caffeine, trigonelline, and HMF. Green coffee had the highest caffeine level, with roasted and ground coffee samples ranging widely in caffeine content from 9.35 mg/g to 17.80 mg/g (Table 4). The compound's thermo stability and the mass loss of thermolabile chemicals as a result of the roasting temperature may be the cause of the caffeine in the roasts (**Crozier et al, 2012**). Interestingly, under the predetermined roasting circumstances, this compound's thermal resistance was primarily stronger in practically all treatments compared to trigonelline and HMF (Table 4). According to reports, the caffeine level of the coffee samples was within the ranges documented in the literature (**Rusinek et al, 2024**). Compared to coffees roasted at high temperatures (240 ºC for 20 minutes), green coffee showed a higher trigonelline concentration in the current investigation. The absence of HMF in the Arabica coffee utilised in this investigation was confirmed across all roasting profiles, demonstrating the compound's rapid breakdown. It is noteworthy that temperature played a significant role in changing the concentrations of the chemical compounds, with roasting at 240 ºC/20 minutes being the most drastic condition for the reduction of these compounds. These results showed that the coffee species and temperatures used did not interfere with the concentration of HMF, resulting in a non-significant interaction. The HMF degradation may have been caused by the reaction between the furan compound and the amino acid decomposition products or compact with sugar alcohols and nitrogen-free polymer to trigger flavour compounds and melanoidins (**Rigo et al, 2021**).

Table 4. Quercetin , kaempferol, Caffeine, , trigonelline, and hydroxymethylfurfural (HMF) content in arabica coffee affected by roasting at 240 ºC/20 min

Components (mg/g)	Green coffee	Dark coffee (240 ºC)
Quercetin	27.30 ±0.88^{b}	42.20±0.65^{a}
Kaempferol	29.60±0.25^{a}	0.00±0.00^{b}
Caffeine	17.80±0.96^{a}	9.35±0.1.2^{b}
Trigonelline	8.95±0.92^{a}	5.24±0.84^{b}
hydroxymethylfurfural	0.00±0.00	0.00±0.00

Values (means ± SD) with different superscript letters are statistically significantly different ($p \leq 0.05$).

GC/MS analysis of dark roasted arabica coffee beans

Table 5 and Figure 1 display the gas chromatograms of the volatile components of the dark-roasted arabica coffee beans used in this investigation. In general, the dark-roasted arabica coffee beans were found to have 120 different chemicals. They are divided into the following 11 chemical classes: Hydrocarbons, acids, aldehydes, terpenoids, ketones, amines, trimethylsilanes, alcohols, ethers, esters, and sec-butyl nitrites The following substances made up the range of 0.17 to 13.21%: caffeine (13.21%), 5-Eicosene, (E)-, (cis)-2-nonadecene (11.18%), 3-Octadecene, (E)-, 3-Tetradecene, (Z)- (11.25%) In addition to the remaining known components, the lowest of which was astaxanthin (0.17%), there were 3-hexadecene, (Z)-, and 5-octadecene, (E)- (8.90%). Along with the degree of intense roasting, the content of primary volatile compounds in coffee beans improved. These compounds included some heterocyclic nitrogen compounds, acetic acids, furans, and furanic compounds, which were present in earlier studies (**Caporaso et al., 2018; Hertz-Schunemann et al., 2013; Somporn et al., 2011**). Following roasting, the most prevalent organic acid in roasted coffee beans was acetic acid, most likely due to the breakdown of saccharides, particularly sucrose (**Diviš et al., 2019**). During roasting, sucrose hydrolyses and any remaining water evaporates, producing fructose, which then undergoes Lobry-de-Bruynvan-Eckenstein rearrangement to yield 2,3-endiol. When these sugars are thermally dehydrated, 1-deoxyglucosone is produced as an acid precursor, which may eventually lead to the creation of acetic acid (**Yeretzian et al., 2014**). As with acetic acid, roasting coffee beans greatly increased their furan and furanic compound concentration. Two common precursors found in relatively high concentrations in green coffee beans are carbohydrates and amino acids (**Chaichi et al., 2015**). The reaction between sucrose, ribose, or deoxyosones and amino acids (cysteine or methionine) during roasting produces furans, such as 2-furanmentaol (furfuryl alcohol), which may be partly responsible for the caramel aroma of roasted coffee beans (**Caporaso et al., 2018; Hertz-Schunemann et al., 2013**). Coffee fragrance may also be influenced by furanic chemicals, such as 5-methylfurfural and furfural, which originate from two different pathways (**Chaichi et al., 2015**). One comes from the Amadori rearrangement products—particularly deoxyribose—that undergo dehydration, cyclisation, and polymerisation following the Maillard reaction (**Caporaso et al., 2018**). Furfuryl alcohol, polyunsaturated fatty acids, and ascorbic acid can also be thermally oxidised to produce furanic chemicals (**Caporaso et al., 2018; Chaichi et al., 2015**). Thus, the improvement of furfuryl alcohol synthesis when the roasting degree is increased from light to dark might significantly increase the content of furfural and 5-methylfurfral, which is consistent with the findings of this study.

