

Stability of the color of roasted coffees stored in different packaging

Laís de Oliveira Silva¹, Flávio Meira Borém¹, Gabriel Carvalhaes Heinerici², Marcelo Ângelo Cirillo³,
Ana Paula de Carvalho Alves^{1*}, Luana Haeberlin⁴, Cláudia Mendes dos Santos¹

¹Universidade Federal de Lavras/UFLA, Departamento de Engenharia Agrícola, Lavras, MG, Brasil

²Universidade Federal Fluminense, Escola de Engenharia, Niterói, RJ, Brasil

³Universidade Federal de Lavras/UFLA, Departamento de Estatística, Lavras, MG, Brasil

⁴Universidade Federal de Viçosa/UFV, Departamento de Engenharia Agrícola/DEA, Viçosa, MG, Brasil

*Corresponding author: anapaula.alves@ufla.br

Editor: Samuel Pereira de Carvalho

Received in October 21, 2024 and approved in December 18, 2024

ABSTRACT

The aim of this study was to evaluate the color behavior (L^* and a_g) and the stability of melanoidin molecules in roasted coffees with different roasting levels, types of packaging and storage conditions. Two roasting intensities were performed (medium roast and dark roast), following the SCA protocol for specialty coffees. The samples were stored in two types of packaging (permeable packaging and hermetic packaging with valve) and evaluated in eight storage times (1, 24, 48, 72, 240, 480, 1080 and 1440 hours) after roasting. The packaging interfered in the preservation of both the color of the roasted coffee and the melanoidin content over time. The permeable packaging allowed greater color loss, a difference also noted when evaluating the L^* . For medium roast coffees stored in hermetic packaging, the maximum storage time should be up to 200 hours, while for dark roast beans when stored in hermetic packaging, the storage time was up to 480 hours. Greater stability of melanoidins was observed for coffees stored in hermetic packaging, with averages of $0.37 \text{ g} \cdot 100 \text{ mL}^{-1}$, while for coffees stored in permeable packaging the average was $0.34 \text{ g} \cdot 100 \text{ mL}^{-1}$, probably due to the oxidation of melanoidin molecules that reacted with oxygen and relative humidity of the ambient air. It is concluded that hermetic packaging presented a greater capacity for preserving the initial characteristics over the storage time, while permeable packaging allowed the loss of color of the roasted beans due to storage and possible modifications of the melanoidin molecules.

Key words: Agtron; luminosity; hermetic packaging; permeable packaging.

1 INTRODUCTION

Coffee beverages are usually consumed hot and prepared by different methods, depending on the social, cultural and geographical context of the consumer region (Angeloni et al., 2019). For a quality coffee beverage, the roasting process has a great influence, since at this stage the coffee beans undergoes physicochemical transformations (weight loss, volume increase, moisture reduction and change in color), giving rise to grains of brown color with various organoleptic properties (aroma, taste and color), responsible for the quality of the drink (Alcantara; Dresch; Melchert, 2021; Lu et al., 2023). The coffee roasting profile, a term widely used in research and industry, It refers to the roasting process used, in order to develop the characteristic flavor and aroma of coffee.

Roasted profile is divided into a light, medium or dark roasting, and is defined by the time of exposure to heat and the air flow during the process. After this stage, coffee cools/rest and then packed as grain roasted coffee to be stored and sent to the market. When packed and sold, the identification of the lot and the expiration date are the responsibility of the packer (Brasil, 2010), however, it is necessary to be more care in the commercialization of roasted coffee, as several factors can influence the conservation and, consequently, in its final quality delivered to the consumer (Zhang et al., 2024).

It is understood that the desirable preservation of sensory attributes is directly depended on the storage conditions of

this product (Borém et al., 2013) that goes through relatively long periods in supermarket gondolas without controlled and adequate conditions. The packaging is responsible for protecting roasted coffee from external elements, such as humidity, light, oxygen and heat, which can affect its color and, consecutively, the taste and aroma of coffee (Lloyd et al., 2019).

Roasted coffee is considered a stable product on a shelf, from the point of view of food safety, when stored with water less than 5% (Smrke et al., 2022). However, oxygen barrier properties, moisture and impact resistance are basic characteristics of a roasted coffee package to avoid oxidation and preserve the scent of coffee (Borém et al., 2021). Thus, coffee packaging materials are currently composed of three layers of films: multi -formal polyethylene (PET), aluminum (AL) and low density linear polyethylene (LLDPE) (Tyagi et al., 2021). This type of high barrier packaging (hermetic) allows physical protection for coffee beans, slowing oxidative coffee aroma degradation, subsequently reducing freshness loss (Glöss et al., 2014). However, permeable packaging, such as paper, has limited application for use in food products and grain or ground coffee, due to their limited properties of barrier to gases and hygroscopicity (Borém et al., 2021).

Despite being considered stable, freshly roasted coffee has changes after roasting (Smrke et al., 2022). Due to intense chemical transformations that occur in the process of roasting, grain and ground roasted coffee produce a large amount of carbon dioxide, reaching a maximum of 1.5% of

the product mass (Lee et al., 2022). The liberation of this CO₂ causes the volatile coffee composition to begin to deteriorate after roasting, requiring suitable packaging and storage to preserve aroma and flavor (Smrke et al., 2022). The impacts of this phenomenon and storage conditions on the volatile and non-volatile chemical composition of roasted coffee beans have already been clarified in the literature (Augustini; Yúsya, 2020), however the impacts on roasted coffee grain color changes, still They are unknown.

Color is a crucial sensory characteristic for defining the acceptability of many consumer food products, which relevant the study and control of color development during food processing (Rodríguez et al., 2019). Some chromatic parameters can be instructed instrumentally using the CIELAB coordinate system defined by the Commission Internationale de l'éclairage - CIE 1976, such as parameter L*, which translates the variation of brightness, ranging from zero 0 - black color up to 100 - white color, as described by Borém et al. (2008). Another chromatic parameter is the AG (Agtron), which was developed specifically for roasted coffee and is part of a Roast Color Classification System) SCA (Specialty Coffee Association) and the classification may vary inside From the 25 scale, established as “very dark”, up to 100 defined as “very light”.

