

EVALUATION OF PHYSICAL PROPERTIES OF COFFEE DURING ROASTING

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ABSTRACT

The main objective of the present study was to evaluate the variation of physical properties of coffee beans during roasting. Characteristics evaluated were: volume, bean and bulk densities, weight loss, and color. Experiments were conducted using a lab-scale roaster, with coffee samples being collected at regular intervals during roasting. The results showed that both volume and weight loss increase during roasting, and that such increase can be described by two lines presenting different slopes, coinciding with the drying and pyrolysis stages. It was also observed that both bulk and bean densities decrease during roasting, due to the increase in volume and simultaneous decrease in mass. The results also show that the variations in color parameters are more expressive at the onset of pyrolysis.

Keywords. coffee; roasting; physical properties; volume; mass; color; bulk density; bean density

INTRODUCTION

The quality of coffee used for beverage is strictly related to the chemical composition of the roasted beans, which is affected by the composition of the green beans and post-harvesting processing conditions (drying, storage, roasting and grinding). The characteristic coffee flavor results from the combination of hundreds of chemical compounds produced by the reactions that occur during roasting.

Roasting can be divided into three consecutive stages: (i) drying, (ii) roasting and (iii) cooling. The first stage is characterized by a slow release of water and volatile substances, during the first half of processing. Bean color changes from green to yellow. Pyrolysis reactions take place during the second stage, resulting in considerable changes in both physical and chemical properties of the beans. Large quantities of CO₂, water and volatile substances are released and the beans turn brown, due to sugar caramelization coupled to Maillard reactions. At this point cooling is required in order to avoid burning the coffee (Sivetz and Desrosier, 1979).

The criteria commonly used to evaluate the quality of coffee beans include bean size, color, shape, roast potential, processing method, crop year, cup quality and presence of defective beans (Banks et al., 1999). The New York Coffee and Sugar Exchange devised the "black bean count basis", according to which all defects are accounted for in terms of its equivalence to black beans. For example, five insect-damaged beans correspond to one black bean, which is equivalent to one defect. This is known as type classification, as shown in Table 1.

Table 1 - Type numbering of green coffee according to maximum defects.

Type no	Maximum allowable number of defects per 300g sample
NY 1/2	4
NY 2/3	8
NY 3/4	19
NY 4	26
NY 4/5	36
NY 5/6	79
NY 6	86
NY 7	160
NY 8	340

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Flavor is the main and most important criterion for evaluating coffee quality. Brazilian coffee is officially categorized by reference to the following flavor scale (Clarke and Macrae, 1987):

- (i) strictly soft: low acidity, mellow sweetness, pleasant row of the mouth easiness (Banks et al., 1999);
- (ii) soft: same characteristics as strictly soft, only less accentuated;
- (iii) softish: same characteristics as soft, only less accentuated;
- (iv) hard: lacks sweetness and softness;
- (v) rioysh: iodine, inky flavor from microbe-tainted beans;
- (vi) rio: same characteristics as rioysh, only more accentuated.

This classification, also known as cup quality, is assessed using the brewing method of steeping. Nearly boiling water is directly poured onto roasted and ground coffee contained in a small cup (10 g of roast and ground coffee per 150mL boiling water; medium roast, fine grind). Coffee particles initially rise to the surface of the water, forming a crust. As time progresses, they begin to sink. The liquid is gently stirred to ensure that all particles sink to the bottom of the cup, during 3 to 5 minutes, after which sensory evaluation takes place (Clarke and Macrae, 1987; Lingle, 1993).

The chemistry of flavor development during roasting of coffee is not well understood. The flavor and aroma of coffee are highly complex, and difficult to describe, resulting from the combined action of over 800 volatile substances. Therefore, the present paper is part of a research study that aims a detailed evaluation of the industrial roasting process, with the purpose of establishing a correlation between green coffee properties, processing conditons, and product quality. Data on physical properties of coffee are aplenty in the literature for green coffee and for roasted coffee at a specific roasting degree (Sivetz and Desrosier, 1979; Clarke and Macrae, 1987; Ghosh, 1996; Chandrasekar and Viswanathan, 1999). However, data on how physical properties change during roasting are scarce, and for some properties, non-existent. Therefore, it was the aim of the present study was to evaluate the variation of physical properties of coffee beans during roasting. The evaluated characteristics were: volume, apparent density, bulk density, weight loss and color.

