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Assessment of acrylamide, microbiological safety, and nutritional quality of commercial coffee in Ghana

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ABSTRACT

Globally, coffee is the most widely consumed beverage and is greatly appreciated for its organoleptic qualities. This study aims to assess the quality and safety standards of coffee sold on the market in Ghana's ten principal regions. A total of 30 coffee samples were collected, including 3 from the major cities in each region. The parameters assessed included acrylamide levels, proximate composition, isolation and identification of fungi, and the minerals: potassium (K), phosphorus (P), calcium (Ca), and magnesium (Mg). Acrylamide was quantified using high-performance liquid chromatography with a dynamic absorbance detector, while proximate composition was determined using standard methods. Fungi were isolated and identified using the dilution plate method, and minerals were determined using atomic absorption spectroscopy. Data were analyzed using one-way analysis of variance at a 5% significance level. The findings demonstrated that the coffee from each region had significantly different acrylamide levels (ranging from 137.62 µg/kg to 328.66 µg/kg). Roasted commercialized coffee contains more fat (5.58–8.15%) and ash (10.45–15.00%) but less moisture (4.84–6.58%), protein (9.42–13.79%), and carbohydrates. Two fungi, Aspergillus niger and Aspergillus flavus, were found in some samples at a 5% occurrence frequency. The coffee samples contained significant amounts of P, K, Ca, and Mg. The results indicate a potential risk from acrylamide intake through coffee consumption. While no neurotoxicity risk was identified, a potential carcinogenic risk was observed based on the MOE results. The findings provide useful evidence for coffee producers, consumers, and regulatory authorities to strengthen quality control in coffee processing.

Contribution/Originality: This study offers a thorough analysis of coffee quality in Ghana, focusing on acrylamide levels, fungal contamination, proximate composition, and mineral content. It highlights regional differences in safety parameters, providing new insights into the safety and nutritional quality of coffee available in Ghana's market.

1. INTRODUCTION

Coffee is one of the most popular beverages globally and is widely valued for its sensory qualities, the stimulant effects of caffeine, and the numerous bioactive compounds it contains, which have been linked to various health benefits (Schouten, Tappi, & Romani, 2020). Furthermore, millions of people depend on it as their primary source of income, making it a crucial economic factor (Zhang et al., 2019). A record 176.1 million kilograms of coffee were produced worldwide in 2020–2021, and there was an increase of 5.5 million kilograms in the year 2021–2022 (International Coffee Organization, 2022). In response to the increasing global demand for coffee and rising

consumption, producing countries have established quality control systems to ensure the safety and nutritional value of coffee products throughout the production and trade processes.

The botanical family Rubiaceae, which includes coffee, has about 6000 species and roughly 500 genera. Of the approximately 100 species in the genus Coffea, only two are commercially available. Coffea arabica (Arabica) and Coffea canephora (Robusta) are the two main species, accounting for about 70% and 30% of the world's coffee production, respectively (da Costa, Albuquerque, Costa, & Bragotto, 2023). In Ghana, Robusta coffee is grown more extensively and mostly processed using the dry method. After being dried, harvested, and roasted, the beans are ground into a powder and sold commercially. The roasting of coffee beans is a critical stage in the coffee processing chain that can influence the quality of the coffee's taste and aroma (Astuti et al., 2024). Temperature and roasting time are also significant factors in achieving a decent sensory profile for a cup of coffee. The best method for improving the desired sensory attributes under controlled conditions is to roast at 220–230°C for 24 minutes. Coffee also develops its unique flavor, color, and aroma through intricate chemical reactions brought on by roasting. Pyrolysis and Maillard reactions produce hundreds of new compounds that contribute to coffee's distinctive profile, including melanoidins, volatile aroma compounds, and acids (Pinheiro, Pinheiro, Osório, & Pereira, 2021). However, when reducing sugars and the amino acid asparagine react at high temperatures, roasting also creates acrylamide, a potentially cancer-causing compound (Schouten et al., 2020). According to Mojska and Gielecińska (2013), acrylamide production peaks in the early stages of roasting and decreases as roasting goes on.

The European Food Safety Authority states that acrylamide levels in roasted coffee can range from an average of 221 μg/kg to a maximum of 2200 μg/kg (European Food Safety Authority, 2012). Another factor is the type of coffee; although this difference is not always apparent, Robusta usually has slightly higher acrylamide levels than Arabica (Deribew & Woldegiorgis, 2021).

