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Tania Marín-Garza [1], Tania García-Herrera [1], Miriam Cristina Pastelín-Solano [1], Javier Emanuel Bulbarela-Marini [1], Jaime Jiménez-Guzmán [1], Alejandra Velásco-Pérez [1], María Elizabeth Márquez-López [1], Guadalupe Vivar-Vera [1] and Odon Castañeda-Castro [1,*]

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Abstract: The main commercial variety of coffee is the Coffea arabica specie, however, it is very susceptible to damage caused by nematodes, for this reason scions of the C. arabica specie are used on robusta (*Coffea canephora*) rootstocks to improve tolerance to these microorganisms, because they modify the organoleptic, nutraceutical and nutritional characteristics. The objective of this work was to assess the effect of five roasting degrees on commercial beans (light, medium light, medium, medium, medium dark and dark) in two varieties of Coffea arabica species (Colombia and Costa Rica) and their respective scions on *C. canephora* of the Romex variety. The scion of the Colombia variety with the medium dark roast had the highest concentration of caffeine, while the coffee beans of the Costa Rica variety with the light roast grade had the highest concentration of chlorogenic acid (5-CQA), while the highest acrylamide content was found in the scion of the Colombia variety with the medium light roast beans and nutritional content differs considerably between varieties, however, there is similarity between roasting degrees. The degree of roasting, variety and scion of coffee influences the organoleptic, nutraceutical and nutritional content of the coffee infusion.

Keywords: coffea arabica; roasting degrees; scion; nutraceuticals; acrylamide; caffeine; minerals

1. Introduction

Caffeine-containing beverages, such as coffee, are consumed worldwide daily to improve cognitive functions. Approximately 3 billion cups of coffee are consumed every day, translated into an economic value of approximately US $ 200 billion per year (Mahmus *et al.*, 2020; Samper *et al.*, 2017).

Coffee crops are very important globally given that they have a high economic impact in developing countries (Villalta-Villalobos & Gatica-Arias, 2019) and therefore constitute a cornerstone for the tropical countries' economies in Latin America (Rahn *et al.*, 2018), representing a multi-billion dollar sector that encompasses a long value chain, from the farmer to the consumer, being the second most consumed beverage worldwide (ICO, 2023).

It is estimated that, throughout the 2022 period, the world's coffee production was 170.5 billion of 60-kilogram bags, implying an increase of about 5.5 million regarding the global consumption of this beverage reported on the previous season (Statista, 2023).

In addition to the important economic aspects, coffee has medical applications with health benefits. Several studies have shown that coffee consumption for extended periods of time, influences against the development of type two myelitis diabetes (Higdon & Frei, 2006). Some chemical compounds that are characteristic of coffee include caffeine and chlorogenic acids, among others

(Amr *et al*., 2021). Caffeine-rich coffee was also found to show an apoptotic effect on cancer cells and function as a chemopreventive agent (Jabir *et al*., 2018).

Coffee flavor is a quality determination, it is considered the main attribute of sensory quality, whereas some chemical substances that are not volatile, are present in green coffee which are subject to drastic changes during the roasting process being responsible for the distinctive flavor serving as precursors, i.e. free sugars, carbohydrates, chlorogenic acid, trigonelline, proteins and lipids (Ribeiro *et al*., 2009).

It is also very important to monitor the identification of contaminants that are generated in the processing of coffee, specifically if there is the presence of some chemical substances posing a health risk (Aguas *et al*., 2006), such as the acrylamide formation, which is an unsaturated amide formed when heating foods to 120°C and that are rich in carbohydrates through the Maillard reaction, which is the reaction of the amino acid asparagine mainly with glucose and fructose that are reduced sugars (Cagliero *et al*., 2016; Fonseca-García *et al*., 2014). This is the case with coffee, where acrylamide is naturally produced during the bean roasting process (Morales and Mesias, 2015).

Roasted coffee exerts an antioxidant action since it is rich in melanoidins that are generated during the roasting process (Esquivel & Jiménez, 2012). In addition to the antioxidant activity of chlorogenic acids, they have been associated with the prevention of cancer, diabetes (Kamiyama *et al*., 2015), they regulate blood pressure and therefore prevent hypertension (Loader *et al*., 2017).

Nutrients perform essential functions in plant metabolism as activators of enzymatic reactions, constituents of organic structures, and osmoregulation (Bustos *et al*., 2008). These vary due to causes such as plant growth and their availability in the soil, resulting in an increased concentration or nutrient dilution in plant tissues (Sadeghian & Salamanca, 2015).

According to ICO (2023), out of the diverse coffee varieties that exist, the two most important are Coffea arabica which is Arabica coffee, this variety accounts for more than 60% of world production and Coffea canephora better known as Robusta coffee. Other varieties are cultivated on a much smaller scale, and they are the Liberica coffee (Coffea liberica) and the Excelsa coffee (Coffea dewevrei).