METHODOLOGY

Arabica green coffee from Viçosa (Minas Gerais State, Brazil) was used in the roasting tests. This coffee was classified according to type and cup quality as type NY3/4, soft.

A lab-scale cylindrical coffee roaster coupled to a gas condensation equipment was employed for roasting (Figure 1). The maximum temperature achieved within the bed of beans was 222°C. The roaster, rotating at 80 rpm, was pre-heated for 10 minutes and then loaded with 1.5 kg green coffee. The roasting time was chosen so it would be enough to char the beans, assuring that the optimal degree of roast was achieved. Bean samples were collected every two minutes. From each sample, 100 beans were randomly selected and properly stored for later use in all determinations.

The average volumes of the beans were calculated from measurements of major, minor and intermediate diameters of individual beans and the assumption that each bean could be taken as half a triaxial ellipsoid (Dutra et al., 2001). Weight loss was evaluated as the percent difference in sample weight, prior to and after roasting. Particle and bulk density were evaluated as the ratio between sample mass and bean and bulk volume, respectively.

Color was evaluated for both whole and ground coffee beans. The measurements using whole beans were performed in triplicate under the following experimental conditions:

Equipment: Hunter Lab Miniscan TMXE Plus

Standard illumination: D₆₅

Colorimetric normal observer angle: 10°

Measured values: Hunter Lab

The measurements using ground beans were performed five times for each sample under the following experimental conditions:

Equipment: Colortec PCM (Clinton, USA).

Standard illumination: D₆₅

Colorimetric normal observer angle: 10°

Measured values: L*a*b*

The measured values (HLab for whole beans and L*a*b* were converted to Luminosity (L*), chroma (c*) and hue angle (h*) values (COLORPRO, 2003). Differences in color were assessed by evaluation of the total color difference parameter:

$$\Delta E = \left((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right)^{1/2} \quad (1)$$

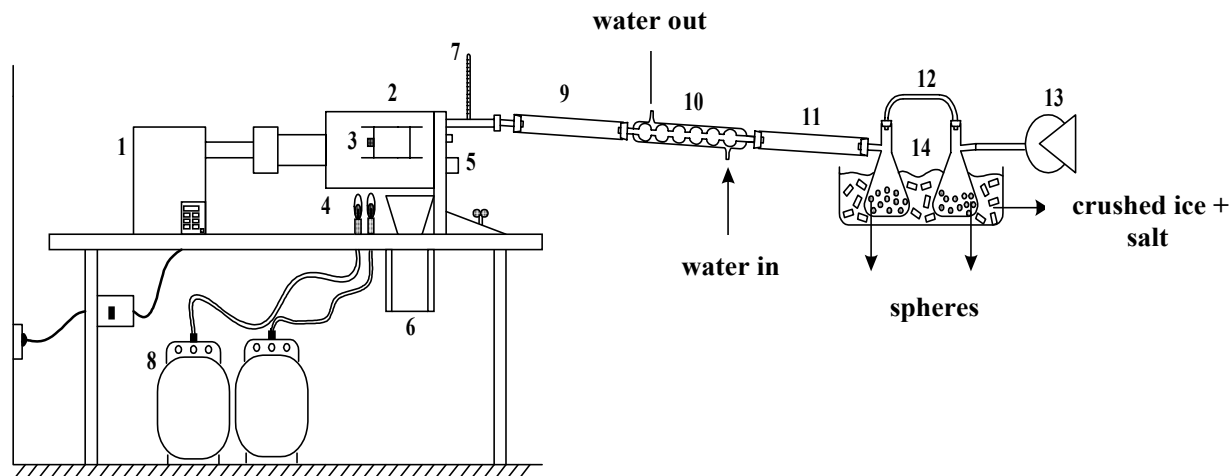


Figure 1. Roasting equipment: (1) motor; (2) roaster; (3) feed; (4) heating flames; (5) beans sampling point; (6) beans discharge; (7) thermometer; (8) fuel tanks; (9), (11) and (12) flexible tubes; (10) ball condenser; (13) vacuum pump and (14) gas trap system.