The prevalence of Robusta and the use of high-temperature roasting in Ghana highlight the need for stringent oversight of roasted coffee due to the acrylamide safety concern. Because acrylamide is regarded as a likely human carcinogen, consuming excessive amounts of it through everyday foods like coffee can be detrimental to one's health. The levels of acrylamide in commercially sold coffee must be routinely monitored to comply with national and international safety regulations. Gaascht, Dicato, and Diederich (2015) and Wachamo (2017) report a diverse phytochemical profile, including essential minerals, lipids, polyphenols, and alkaloids. The most prominent compound that can enhance mental clarity and physical performance and potentially reduce the risk of certain neurological disorders is caffeine (Heckman, Weil, & De Mejia, 2010). Coffee has additional health benefits due to the presence of trigonelline, chlorogenic acids, and other antioxidants (Farah & de Paula Lima, 2019; Makiso, Tola, Ogah, & Endale, 2024).

Moisture, ash, crude protein, crude fat, fibre, and carbohydrates make up the proximate composition of coffee beans. These components impact the flavour, consistency, and intensity of the final beverage. Specifically, shelf life and microbial safety are affected by moisture content. Proteins and carbohydrates are altered during roasting, which affects the development of colour and flavour. Additionally, coffee has dietary fibre, and roasting increases its soluble fibre content (Silván, Morales, & Saura-Calixto, 2010). The mineral composition of coffee is equally significant. For human health, minerals such as calcium (Ca), magnesium (Mg), potassium (K), and phosphorus (P) are essential. While phosphorus aids in bone formation and energy metabolism, calcium helps maintain strong bones and supports muscle contraction (Nabrzyski, 2006). Magnesium supports more than 300 enzymatic reactions in the body, and potassium controls fluid balance and nerve function (McDowell, 2003; Prashanth, Kattapagari, Chitturi, Baddam, & Prasad, 2015). Coffee is a reliable source of micronutrients because, in contrast to organic components, these minerals remain stable during roasting (Bitter, Fernandez, Driscoll, Howa, & Ehleringer, 2020).

Coffee is a tropical product produced extensively in roughly 60 tropical and subtropical countries (Esquivel & Jiménez, 2012). However, farmers encounter several difficulties in coffee production in these areas (Harvey et al., 2014). As a crop sensitive to climate change, coffee's quality and yield have been greatly affected by numerous pests,

diseases, and fungi (Pham, Reardon-Smith, Mushtaq, & Cockfield, 2019; Rutherford & Phiri, 2006). Fungal growth is facilitated by tropical climates, which are characterized by high humidity, high temperatures, and high precipitation (Zinedine et al., 2006). Climate change can accelerate fungal growth and spore formation, especially during periods of heavy precipitation. Fungal diseases are more diverse and cause the greatest losses in global coffee production compared to bacterial and viral pathogens (Shuping & Eloff, 2017). These fungi can be broadly classified into two categories: those that cause crop damage before harvest and those that cause postharvest infections (Brown & Ogle, 1997; Ruffo Roberto, Youssef, Hashim, & Ippolito, 2019). Fungal infestation can occur at any stage of the production process, from growth and harvest to storage and processing (Varga, Kocsubé, Péteri, Vágvölgyi, & Tóth, 2010). Ismaiel and Papenbrock (2015) state that while pre-harvest infections are often linked to interactions between the coffee plant and other organisms, such as insects, post-harvest infections are influenced by variables such as temperature, humidity, nutrient availability, and biological conditions. Among the numerous secondary metabolites generated by fungi is ochratoxin A, the most common mycotoxin in agricultural products (Lu et al., 2022). Aspergillus and Penicillium species are the main producers of this toxin.

Numerous factors, such as soil type, geographic origin, cultivation techniques, and processing methods, affect the mineral content of coffee (Olechno, Puścion-Jakubik, Socha, & Zujko, 2021). For example, beans grown in mineral-rich soils usually have higher nutrient levels. To improve consumer health and increase the market price of Ghanaian coffee, a geographic study of coffee composition is particularly crucial. Furthermore, packaging and storage conditions significantly impact the safety and quality of coffee. Exposure to oxygen, light, or moisture can degrade aroma compounds in food and promote microbial growth (Ross, Pecka, & Weller, 2006). Proper packaging, such as vacuum sealing or nitrogen flushing, helps preserve volatile compounds and increase shelf life.

