Original

Use of colour parameters for roasted coffee assessment

Utilização dos parâmetros de cor para avaliação do café torrado

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Abstract

Fast and non-destructive indicators were evaluated as tools to measure the technological quality of Arabica and Robusta coffee. Accordingly, considering the roasting intensity in highly valuable commercial samples, volume, mass, apparent density, moisture, total ash, ash insoluble in hydrochloric acid, and ether extract were characterized. The chromatic parameters L*, C*, H° were measured using illuminants D_{65} and C. It was found that in roasted coffee beans, the parameters L*, C*, H°, and coordinate b* had an antagonist interaction due to an increase in the roasting intensity, whereas after milling, only L* and H° decreased progressively. Considering that the parameters L* and H° followed similar patterns using both illuminants, D_{65} and C, it can be concluded that they are appropriate to evaluate coffee colour changes during roasting, enabling a relationship with coffee quality.

keywords: *arabica coffee; chromatic parameters; robusta coffee.*

Resumo

Avaliaram-se indicadores não destrutivos e de execução rápida, para aferir a qualidade tecnológica de cafés Arábica e Robusta. Neste contexto, considerando a intensidade da torra em amostras com elevado interesse comercial, caracterizaram-se o volume, massa, densidade aparente, umidade, cinzas totais e insolúveis em ácido clorídrico e do extrato etéreo. Foram então analisados os parâmetros cromáticos L*, C*, H° utilizando os iluminantes D_{65} e C. Verificou-se que em grãos de café torrado os parâmetros L*, C*, H° e a coordenada b* mostraram uma interação antagônica face ao acréscimo da intensidade da torra, enquanto, após a moagem, apenas o L* e o H° decresceram progressivamente. Considerando que a coordenada L* não variou significativamente com a aplicação dos dois iluminantes, concluiu-se que este parâmetro é o mais adequado para estudar a evolução da cor durante a torra, permitindo ainda estabelecer uma correlação com a qualidade.

Palavras-chave: *café arábica; parâmetros cromáticos; café robusta.*

1 Introduction

During classic roasting, green coffee beans are usually subjected to temperatures ranging between 180-190 and 220-230 °C for 12-15 minutes (CORREIA, 1995; BICHO et al. 2011). Tissue structure of coffee beans starts changing at *ca.* 50 °C, and with a continued temperature elevation protein denaturation and water evaporation increase. Above 100 °C, beans undergo browning related to a series of reactions (Maillard and Strecker mechanisms) giving rise to various substances, including melanoidins. Around 150 °C, gaseous substances (water vapour, carbon dioxide, and carbon monoxide) are released, and the bean volume increases. At 180-200 °C, with the disruption of the endosperm, bean cracking occurs, bluish smoke and aroma appears, and caramelization develops (BELITZ; GROSCH, 1988). Thereafter, to prevent excessive browning and aroma lost, coffee beans are removed from the roasting chamber and rapidly cooled with a stream of cold air or water spray (BELITZ; GROSCH, 1988; SMITH, 1985).

During the roasting process, weight loss usually varies between 14-23% depending on the botanical origin, green coffee moisture, storage conditions, and the roasting method. Weight loss results mainly from water and volatile substances release from the beans as well as of silver skin detachment (BICHO, 2005). The increase in bean volume is related to the release of bean tension and gases expansion in the endosperm (which implies cell swelling), stretching of cellular membranes, and partial destruction of polyoses, cellulose, and lignin (CORREIA, 1995). At the end of roasting, the apparent density of green coffee beans also decrease, cracks and fissures are formed, and pressure resistance sharply declines in parallel with multiple and complex chemical transformations, namely, Maillard and Strecker reactions.