Worldwide, Mexico ranks eleventh place in coffee production and more than three million people depend on coffee production. Total coffee production is grown in 14 Mexican states (SIACON-SAGARPA, 2023; SADER, 2023). Approximately 96% of the coffee produced in Mexico is Arabica, while 4% is Robusta. However, Arabica varieties are more susceptible to coffee rust, a pest that has affected the coffee sector in the country since 2012, which has caused a reduction in production of more than 50% between 2012 and 2016 (CEDRESSA, 2019) in addition to nematodes, which are capable of reducing yields from 15% to 60% in Coffea arabica species (ICO, 2023; Cepeda-Siller *et al*., 2020; ANACAFÉ, 2017).

For this reason, in Mexico, the cultivation of Arabica varieties with greater rust resistance has been started, such as the coffee variety Colombia (Coffea arabica) presents resistance to coffee rust and has as its progenitors the variety Caturra, of the species Coffea arabica and the hybrid Timor (Federacióna Nacional de Cafeteros, 1997) as well as the variety of coffee Costa Rica, which is the result of the hybridization of Timor with Caturra, as main character it presents resistance to coffee rust, has high yields, adapts to warm zones and acid soils (https: //varieties. worldcoffeeresearch.org/en).

For the control of nematodes, grafts of arabica varieties (susceptible) have been used on less susceptible robusta coffee rootstocks, which has resulted in a successful strategy in the control of this pest (Sánchez-González & Muñoz, 2022).

This study analyzed the content of acrylamide, caffeine, chlorogenic acids, and minerals in coffee beans from Colombia, Colombia Injerto, Costa Rica, and Costa Rica Injerto at five different roasting levels in order to determine whether quality variables differ between the varieties and grafts.

2. Materials and Methods

Plant Material and Experimental Conditions: The study was conducted using coffee beans from plants of the varieties Colombia, Colombia Graft, Costa Rica, and Costa Rica Graft, planted in the congregation La Laja, municipality of Tlaltetela, Veracruz, Mexico (19° 17' 10.8" N, 96° 56' 51.9" W and altitude of 1250 m). Plants were cultivated under manageable shading, with approximately 70% of solar radiation, using the traditional selective plantation method (sowing, fertilizing, and pruning), with 2000 to 2500 shrubs ha^{-1} in cambisol type soils.

Roast Levels: The coffee beans were roasted (Table 1) in an MT-1 fluid bed roaster (Trejo; Zacatlán, Puebla, Mexico), with a capacity of 5 to 7 kg, following the protocol established by the Specialty Coffee Association of America (SCAA, 2020). The roasting levels were light, medium light, medium, medium dark and dark. The measured variables were initial humidity (%), initial and final temperatures (°C), initial weight (g), first and second cracks (roasting curve), and temperature increase (5°C every 30 seconds).

Table 1. Conditions of coffee beans with five roast levels.

	Roast level				
Conditions	**Light**	**Medium-light**	**Medium**	**Dark-medium**	**Dark**
Charge temperature (°C)	150	150	160	190	220
Final temperature (°C)	174.81	180-190	190-210	200-220	230-240
Initial weight (g)	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00
Agtron Color (Å)	75-70	70-65	65-58	58-45	45-35
Initial Humidity (%)	12	12	12	12	12

5-CQA and caffeine concentrations: The analysis of Chlorogenic acid (5-CQA) was performed on an HPLC system (Dionex, ICS 3000; San Jose, CA, USA) equipped with a UV/VIS detector at a wavelength of 325 nm with an isocratic mobile phase composed of 75 % HPLC grade water and 25% H3PO4-acidified methanol at a flow rate of 1.2 mL min^{-1}, using an Acclaim™ 120 C18 5 mm 4.6 × 150 mm reversed phase column (ThermoFisher®, Sunnyvale, CA, USA) and a ZORBAX C18 5 µm, 10 × 2 mm column (Agilent technologies, Santa Clara, CA, USA), with a variation of the DIN 10767 method (German Institute for Standardization, 1992). Caffeine concentration was determined by a variation of NMX-F-182-SCFI-2011 (Secretaría de Economía, 2011). Results were expressed as a percentage of dry matter weight (% PMS).

Caffeine was extracted using a thermoreactor (Hach, DRB200; Loveland, CO, U.S.A) at 135 °C for 5 min. Quantification was performed in a Dionex ICS 3000 HPLC equipped with a UV/vis detector at a wavelength of 272 nm with an isocratic mobile phase composed of 75 % HPLC-grade water and 25 % H3PO4-acidified methanol applying a flow rate of 1. 5 mL min^{-1} on a 120 C18 5 mm 4.6 × 150 mm column (ThermoFisher® model Acclaim™, Sunnyvale, CA, USA) with H3PO4; samples were made in triplicate. Results were expressed as a percentage of dry matter weight (% PMS).