Accurate labelling helps ensure traceability in the event of quality issues and provides consumers with information about nutritional value, roast level, origin, and expiration date. Globally, demand for coffee is increasing, raising the bar for quality control (Pancsira, 2022). Customers' perceptions of products are greatly influenced by consistency, flavour, and aroma. Quality control methods such as mineral profiling, proximate analysis, and sensory evaluation (e.g., cupping tests) are essential for meeting these standards (Asrade, 2023). The presence of acrylamide and mycotoxins, as well as potential contamination with heavy metals or pesticide residues, necessitates stricter regulatory oversight and the adoption of good agricultural and manufacturing practices. The nutritional and safety profile of commercially available coffee in Ghana is poorly documented, particularly regarding acrylamide levels and essential minerals such as P, K, Ca, and Mg. While many studies have assessed the proximate composition and antioxidant capacity of coffee in various countries (Adetunji et al., 2021; Degefa, Alamerew, Mohammed, & Gemechu, 2022), previous research in Ghana has examined raw and roasted Robusta coffee in specific regions (Boadu, Teye, Lamptey, Amuah, & Sam-Amoah, 2024; Gyedu-Akoto, Opoku, & Ofosu-Agyei, 2019).

However, none has offered a comprehensive national overview. The current study sought to address this gap by evaluating the acrylamide content, proximate composition, and mineral levels (particularly calcium, magnesium, phosphorus, and potassium) of commercially available coffee in Ghana's ten regions. Enhancing quality control, promoting public health, and directing the implementation of national food safety regulations are all anticipated outcomes of this research.

2. MATERIALS AND METHODS

2.1. Sample Preparation

A total of 30 coffee powder samples (3 from each region) were randomly purchased from different retailers across Ghana. They were bought in the major markets across Ghana's regions. While being transported to the laboratory, the samples were kept in sterile polyethylene bags. All samples were kept in a cold room following delivery until use. Samples were labelled according to the regions from which they were purchased. All analyses were carried out in triplicate.

2.2. Chemicals and Equipment

All chemicals and equipment used in the analysis were of analytical grade and were obtained from the Food Science Laboratory of the Department of Food Science and Technology, Kwame Nkrumah University of Science and Technology.

2.3. Determination of Acrylamide Levels

2.3.1. Extraction and Clean-Up

In this study, a slight modification was made to the coffee sample mass, using 2 grams instead of the recommended 5 grams. The respective amounts of MgSO4 (4000 mg) and NaCl (1000 mg) were weighed along with the coffee samples and transferred into 50 mL centrifuge tubes. Five millilitres of hexane were added and vortexed (using a Wilten and Co. B.V. vortex mixer from Holland) for 1 minute to help separate the hydrophilic and hydrophobic components of the coffee. After this, 10 millilitres of acetonitrile and 10 millilitres of distilled water were added, and the mixture was vortexed for another minute before being centrifuged at 3000 rpm for 5 minutes. The resulting aqueous acetonitrile phase (1 mL) was then treated with 1500 mg of MgSO4 and 500 mg of NaCl, vortexed, and agitated at 4000 rpm for 5 minutes. Finally, 2 mL of supernatant was siphoned for HPLC analysis.

2.3.2. HPLC Analysis

A Cecil-Adept binary-pump HPLC equipped with a Dynamic Absorbance detector was utilized for the analysis. The column was an Agilent Eclipse Plus C18 column (4.6 mm × 150 mm, 3.5 µm), and the column oven temperature was maintained at 25 °C. The mobile phase was composed of acetonitrile and water (20:80 v/v) and adjusted to pH 3.5 with orthophosphoric acid. The flow rate of the mobile phase was set to 1 ml/min, and the absorbance was detected at 225 nm. For both the sample and the standards, 60 µl was injected into the HPLC using an autosampler. Acrylamide was detected and quantified by matching its peak to the standard retention time, and the area under the peak was automatically integrated by the Cecil-Adept PowerStream (CE4300, UK) and used to determine the concentration of acrylamide in the coffee samples.

2.3.3. Quality Control

The recovery of the method was determined by spiking 2 g of the analytical starch with different concentrations (20, 50, and 100 µg) of acrylamide standard. The mean recovery was 97%, indicating that the method had a limit of detection (LOD) and a limit of quantification (LOQ) of 0.03 µg/g and 0.1 µg/g, respectively. The calibration curve for this method was linear, with an r2 of 0.0998.

2.4. Proximate Determination of Commercially Sold Coffee

A proximate examination was performed on commercially sold coffee. According to Aguilar-Raymundo, Sánchez-Páez, Gutiérrez-Salomón, and Barajas-Ramírez (2019), AOAC International (2005) and AOAC (2008) measurements of moisture, protein, ash, crude fat, and carbohydrate were performed. To determine protein content, 1 g of each sample was weighed into a Kjeldahl flask along with 25 mL of concentrated sulfuric acid. A catalyst and the sample were digested on a heater for 30 min to produce a clear solution. The solution was cooled using Kjeldahl's method, and then 50 mL of a 40% NaOH solution was added to neutralize the acid. Following distillation, this was added to a 20 mL drop-mixed indicator and 4% boric acid solution in a 25 mL Erlenmeyer flask. Titrating the solution with 0.1 N H2SO4 gave the solution a light pink hue. The nitrogen content was calculated and multiplied by 6.25 to get the protein content. For fat determination, 2.0 g of the dried sample was placed in an extraction thimble and placed inside a Soxhlet apparatus. After being thoroughly cleaned and dried, Soxhlet flasks were filled with weighed petroleum ether (60 °C). After assembly, the extractors were refluxed for 6 h. After the ether had been allowed to evaporate in a rotary vaporizer, the flasks were removed, cooled, and weighed. The weight of the extracted fat was determined as