Because 2,5-dimethylpyrazine and 2,6-dimethylpyrazine originate from the same Maillard reaction but have different functional group positions, a clustering was discovered in the pyrazine group based on Table 3 (**Lee et al., 2016**). With a few exceptions, the pyrazine content was found to be largely constant throughout roasting. According to some other researchers, pyrazines would be reduced in melanoidins when the temperature rose over 250°C because they would be absorbed into the molecule (**Schenker et al., 2002**). The usual roasting products found in this study, pyrroles and pyridines, had an increased propensity as the roasting degree increased. Pyrazines and these two group chemicals are formed in roasted coffee beans using a similar process. Other amino acids would then participate in the Strecker reaction between aldoses (aldehydes) and alkylamines (aminoketones), which would lead to heterocyclization and the production of a number of volatile compounds with strong aromas, such as pyrroles, pyridines, and pyrazines (**Caporaso et al., 2018**). Trigonelline breakdown may also provide pyridine (**Hertz-Schunemann et al., 2013**). Thus, excessive roasting would lower the pyridine concentration. In this study, the degree of intense roasting also enhanced the tendency of phenol content. These most likely results from the production of phenol in roasted coffee beans, which is caused by the breakdown of caffeoylquinic acid and ferulic acid, which are produced when chlorogenic acids break down during exothermic roasting (**Caporaso et al., 2018**). In general, appropriate high-intensity roasting may increase the volatile chemical content of coffee beans, which is advantageous for the development of coffee bean flavour (**Wu et al, 2022**).