Colour analysis has proved to be a valuable tool to adequately characterize fruit maturation (VOSS, 1992; LIDON et al., 2012). The Hue angle (H°) and Chroma (C*), are amongst the most widely used colour parameters (CAMELO; GÓMEZ, 2004; SPÓSITO; BASSANEZI; AMORIM, 2004; LIDON et al., 2012). The parameter H° is a cylindrical coordinate that represents tonality varying between red (0°), yellow (90°) and green (180°)

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and is useful in interpreting colour differences (CAMELO; GÓMEZ, 2004; VOSS, 1992) and in the perception of fruit and vegetable quality (SHEWFELT, 1993). Chroma is the colour purity or saturation (SPÓSITO; BASSANEZI; AMORIM, 2004).

To evaluate the quality of roasted coffee, classic standard methods have usually been used, namely volume, mass, apparent density, moisture, total ash, ash insoluble in hydrochloric acid, and ether extract. Several studies have been carried out to correlate colour with coffee drink quality (MAZZAFERA; GUERREIRO FILHO; CARVALHO, 1988). Accordingly, the use of fast and non-destructive indicators might contribute to roast coffee quality assessment allowing the definition of the technological quality that might influence the sensory quality of the drink. Hence, using the illuminants D_{65} and C, the chromatic parameters of *C. arabica* and *C. canephora* species (known as Arabica and Robusta coffees, respectively) related to the increase in roasting intensity and their physical characteristics were evaluated.

2 Materials and methods

2.1 Sampling

Sampling of *Coffea arabica* (Brazil) and *Coffea canephora* (India) was carried out according to the Instrução Normativa Nº 8 (BRASIL, 2003), NP 1666 (PORTUGAL, 1980) and ISO 4072 (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, 1982), as described in Bicho et al. (2011). Briefly, the sampling process began with the selection of green coffee bags, following PSCB Nº 36/02 (INTERNATIONAL COFFEE ORGANIZATION, 2002), at random (a minimum of 10% of the lot, with *ca*. 2000 kg). The selected bags were separated from the lot and, using a probe, 30 + 6.0 g of coffee were collected in triplicate from three different points (top, middle and bottom) of each bag. These collected samples were then joined in a pool representing an overall take of green coffee, with a minimum mass of 1.5 kg. Arabica and Robusta green coffee samples were therefore submitted to three degrees of roasting intensity (T_1, T_2, and T_3; 200-240 °C, 5-12 minutes) for all the subsequent analyses.

2.2 Volume, mass, and apparent density

The volume increase of roasted coffee was determined following the method described by Aguiar and Vilar (1979) with minor modifications. The apparent volume of coffee beans was measured before and after roasting using a beaker of known volume (500 mL). The percentage of increased volume of coffee beans during roasting (Δv) was therefore calculated, using the formula $\Delta v = 100\frac{(v_t - v_v)}{v_v}$, in which: Δv is the increase of apparent volume, expressed in percentage by volume (% v/v); v_t is the apparent volume of the test sample of roasted coffee, in cm^3; and v_v is the mean apparent volume of coffee green in cm^3. Data represent the average of five replicates. To quantify the mass loss, 100 coffee beans were weighed before and after roasting. Therefore, the percentage of mass loss after roasting (Δm) was determined through the formula $\Delta m = 100\frac{(m_v - m_t)}{m_v}$ considering that: Δm is the mass decrease, expressed as a percentage by mass (% m/m); m_t is the mass of the roasted coffee sample in grams; m_v is the average mass of green coffee in grams. Data represent the average of five replicates.

The determination of apparent density followed NP 2285 (PORTUGAL, 1991) and Bicho (2005), using a beaker of 250 mL, with a precision of 0.01 g. The difference between the replicates did not exceed 2%. Based on the apparent density of roasted coffee and green coffee, the relative percentage was determined.

2.3 Moisture

The moisture of the roasted coffee was determined according to ISO 11294 (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, 1994) using a weighing vessel which was placed in an oven (103 ± 1 °C, for 1 hour), cooled in a desiccator, and weighed. Next, approximately 12 g of roasted coffee were weighed ground using a mortar and pestle. Approximately 5 g of roasted ground coffee were placed in the weighing vessel, covered, and weighed to an accuracy of 0.1 mg. The samples were then placed in an oven (Heraeus, Germany) at 103 ± 1° C for 4 hours, cooled in a desiccator to room temperature, and weighed to an accuracy of 0.1 mg. Data represent the average of five replicates.