Calibration curves for chlorogenic acids and caffeine, were performed with eight concentration points (0, 0.1, 0.08, 0.065, 0.05, 0.04, 0.02, and 0.005 %) in duplicate to check the linearity of the methods. For the calibration curves, chlorogenic acid, 95% CAS 327-97-9 (Sigma-Aldrich; Saint Louis, MO, USA) and ≥ 95% CAS 58-08-2 C1778 (Sigma-Aldrich Saint Louis, MO, USA) and caffeine ≥ 99 % CAS 58-08-2 C1778 (Sigma-Aldrich Saint) were used respectively.

Mineral analysis: The concentration of nutrients P, K, Ca, Mg, Fe, Cu, Zn, Mn, and B were determined with coupled plasma induction atomic emission spectrophotometry (Agilent ICP-AES, model 725-ES; Victoria, Australia), and the N content was measured using the micro-Kjeldahl method. Results were expressed in g kg^{-1} for macronutrients and mg kg^{-1} for micronutrients.

Experimental design: A completely randomized design with the factorial arrangement was used, where the study factors were genotype (four levels: Coffea arabica L. var. Colombia and Costa Rica as well as their respective grafts, which were grafted on Coffea canephora P. var. Romex), resulting in 20 treatments. For each treatment, four replicates were performed.

Statistical analysis: With the resulting data, it was performed an ANDEVA with Tukey's comparison test (p£0.05) with the SAS statistical package (SAS Institute, 2011).

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3. Results

In a study analyzing the concentration of caffeine in the beans of four different varieties of coffee, it was found that there was a significant statistical difference between treatments. The variety Colombia graft registered the highest concentrations of caffeine, surpassing the other varieties in descending order, the Costa Rica, Costa Rica graft, and Colombia, which presented the lowest contents of caffeine (Figure 1).

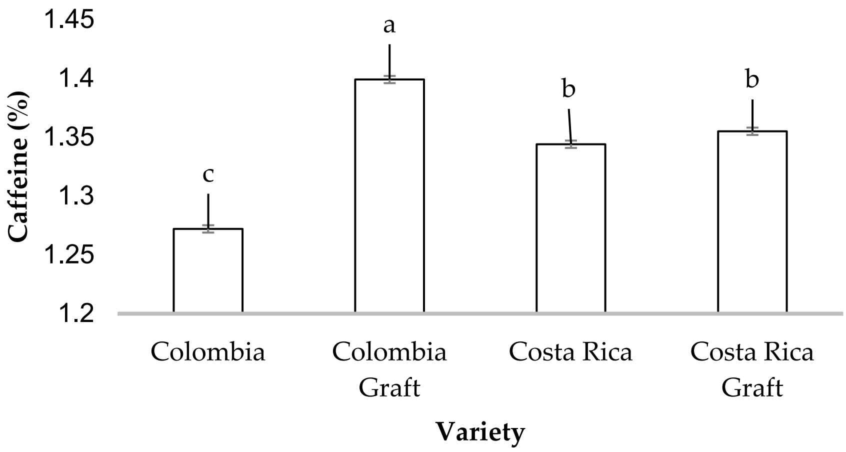

Figure 1. Caffeine concentration in beans of four coffee varieties.

Means ± SE with different letters in each bar indicate significant statistical differences ($p \leq 0.05$).

When analyzing the caffeine content in coffee beans with different roasting levels, the highest caffeine content in coffee beans was positively correlated with the highest roasting level, decreasing until the dark roast (Figure 2).

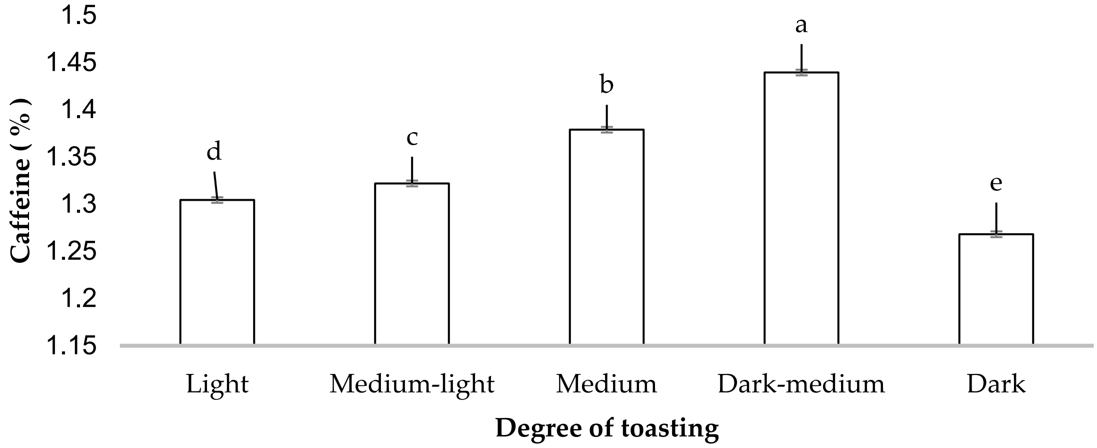

Figure 2. Caffeine concentration in coffee beans with five different levels of roasting. Means ± SE with different letters in each bar indicate significant statistical differences ($p \leq 0.05$).