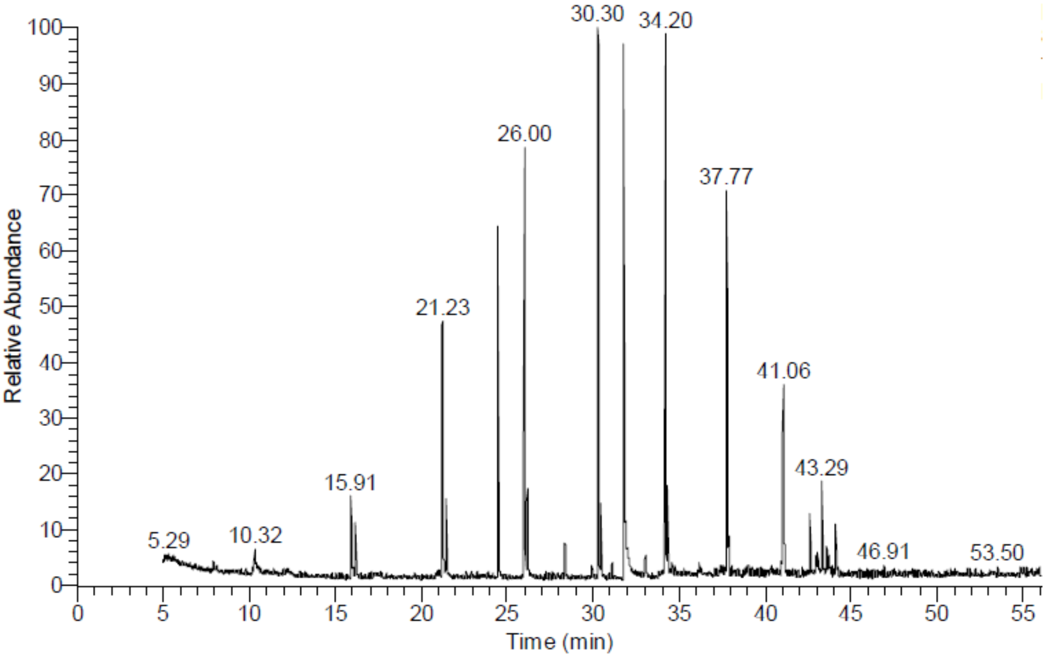

Fig. 1. GC/MS analysis of dark roasted arabica coffee beans

Table 5. The percentage of volatile compounds in dark roasted arabica coffee beans

Peak No.	RT (Min.)	MW	MF	Area %	Identified Compounds
1	7.93	636	$C_{18}Cl_{12}$	0.29	Dodecachloro-3,4-benzo phenanthrene
2	7.93	166	$C_2H_2Cl_4$	0.29	1,1,2,2-tetrachloro- (CAS)
3	7.93	264	$C_{17}H_{28}O_2$	0.29	Methyl 13c hexadecatrienoate
4	10.17	148	$C_8H_{17}Cl$	0.19	Octane, 2-chloro-
5	10.17	148	$C_8H_{17}Cl$	0.19	Octane, 3-chloro-
6	10.32	84	C_6H_{12}	0.71	1-Hexene (CAS)
7	10.32	102	$C_6H_{14}O$	0.71	1-Hexanol (CAS)
8	10.32	130	$C_7H_{14}O_2$	0.71	Formic acid, 2-methylpentyl ester
9	12.27	260	$C_{19}H_{32}$	0.21	1-methyldodecylbenzene
10	12.27	260	$C_{18}H_{28}O$	0.21	(9'R,9"R)-dispiro[Bicyclo (4.2.1) nonane-9,2'-oxirane-3',9"-bicyclo (4.2.1) nonane]
11	12.27	260	$C_{15}H_{20}N_2O_2$	0.21	3-(2,2-dimethylhydr azino)-5-(3-methoxy phenyl)-2-cyclohexen-1-one
12	15.92	126	C_9H_{18}	1.98	Cyclooctane, methyl-
13	15.92	140	$C_{10}H_{20}$	1.98	Trans-3-Decene
14	15.92	140	$C_{10}H_{20}$	1.98	Cyclopentane, (2-methylbutyl)
15	16.15	324	$C_{23}H_{48}$	1.33	Tricosane (CAS)
16	16.15	170	$C_{12}H_{26}$	1.33	Dodecane (CAS)
17	16.15	168	$C_{12}H_{24}$	1.33	2-undecene, 5-methyl-
18	17.59	585	$C_{28}H_{33}CdN_5O_2$	0.19	cadmium(ii)-1,2,2,7,7, 12,12-heptamethyl-15-cyano-19- oxycarbonylcarrinate
19	17.59	260	C_9H_9IO	0.19	2-Iodomethyl-2,3- dihydro-benzofuran
20	17.59	668	$C_{30}H_{26}IN_2OP$	0.19	[2-(N-Acetylanilino)- 1,3-selenazol-4-ylmethyl]

			Se		triphe nylphosphonium iodide
21	21.00	270	$C_{15}H_{20}Cl_2$	0.20	3,3-Dichlorodispiro[Cyclo propane 1,6': 2,6''-bis (exo-6-bicyclo[3.1.1]heptane)]
22	21.00	368	$C_{25}H_{36}O_2$	0.20	6,9,12-Octadecatrienoic acid, phenylmethyl ester, (Z,Z,Z)
23	21.23	196	$C_{14}H_{28}$	5.24	1-Tetradecene (CAS)
24	21.23	168	$C_{12}H_{24}$	5.24	3-Dodecene, (E)-
25	21.43	198	$C_{14}H_{30}$	1.61	Tetradecane (CAS)
26	21.43	212	$C_{15}H_{32}$	1.61	Dodecane, 2,6,11-trimethyl-