2.4 Total and acid-insoluble ash

Total ash was determined according to AOAC (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS,1996). Five grams of ground coffee (sieve nº 30) were dried in a muffle furnace (Heraeus, Germany) at 100 °C. Next, the temperature was gradually increased up to 525 ± 25 °C to obtain the ash. The ash was then moisturised with several drops of water and placed in a water bath for drying and then on a hot plate for final drying. Thereafter, the residue was taken back to the muffle furnace (at 525 ± 25 °C, for 1 hour), after which was cooled to room temperature in a desiccator, and weighed. Weight determination was repeated at 30 minutes-intervals to obtain constant mass.

The ash insoluble in hydrochloric acid was determined according to AOAC method (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 1996). The ash insoluble in hydrochloric acid was obtained from the ash insoluble in water, to which 25 cm^3 of 10% (w/w) hydrochloric acid (Merck, 37% purity) was added, followed by boiling for 5 min and filtration. The filter (ash free) and its residue were initially burnt in a heating plate (5 minutes) and afterwards placed in the muffle furnace (525 ± 25 °C) for 10 minutes. Weight measurements were carried out in triplicate to an accuracy of 0.1 mg.

2.5 Ether extract

The ether extract content was determined according to Esteves and Oliveira (1970) and AOAC (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 1996). Five grams of ground (sieve nº 30) green or roasted coffee were dried in an oven (100 °C, 2 hours), transferred to a filter cartridge, and placed in a Soxhlet glass extractor. Petroleum ether (boiling point 30-60 °C) was added, and the extraction was carried out for 16 hours. Thereafter, the solvent was evaporated and the residue dried in an oven at 100 °C. The residue was cooled to room temperature and weighed until the difference between two successive weighings did not exceed 0.1% of the original mass of the sample. Weight measurements were carried out in triplicate.

2.6 Colour evaluation

The colour of coffee beans and ground coffee was measured using a CR-300 colorimeter (Minolta, Japan) and the illuminants D_{65} and C (device manufacturer specifications). The colorimeter was calibrated with a white standard tile, in order to obtain the coordinates for each illuminant: L* = 97.27, a* = - 0.01, b* = 1.98, for the illuminat D_{65} and L* = 97.26, a*= + 0.01, b* = 1.94, for the illuminant C. The colour space was chosen to obtain the results expressed in the chromaticity coordinates L* a* b* samples for the selected illuminant. According to McGuire (1992), the coordinated L* represents lightness (contribution of black or white varying between 0 and 100); a* represents the contribution of green or red (positive or negative); and b* represents the contribution of blue or yellow (negative or positive). The coordinated L* is perpendicular to the plane containing the chromaticity coordinates a* and b* (McGUIRE, 1992). Considering the coordinates L* a* b*, the colour is expressed through L* C* H°, where: L* is brightness; C* is chroma or saturation (FLORÊNCIO; RAPOSO, 1974; CHERVIN; FRANZ; BIRRELL, 1996); and H° is tone (or hue or angle of ink or hue angle, which indicates colour variation in the plane formed by the coordinates a* and b*) (FLORÊNCIO; RAPOSO, 1974; CHERVIN; FRANZ; BIRRELL, 1996). These parameters were determined considering (McGUIRE, 1992; CHERVIN; FRANZ; BIRRELL , 1996): $C^*=(a^2 + b^2)^{1/2}$; $H° = (\arctan(b/a)/6.2832) \times 360$ (if $a > 0$ and $b \geq 0$), or $H° = 180 + (\arctan(b/a)/6.2832) \times 360$ (if $a < 0$ and $b \geq 0$ or $b < 0$), or $H° = 360 + (\arctan(b/a)/6.2832) \times 360$ (if $a > 0$ and $b < 0$). The overall colour difference, ΔE, was determined using the equation $\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$ (CHERVIN; FRANZ; BIRRELL, 1996).