The Costa Rica variety of coffee beans had the highest chlorogenic acid content, exceeding Colombia, Colombia Graft, and Costa Rica varieties, which decreased their chlorogenic acid contents according to the order in which they were harvested (Figure 3).

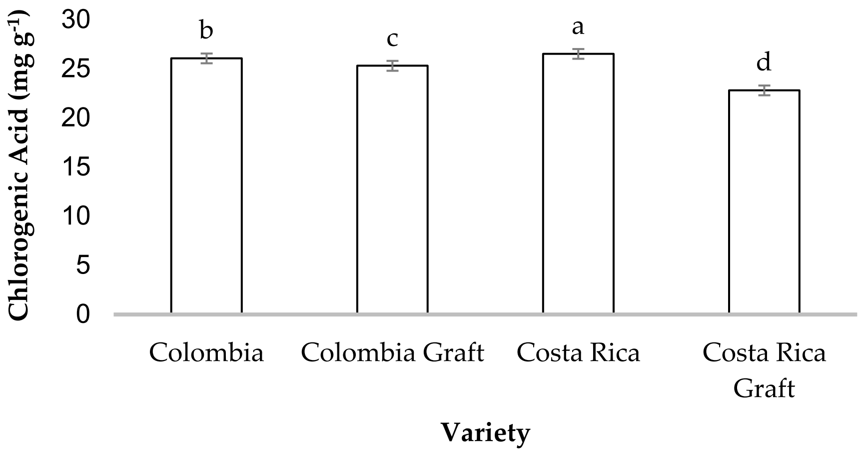

Figure 3. Chlorogenic acid (5-CQA) concentration in beans of four coffee varieties. Means ± SE with different letters in each bar indicate significant statistical differences ($p \leq 0.05$).

The highest level of chlorogenic acid was found in lightly roasted coffee beans, and the level of chlorogenic acid gradually declined with increased roast levels, ranging from light roasts to medium roasts, medium dark roasts, and dark roasts (Figure 4).

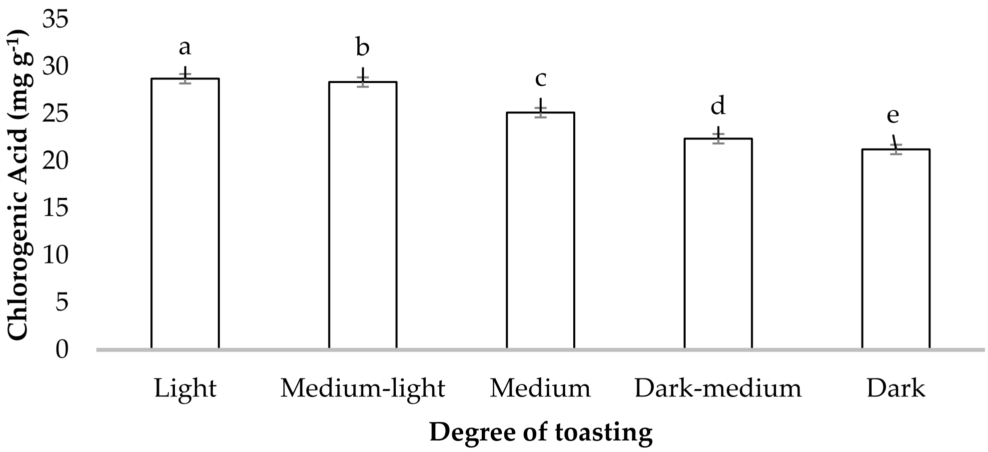

Figure 4. Chlorogenic acid concentration in coffee beans at five different roasting levels. Means ± SE with different letters in each bar indicate significant statistical differences ($p \leq 0.05$).

The contents of acrylamide in coffee beans, had their highest concentrations in the variety Colombia Graft and these contents gradually decreased from the variety Colombia Graft to Colombia, Costa Rica Graft, and Costa Rica, this variety had concentration levels 50% below than the variety Colombia Graft (Figure 5).

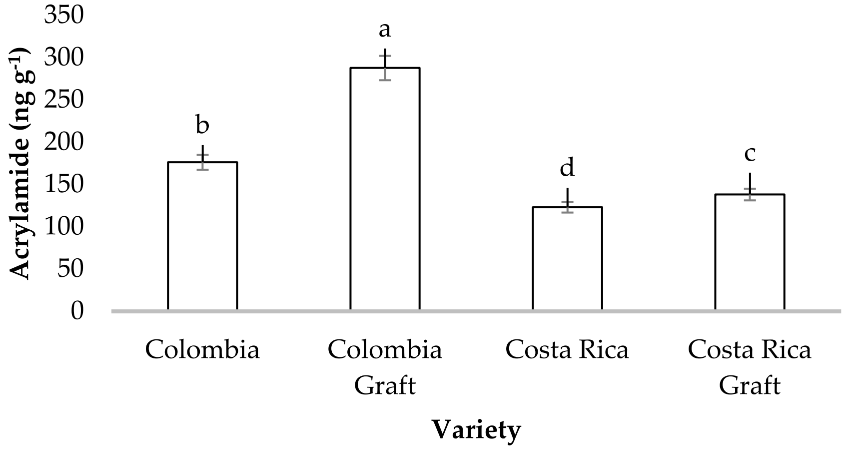

Figure 5. Acrylamide concentration in beans of four coffee varieties. Means ± SE with different letters in each bar indicate significant statistical differences ($p \leq 0.05$).