a portion of the sample weight. Moisture content was determined by weighing 5.0g of each sample into porcelain crucibles and drying them in an oven to a constant weight at 105 °C. The percentage of the samples' total weight was used to calculate the amount of moisture lost during drying. About 2 g of each sample was weighed, placed in porcelain crucibles, and burned in a muffle furnace for 4 hours at 550 °C to produce carbon-free ash. This was used to determine the amount of ash present. The weight of the ash was calculated as a proportion of the sample weight. Differences from 100% given by Equation 1 in moisture, protein, fat, and ash yielded carbohydrates. Equation 2 was used to compute the energy.

$$\% \text{ Carbohydrate} = 100 - (\text{moisture} + \text{protein} + \text{ash} + \text{fat}) \quad (1)$$

$$\text{Energy (Kcal/100g)} = (\text{Protein x } 9) + (\text{Fat x } 4) + (\text{Carbohydrate x } 4) \quad (2)$$

2.5. Extraction and Isolation of Fungi

2.5.1. Simple Dilution Plate Method

Threefold dilutions were prepared from 1 g of the sample in 9 mL of sterilized distilled water. One (1) mL of the final dilution (10^{-3}) was flooded onto three replicates of sterile Potato Dextrose Agar (PDA) medium amended with chloramphenicol antibiotic to suppress bacterial growth.

2.5.2. Identification of Fungi

The plates were thereafter incubated at room temperature (25–28 °C) for 7 days. All fungal growths were counted with a colony counter and identified with the aid of the Illustrated Genera of Imperfect Fungi Manual (Barnett & Hunter, 1972). Their frequencies of occurrence were consequently determined.

2.6. Mineral Determination of Commercially Sold Coffee

The mineral contents (P, K, Ca, Mg) in the samples were determined by AOAC (1990) with modification using atomic absorption spectroscopy. Approximately 0.25 g of each sample was weighed into Kjeldahl digestion tubes. Then, 7.5 mL of concentrated H_2SO_4 was added, followed by 2.5 mL of concentrated HNO_3. The samples were digested at 300 °C for 4 hours until the solution changed from dark to clear. Once cooled to room temperature, the clear solution was diluted with 50 mL of distilled water. The diluted solution was then warmed to vaporize and atomize the mineral components before their quantification.

2.7. Data Analysis

The means and standard deviations across all three replications were examined using Minitab 16. The differences among the test parameters were identified using one-way analysis of variance (ANOVA) with Fisher's least significant difference (LSD) test. The significance level for all statistical tests was set at 5%. The concentrations of acrylamide in the coffee samples, as determined by HPLC, were measured in ug/kg. An average body weight (BW) of 70 kg for an adult and an ingestion rate of 0.01 (10 g of powdered coffee in 1 cup/day) were used to calculate the estimated daily intake (EDI), as expressed in Equation 3.

The margin of exposure (MOE) was calculated using the benchmark dose lower limit (BMDL10) for food relative to the EDI value, as expressed in Equation 4. The BMDL10 values for carcinogenicity and neurotoxicity used were 0.17 and 0.43mg/kg (170 and 430 µg/kg), respectively.

$$EDI = \frac{C \; X \; IR}{BW} \quad (3)$$

$$MOE = \frac{BMDL_{10}}{EDI} \quad (4)$$

3. RESULTS AND DISCUSSION

3.1. Acrylamide Levels in Coffee

Acrylamide has been found in a wide range of foods. In Ghana, acrylamide levels in commercially sold coffee ranged from 137.62 µg/kg to 328.66 µg/kg. The WR had the highest record, while the BR had the lowest. There were statistically significant differences between the regions' means for acrylamide content. The roasting conditions, which may include factors such as roasting temperature, duration, and degree, may be linked to the notable variation in acrylamide levels among the samples in the current investigation. Numerous studies have shown that acrylamide production in the early stages of roasting increases dramatically to a peak before declining rapidly. Therefore, compared to dark-roasted coffee, medium-roasted coffee contains more acrylamide (Mojska & Gielecińska, 2013).