2.7 Statistical analysis

The data were statistically analyzed using two-way ANOVA ($p \leq 0.05$) applied to the studied parameters (considering both roasting degrees and coffee types). Based on the ANOVA results, the Tukey's test was performed for mean comparison at 95% confidence level.

3 Results and discussion

The volume of roasted coffee was closely related to the intensity of roasting (Table 1), but a higher increase was found for Arabica coffee (Table 1). The patterns displayed by Robusta and Arabica coffees were similar to previous reports (COSTE, 1992; XABREGAS et al., 1971; CORREIA, 1990), with the volume increase being related to the release of beans tension and gases expansion in the endosperm (implying cell swelling), as well as to the stretching of cellular membranes (CORREIA, 1995). Therefore, the highest volumes of Arabica roasted coffees

Table 1. Volume increase, mass losses, apparent density, percentage relation of apparent density, moisture content, total and insoluble in HCl ashes and ether extract of Arabica and Robusta coffees. Each value represents the mean ± S.E. (n = 5).*

	Arabica coffee				Robusta coffee			
	Green	Roasted			Green	Roasted		
		T_1	T_2	T_3		T_1	T_2	T_3
Volume increase (%)	-	40.2 ± 0.5^{ar}	58.3 ± 0.4^{br}	69.0 ± 0.5^{cr}	-	48.1 ± 0.5^{as}	50.1 ± 0.6^{as}	57.0 ± 1.0^{bs}
Mass losses (%)	-	10.5 ± 0.2^{ar}	13.4 ± 0.1^{br}	19.4 ± 0.4^{cr}	-	10.1 ± 0.4^{ar}	12.5 ± 0.2^{br}	16.7 ± 0.4^{cs}
Apparent density ($g.cm^{-3}$)	0.630 ± 0.000^{ar}	0.400 ± 0.000^{br}	0.340 ± 0.000^{cr}	0.300 ± 0.000^{dr}	0.630 ± 0.00^{ar}	0.380 ± 0.000^{bs}	0.370 ± 0.000^{cs}	0.330 ± 0.000^{ds}
Relation of apparent density (%)	-	63.8	54.7	47.7	-	60.7	58.3	53.1
Moisture content (mass %)	9.06 ± 0.03^{ar}	3.12 ± 0.01^{br}	1.95 ± 0.02^{cr}	1.32 ± 0.00^{dr}	9.24 ± 0.03^{ar}	2.42 ± 0.01^{bs}	1.63 ± 0.01^{cs}	1.11 ± 0.00^{ds}
Total ash (mass %)	4.54 ± 0.14^{ar}	4.55 ± 0.06^{ar}	4.53 ± 0.02^{ar}	4.64 ± 0.03^{ar}	4.44 ± 0.14^{ar}	4.60 ± 0.05^{ar}	4.43 ± 0.02^{ar}	4.65 ± 0.04^{ar}
Ash insoluble in HCl (mass %)	0.007 ± 0.001^{ar}	0.006 ± 0.001^{ar}	0.008 ± 0.001^{ar}	0.016 ± 0.014^{ar}	0.028 ± 0.001^{ar}	0.022 ± 0.005^{ar}	0.024 ± 0.010^{ar}	0.025 ± 0.016^{ar}
Ether extract (mass %)	15.2 ± 0.1^{ar}	14.4 ± 0.0^{ar}	15.1 ± 0.0^{ar}	16.7 ± 0.2^{ar}	8.46 ± 0.06^{as}	7.77 ± 0.01^{as}	8.07 ± 0.02^{as}	8.51 ± 0.18^{as}

*Different letters indicate significant differences (a,b,c between roasting degrees within the same coffee type and r,s between coffee type samples within the same roasting degree), after a mean comparison by the Tukey's test, at a 95% confidence level.

were associated to the additional production, retention, and expansion of carbon dioxide, and lower resistance of the cell wall (CLIFFORD, 1987).