Peak No.	RT (Min.)	MW	MF	Area %	Identified Compounds
27	24.45	234	$C_{15}H_{26}N_2$	7.78	(1à,4à,4aà,10aà)-1,4,4a, 5,6,7,8,9,10,10a-decahydro-1,4,11,11-tetramethyl-1,4-methanocycloocta[d]p yridazine
28	24.45	206	$C_8H_9F_3N_2O$	7.78	5-Isopropyl-4-(trifluorom ethyl)-1-Hpyrimidin-2-one
29	24.45	206	$C_{13}H_{18}O_2$	7.78	3,4-Dihydro-2H-1,5-(3''-t-butyl) benzodioxepine
30	26.00	224	$C_{16}H_{32}$	8.90	3-Hexadecene, (Z)-
31	26.00	252	$C_{18}H_{36}$	8.90	5-Octadecene, (E)-
32	26.17	226	$C_{16}H_{34}$	1.72	Hexadecane (CAS)
33	27.97	416	$C_{24}H_{48}O_3S$	0.26	Sulfurous acid, cyclohexylmethyl heptadecyl ester
34	27.97	430	$C_{25}H_{50}O_3S$	0.26	Sulfurous acid, cyclohexylmethyl octadecyl ester
35	27.97	154	$C_{10}H_{18}O$	0.26	3-butylcyclohexanone
36	28.36	198	$C_{14}H_{30}$	0.81	Tetradecane
37	28.36	240	$C_{17}H_{36}$	0.81	Heptadecane
38	29.92	238	$C_{12}H_{11}ClO_3$	0.44	3-(Chloromethyl)-8-ethoxycoumarin
39	29.92	238	$C_{12}H_8Cl_2O$	0.44	Benzene, 1,1'-oxybis[4-chloro-
40	30.30	252	$C_{18}H_{36}$	11.25	3-Octadecene, (E)-
41	30.30	196	$C_{14}H_{28}$	11.25	3-Tetradecene, (Z)-
42	30.44	200	$C_{13}H_{28}O$	1.73	Ether, heptyl hexyl
43	30.44	272	$C_{15}H_{28}O_4$	1.73	Oxalic acid, Heptyl isohexyl ester
44	31.10	710	$C_{36}H_{54}O_{14}$	0.34	Card20(22)-enolide, 3-[(2,6-dideoxy-4-O-á-D-glucopyranosyl-3-O-methyl-á-D-ribo-hexopyranosyl)oxy]-5,14-dihydroxy-19-oxo-, (3á,5á)-
45	31.10	270	$C_{12}H_{18}N_2O_5$	0.34	Uridine, 2'-deoxy-3-methyl-3', 5'- di-O-methyl
46	31.76	194	$C_8H_{10}N_4O_2$	13.21	Caffeine (CAS)
47	33.04	270	$C_{17}H_{34}O_2$	0.73	Hexadecanoic acid, methyl ester (CAS)
48	33.04	284	$C_{18}H_{36}O_2$	0.73	Heptadecanoic acid, methyl ester (CAS)
49	34.21	280	$C_{20}H_{40}$	11.18	5-Eicosene, (E)-
50	34.21	266	$C_{19}H_{38}$	11.18	(cis)-2-nonadecene
51	34.31	422	$C_{30}H_{62}$	2.08	Triacontane (CAS)
52	34.31	198	$C_{14}H_{30}$	2.08	Decane, 2,3,5,8-tetramethyl