The medium light roast level in coffee beans presented the highest acrylamide contents, while the lowest contents were found in coffee beans with the dark roast level (Figure 6).

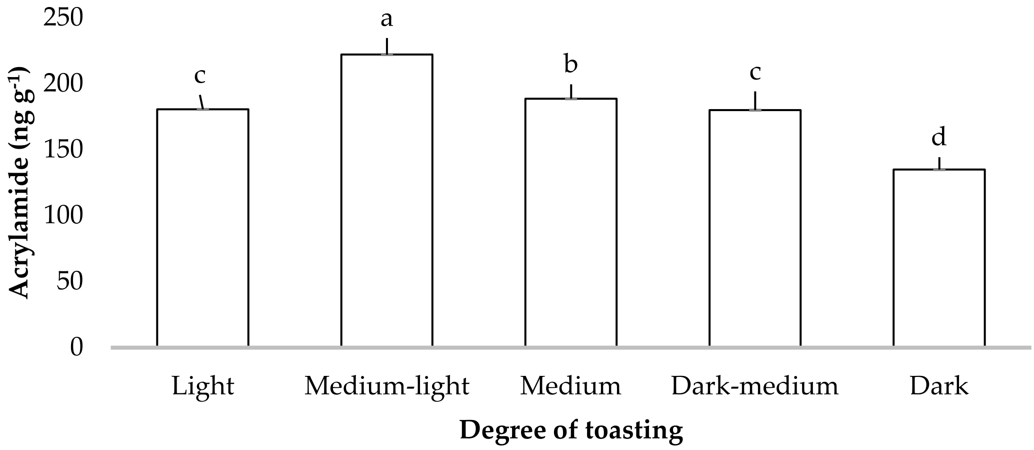

Figure 6. Acrylamide content in coffee beans with five different degrees of roasting. Means ± SE with different letters in each bar indicate significant statistical differences ($p \leq 0.05$).

Upon analysis on the effect of the interaction factor variety by roasting level, there were no significant statistical differences in nitrogen contents for the coffee varieties Colombia, Colombia Graft, and Costa Rica in the five roasting levels, however, the variety Costa Rica Graft deviates from this trend by presenting the highest contents of nitrogen in coffee beans with dark roast level and the lowest with medium roast. Regarding the content of phosphorus, potassium, and magnesium there were statistical differences between treatments in the four varieties and with the five roast levels, as for calcium the highest contents of this nutrient (0.010±0.000 a). 010±0.000 a) were found in coffee beans of the Colombia variety with medium dark roast level and the lowest contents (0.006±0.000) were found in the coffee varieties Colombia Graft and Costa Rica with medium and dark roast levels, respectively (Table 2).

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Table 2. Concentración de macronutrimentos por la interacción de variedad y grados de tostado en gtranos de café.