As previously reported for Angola and Brazilian coffees (ESTEVES; OLIVEIRA, 1970; CORREIA, 1990; DAGLIA; CUZZONI; DACARRO, 1994), the increase in the intensity of green coffee roasting followed a significantly mass loss that ranged from 10.5 to 19.4% and 10.1 to 16.7% in Arabica and Robusta coffee, respectively (Table 1). Significant differences were found between these two coffee genotypes in terms of roasting intensity. The mass loss of green coffee, which occurred with the increased roasting intensity, resulted from the removal of water, organic substances, and silver skin (ESTEVES; OLIVEIRA, 1970; BELITZ; GROSCH, 1988; CORREIA, 1990; COSTE, 1992). Nevertheless, the higher mass losses observed in Arabica coffee can additionally be attributed to an increase in the content of volatiles, which are released during the roasting process (CORREIA, 1990).

The green coffee beans of Arabica and Robusta genotypes had similar apparent density values. However, this parameter significantly decreased in both genotypes with the increased roasting degree, whereas the differences between genotypes related to volume increase and mass losses increased (Table 1). Indeed, the ratio between the apparent density of roasted and green coffee samples was over 60%, in roasting T_1 but decreased in roasting T_2 and was further reduced in roasting T_3, in which the minimal values of 47.7% (Arabica) and 53.1% (Robusta) were found (Table 1).

The moisture content of green and roasted coffee beans varied within the ranges of 9.06-9.24 and 3.12-1.11 wt. (%), respectively, which allows its commercialization (ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA DO CAFÉ, 2007) independently of the roasting degree. Differences between coffee types were noticed only due to the roasting process (Table 1). Comparing data from the two coffee genotypes, Arabica coffee proved to be less sensitive during dehydration, what might be related to its shorter roasting process, leading therefore to a reduced water loss. On the other hand, the green Arabica coffee usually shows a higher fat content (FOLSTAR, 1985). That would increase the calorific values of the beans, leading to shorter time interval temperatures that favour the Maillard reactions, responsible for the development of the characteristic colour and pleasant aromas (BICHO, 2005).

Depending on the type of processing, soil conditions and use of fertilizers, especially those that supply potassium (CLARKE, 1985; MORGANO et al., 2002), the content of total ash might vary. Yet, in the analysed Arabica and Robusta

Table 2. Chromatic parameters of Arabica and Robusta whole coffee beans. Each value represents the mean ± S.E. (n = 9).*