53	34.60	282	$C_{18}H_{34}O_2$	0.23	9- Octadecenoic acid (Z)- (CAS)
54	34.60	254	$C_{16}H_{30}O_2$	0.23	9- Hexadecenoic acid (CAS)
55	36.18	292	$C_{19}H_{32}O_2$	0.32	6,9,12-Octadecatrienoic acid, methyl ester (CAS)
56	36.18	294	$C_{19}H_{34}O_2$	0.32	9,12-Octadecadienoic acid, methyl ester, (E,E)- (CAS)
57	36.18	294	$C_{19}H_{34}O_2$	0.32	9,12 – Octadecadienoic acid (Z,Z), methyl ester (CAS)
58	37.14	572	$C_{28}H_{38}Cl_2O_8$	0.19	Butanoic acid, 4-chloro-, 1,1a,1b,4,4a,5,7a,7b,8,9 – decahydro-4a, 7b-dihydroxy-3-(hydroxymethyl)-1,1,6,8-tetramethyl-5-oxo-9aH-cyclopropa[3,4]benz[1,2-e] azulene-9,9a-diyl ester, [1ar-(1aà,1bá,4aá,7aà,7bà ,8à,9á,9aà)]-
59	37.14	304	$C_{17}H_{20}O_5$	0.19	Acetyloxyparthenin
60	37.38	484	$C_{25}H_{44}N_2O_5S$	0.18	2- Myristynoyl pantetheine

Peak No.	RT (Min.)	MW	MF	Area %	Identified Compounds
61	37.38	216	$C_{10}H_{12}N_6$	0.18	5- Amino-1-(dimethylamino)-2-methyl-1,2-dihydro-3H-pyrrole-3,3,4-tricarbo nitrile
62	37.38	417	$C_{19}H_{13}BrClNO_3$	0.18	3-[3-Bromophenyl]-7- chloro-3,4-dihydro-10-hydroxyl-1,9-(2H,10H)- acridinedione
63	37.44	322	$C_{17}H_{22}O_6$	0.23	Tetraneurin A
64	37.44	0	N/A	0.23	Glangin
65	37.44	332	$C_{14}H_8N_2S_4$	0.23	Di-2-benzothiazole disulfane
66	37.77	280	$C_{20}H_{40}$	8.33	3-Eicosene, (E)-
67	37.77	280	$C_{20}H_{40}$	8.33	5-Eicosene, (E)-
68	37.87	310	$C_{22}H_{46}$	1.12	Docosane (CAS)
69	37.87	408	$C_{29}H_{60}$	1.12	Nonacosane (CAS)
70	37.87	296	$C_{21}H_{44}$	1.12	Heneicosane (CAS)
71	38.07	302	$C_{17}H_{18}O_5$	0.31	2-Acetyl-8-methyl-4-oxa-bicyclo [9.3.1] pentadeca-1(14),8,11-triene-3,13,15-trione
72	38.07	428	$C_{31}H_{56}$	0.31	Pentacosane, 13-phenyl- (CAS)
73	38.92	502	$C_{32}H_{54}O_4$	0.46	7,8-Epoxylanostan-11-ol, 3-acetoxy-
74	38.92	518	$C_{31}H_{50}O_6$	0.46	Tetradecanoic acid, 3,3a,4,6a,7,8,9,10,10a,10b-decahydro-3a,10a-dihydroxy-5-(hydroxymethyl)-2,10-dimethyl-3-oxobenz[e] Azulen-8-yl ester, [3aR-(3aà,6aà,8à,10á,10a á,10bá)]-
75	39.27	596	$C_{40}H_{52}O_4$	0.17	Astaxanthin
76	39.27	478	$C_{12}H_{22}N_4O_8S_4$	0.17	2,6-Bis[2-[2-S-thiosulfur oethylamino]ethoxy] pyrazine
77	39.49	572	$C_{28}H_{38}Cl_2O_8$	0.17	Butanoic acid, 4-chloro, 1,1a,1b,4,4a,5,7a,7b,8,9-decahydro-4a, 7b-dihydroxy-3- (hydroxymethyl)-1,1,6 ,8-tetramethyl-5-oxo-9a H-cyclopropa [3,4]benz[1,2-e] azulene9,9adiyl ester, [1ar- (1aà,1bá,4aá,7aà,7bà ,8à,9á,9aà)]
78	39.49	408	$C_{30}H_{48}$	0.17	2,6,10,14,18,22-Tetracosahexaene, 2,6,10,15,19,23-hexamethyl, (all-E)-, didehydroderiv
79	40.08	1156	$C_{46}H_{82}Hg_2P_2Si_2$	0.24	2,2,4,4-tetrakis[(t-butyl)]-1,3-bis{[(2',4',6'-triisopropyl) phenyl]mercurio}-1,3- diphospha-2,4-disiletane