Variedad	Degree of toasting	N	P	K	Ca	Mg
		g kg-1				
Colombia	Light	18.2875±1.646 bcde	0.015±0.000 abcd	0.876±0.041 a	0.008±0.000 bc	0.042±0.133 a
	Medium-light	20.475±1.646 abcd	0.015±0.000 abcd	0.937±0.041 a	0.008±0.000 bcd	0.036±0.133 a
	Medium	22.225±1.646 abcd	0.016±0.000 abcd	0.945±0.041 a	0.007±0.000 bcde	0.043±0.133 a
	Dark-medium	22.400±1.646 abcd	0.015±0.000 bcd	0.941±0.041 a	0.010±0.000 a	0.071±0.133 a
	Dark	17.675±1.646 cde	0.015±0.000 abcd	0.970±0.041 a	0.007±0.000 cde	0.471±0.133 a
Colombia Graft	Light	18.200±1.646 bcde	0.015±0.000 abcd	1.060±0.041 a	0.007±0.000 cde	0.044±0.133 a
	Medium-light	21.700±1.646 abcd	0.015±0.000 bcd	0.877±0.041 a	0.007±0.000 cde	0.040±0.133 a
	Medium	24.150±1.646 abc	0.016±0.000 abcd	0.929±0.041 a	0.006±0.000 de	0.044±0.133 a
	Dark-medium	21.350±1.646 abcd	0.015±0.000 abcd	0.982±0.041 a	0.007±0.000 bcde	0.062±0.133 a
	Dark	25.725±1.646 abc	0.016±0.000 abcd	1.041±0.041 a	0.006±0.000 de	0.038±0.133 a
Costa Rica	Light	21.175±1.646 abcd	0.015±0.000 abcd	0.985±0.041 a	0.007±0.000 cde	0.044±0.133 a
	Medium-light	20.388±1.646 abcd	0.015±0.000 bcd	0.942±0.041 a	0.009±0.000 ab	0.092±0.133 a
	Medium	24.325±1.646 abc	0.014±0.000 d	0.881±0.041 a	0.006±0.000 e	0.036±0.133 a
	Dark-medium	26.075±1.646ab	0.015±0.000 bcd	0.970±0.041 a	0.007±0.000 cde	0.085±0.133 a
	Dark	18.375±1.646 abcd	0.015±0.000 dc	0.933±0.041 a	0.006±0.000 de	0.048±0.133 a
Costa Rica Graft	Light	19.863±1.646 abcd	0.017±0.000 abc	0.897±0.041 a	0.007±0.000 cde	0.064±0.133 a
	Medium-light	15.750±1.646 de	0.018±0.000 abc	1.008±0.041 a	0.007±0.000 bcde	0.102±0.133 a
	Medium	10.763±1.646 e	0.018±0.000 abc	0.968±0.041 a	0.008±0.000 bcde	0.060±0.133 a
	Dark-medium	26.513±1.646 a	0.018±0.000 ab	0.995±0.041 a	0.007±0.000 cde	0.043±0.133 a
	Dark	23.713±1.646 abcd	0.016±0.000 abcd	1.014±0.041 a	0.007±0.000 cde	0.048±0.133 a

Means ± SE with different letters in each column indicate significant statistical differences ($p \leq 0.05$).

Upon analysis of the micronutrient content, by the effect of the interaction factor coffee variety by roast level, there were significant statistical differences between treatments, and the highest concentrations of Fe (17676.00±902.98a) were found in the Colombia variety with a light roast level, Cu (1510. 66±37.90 a) Costa Rica with Medium roast, Zn (34.07±0.93 a) in the Colombia variety with medium roast and Mn (34.07±0.93 a) in the Colombia variety with Dark roast, the case of Bo is excluded from this trend, since there were no significant statistical differences between treatments (Table 3).

Table 3. Concentración de micronutrimentos por la nteracción de variedad y grados de tostado en granos de café.

Variedad	Degree of toasting	Fe	Cu	Zn	Mn	B
		mg kg-1				
Colombia	Light	17676.00±902.98 a	1214.45±37.90 c	28.07±0.93 bcde	1333.09±36.84 abc	2.14±1.20 a
	Medium-light	14830.00±902.98 abc	1245.56±37.90 bc	28.908±0.93 bcd	1277.63±36.84 abc	1.41±1.20 a
	Medium	15753.00±902.98 abc	1302.38±37.90 bc	34.07±0.93 a	1309.83±36.84 abc	2.51±1.20 a
	Dark-medium	15444.00±902.98 abc	1356.38±37.90 abc	31.31±0.93 abc	1378.24±36.84 abc	2.33±1.20 a
	Dark	16741.00±902.98 ab	1365.49±37.90 abc	31.18±0.93 abc	1541.23±36.84 a	1.12±1.20 a
Colombia Graft	Light	13579.00±902.98 abc	1239.24±37.90 bc	26.74±0.93 cdef	1265.73±36.84 bc	2.85±1.20 a
	Medium-light	14491.00±902.98 abc	1265.17±37.90 bc	26.24±0.93 def	1271.03±36.84 abc	2.74±1.20 a
	Medium	15280.00±902.98 abc	1316.97±37.90 abc	26.09±0.93 def	1257.51±36.84 bc	0.00 ±1.20 a
	Dark-medium	14243.00±902.98 abc	1372.35±37.90 abc	28.03±0.93 bcde	1313.82±36.84 abc	0.51±1.20 a
	Dark	16192.00±902.98 abc	1370.34±37.90 abc	35.06±0.93 a	1329.59±36.84 abc	0.15±1.20 a
Costa Rica	Light	13560.00±902.98 abc	1303.38±37.90 bc	30.37±0.93 abcd	1231.61±36.84 bc	0.42±1.20 a
	Medium-light	15025.00±902.98 abc	1315.15±37.90 abc	28.41±0.93 bcd	1187.46±36.84 bc	0.25±1.20 a
	Medium	13760.00±902.98 abc	1194.96±37.90 c	27.36±0.93 bcde	1091.69±36.84 c	3.18±1.20 a
	Dark-medium	14265.00±902.98 abc	1296.80±37.90 bc	31.71±0.93 ab	1162.51±36.84 bc	1.22±1.20 a
	Dark	15102.00±902.98 abc	1417.83±37.90 ab	31.17±0.93 abc	1274.55±36.84 abc	0.38±1.20 a
Costa Rica Graft	Light	11993.00±902.98 c	1245.71±37.90 bc	19.69±0.93 g	1203.32±36.84 bc	2.87±1.20 a
	Medium-light	12698.00±902.98 bc	1322.50±37.90 abc	20.11±0.93 g	1210.01±36.84 bc	2.35±1.20 a
	Medium	14580.00±902.98 abc	1510.66±37.90 a	23.43±0.93 efg	1391.90±36.84 ab	1.89±1.20 a
	Dark-medium	15038.00±902.98 abc	1418.01±37.90 ab	22.31±0.93 fg	1302.97±36.84 abc	3.15±1.20 a
	Dark	14620.00±902.98 abc	1365.60±37.90 abc	20.75±0.93 g	1230.55±36.84 bc	1.97±1.20 a