	Chromatic parameters				
	L*	**a***	**b***	**C***	**H°**
			Illuminant D_{65}		
Green beans					
Arabica	57.5 ± 0.8^{ar}	2.0 ± 0.2^{ar}	13.4 ± 0.4^{ar}	13.5 ± 0.4^{ar}	81.5 ± 0.6^{ar}
Robusta	56.9 ± 0.9^{ar}	3.5 ± 0.3^{acs}	16.2 ± 0.4^{as}	16.6 ± 0.4^{as}	77.8 ± 0.9^{as}
Roasted beans					
Arabica					
T_1	45.2 ± 0.6^{br}	6.48 ± 0.29^{br}	$9.81 \pm 0{,}66^{br}$	11.8 ± 0.7^{br}	56.1 ± 1.5^{br}
T_2	40.0 ± 0.5^{cr}	3.85 ± 0.24^{cr}	4.00 ± 0.44^{cr}	5.56 ± 0.48^{cr}	45.0 ± 1.5^{cr}
T_3	37.1 ± 0.3^{dr}	2.61 ± 0.16^{ar}	1.58 ± 0.20^{dr}	3.07 ± 0.24^{dr}	30.1 ± 1.8^{dr}
Robusta					
T_1	45.8 ± 0.4^{br}	6.25 ± 0.24^{br}	9.48 ± 0.39^{br}	11.4 ± 0.5^{br}	56.6 ± 0.5^{br}
T_2	40.5 ± 0.5^{cr}	4.58 ± 0.40^{cr}	4.98 ± 0.62^{cr}	6.78 ± 0.72^{cr}	46.5 ± 1.1^{cr}
T_3	38.2 ± 0.3^{dr}	3.17 ± 0.19^{ar}	2.16 ± 0.24^{dr}	3.85 ± 0.29^{dr}	33.4 ± 1.6^{dr}
			Illuminant C		
Green beans					
Arabica	57.2 ± 0.7^{ar}	1.41 ± 0.14^{ar}	13.5 ± 0.6^{ar}	13.6 ± 0.6^{ar}	84.1 ± 0.5^{ar}
Robusta	57.3 ± 0.9^{ar}	3.03 ± 0.25^{as}	16.2 ± 0.2^{as}	16.5 ± 0.2^{as}	79.4 ± 0.9^{as}
Roasted beans					
Arabica					
T_1	44.8 ± 0.8^{br}	6.10 ± 0.31^{br}	9.55 ± 0.84^{br}	11.4 ± 0.9^{ar}	56.8 ± 1.1^{br}
T_2	40.2 ± 0.3^{cr}	3.22 ± 0.34^{cr}	3.56 ± 0.47^{cr}	4.81 ± 0.57^{br}	47.0 ± 1.3^{cr}
T_3	37.7 ± 0.5^{dr}	2.55 ± 0.09^{acr}	1.81 ± 0.17^{dr}	3.13 ± 0.17^{br}	34.7 ± 1.7^{dr}
Robusta					
T_1	44.0 ± 0.7^{br}	5.94 ± 0.35^{br}	8.65 ± 0.77^{br}	10.5 ± 0.8^{br}	54.8 ± 1.4^{br}
T_2	40.9 ± 0.6^{cr}	4.04 ± 0.33^{cr}	4.58 ± 0.65^{cr}	6.10 ± 0.72^{cr}	46.6 ± 2.0^{cr}
T_3	38.1 ± 0.5^{dr}	2.75 ± 0.30^{ar}	2.06 ± 0.37^{dr}	3.45 ± 0.64^{cr}	34.6 ± 2.4^{dr}

*Different letters indicate significant differences (a, b, c, d, between roasting degrees within each coffee type and r, s between coffee type samples within the same roasting degree), after a mean comparison by the Tukey's test at a 95% confidence level.

genotypes, the total ash values of the green coffee samples remained quite similar and close to 4% (Table 1), which is within the range reported by Smith (1985) and Clarke (1985). Furthermore, total ash in roasted Arabica and Robusta coffees did not vary significantly with roasting intensity (Table 1) remaining within the range of 4.53-4.64% (Arabica) and 4.60-4.65% (Robusta), which were similar to those reported by Smith (1985) and considered admissible for marketing (ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA DO CAFÉ, 2007). This data revealed an absence of significant variation in the mineral components with roasting, with the minerals being separated from the original organic compounds to catalyze the pyrolysis reactions.

It can be said that the ash insoluble in hydrochloric acid is the earthy residue of the coffee samples (ESTEVES; OLIVEIRA, 1970) and is, therefore, an indicator of the absence of silica and silicon constituents. Its content did not presented significant differences (Table 1) and, since was lower than 1%, will allow the commercialization of green and roasted coffee (ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA DO CAFÉ, 2007).

The content of ether extract in Arabica and Robusta coffee is known to vary with the geographical origin of the plants, but it is usually close to 15 and 9%, respectively (XABREGAS et al., 1971; CLIFFORD, 1987; FOLSTAR, 1985; MAZZAFERA et al., 1998; AGUIAR et al., 2005). The studied green coffee samples showed a content of ether extract close to those referred values, with Arabica displaying a higher value than that of Robusta (Table 1), following what was found in other genotypes (ESTEVES; OLIVEIRA, 1970; FOLSTAR, 1985; AGUIAR et al., 2005; MAZZAFERA et al., 1998). Roasting did not change the contents of ether extract of Arabica and Robusta coffees, thus, maintaining the differences between them already observed in the green bean values. Still, for both coffee genotypes slight decreases in T_1 and T_2, and some increases in T_3 were observed, and the latter can be attributable to mass losses (FOBÉ; NERY; TANGO, 1968; FOLSTAR, 1985; TOCI; FARAH; TRUGO, 2006) (Table 1). In fact, with the roasting intensity increase, the outer layer of the coffee beans become more oily as the lipids (mostly located in the endosperm with an additional small amount of wax) are expelled to the external areas of the bean and form an impermeable protective layer, which would minimize the loss of substances responsible for the organoleptic characteristics of the beverage (CLIFFORD, 1987; COSTE, 1992; AGUIAR et al., 2005; SPEER; KÖLLING-SPEAR, 2006).