Peak No.	RT (Min.)	MW	MF	Area %	Identified Compounds
80	40.08	696	$C_{51}H_{68}O$	0.24	Bis(3,6-di-tert-butyl-1-azulenyl)(3,5-ditertbutyl 4-hydroxyphenyl) methane
81	40.08	712	$C_{38}H_{40}N_4O_{10}$	0.24	Dimethyl (2RS,7SR)-17-(3'-methoxy-3'-Oxoprop-2'-enyl)-13-(3-'methoxy-3'-oxopropyl) 2,3,7,8-tetrahydro-2,7,12,18- tetramethyl -3,8- dioxo-21H,23H-porphin-2,7-diacetatedipropanoate
82	40.40	496	$C_{30}H_{40}O_6$	0.26	Ergosta-2,24-dien-26-oic acid, 27-(acetyloxy)-5,6-epoxy-22-hydroxy-1-oxo-, ë-lactone (CAS)
83	40.40	462	$C_{25}H_{42}N_4O_4$	0.26	2-Nonadecanone 2,4-d. n.p.h.
84	40.40	332	$C_{14}H_8N_2S_4$	0.26	Di-2-benzothiazole disulfane
85	41.06	336	$C_{24}H_{48}$	5.15	Cyclotetracosane
86	41.06	252	$C_{18}H_{36}$	5.15	5-Octadecene, (E)-
87	41.91	416	$C_{24}H_{32}O_6$	0.19	Desacetylcinobufotalin
88	41.91	496	$C_{20}H_{32}O_{10}S_2$	0.19	D-Galactose, diethyl mercaptal, pentaacetate
89	42.13	190	$C_{12}H_{14}O_2$	0.25	Cyclopropanecarboxylic acid, 2-methyl-1-(phenylmethyl)-
90	42.13	644	$C_{37}H_{68}O_3Si_3$	0.25	Tristrimethylsily l ether derivative of 1,25-dihydroxyvit amin d2
91	42.60	146	$C_{11}H_{14}$	1.62	1H-Indene, 2,3-dihydro-4,7-dimethyl-
92	42.60	146	$C_{11}H_{14}$	1.62	1H-Indene, 2,3-dihydro-4,6-dimethyl (CAS)
93	42.60	146	$C_{11}H_{14}$	1.62	Indan, 5,6-dimethyl-(CAS)
94	42.94	296	$C_{18}H_{20}N_2S$	0.58	Benzimidazole, 2-methyl-1-(3-phenylpro pylthio)-methyl-
95	42.94	216	$C_{15}H_{20}O$	0.58	2,5,5-Trimethyl-3-phenyl-cyclohexanone
96	43.05	296	$C_{20}H_{24}O_2$	0.56	Creatindial
97	43.05	356	$C_{23}H_{32}O_3$	0.56	16-Dehydropregnenolone acetate
98	43.05	440	$C_{30}H_{48}O_2$	0.56	Ergosta-5,22-dien-3-ol, acetate, (3á,22E)-
99	43.29	384	$C_{26}H_{40}O_2$	2.66	Butyl 4,7,10,13,16,19-docosahexaenoate
100	43.29	328	$C_{22}H_{32}O_2$	2.66	Doconexent
101	43.29	318	$C_{21}H_{34}O_2$	2.66	Androstan-17-one, 3--ethyl-3-hydroxy-, (5à)-
102	43.58	298	$C_{18}H_{22}N_2S$	0.95	6H-1-(4-Methylphenyl) 2,7,7-trimethyl-4,5,7,8-tetrahydropyrrolo[3,2-c] azepin -4-thione
103	43.58	298	$C_{18}H_{18}O_4$	0.95	1-[p-Methoxyphenyl] -2-(3',4',5'-trimethoxyphenyl) ethyne
104	43.58	298	$C_{18}H_{18}O_4$	0.95	2-Methyl-1,4,8-trimethoxyanthracen-9-ol
105	43.73	204	$C_{15}H_{24}$	0.57	Cis-(-)-2,4a, 5,6,9a-HexahYdro-3,5,5,9-tetramethyl(1H)benzocycloheptene
106	43.73	134	$C_9H_{10}O$	0.57	Chavicol
107	43.73	360	$C_{24}H_{40}O_2$	0.57	10,12-Tricosadiynoic acid, methyl ester
108	44.10	490	$C_{35}H_{70}$	1.69	17-Pentatriacontene (CAS)
109	44.10	348	$C_{25}H_{48}$	1.69	Dodecane,1-cyclopentyl-4-(3-cyclopentylpropyl)-
110	45.56	362	$C_{15}H_{22}O_{10}$	0.24	d-Xylitol, pentaacetate (CAS)
111	45.56	440	$C_{28}H_{40}O_4$	0.24	Trans-2-phenyl-1,3-dioxolane-4-methyloctadec-9,12,15-trienoate
112	45.56	378	$C_{12}H_8Cl_6O$	0.24	1,2,3,4,10,10-hexachloro-6,7-epoxy-