Means ± SE with different letters in each column indicate significant statistical differences ($p \leq 0.05$).

4. Discussion

The amount of caffeine contained in a cup of coffee is quite different, depending on its origin or blend and brewing method, but in general, Robusta coffees contain approximately twice as much caffeine as Arabica species coffees (FDA, 2023).

The roasting level is a parameter in the quality of the product, although there is no agreement on the relationship between control in the parameters and those indicative of color, which is why the comparison between data is difficult (Dias & Benassi, 2015). Roasting coffee beans involves chemical changes in their content (De Luca *et al*., 2016). During this process, reactions are carried out between components that are present in the beans. Where the decrease of polysaccharides, proteins, chlorogenic acids, and trigonelline stands out, ocurring a degradation of sucrose, ash increases, and melanoidins are created (Puerta, 2011).

The increase of caffeine in darker roasting levels could be mainly because of the thermostability of caffeine and the loss of mass of thermolabile compounds during the roasting process (Mehaya, &. Mohammad, 2020). Probably the increase in temperature reduces the water content in coffee beans, helping to release volatile and thermostable compounds such as caffeine, this decrease probably results from the sublimation of caffeine at higher temperatures during roasting (Macrae, 1985).

The difference between pure lines and grafting could be because, in grafts, RNA molecules are highly transmissible between adjacent cells and throughout the plant utilizing the plant plasmodesmata (Lucas *et al*., 2001), an example of this is found by Kim *et al*. (2001) where they observed in grafts the long-distance movement of mRNA from the stock into scion induces a visible change in the morphology of the leaves of the latter, hinting that the translocated RNAs were functional. Therefore, it has been proposed that if the mRNAs transferred from the stock carrier have complete retrotransposons, they can be transcribed to produce cDNA and reintegrated into the scion, which would generate genetic changes (Liu, 2006).

Coffee beans have significant amounts of chlorogenic acids that considerably influence the quality of coffee, as well as its aroma and flavor (Rahn *et al*., 2013; Brigitta *et al*., 2016). A cup of coffee can contain 200 to 550 mg of phenolic compounds (Natella & Scaccini, 2012), and in roasted coffee, there can be up to 14% chlorogenic acids (Somporn *et al*., 2011). Chlorogenic acid, which is present in coffee beans, has high beneficial potential in humans, as it has high antioxidant, hypoglycemic, antiviral, hepatoprotective, and nutraceutical capacity (Somporn *et al*., 2011; Monteiro & Farah, 2012; Tfouni *et al*., 2013; Janissen & Huynh, 2018).

Several studies have shown that, during the roasting process of coffee beans, CGA levels decrease, because the high temperatures used during coffee roasting could lead to the breakdown of carbon-carbon bonds of chlorogenic acids, causing a degradation and isomerization of chlorogenic acids (Ayelign & Sabally, 2013). Among the hydroxycinnamic acids, 5-CQA acid is found in greater proportion in coffee beans; however, the arabica variety is the one with the lowest 5-CQA acid content.

Edaphoclimatic conditions of cultivation, such as altitude, affect the characteristics of coffees as well as their composition (Guyot *et al*., 1996), where free cinnamic acids, such as caffeic and p-coumaric, are released when the beans are roasted, these free cinnamic acids will vary according to the roasting temperature and time (Clifford & Clifford, 1999).

Although no empirical evidence is available to date, the differences between pure and grafted varieties are probably due to mRNA translocation from rootstocks to scion; this possibility is theoretically feasible (Wu *et al*., 2013).

Inter-specific transfer of somatic cells at the graft union has been documented (Thysenn *et al*., 2012). Furthermore, Stegemann and Bock, (2009) observed that the green fluorescent protein (GFP) marker encoded in plastids was transferring from one grafted tobacco plant to another at the graft union. It is important to remark that, in the observed cases, plastidial genome transfer was shown at the junctions close to the graft. However, although the mechanism responsible for the intercellular DNA exchange is relatively unknown, nucleic acids such as microRNAs are known to spread systemically through the phloem involving medium-dark. In grafts, plasmodesmata are probably responsible for the lateral transport of genes, even though they normally only allow the passage of small molecules (Rusk, 2009).