The analysis of the chromatic parameters, using the illuminants D_{65} and C, showed that lightness (L*) as well as parameters a*, b*, C* and H° were not significantly different between genotypes when comparing the same roasting degree

Table 3. Chromatic parameters of Arabica and Robusta coffee powder. Each value represents the mean ± S.E. (n = 9).*

	Chromatic parameters				
	L*	**a***	**b***	**C***	**H°**
			Illuminant D_{65}		
Green powder					
Arabica	72.1 ± 0.3^{ar}	1.06 ± 0.04^{ar}	15.8 ± 0.1^{ar}	15.9 ± 0.1^{ar}	86.2 ± 0.2^{ar}
Robusta	75.3 ± 0.2^{as}	0.89 ± 0.02^{ar}	15.8 ± 0.1^{ar}	15.9 ± 0.1^{ar}	86.8 ± 0.1^{ar}
Roasted powder					
Arabica					
T_1	49.8 ± 0.3^{br}	10.1 ± 0.1^{br}	17.2 ± 0.2^{br}	19.9 ± 0.2^{br}	59.5 ± 0.3^{br}
T_2	41.9 ± 0.1^{cr}	7.44 ± 0.05^{cr}	8.61 ± 0.10^{cr}	11.4 ± 0.1^{cr}	49.2 ± 0.2^{cr}
T_3	37.4 ± 0.0^{dr}	4.63 ± 0.05^{dr}	3.74 ± 0.08^{dr}	5.95 ± 0.08^{dr}	38.9 ± 0.3^{dr}
Robusta					
T_1	52.5 ± 0.2^{bs}	9.41 ± 0.12^{bs}	18.8 ± 0.2^{bs}	21.0 ± 0.3^{bs}	63.5 ± 0.1^{bs}
T_2	45.7 ± 0.2^{cs}	8.77 ± 0.05^{cs}	13.5 ± 0.2^{cs}	16.1 ± 0.2^{as}	57.0 ± 0.4^{cs}
T_3	39.8 ± 0.1^{ds}	5.78 ± 0.08^{ds}	6.77 ± 0.08^{ds}	8.90 ± 0.11^{cs}	49.5 ± 0.2^{ds}
			Illuminant C		
Green powder					
Arabica	71.7 ± 0.1^{ar}	0.90 ± 0.01^{ar}	15.9 ± 0.1^{ar}	15.9 ± 0.1^{ar}	86.6 ± 0.0^{ar}
Robusta	76.0 ± 0.1^{as}	0.66 ± 0.02^{as}	15.9 ± 0.1^{ar}	15.9 ± 0.1^{ar}	87.6 ± 0.1^{as}
Roasted powder					
Arabica					
T_1	49.1 ± 0.1^{br}	9.73 ± 0.04^{br}	16.8±0.1 ^{br}	19.4±0.1 ^{br}	59.9 ± 0.2^{br}
T_2	41.6 ± 0.1^{cr}	7.18 ± 0.06^{cr}	8.10±0.09 ^{cr}	10.8±0.1 ^{cr}	48.5 ± 0.1^{cr}
T_3	37.5 ± 0.1^{dr}	3.46 ± 0.03^{dr}	2.41 ± 0.03^{dr}	4.22 ± 0.04^{dr}	34.9 ± 0.2^{dr}
Robusta					
T_1	52.1 ± 0.2^{bs}	9.51 ± 0.04^{bs}	18.6 ± 0.2^{bs}	20.9 ± 0.2^{bs}	62.9 ± 0.2^{bs}
T_2	46.0 ± 0.1^{cs}	8.26 ± 0.06^{cs}	13.1 ± 0.1^{cs}	15.5 ± 0.1^{as}	57.9 ± 0.2^{cs}
T_3	39.6 ± 0.1^{ds}	5.53 ± 0.05^{ds}	6.06 ± 0.10^{ds}	8.20 ± 0.10^{cs}	47.6 ± 0.3^{ds}