					1,4,4a,5,6,7,8,8a-octahydroexo-1,4-exo-5,8-dimethano-naphthalene
113	46.82	282	$C_{11}H_{14}N_4O_5$	0.17	4-Hydroxyvaleraldehyde-2,4-dinitrophenylhydrazone

Peak No.	RT (Min.)	MW	MF	Area %	Identified Compounds
114	46.82	616	$C_{36}H_{56}O_8$	0.17	Tetradecanoic acid, 9a-(acetyloxy)-1a, 1b,4,4a, 5,7a,7b,8,9,9a-decahydro-4a, 7b-dihydroxy-3-(hydroxymethyl)-1,1,6,8tetramethyl-5-oxo-1H-cyclopropa[3,4]benz[1,2e] azulen-9-yl ester, [1aR-(1aà,1bá,4aá,7aà,7bà,8à,9á,9aà)]-
115	46.82	589	$C_{32}H_{44}ClNO_7$	0.17	Milbemycin B, 5-demethoxy-5-one-6,28-anhydro-25-ethyl-4-methyl-13-chlorooxime
116	46.92	546	$C_7Br_5ClO_2$	0.53	2,3,4,5,6-Pentabromophenyl carbonochloridate
117	46.92	596	$C_{35}H_{43}CuN_5$	0.53	10-dimethylaminomethyl-2,8,12,18-tetramethyl-3,7,13,17-tetraethyl-21H, 23H-porphin
118	46.92	0	N/A	0.53	Hahnfett
119	52.26	610	$C_{27}H_{30}O_{16}$	0.24	Lucenin 2
120	52.26	430	$C_{12}H_{38}O_5Si_6$	0.24	Hexasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11-dodecamethyl

Sensory properties

With an average of 78.50, the cup test results (total scores) in this study range from 75.80 to 81.20. The percentage of Arabica coffee and roasting level had a highly significant ($P \leq 0.01$) impact on the coffee brew's flavour, according to the analysis of variance. The impact of roasting level on coffee brew is displayed in Table 6. Light coffee receives the greatest cup test score (81.20), while Dark coffee has the lowest overall score (75.80). Properties and chemical constituents in each coffee have an impact on variations in the overall cup test score. (**Coelho et al., 2024**) corroborate this claim by explaining that the coffee brew's overall cup test score dropped as the roasting temperature rose. According to **Muzaifa and Hasni (2016)**, gayo Arabica coffee often received a score of at least 80. According to (**Abubakar et al., 2020**), the average cup test score for Gayo Arabica coffee is 83.31, with a range of 80.02±2.09 to 85.48±0.42. The study's total cup test results for coffee brew have achieved the desired goal of ≥ 80 on the scale.