In some of the samples examined, variations in roasting level were visually identifiable. It is possible that variations in roasting levels contributed to the variation in acrylamide levels of the coffee powders under study, but this may not be the only explanation. Asparagine content is more than twice as high in defective coffee beans, specifically immature beans, as in mature beans. Therefore, using immature coffee beans to make roasted coffee powder could lead to higher acrylamide levels. The amount of acrylamide generated during roasting also varies depending on the type of coffee. Robusta coffee has higher levels of asparagine than Arabica coffee, which is a limiting factor in the production of acrylamide in coffee (Bagdonaite, Derler, & Murkovic, 2008; Lantz et al., 2006). Acrylamide levels in coffee powder are also affected by storage, declining over time (Andrzejewski, Roach, Gay, & Musser, 2004; Soares, Cunha, & Fernandes, 2006). The European Commission set the standard for acrylamide in roasted coffee powder at 400 µg/kg (European Commission, 2017). Acrylamide levels were below the European Commission's 400 µg/kg benchmark in Table 1 for all 30 samples of roasted coffee powder collected from the 10 regions of Ghana.

Table 1. Acrylamide levels in commercially sold coffee in Ghana.

Samples	Acrylamide content (ug/kg)
AS	258.95±0.55^{c}
BA	137.62±0.59 ^{j}
CR	204.20± 0.47^{f}
ER	156.49± 0.01^{i}
GR	224.39 ± 0.41^{e}
NR	170.53± 0.73 ^{g}
UER	165.69 ± 0.42 ^{h}
UWR	262.12± 0.09^{b}
VR	236.02 ± 0.09^{d}
WR	328.66 ± 0.27^{a}
EC benchmark level	400

Note: Means with the same letters (a, b, c, d, e, f, g, h, i, j) are not significantly different (P< 0.05). Values represent means ± SD from at least three replicates. AS -Ashanti Region, BA – Brong Ahafo Region, CR – Central Region, ER – Eastern Region, GR – Greater Accra Region, NR – Northern Region, UER – Upper East Region, UWR – Upper West Region, VR – Volta Region, WR – Western Region, EC- European Commission.

Table 2. Acrylamide levels in commercial coffee powder sold in other countries.

Countries	Maximum acrylamide content (ug/kg)	Minimum acrylamide content (µg/kg)	Authors
Europe	1188	79	Guenther, Anklam, Wenzl, and Stadler (2007)
Ethiopia	1139	135	Deribew and Woldegiorgis (2021)
Poland	776.1	17.7	Surma, Sadowska-Rociek, Cieślik, and Sznajder-Katarzyńska (2017)
Latvia	503	166	Pugajeva, Jaunbergs, and Bartkevics (2015)

The amount of acrylamide in roasted coffee has been studied by researchers from a wide range of nations, as shown in Table 2. In Europe, 291 roasted coffee samples were examined, with acrylamide concentrations ranging from 79 µg/kg to 1188 µg/kg (Guenther et al., 2007). Using 30 samples of Ethiopian Arabica coffee, Deribew and Woldegiorgis (2021) found that the minimum acrylamide level was 135 µg/kg and the maximum was 1139 µg/kg. In Poland, Surma et al. (2017) analysed 17 roasted coffee samples and found acrylamide levels ranging from 17.7 µg/kg to 776.1 µg/kg. A total of 22 commercial coffee samples from Latvia had acrylamide levels ranging from 166 to 503 µg/kg (Pugajeva et al., 2015). The minimum acrylamide levels reported by other researchers were lower than the recorded levels in Ghana, but the maximum values were higher. The European Commission's standard for acrylamide in roasted coffee powder is 400 µg/kg, which is considerably higher than the acrylamide levels found in commercial coffee powder in Ghana. The reduced acrylamide levels may be due to the roasting conditions of Robusta coffee (Mojska & Gielecińska, 2013) and extended storage (Andrzejewski et al., 2004; Soares et al., 2006).

Table 3. Estimated Daily Intake (EDI) and Margin of Exposure (MOE) of Acrylamide per day.

Samples	Acrylamide content (ug/kg)	EDI (ug/kg bw/day)	MOE ($BMDL_{10}$=170 µg/kg)	MOE ($BMDL_{10}$=430µg/kg)
AS	258.95±0.55^{c}	0.036	4722	11944
BA	137.62±0.59 ^{j}	0.019	8947	22631
CR	204.20± 0.47^{f}	0.029	5862	14827
ER	156.49± 0.01^{i}	0.022	7727	19545
GR	224.39 ± 0.41^{e}	0.032	5312	13434
NR	170.53± 0.73 ^{g}	0.024	7083	17916
UER	165.69 ± 0.42 ^{h}	0.023	7391	18695
UWR	262.12± 0.09^{b}	0.037	4594	15925
VR	236.02 ± 0.09^{d}	0.033	5151	13030
WR	328.66 ± 0.27^{a}	0.046	3695	9347

Note: Means with the same letters (a, b, c, d, e, f, g, h, i, j) are not significantly different (P< 0.05). Values represent means ± SD from at least three replicates. $BMDL_{10}$=170 µg/kg) - carcinogenic, MOE ($BMDL_{10}$=430µg/kg) – neurogenicity.AS -Ashanti Region, BA – Brong Ahafo Region, CR – Central Region, ER – Eastern Region, GR – Greater Accra Region, NR – Northern Region, UER – Upper East Region, UWR – Upper West Region, VR – Volta Region, WR – Western Region.