Melanoidins are generally polymeric macromolecular compounds that give dark brown color in many thermally treated foods such as coffee, cocoa, bread and vinegar (Wang et al., 2021). This group is generated through Maillard's reactions, between the amino group of an amino acid, protein or vitamin E the carbonyl group of an oxidized lipid sugar or lipid (Rufián Henares; Pastoriza, 2016), and result in a complex structure that has Its composition strongly dependent on the nature of food and processing conditions, thus the detailed structure of melanidin is not known (Murata, 2021; Pérez-Burillo et al., 2020).

In coffee, the structural elucidation of melanoidins is hampered by the extreme complexity and diversity of their structures, as well as the difficulty of isolation of pure melanoidin fractions (Moreira et al., 2012). They are produced from D-Glucose and L-Alanine under alkaline and high temperature conditions (> 200°C), have lower molecular weight than melanoidins found in bread and cookies (Wang et al., 2021) and usually incorporate phenolic compounds such as chlorogenic acids or catechins (Murata, 2021). There are studies that report that phenolic compounds incorporated into the structure of melanoidins have health benefits (Machado et al., 2023; Yang; Fan; Xu, 2022) with many potential biological properties, including antioxidant, antimicrobial, anti-inflammatory, antihypertensive, and antiglycative properties (Moreira et al., 2012) as well as prebiotic effects (Shaheen et al., 2022).

Studies from food sectors similar to coffee, such as cocoa and tea, demonstrate that the stability of the color e

and melanoidins is also a critical aspect. Roasting and storage affect the formation, stability, and antioxidant properties of melanoidins in cocoa (La Mantia et al., 2023; Lima et al., 2024). Melanoidins and pigments related to teas, especially in varieties such as black and oolong tea, undergo changes during processes such as fermentation, drying, and storage (Iriondo-DeHond et al., 2020; Olennikov; Kirillina; Chirikova, 2021).

Given the above, it is well established that roasted coffee beans undergo significant changes in both volatile and non-volatile chemical compositions, largely influenced by packaging and storage conditions. However, limited information exists on how these same conditions affect the preservation of key quality components, particularly color and melanoidins. Melanoidins play a dual role by contributing to the characteristic color of roasted coffee and offering potential health benefits due to their bioactive properties, making their stability crucial for both industry and consumer interests. Additionally, the stability of coffee's color is closely linked to consumer perceptions of freshness and quality. Any degradation in color may negatively impact perceived product value, underscoring the importance of optimizing storage conditions to meet consumer expectations.

This study aims to evaluate the behavior of Agtron (AG) values, luminosity (L*), and melanoidin content in roasted coffee at two roasting levels (medium and dark), stored for up to 60 days in a controlled environment.

2 MATERIAL AND METHODS

2.1 Sample preparation

The raw coffee beans used in this research are of the species *Coffea Arabica* L., originated from the Serra do Cabral region, at 1100 m altitude, located in the center-north of the state of Minas Gerais, Brazil, produced under natural processing. The moisture content of the coffees purchased for the experiment was 11.5%. Only flat beans from 16 to 18/64 inch sieves were used. Subsequently, all defective, imperfect beans were removed from the sample. This procedure aims to standardize and, above all, minimize interferences that are not related to the different pigments in the growing environment, the varieties tested separately in the function of the fruit color and the processing methods.

The sample roasting was carried out in a 5 kg-capable Attila torsion and coupled to the torsal, the Artisan 2.6.0 software-showroom coffee, for monitoring and standardization of the roasting, was used. Detailed data with a high degree of process control as described below were obtained.

Two distinct roasts for 3 kg were made, following the protocol developed by the SCA for specialty coffees. For the two profiles (medium and dark roasting) the roasts were conducted similarly, as observed in Artisan software (Figure 1).

The definition of the color pattern was effected by determining the Agtron color of the ground roasted grains. For medium roast profile, the Agtron standard of the ground samples, immediately after the roasting, was between Ag 60 and 65. For roasting named as dark, immediately after the roasting, the Agtron standard of the ground samples was between Ag 50 and 55. The medium roast was performed at a time of 10 minutes and 58 seconds, final temperature of 208 °C and final mass of 2650g (350g reduction); And the dark roast had the process completed in 11 minutes and 30 seconds, final temperature of 213 °C and final mass of 2615g (385g reduction). Thus, there was a temperature difference of 5 °C and 32 seconds of roasting time between the two roasting patterns.

After the roasting, the experiment was conducted in randomized block design (DBC) with three repetitions, in a 2x2x8 factorial scheme, corresponding to roasted profiles

(medium and dark roasting), two storage packaging (permeable and hermetic packaging with valve) Eight storage periods after toast (1h, 24h (1 day), 48h (2 days), 72h (3 days), 240h (10 days), 480h (20 days), 1080h (45 days) and 1440h (60 days). These samples were stored in a controlled temperature of 25 °C.

The permeable package consisted of a plastic container, wrapped in a kraft paper package, simulating traditional coffee packaging whose material is permeable and allows water vapor exchanges and gases with decreased light contact. The impermeable packaging was composed of laminate material being one of the metallic components (PET or BOPP-Bi-orientated polypropylene), with a function of high barrier to gases, water vapor and light. This packaging has also coupled a “one-way” valve system, which allows the CO₂ produced by the roasted grain to be eliminated inside the package without the entry of the environment (Alves et al., 2003).