RESULTS AND DISCUSSION

All results correspond to averages of determinations for two replicates, with the error bars in the curves referring to standard deviation values. The temperature of the gases at the exit of the roaster was monitored in order to assure that heating conditions were the same for all experiments.

The variation of the average bean volume during roasting is presented in Figure 2. These results show that volume increases during roasting and that such increase can be described by two lines presenting different slopes. According to Sivetz and Desrosier (1979), the increase in bean volume results from the softening of the cellulose bean structure coupled to the increase in pressure from the release of pyrolysis products. Therefore, the increase in slope after 12 minutes could be associated to the start of pyrolysis reactions.

The weight loss curve (Figure 3) presents a behavior similar to that reported in the literature (Sivetz and Desrosier, 1979; Dutra et al., 2001), occurring at two rates. The weight loss during the first twelve minutes is due to the slow release of water and volatile components. The increase in weight loss after that time can be attributed to an intensive release of organic compounds and CO₂ during pyrolysis. The onset of pyrolysis can be associated with the transition between the two slopes. According to the reviewed literature, transition should occur at about 10% weight loss (Sivetz and Desrosier, 1979). In our case, transition occurred at approximately 7%.

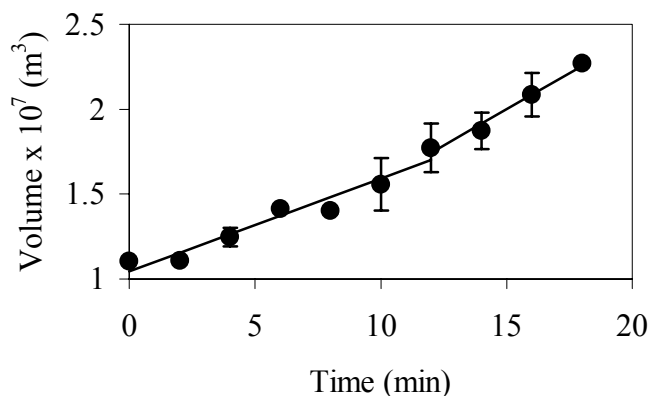


Figure 2. Variation of the average bean volume with roasting time.

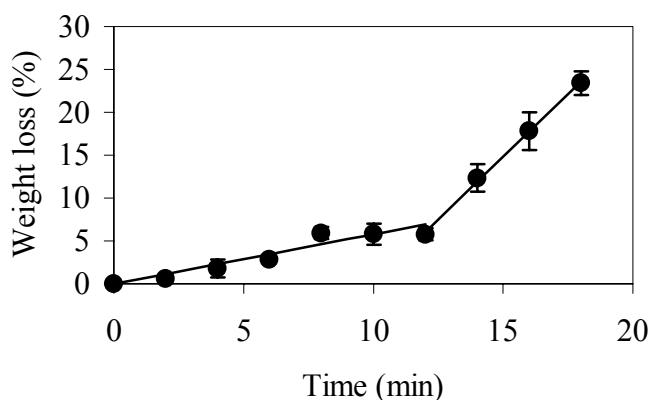
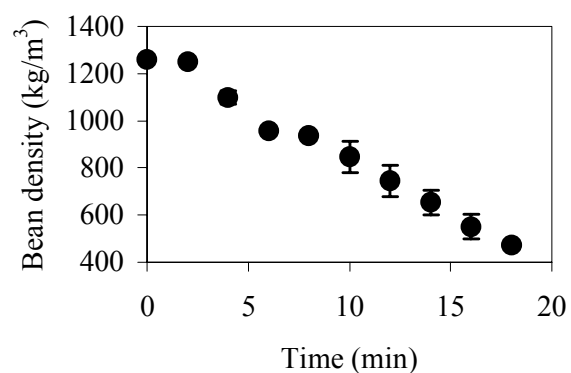
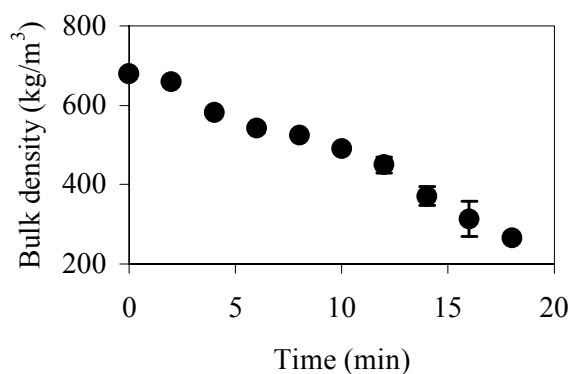


Figure 3. Weight loss during roasting.