Table 3 shows the calculated Estimated Daily Intake (EDI) and Margin of Exposure (MOE) of acrylamide per day for an average weight of 70 kg. The Margin of Exposure approach provides a way to assess the level of health concern associated with the presence of a substance in food. However, it does not quantify the associated risk. Utilizing the MOE can help minimize exposure to such substances. The MOE values for neurotoxicity and carcinogenicity ranged from 9347 to 22631 and 3695 to 8947, respectively. Neurotoxicity is considered a non-neoplastic outcome; therefore, MOE values above 100 are accepted as a safety margin for no health concern. On the other hand, when carcinogenic or genotoxic effects are being studied, MOE values below 10,000 are considered of concern (Jaikel-Víquez et al., 2026). All the above have lower values than 10,000 and, therefore, are likely to pose health effects.

3.2. Mycological Analysis

Table 4 presents the total fungal count in different coffee powders in the regions. Two contaminating fungi, Aspergillus niger and Aspergillus flavus, were isolated and identified in some of the coffee samples bought from the market. Aspergillus flavus was isolated and identified in some of the coffee samples from the WR. Both Aspergillus niger and Aspergillus flavus were isolated and identified in some of the coffee samples from the NR. However, no growth was observed in other regions.

Table 4. Total fungal count in different coffee powders in the regions.

Region of coffee	Fungi isolated	Number isolated	Percentage of contaminated coffee (%)
AS	Negative	0	0
BA	Negative	0	0
CR	Negative	0	0
ER	Negative	0	0
GR	Negative	0	0
NR	A. niger and A. flavus	4	80
UER	Negative	0	0
UWR	Negative	0	0
VR	Negative	0	0
WR	A. flavus	1	20
Total		5	100

Note: AS -Ashanti Region, BA – Brong Ahafo Region, CR – Central Region, ER – Eastern Region, GR – Greater Accra Region, NR – Northern Region, UER – Upper East Region, UWR – Upper West Region, VR – Volta Region, WR – Western Region.

Table 5. Number of fungi isolated from the commercially sold coffee powder.

Fungi	Number isolated
A. niger	2
A. flavus	3
Total	5

Mycological analysis revealed that 20% of the coffee in the WR had A. flavus, 80% of the coffee powder in the NR had both A. Niger and A. flavus, and 0% in the other regions. Coffee that was roasted in the NR had the highest level of contamination (80%). At least five fungal isolates from various species but the same genus were found, and the majority of these are food-borne fungi. The fungi isolated from the different products of commercially available powders may be caused by the nature of sun-drying coffee beans, which is often done in open spaces (Vega, Posada, Aime, Peterson, & Rehner, 2008). Mold spores were likely eliminated during roasting, but some spores are resistant and can lie dormant on a product for a very long period (Tournas & Katsoudas, 2008). Airborne pathogens in the processing area may result from improper handling of materials after processing, particularly when hygiene and strict good manufacturing practices are not maintained. In this study, we identified some of the most common fungi in the environment. They can grow in a wide range of substrates and environmental conditions, but they are difficult to eradicate. According to Silva, Batista, and Schwan (2008), Aspergillus is a naturally occurring coffee contaminant that extends from the field to the storage facility. The contamination of commercial coffee powder by these fungi may also be caused by unsanitary conditions, poor heat treatment during roasting or after roasting, and contamination during packaging, storage, or transportation. Toxic mycotoxins that are harmful to both humans and animals are produced by Aspergillus, one of the environmental molds whose isolation is most concerning. Aflatoxin and ochratoxin A are harmful metabolites produced by Aspergillus (Rahim, Ayob, & Ramli, 2011). The number of fungi isolated from the commercial coffee powder is shown in Table 5.