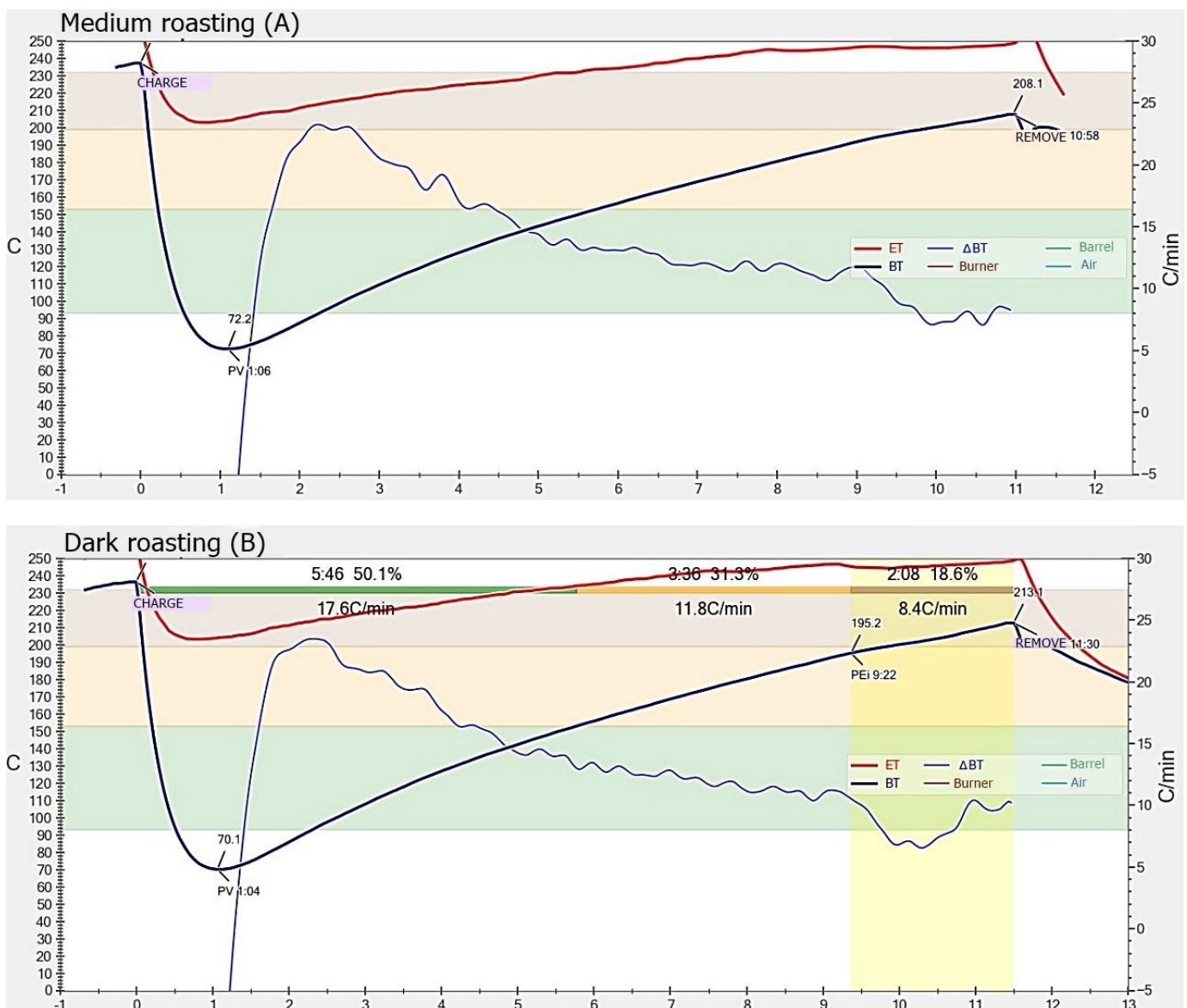


Figure 1: Roast profiles developed for medium roast (A) and dark roast (B) by Artisan 2.6.0 software - Showroom coffee.

2.2 L* and Agtron Color analysis

The color was determined in the whole and ground grains. For analysis of the internal color of the grain (ground coffee), the roasted grain was grinded in the G3A HD Black model, BUNN brand, regulated for thin grinding, suitable for strained coffee. The reading of color parameters was performed in Colormeter/Delta Color Delta Delta D.0° Spectrophotometer, measured by reflectance and spectral range between 400nm and 700nm. This instrument has a coffee calibration program, with repeatability and reproducibility parameters that involved reading a series of color patterns measurements. For the analysis, the instrument was previously calibrated with D65 lighting source and 10° observation angle.

Approximately 15 g of grain roasted coffee and 13 g of ground roasted coffee was inserted without compacting, filling the container provided by the equipment. In the same determination, the equipment read the parameters L* (Luminosity) and AG (Agtron). The scale at Delta Vista is from Agtron & Specialty Coffee Association of America (SCAA), consisting of 8 roasted coffee color discs with values of 25 to 95, being 25, 35, 45, 55, 65, 75, 85 and 95, according to Table 1. In the equipment, the software performs linear calculations to inform values proportional to measured color, and may reach values such as 20, 21, 46, etc. Parameter L* has its scale between 0 (absolute black) and 100 (absolute white).

Table 1: Roasted coffee color classification compared to the Agtron scale (Agtron -SCAA, 1995).

Bulk Roast Classification	Agtron Number
Very Light	95-100
Light	85-90
Moderately Light	75-80
Light Medium	65-70
Medium	55-60
Moderately Dark	45-50
Dark	35-40
Very Dark	25-30

The analysis of the Ag and L* color was performed in duplicate for all evaluation times and after reading, the portions of ground roasted coffee were packed in 50ml Falcon® tubes and stored in biofreezer at a temperature of -81°C, to subsequent analysis of melanidin estimation.

2.3 Melanidins Estimation Analysis

For melanoidins estimation analysis, 3 g of ground coffee samples were infused by 50 ml of ultra pure water at 98 °C (6% proportion). Then the infusion was filtered into a plain paper filter. The filtered solution was diluted 1:20 and homogenized in vortex. The reading was performed in

triplicate in the Spectrophotometer of the Bel Engineering brand, model UV-M51, at 420 nm second Portela et al. (2021).