*Different letters indicate significant differences (a, b, c, d, between roasting degrees within each coffee type and r, s between coffee types samples within the same roasting degree), after a mean comparison by the Tukey's test at a 95% confidence level.

(Table 2). Moreover, within each type of roasted coffee beans, the pattern of lightness (L*) revealed an antagonist interaction with increased roasting intensity. The parameter a* increased significantly in roasting T_1 of Arabica and Robusta coffee due to the yellowish intensification in the initial phase of the burning process, but a decrease was found in T_2 and T_3 (Table 2). The coordinate b* also showed an antagonist pattern with the increased roasting intensity, due to the increased browning of the beans (Table 2). Accordingly, parameters C* and H° also decreased significantly along the roasting process showing an increased reduction from green coffee to the T_3 roasting intensity degree (Table 2).

After milling, significant differences were found between green Arabica and Robusta coffees in several colour parameters for the two illuminants (Table 3). The parameter L* decreased significantly with roasting, whereas a* (green/red contribution) increased sharply in Arabica and Robusta T_1 roasting degree and decreased in T_2 and T_3 degrees (contributing therefore to the red colour of the roasted coffee powder), similarly to what happened before milling the beans. Yet, after milling a* values in T_2 and T_3 were still much higher than in green coffee (Table 3), contrary to what happened for the whole bean (Table 2). Also, the coordinate b* (yellow/blue contribution) increased in roasting T_1 degree (contrary to what was observed with whole beans) and decreased significantly in T_2 and T_3 degrees. The parameter C* varied similarly to the chromatic coordinates a* and b* with a substantial increase in T_1 degree, decreasing thereafter for T_2 and T_3, although maintaining higher values than those of the whole bean. The parameter H° (hue) decreased sharply with the increased roasting intensity (Table 3) following a similar pattern found of the whole bean. The brightness and tone of the coffee powder samples showed similar variations, exhibited antagonist patterns with increased roasting intensity.

4 Conclusions

The samples of green and roasted coffee powder proved to have the standard characteristics for commercialization. They showed higher values of brightness and chromatic coordinates, mainly in Robusta coffee, yet the colour difference decreased with the roasting intensity, possibly as a result of the temperature gradient across the bean, which inevitably leads to colour deviation in relation to ground roasted coffee.

The coordinates a* and b* of whole and ground coffee beans are located in the chromatic plane, close to the axis of light, with greater influence of one or another chromatic coordinates. Therefore, depending on the roasting intensity, it follows that roasted coffee can show a brownish colour, yellower in lighter roasts, becoming reddish brown in medium roasting and dark brown in intense roasting.

Moreover, lightness (L*) decreases significantly with increased roasting intensity, as a result of the contribution of the development of a higher brown colour intensity (becoming darker), related to a saturation dependence of the variation of coordinates a* and b*.

The illuminants D_{65} and C for colour analysis of coffee beans and powder showed similar variation patterns for the parameters L*, a*, b*, C* and H°. Some differences were found for the parameters a*, b* e C* in relation to the roasting process, although without a useful trend for coffee quality assessment .

On the other hand, the L* and H° parameters followed the same and consistent pattern of variation, which did not differ among illuminants. Therefore, they constitute reliable and easy-to-use parameters to study colour change that occur during roasting, enabling a relationship with coffee quality.

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