3.3. Proximate Composition of Commercially Sold Coffee

The proximate composition of the coffee analysed showed minimal statistically significant differences across the ten regions, as shown in Table 6. The commercially available powder had a moisture content ranging from 4.84% to 6.58%, with no significant differences among the samples ($p > 0.05$). All of the samples had a higher moisture content than the light (0.9%), medium (0.9%), and dark roast (1.0%) coffee values reported by Vasconcelos, Franca, Glória, and Mendonça (2007) and the 3.7% stated in the literature (Gyedu-Akoto et al., 2019). This was less than the DFCD (2009) value of 14.6%. The food's moisture content is used to measure its water activity and assess its susceptibility and microbiological stability (Adetunji et al., 2021). Because they are more susceptible to deterioration and microbial attack, high-moisture food products have a shorter shelf life (Hassan & Umar, 2004).

Table 6. Proximate Analysis of commercially sold coffee.

Samples	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	CHO (%)	CME (kCal/100g)
AS	5.96±0.63^{a}	13.80±2.26^{ab}	9.42±1.39^{b}	7.50±2.12^{a}	52.59±1.15^{a}	303.54
BA	6.15±0.14^{a}	14.30±2.55^{ab}	11.95±0.48^{ab}	7.20±0.99^{a}	43.59±1.53^{ab}	286.96
CR	5.75±0.18^{a}	14.85±0.49^{ab}	11.51±1.17^{ab}	7.80±0.14^{a}	41.71±0.54^{ab}	295.08
ER	5.91±0.89^{a}	15.00±0.84^{a}	12.76±0.59^{a}	8.15±2.33a	41.42±2.23^{b}	290.07
GR	5.43±0.36^{a}	14.65±1.63^{ab}	11.59±0.20^{ab}	6.70±1.41a	45.74±3.05^{ab}	289.62
NR	4.84±0.40^{a}	10.55±2.62^{b}	13.79±0.67^{a}	6.10±1.27a	49.84±2.17^{a}	309.42
UER	5.12±0.10^{a}	12.20±2.83^{ab}	12.87±0.62^{a}	5.85±0.49a	47.63±4.63^{ab}	294.65
UWR	6.52±0.19^{a}	12.30±1.56^{ab}	11.17±0.30^{ab}	7.65±1.20a	48.30±2.07^{a}	306.73
VR	5.47±0.50^{a}	14.15±1.77^{ab}	12.92±0.55^{a}	6.90±2.26a	48.91±4.42^{a}	309.42
WR	6.58±1.96^{a}	10.45±0.070^{b}	12.94±0.651^{a}	7.50±1.84a	46.31±3.51^{ab}	304.50
DFCD (2009)	14.6	4.0	15.4	5.5	60	322

Note: Means with the same letters (a, b) are not significantly different ($P< 0.05$). Values represent means ± SD from at least three replicates. AS -Ashanti Region, BA – Brong Ahafo Region, CR – Central Region, ER – Eastern Region, GR – Greater Accra Region, NR – Northern Region, UER – Upper East Region, UWR – Upper West Region, VR – Volta Region, WR – Western Region, CHO – Carbohydrate, CME - Calculated Metabolic Energy, DFCD – Danish Food Composition Databank.

According to Marshall (2010), the ash content of food represents its overall mineral composition. The ash content varied slightly, with NR (10.55%) and ER (15.00%) differing significantly. This could be because of variations in mineral accumulation. In the range of 4.4% to 4.6% for Vasconcelos et al. (2007) and 4.4% for Gyedu-Akoto et al. (2019), the recorded ash levels were higher than the values found in the literature. Additionally, it was greater than the 4.0% noted by DFCD (2009). In Ghana, coffee is grown in six of the ten regions: Ashanti, Brong Ahafo, Eastern, Central, Western, and Volta Region (Wongnaa et al., 2021). Coffee powder is processed commercially and shipped to nearby areas where coffee is not grown. Variations in ash content in coffee-growing regions may be explained by variations in coffee plantations and their locations (Oliveira et al., 2013). A significant amount of impurities in the roasted coffee powder samples may also be the cause of the higher ash content (Müller, Huebner, & de Souza, 2013). Husks, sticks, leaves, defective coffee, foreign objects, and other unidentified adulterants are among the impurities.

Carbohydrate and protein content ranged from 41.42 to 52.59% and 9.42 to 13.79%, respectively, in the samples, which were all lower than those reported in the literature (DFCD, 2009; Gyedu-Akoto et al., 2019; Vasconcelos et al., 2007). Proteins interact with carbohydrates during roasting to produce flavour and aroma in Maillard reactions, which may cause the reduction of these compounds (Mazzafera, Schimpl, & Kiyota, 2019). It has also been discovered that the roasting temperature and duration affect the coffee beans' color, aroma, and chemical composition (Buffo & Cardelli-Freire, 2004). Amino acids, peptides, and proteins are essential for coffee cup quality. Notwithstanding these minor variations, the general similarities in proximate values indicate that the commercially available coffee samples have a comparatively consistent nutritional profile. This might be the result of regionally similar bean varieties, roasting techniques, or blending practices.