2.4 Statistical analysis

The adjustment of response surface models was performed considering the combination of smoothers cubic polynomials, with new experimental points interpolated in the experimental region, defined by luminosity (L*), Agtron (AG) and storage time (T) factors.

The specification for each polynomial in each factor was given, according to Equations 1 to 3.

$$L^*(y) = a(L^*y^3) + b(L^*y^2) + c(L^*y) + d(L^*), \quad (1)$$

$$Ag(y) = a(Agy^3) + b(Agy^2) + c(Agy) + d(Ag), \quad (2)$$

$$T(y) = a(Ty^3) + b(Ty^2) + c(Ty) + d(T), \quad (3)$$

Being y, a sequence of values defined by $0 \leq y \leq 1$, ranging every 0.05 units. Therefore, the combination of estimated values, represented by $[L^*(\hat{y}), Ag(\hat{y}), T(\hat{y})]$, a grid of experimental points was generated, making it possible to plot the response surfaces (Foley, 1990).

The L* color coordinate is viewed on a vertical axis ranging from 0 (black) to 100 (white), so high values from L* represent lighter colors while darker colors occur in lower values (Ferreira; Spricigo, 2017), in this case it is not necessary to convert the graph values through the equation, occurring a proportionally direct conversion between the values.

The results of the melanidin estimation analysis were subjected to variance analysis using the Sisvar 4.2 statistical program (Ferreira, 2011). When significant differences were detected due to storage packaging over the storage time, the averages were compared using the Scott-Knott test. This analysis was performed, precisely because it has a robust normality assumption and characterizing a multiple comparison test not being conservative, with moderate type I error control rates at the nominal level of 5% significance level (Girardi; Cargnelutti Filho; Storck, 2009).

3 RESULTS

3.1 Coffee beans color analysis

Color analysis was performed through contour charts, elaborated with the abscissa indicating the storage time (in hours), the ordered representing the color coordinate L* (Luminosity) and the contour curves representing the Agtron of the coffee roasted. The color graph has the Agtron scale of the smallest for the highest quantity, determined experimentally, going through shades of blue, green, yellow, orange to the red color, respectively.

The effect of storage time on the color characteristics of the medium and dark roast coffee beans stored in permeable and impermeable packaging is presented in Figure 2. The parameter estimates of the adjusted model presented in Figure 2 are described in Table 2.

Table 2: Estimates of the adjusted model parameters from the response surface graphs presented in figure 2.

Medium roast coffee beans in hermetic packaging ($R^2=0,9930$)			
Coordinate	Estimate	Standard Error	P-value
L* (luminosity)	1.3976345	0.0121088	< 2e-16 *
Time	-0.0076951	0.0005788	4.51e-11 *
Medium roast coffee beans in permeable packaging ($R^2=0,9953$)			
Coordinate	Estimate	Standard Error	P-value
L* (luminosity)	1.129975	0.029501	<2e-16 *
Time	0.001292	0.001419	0.374
Dark roast coffee beans in hermetic packaging ($R^2=0,9986$)			
Coordinate	Estimate	Standard Error	P-value
L* (luminosity)	0.940942	0.011942	< 2e-16 *
Time	-0.004244	0.000564	4.11e-07 *
Dark roast coffee beans in permeable packaging ($R^2=0,9920$)			
Coordinate	Estimate	Standard Error	P-value
L* (luminosity)	0.9179210	0.0096681	<2e-16 *
Time	0.0007968	0.0004571	0.0974 .

Legend: R^2 = coefficient of determination.

Analyzing the color and time coordinate charts for the medium roasting grains stored in the two different packaging (Figure 2A and 2B), it is noticed that the shades of the grain measured in time range from 34 (very dark/dark color) to 54 (moderately dark/ medium color). While dark roast grains stored in the same types of packaging as the medium roast (Figure 2C and 2D) had agron shades between 30 (very dark color) and 38 (dark color).

It was observed that the external coloration of the medium roasted grains as have very dark coloration. This probably occurred due to the color gradient that can occur between the end and center of the grain, during the roasting process, where the energy is transferred from the outer limit of the grains to the interior, causing to chemical and physical changes. It was found that these same samples when ground had color within the standard range for medium roast.

It is noted that for stored roasted grains, there is a reduction in Luminosity (L^*) to the 360 h storage period (15 days), regardless of the roasting profile and storage packaging. This fact suggests that the reactions triggered by the roasting may still be influencing the stability of the compounds up to 360 hours after the roasting and that these transformations reduce the luminosity of the toasted grain surface.

The data obtained for roasted grains within the medium roasting scale stored in hermetic packaging (Figure 2A) showed that to maintain the initial ages of Ag for the maximum storage time, L^* values must be maintained below 39.25 (Figure 2A), or if there is a variation in coordinate values L^* , the maximum storage time should be up to 200 hours. Grain color stability changed under light conditions greater than 39.25 and storage time over 200h, with grain whitening. Medium roasted grains stored in a permeable packaging clarified over time of storage when luminosity reaches values exceeding 39.40, while in the early hours, and it is possible from the graph to perceive greater changes.

In the whole grains with dark roast (Figure 2C and 2D), when stored in hermetic packaging (Figure 2C), the darker shades of the grain remains throughout the storage time, with a slight whitening in the luminosity condition above 38.60 and storage time up to 480h, however, even with this noticeable whitening by the equipment, the grains remain classified as a dark roasting. The opposite is observed in permeable packaging (Figure 2D), where the only condition in which the initial color classified as very dark remained was in the triangular region on the left, with storage time up to 360h and light below 38.60. Excluding this small triangular area, at any other point in the graph there is a grain whitening. Thus, most of the time analyzed, the grains clarified according to growing luminosity, demonstrating the influence of color packaging over time, as the primary color of the dark roasting only remained in the early hours.

The roasted and stored grains were ground and the homogenized powder for the general evaluation of coffee color changes.