The average bean density and the bulk density variation with roasting time are presented in Figure 4. There is a visually significant decrease in both bean and bulk densities during roasting due to the simultaneous increase in volume and decrease in mass. The measured values are in agreement with those reported in the reviewed literature (Table 2).



(a)



(b)

Figure 4. Variation of (a) bean and (b) bulk densities with roasting time.

Table 2. Average density values for green and roasted coffee beans (kg/m^3).

Particle Density				
	This study	Sivetz and Desrosier (1979)	Clarke and Macrae (1987)	Dutra et al. (2001)
Before roasting	1260	1200	1250	1284
Light to medium roast	550	720	755	607
Medium to dark roast	470	600	-	438
Bulk Density				
	This study	Sivetz and Desrosier (1979)	Clarke and Macrae (1987)	Dutra et al. (2001)
Before roasting	680	-	700	707
Light to medium roast	314	-	369	304
Medium to dark roast	265	-	289	250

Results for color parameters are presented in Figures 5 and 6. Luminosity (L^*) decreases during roasting, due to the darkening of the beans resulting from sugar caramelization and Maillard reactions. Similar behavior was observed for Robusta coffee (Mendes et al., 2001). These authors also obtained higher values of luminosity for ground coffee compared to whole roasted beans, as observed in the present study. This behavior indicates that roasting occurs from the outside of the beans. It was also observed that luminosity decreases more rapidly during the pyrolysis stage and that the difference in luminosity values between ground and whole beans decreases during that period.

Chroma remains approximately constant during the first four minutes of roasting, increases for a few minutes and then decreases during pyrolysis. Higher values were observed for the whole beans compared to ground coffee. Again, this difference could be attributed to the lack of color uniformity from the surface towards the interior of the coffee bean. Variation of the hue angle for whole beans is characterized by a decrease in angle accompanied by a decrease in luminosity, with the corresponding color changing from light greenish brown to very dark brown. Variation of the hue angle for the ground beans can be divided into three steps, with the corresponding colors varying from light green in the beginning, passing from light yellowish brown to dark

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brown. Differences in color between ground and whole beans can be assessed by evaluation of the total color difference parameter, as shown in Figure 7. These results indicate that bean color tends to become more uniform towards the end of the roasting process.