3.4. Mineral Composition of Commercially Sold Coffee

The mineral composition of the coffee samples revealed variation in phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) content, although most differences were not statistically significant at $p < 0.05$. Table 7 presents the findings from the mineral analysis of commercially sold coffee. The phosphorus (P) content ranged from 0.35% to 0.43%. The Western Region's sample had the highest phosphorus content, while the Ashanti Region's sample had the lowest. With a potassium (K) content of 2.03%, commercially sold coffee from Greater Accra had the highest, while the Upper West Region had the lowest at 1.46%.

The recorded values for potassium and phosphorus did not differ significantly. Magnesium (Mg) and calcium (Ca) ranged from 0.18% to 0.26% and 0.46% to 0.63%, respectively. This bolsters assertions that the mineral content of coffee beans is influenced by a variety of factors, such as post-harvest management, agronomic practices, geography (water, soil, flora, and climate), and other stressors (Gyedu-Akoto et al., 2019). It has been said that the presence of

major and minor mineral elements in coffee and its derivatives is essential because they exhibit a specific nutritional and dietary value, especially given the incredibly high global consumption of coffee (Pohl, Stelmach, Welna, & Szymczycha-Madeja, 2013). Coffee mineral analysis is therefore crucial for determining daily intakes of various minerals and trace elements.

Table 7. Mineral composition (%) of commercially sold coffee.

Samples	P/%	K/%	Ca/%	Mg/%
AS	0.37 ± 0.01^{a}	1.58 ± 0.07^{a}	0.63 ± 0.01^{a}	0.26 ± 0.00^{a}
BA	0.39 ± 0.07^{a}	1.83 ± 0.07^{a}	0.53 ± 0.06^{bc}	0.20 ± 0.044^{bc}
CR	0.35 ± 0.04^{a}	1.98 ± 0.00^{a}	0.51 ± 0.03^{bc}	0.22 ± 0.05^{abc}
ER	0.42 ± 0.00^{a}	1.83 ± 0.24^{a}	0.51 ± 0.01^{bc}	0.22 ± 0.02^{abc}
GR	0.38 ± 0.04^{a}	2.03 ± 0.07^{a}	0.63 ± 0.02^{a}	0.22 ± 0.01^{abc}
NR	0.39 ± 0.02^{a}	1.51 ± 0.67^{a}	0.49 ± 0.01^{bc}	0.19 ± 0.02^{bc}
UER	0.38 ± 0.07^{a}	2.05 ± 0.20^{a}	0.55 ± 0.03^{ab}	0.20 ± 0.01^{bc}
UWR	0.36 ± 0.06^{a}	1.46 ± 0.60^{a}	0.51 ± 0.02^{bc}	0.21 ± 0.00^{abc}
VR	0.40 ± 0.02^{a}	1.99 ± 0.18^{a}	0.54 ± 0.03^{b}	0.25 ± 0.01^{ab}
WR	0.43 ± 0.00^{a}	1.59 ± 0.08^{a}	0.46 ± 0.05^{c}	0.18 ± 0.03^{c}

Note: Means with the same letters (a, b, c) are not significantly different ($P< 0.05$). Values represent means ± SD from at least three replicates. AS -Ashanti Region, BA – Brong Ahafo Region, CR – Central Region, ER – Eastern Region, GR – Greater Accra Region, NR – Northern Region, UER – Upper East Region, UWR – Upper West Region, VR – Volta Region, WR – Western Region.

4. CONCLUSION

The results suggest a potential or considerable risk of acrylamide exposure from consuming coffee. Thus, no neurotoxicity risk was identified; however, a potential carcinogenic risk was observed based on the MOE results. The proximate analysis revealed that commercialized coffee powder had a high ash content due to variations in coffee plantations and their locations, as well as the presence of considerable impurities in the roasted coffee powder samples. Two distinct fungal species were also isolated from various commercial coffee powders during the mycological analysis. The discovery of Aspergillus niger and Aspergillus flavus suggests unsanitary conditions, improper handling, poor packaging, storage, or transportation. P, K, Ca, and Mg were all found in considerable amounts in the coffee samples. To ensure safety, Ghana should implement national monitoring initiatives and adopt recommended thresholds for acrylamide levels in roasted coffee. Regulators must enforce good manufacturing practices, promote regular testing, and encourage the use of techniques to reduce acrylamide throughout the coffee processing chain. In this current study, samples were drawn from only three major markets in each of Ghana's ten regions. Future research should include smaller markets within these regions to capture a more comprehensive view of regional variations in samples.

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