Thus, the contour curves are presented in Figure 3 to evaluate the shade of Agron and overall luminosity of the grains that were moved, over the storage time in permeable and impermeable packaging. The parameter estimates of the adjusted model presented in Figure 3 are described in Table 3.

Color coordinates over the storage time of roasted grain and classified within the medium roasted when ground display Agron shades between 58 and 62 (Figure 3A) for impermeable packaging, showing that classification as medium color is correct and, between 56 a 62 (also medium color) in Figure 3B (permeable packaging). While the grains classified as dark roast, they showed the shades range from 42 to 52 (dark/moderately dark color) in Figure 3C (hermetic packaging) and from 42 to 64 (medium/ light medium color) in Figure 3D (permeable packaging) when were ground.

Coffee with medium roast stored in hermetic packaging (Figure 3A) had a slight tendency to darken during storage, with ages of 58, from 1000h (about 42 days) of storage, regardless of Luminosity. In the permeable packaging (Figure 3B) it is observed that ground coffee has a tendency to lighten as there is an increase in Luminosity regardless of storage time.

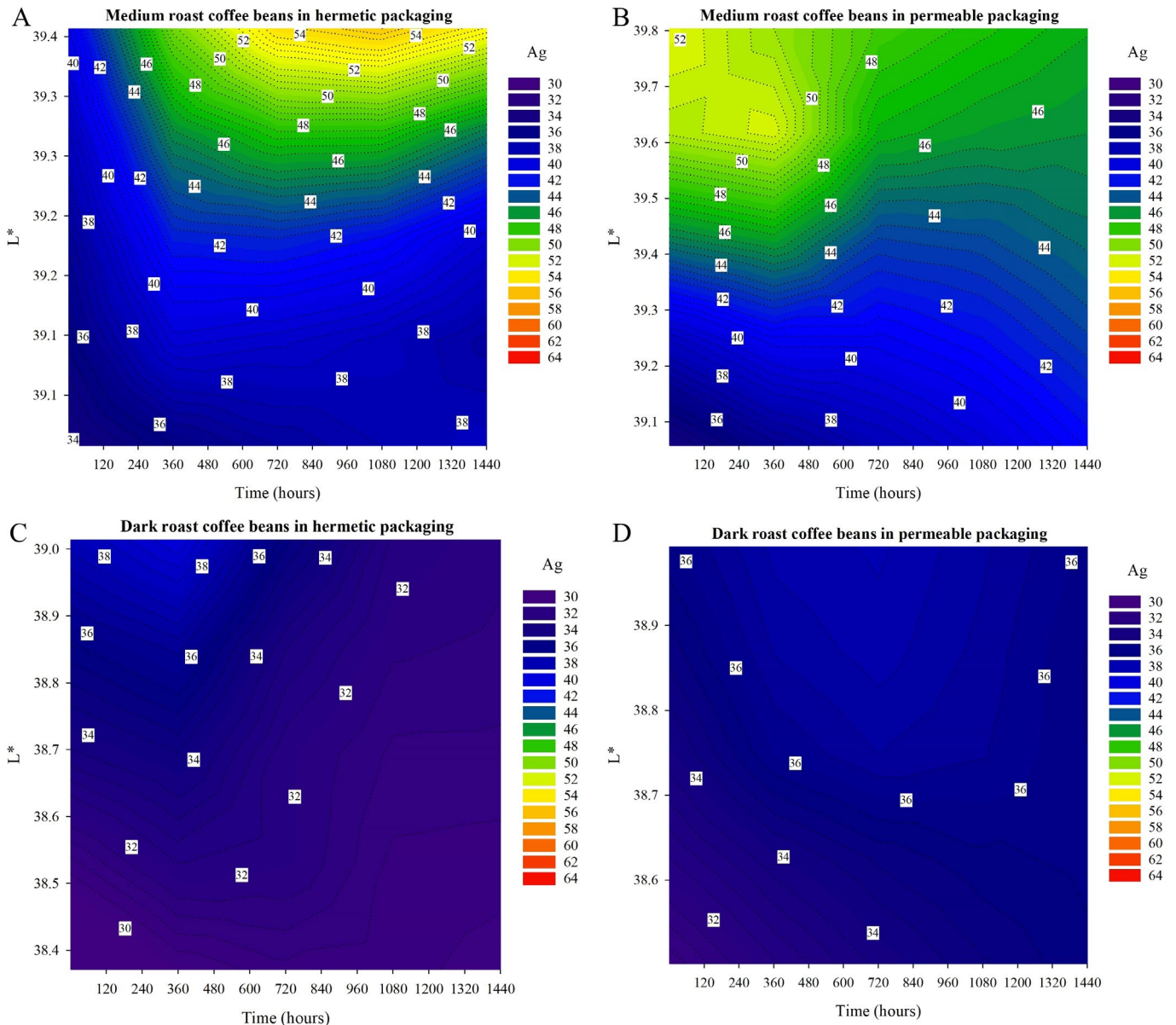


Figure 2: Contour plot for color analysis of roasted coffee samples, in beans, stored in different packages.

For the ground coffees roasted within the dark tone scale, the protective influence of packaging over the storage time is more noticeable, as the coffees preserved in hermetic packaging (Figure 3C), presented in different storage times small color change (42 A 52 - dark/ moderately dark color), being dependent on Luminosity. In lower luminosity values (below 38.40) or in higher values (above 39.00) for a certain time the tones have become darker in ground coffees. When analyzing samples stored in permeable packaging (Figure 3D), the color of ground coffee ranged from 42 (dark color) to 64 (medium / light medium color). This color variation is found when Ag reaches 64, at the beginning of storage from 240h (10 days) in light above 39.00. In longer periods of storage (1080h, 45 days) the grain reaches the value of Ag of 64 in light below 38.9. In this condition, it is observed that the permeable packaging favored the color change

of roasted coffee, allowing significant whitening detected when roasted grains are ground. There is a large variation in the Ag scale (24 points) for the coffees packed in permeable packaging, while the variation for coffee stored in hermetic packaging was an average of 10 points on the Ag scale.