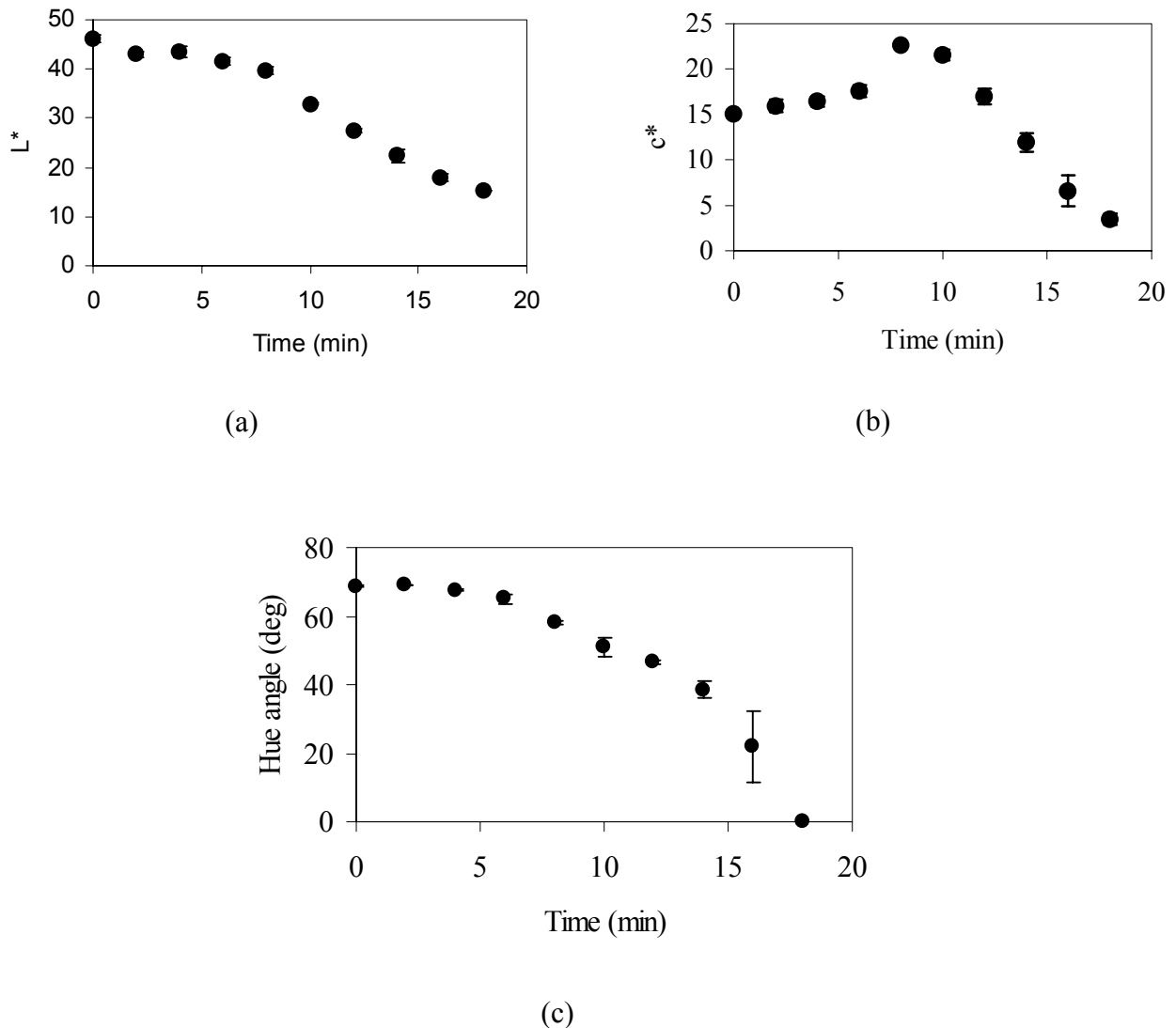


Figure 5. Variation of color parameters with roasting time for whole beans (a) luminosity (b) chroma and (c) hue angle.