In 1994, the International Agency for Research on Cancer (IARC) classified acrylamide as probably carcinogenic for humans in classification 2A due to its broad spectrum of toxic effects; however, in 2002, the University of Stockholm supported Swedish researchers in alerting to the fact that some foods undergo thermal processing at temperatures exceeding 100°C and contain high amounts of acrylamide, and this is the specific case of roasting coffee beans, which is carried out at temperatures ranging from 150 to 250 °C, the temperature at which acrylamide has the optimum conditions for its formation (Claus *et al*., 2008).

The Coffea genus represents about 70 species, outstanding among them Coffea arabica L., (arabica coffee) and Coffea canephora (robusta coffee), due to their high global economic importance, these are the two most important species because they account for three-quarters of the world's coffee production (Cid, 2016).

Pohl *et al*. (2013) mention a variation in coffee beans' nutritional content based on their geographical origin. In fact, Oliveira *et al*. (2015) found differences between countries and continents, in the mineral profiles of coffee bean samples and considered the above because Brazil and Mexico are among the first 10 coffee-producing countries worldwide (Statista, 2023).

The roasting process of coffee beans is an operation that causes physical, chemical, and sensory changes (Nakilcioğlu-Taş & Ötleş, 2019). According to Pohl *et al*. (2013), the elemental analysis does not allow retrieving information about the speciation forms in which elements might be present in solid coffee and coffee brew, however, Vitorino *et al*. (2001) mention that the quality of the coffee beverage is directly related to the chemical composition of the roasted coffee beans, which in turn is influenced by the composition of the coffeé kernel, which in turn depends on the variety, origin, climate and post-harvest processes of the coffee.

By reducing sugars and fragmentation products, such as melanoidin and their acid precursors, many volatile and non-volatile compounds are formed, due to the Maillard reaction, which has a lower activation energy and is favored when reactive nitrogen compounds, such as amino acids and free amino groups in proteins and peptides, are present (Illy & Viani, 2005).

Pohl *et al*. (2013) mention that various elements can be divided into macronutrients (Ca, K, Mg, Na, S, P) and micronutrients (Cl, Co, Cr, Cu, Fe, Mn, Mo, Ni, Se, Sr, Zn) have been reported in green, roasted, and instant coffee.

The nutrient contents in green and roasted Arabica coffees are very different, with roasted coffee beans having higher concentrations of K, Na, Ca, Mg, and Fe than unprocessed coffee (Filho *et al*. 2007). Martin *et al*. 1998a, 1999 stated that the P and Cu content of green and roasted robusta coffee is often higher than the arabica coffee, but green and roasted beans have higher Mn content.

The concentration of nutrients is diverse, and this is associated with the influence of the origin, variety, and type of coffee (dos Santos & de Oliveira, 2001; Vega-Carrillo *et al*. 2002; Zaidi *et al*. 2006; Grembecka *et al*. 2007; dos Santos *et al*., 2010; Ashu & Chandravanshi, 2011). Within the nutrients of natural coffees, K presents the highest values, followed by P, Mg, S, Ca, and Na (Jaganyi and Madlala, 2000; dos Santos & de Oliveira, 2001; Suseela *et al*. 2001; Vega-Carrillo *et al*. 2002; Tagliaferro *et al*. 2006; Zaidi *et al*. 2006; Grembecka *et al*. 2007; Ashu & Chandravanshi, 2011).

When brewing coffee, many elements are released and become available in the beverage, therefore, the leachability of elements is very different for different types of coffee (Grembecka *et al*. 2007; Ashu & Chandravanshi, 2011; Oliveira *et al*. 2012). Frankova *et al*. (2009) have found that the brewing method influences the elements' content. In roasted and ground coffees, extraction efficiencies are intermediate for Cr (50.9-63.4%), Al (1.9-64.0%), Zn (8.6,61.5%), Co (25.7.49.8%), Ni (29.4-44.7%) and Mn (18.5-38.7%), while the lowest is for Iron (5.6-13.2%) and Copper (2.6-8.2%) (Rajwanshi *et al*., 1997; Grembecka *et al*., 2007; Frankova *et al*., 2009; Ashu & Chandravanshi, 2011).

Acid soils with high Iron and Aluminum contents cause cups with intermediate and high quality, while cups with low quality are associated with moderately acid soils and high levels of Cu and Zn (Suárez *et al*., 2015), and Fe has a positive influence on fragrance, contrary to Cu, which hurts the acidity of the beverage (Rosas *et al*., 2008).

5. Conclusions

The coffee beans of the Colombia variety presented the highest concentrations of caffeine, while the Costa Rica variety had the highest concentrations of chlorogenic acids, but the Colombia Graft variety presented the highest concentrations of acrylamide, while the nutritional content of all roasted coffee varieties was very similar.

Chlorogenic acids, acrylamide, and caffeine levels increase from light to medium roasting. The increase in roasting temperatures resulted in the degradation of the phenolic compounds in the beans. It is thus evident that the degree of roasting and the variety of beans have a direct effect on these compounds.

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