The relative humidity variation shown in Figure 4 represents the oscillation of this parameter in the environment where the coffees were stored, which may have contributed to coffee color changes, especially in permeable packaging due to the change of gases, water and light between the product and the environment. It was possible to identify in the experiment that coffee stored in hermetic packaging, maintained the initial color of the roasting, being preserved the same tone over time, unlike cafes stored in permeable packaging, which reached high values for Ag (over 64).

Table 3: Estimates of the adjusted model parameters from the response surface graphs presented in figure 3.

Ground coffee from Medium roast coffee beans in hermetic packaging ($R^2=0,9239$)			
Coordinate	Estimate	Standard Error	P-value
L * (luminosity)	0.683647	0.172427	0.00083 *
Time	0.012010	0.006805	0.09363
Ground coffee from Medium roast coffee beans in permeable packaging ($R^2=0,9970$)			
Coordinate	Estimate	Standard Error	P-value
L * (luminosity)	1.5246125	0.0043264	< 2e-16 *
Time	-0.0019754	0.0002095	1.34e-08 *
Ground coffee from Dark roast coffee beans in hermetic packaging ($R^2=0,9965$)			
Coordinate	Estimate	Standard Error	P-value
L * (luminosity)	1.285865	0.025533	< 2e-16 *
Time	-0.003780	0.001199	0.00523 *
Ground coffee from Dark roast coffee beans in permeable packaging ($R^2=0,9930$)			
Coordinate	Estimate	Standard Error	P-value
L * (luminosity)	1.4106285	0.0119037	< 2e-16 *
Time	-0.0075501	0.0005628	3.86e-11 *

Legend: R^2 = coefficient of determination.

In this experiment, the storage of the coffees was performed in an environment with controlled temperature (around 25°C), however, the relative humidity is variable, having incidence on the maintenance of coffee color and thus, affecting color throughout from time to permeable packaging, confirmed by Benković and Tusek (2018) who pointed out a significant influence on intrinsic factors (sample moisture content) and external (UR and temperature) in the color change of roasted coffee. It can be observed in the graph (Figure 4), the climatic conditions of the coffee storage environment and how the relative humidity of the environment was variable and remained in high rates.

How much darker the roast, the closer to the black color the grain is, and the lower the color coordinates (Lawless; Heymann, 2010). According to Yeager et al. (2022), the closer to black the values become, the more difficult to detect color differences, which is why dark roasts tend to have the lower significant differences. These statements corroborate the results found, in which it was observed for dark roasts in the smaller amplitude of the color, compared to the roasted coffees and stored in permeable packaging. According to Smrke et al. (2022) in hermetic packaging, a modified atmosphere is created that protects coffee within the packaging, however, the immediate change of the composition of the modified package environment to essentially ordinary air, when this package is open and there is contact with the ambient air, it makes coffee much more exposed to oxidative degradation and, consequently, to aging. This fact may explain changes that may have occurred when opening the packaging during the experiment.

3.2 Melanoidin estimation through the UV-VIS spectrum

Melanoidins have a high absorbance, almost completely covering the spectral regime, this light absorption methodology can be used to evaluate contents of high molecular weight structures formed in Maillard's reaction (Mohsin et al., 2018).

Coffee with the average toces have melanoidin content approximately 0.36g 100ml⁻¹ (Figure 5) while the cafes with the darkest roasting a content of approximately 0.32g 100ml⁻¹ with no significant difference between the cafes, according to the cafes, according to With the Scott-Knott test at 5% significance level, right after roasting. However, significance is observed in the concentration of melanoidins according to the storage packaging (Table 4 and Figure 5) and time. The medium roast coffees and dark roasting coffees stored in hermetic packaging showed 0.42g 100mL⁻¹ and 0.40g 100mL⁻¹ melanoidin contents respectively, while the coffees in permeable packaging lost an average of 0.10g 100mL⁻¹ melanidine over 60 days compared to hermetic packaging, with the end of 0.32g 100mL⁻¹ concentration for the medium roast and 0.30g 100mL⁻¹ cafes for dark roasting coffees.

As observed (Figure 5), the hermetic packaging retained the melanoidins with greater efficiency and with slight increase in the content extracted over 60 days. The initial limitation of melanoidin extraction is due to its high molecular weight (> 10 kda) (Moreira et al., 2012). Over time what may have occurred is a slight increase in melanoidin extraction due to probable breaks in the bonds between and chlorogenic proteins, which