Generally speaking, a coffee brew's overall cup score decreases with increasing roast level. Light-roasted coffee yielded a total cup score of 81.20, which is statistically identical to the medium-roasted coffee's total cup score of 79.50. As a result, the dark roast coffee's overall cup score drops dramatically to 75.80. According to **Abubakar et al. (2020),** the chemical components found in coffee beans will be scorched by the dark roast. This suggests that some of the chemical components that give coffee its flavour and aroma will be harmed by roasting at a dark level. The coffee brew with the highest overall cup score (80.72) is produced by medium roasting.

Coffee with a light roasting degree receives the top ratings for fragrance, flavour, and aftertaste. Conversely, coffee with a dark roasting degree has the lowest smell rankings. Panellists must consider the fragrance and flavour from the very beginning, from preparation to slurping the brew, when evaluating this criterion. According to (**Bhumiratana et al., 2011**), coffee's aroma is influenced by its place of origin, but it is not the primary one because coffee quality is affected by a variety of elements and comprehensive coffee processing methods (**Sunarharum et al., 2014**).

Coffee with a light roasting degree received the highest acidity score. In contrast, Arabica coffee with a dark roasting degree had the lowest acidity score. Arabica coffee with dark roasting levels receives a better score for the body parameter. On the other hand, light roasting degrees yield the lowest body score. Arabica coffee with a light roast level receives the greatest score for the balance parameter. However, the dark roasting degree yields the lowest balance score. Arabica coffee with a light roasting degree receives the greatest score for the parameter overall. Arabica coffee that has been darkly roasted receives the lowest overall grade. Arabica coffee with a light roasting degree receives the highest overall score out of all the samples. **Abubakar et al. (2020)** also corroborate this assertion.

Table 6. Sensory properties of light, medium, and dark coffee brew

Sensory property	Light coffee (210 ºC)	Medium coffee (230 ºC)	Dark coffee (240 ºC)
Fragrance	8.0±0.15^{a}	7.70±0.22^{b}	7.50±0.26^{c}
Flavor	7.80±0.12^{a}	7.50±0.18^{b}	7.10±0.14^{c}
Aftertaste	7.50±0.16^{a}	7.30±0.20^{b}	7.0±0.22^{c}
Acidity	8.20±0.20^{a}	7.80±0.25^{b}	7.30±0.32^{c}
Body	7.20±0.24^{c}	7.40±0.30^{b}	7.70±0.25^{a}
Balance	7.50±0.20^{a}	7.20±0.28^{b}	6.80±0.30^{c}
Overall	8.0±0.22^{a}	7.50±0.25^{b}	7.20±0.18^{c}
Total	81.20±1.02^{a}	79.50±1.05^{b}	75.80±1.12^{c}

Values (means ± SD) with different superscript letters are statistically significantly different ($p \leq 0.05$).

Arabica coffee, green, light, medium, and dark and its brew

4. Conclusion

The results of the current investigation showed that commercial light-roasted coffee beans had a comparatively greater level of antioxidant potential and total phenolic compounds (TPC). Total flavonoids and condensed tannins (TFC and TCT) were more abundant in the dark-roasted. However, in terms of phenolic content and antioxidant potential, the commercial light-roasted coffee beans performed better overall. A total of 120 volatile chemicals were found and measured in all dark-roasted coffee beans using GC-MS. Light-roasted coffee beans have the highest overall sensory score out of all the samples.. In conclusion, when roasting intensifies, the amount of phenolic chemicals in coffee beans would decrease. Due to the creation of new compounds with exceptional antioxidant activity, coffee beans' antioxidant properties may be preserved or even enhanced to some degree even after intense roasting. The most diverse phenolic components and comparatively exceptional fragrance qualities are found in light-roasted coffee beans.

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