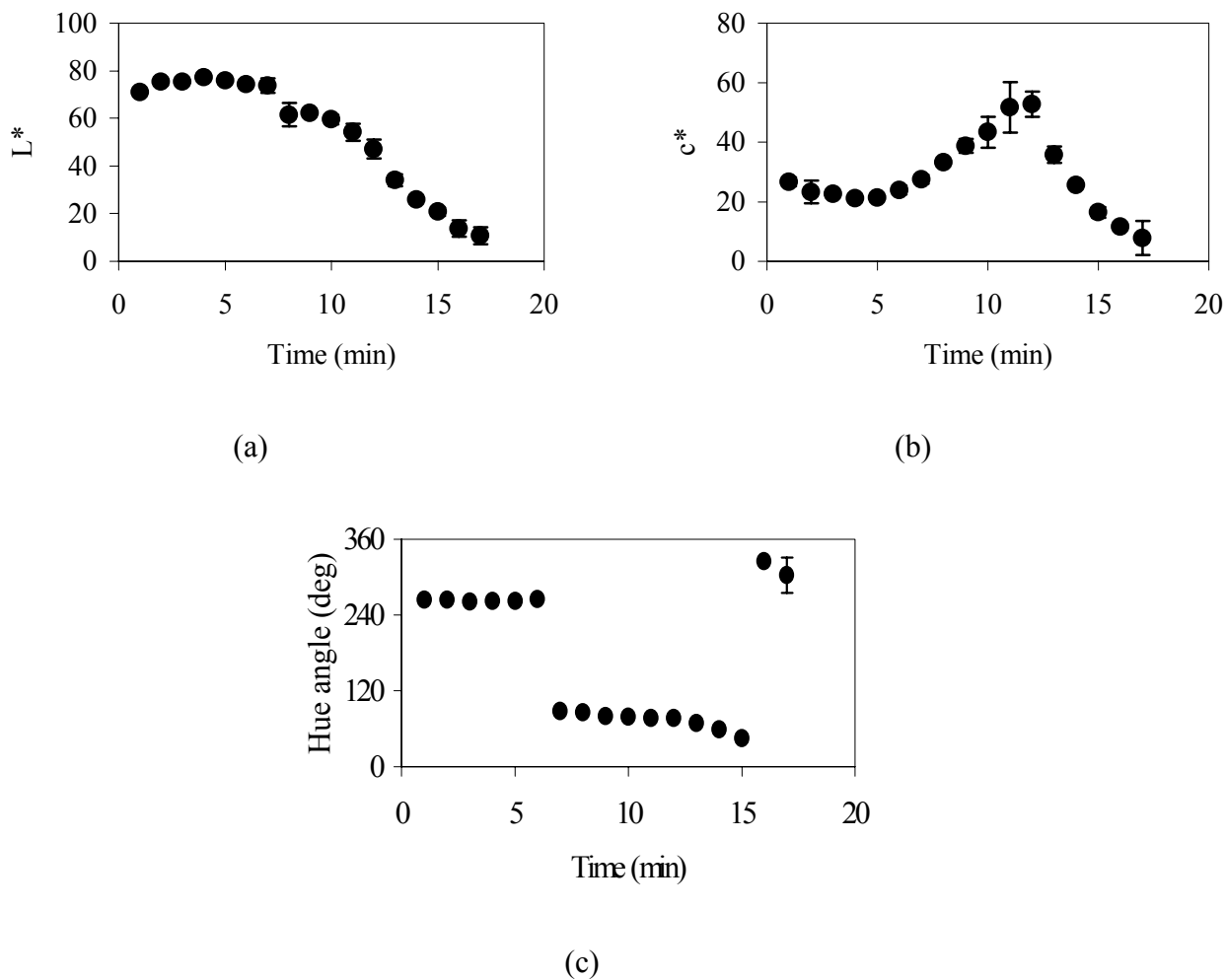


Figure 6. Variation of color parameters with roasting time for ground beans (a) luminosity (b) chroma and (c) hue angle.

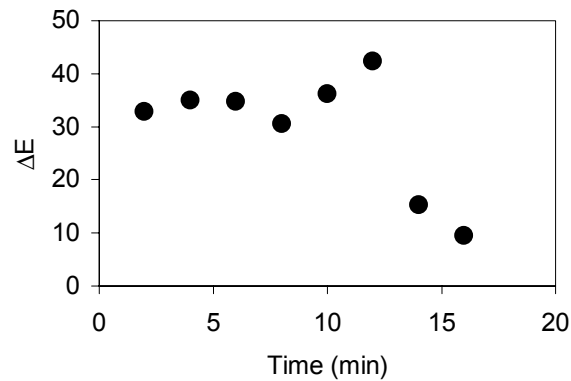


Figure 7. Variation of the total color difference parameter during roasting.

CONCLUSIONS

The main objective of the present study was the evaluation of the variation of physical properties of coffee beans during roasting. The evaluated characteristics were: volume, apparent and bulk densities, weight loss and color. The results show that both volume and weight loss increase during roasting, and that such increase can be described by two straight lines presenting different slopes. The transition between slopes is associated to the start of pyrolysis reactions. There is a significant decrease in both bean and bulk densities during roasting, due to the simultaneous increase in volume and decrease in mass. Color was evaluated for both whole and ground coffee beans. It was observed that luminosity decreases during roasting, more rapidly during the pyrolysis stage. Ground coffee presented higher luminosity values compared to whole roasted beans, showing that roasting occurs from the outside towards the inside. It was also observed that bean color tends to become more uniform towards the end of the roasting process. Further studies will be conducted aiming the correlation of the evaluated properties with roasting conditions (roasting temperature and cylinder rotation speed) and product quality (chemical composition and cup quality).

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