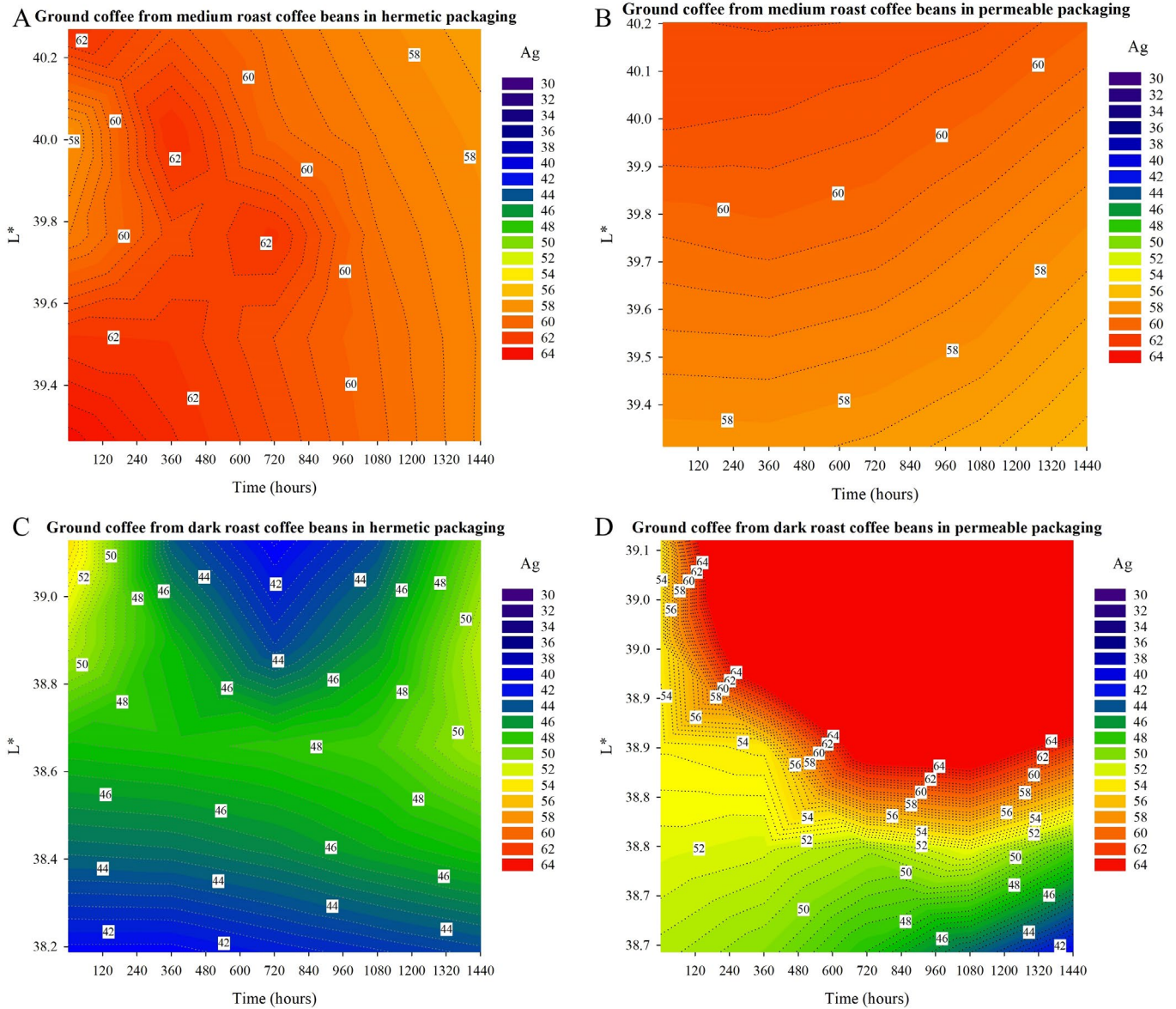


Figure 3: Contour plot for color analysis of ground roasted coffee beans, stored in beans, stored in different packages.

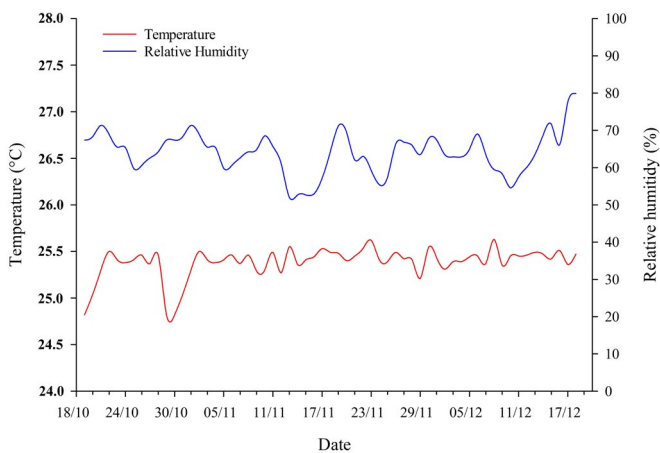


Figure 4: Climatic conditions of temperature and relative humidity of the storage environment of grain coffee roasted.

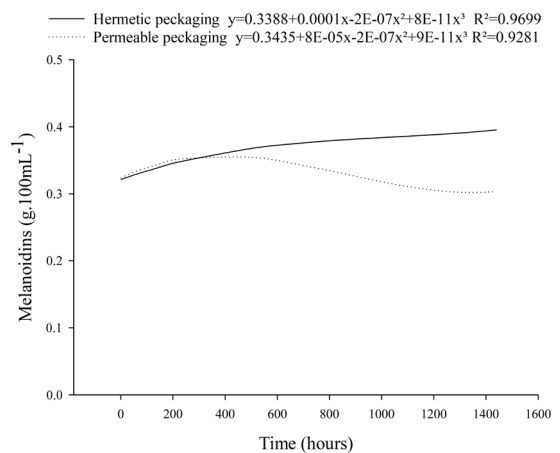


Figure 5: Concentration of melanoidins in each type of packaging during storage over time.

Table 4: Medium values of melanoidine concentrations on each roast and packaging profile over 60 days.

Roast	Packaging	Melanoidins concentration (g.100mL ⁻¹)
Darkroast	Paper	0.33a
Mediumroast	Paper	0.34a
Darkroast	Hermetic	0.36b
Mediumroast	Hermetic	0.37b

The averages followed by different lowercase letters in the column differ by Scott-Knott a test a probability of 5%.

according to literature are part of the constitution of roasted coffee brown macromolecules, which Because they are extremely complex has no fully known structure (Moreira et al., 2012; Nunes; Coimbra, 2010).

The decrease in melanoidin content found in coffees stored in permeable packaging prove with the whitening described in color measurement over time when analyzed Ag and L*. The roasted coffee is susceptible to loss of quality by exposure to oxygen and moisture and storage in high temperatures, occurring oxidation of the substances responsible for aroma and taste (Alves et al., 2003) and possible degradation of melanidin structures. Color is a primary indicator in the quality assessment of coffee (Ferreira; Bassotto; Castro Junior, 2020; Lawless; Heymann, 2010; Mazzafera et al., 1988) which can denote changes in the sensory characteristics of aroma and taste (Lawless; Heymann, 2010), showing the roasting and consumer that measures should be taken for greater conservation of the products.

4 DISCUSSION

When comparing the data obtained in a whole grain with ground grain, it is observed that in the whole grain the color variation is smaller than the change in ground grains, and these color changes also occur to stored cafes also. In permeable packaging (gases, water vapor and light), possibly due to exchanges with the environment, making these coffees different from the initials.

The sensory evaluation of coffee and the perception of consumers are not only related to the aroma and flavor, but also to the color and appearance of coffee, both in whole grain and ground, and in the prepared drink (Espan-diez et al., 2004). Thus, the forecast of changes that occur in coffee products during storage is of great importance, and influences consumers' perception of product quality (Benković; Tusek (2018), These color changes that occur in coffee are noticeable to the naked eye, but when analyzed without the help of parameters defined through equipment and color coordinates, they are considered very subjective sensory measures (Anisa; Solomon; Solomon, 2017; Dos Santos Scholz et al.,

2018; Kalschne et al., 2019). On the other hand, the color measurement performed by colorimetric analysis instruments is dependent exclusively on the composition of the object by eliminating any lighting or sensitivity eye variations of the observer, so generating concrete, reliable and objective results of the product color and its difference between roast coffee levels (Yeager et al., 2022). Anese, Manzocco and Nicoli (2006) state that color analysis can be used to predict quality during product life, where susceptibility to ambient light, air and temperature can cause coffee degradation reactions and consequently color changes. In this I work we observe that in coffees stored in permeable packaging there was a greater amplitude of color measurement when compared to hermetic packaging, suggesting likely degradations.

In the roasting process, temperature and time of exposure to heat play a crucial role in sensory and color changes, while during storage water content, relative moisture and temperature appear to be the factors that cause greater degradation (Benkovic; Tusek, 2018).

Illy and Viani (2005) confirm that the largest readings of Agtron and L* in ground coffee when compared to the whole grains can be explained by the grinding process that homogenizes the mixture and exposes the less roasted interior of the grain, and according to Kallio et al. (1990), packaging types and packaging permeability are of primordial importance when it comes to coffee storage stability. When stored in a permeable packaging, coffee is especially subject to rapid changes, especially in the content of volatile compounds responsible for its aroma, as well as changes in lipid composition, which affect sensory properties and coffee color (Benkovic; Tusek, 2018).

How much darker the roast, the closer to the black color the grain is, and the lower the color coordinates (Lawless; Heymann, 2010). According to Yeager et al. (2022), the closer to black the values become, the more difficult to detect color differences, which is why dark raosts tend to have the lower significant differences. These statements corroborate the results found, in which it was observed for dark roasts in the smaller amplitude of the color, compared to the roasted coffees and stored in permeable packaging. According to Smrke et al. (2022) in hermetic packaging, a modified atmosphere is created that protects coffee within the packaging, however, the immediate change of the composition of the modified package environment to essentially ordinary air, when this package is open and there is contact with the ambient air, it makes coffee much more exposed to oxidative degradation and, consequently, to aging. This fact may explain changes that may have occurred when opening the packaging during the experiment.

In barley studies, the highest intensity of barley toothpicks for beer production is directly proportional to the largest concentration of melanidin (Patrignani; González-Forte, 2020), reinforced by Yeager et al. (2022) that claim

that increased levels of melanoidins of high molecular weight could explain the darker colors of dark roasted coffee. The same was not observed in this work, in which the greatest intensity of roasting did not have a greater concentration of melanidin, however, it is understood that the roasting has a direct effect on the formation of these molecules. According to Laukaleja and Kruma (2019), coffee roasting is widely investigated, however, it is a great challenge to compare roasting levels between studies because there are different parameters of roasting. Also according to the authors, there are roasting studies that do not specify time and temperature during roasting, given these presented in this study, which is another difficulty in comparing different research, with a need to standardize this process. In agreement, the non-significance in the concentration of melanoidins may have been caused due to the time of roasting, which was close to both shades of roasting (medium and dark), however, this research sought to rigidly follow the scaa procedure to rigid to Specialty coffees (maximum 12 -minute roasting). Specialty coffees have higher standards compared to sensory attributes helping to exclude damaged coffee defects before the roasting and after the roasting process during storage (Laukaleja; Kruma, 2019).

The infusion temperature for the extraction of brown compounds also influences the extraction of melanoidins. According to Yeager et al. (2022) there are two classes of compounds that generate brown pigmentation, melanoidins and the caramelization of sucrose, which suggests the possibility of extraction at different infusion temperatures, although not quite clear as this infusion temperature They affect the end result of the color of the drink where melanoidin analysis is performed.

In addition, the roasting process is responsible for waterfall chemical reactions, with degradation of non -volatile compounds leading to new compounds with potential flavor attributes (Toledo et al., 2016). Melanoidins can be divided into two classes, melanosaccharides (structures composed mainly of polysaccharides), present in beverages such as coffee and beer, and melanoproteins (mainly protein composed structures), present in bakery products (Helou et al., 2016, Pastoriza; Rufián Henares, 2014), thus, are polymer products divided into three levels based on their molecular weight: low, intermediate and high (Bekedam et al., 2008) and the higher the molecular weight of melanidins, but dark is grain of roasted coffee, however, the higher the molecular weight, the more insoluble in water this molecule (Yeager et al., 2022), making it difficult to extraction according to the methodology of this work that was performed by the filtration method.

5 CONCLUSION

In this study, the type of packaging influences the conservation and preservation of both the roasted coffee and melanoidin color over time.

Hermetic packaging showed greater conservation capacity of the initial characteristics over the time of storage, while permeable packaging allowed the loss of color with roasted grain whitening due to storage and possible modifications of melanoidine molecules.

By gauging the color of the grain roasted coffee, there was less variations in the shades of the roasting when compared to ground coffee, where there were greater variations in coffee color over time.

6 ACKNOWLEDGEMENTS

The authors acknowledge CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico), FAPEMIG (Fundação de Amparo à Pesquisa do Estado de Minas Gerais), and INCT Café (Instituto Nacional de Ciência e Tecnologia do Café).

7 AUTHORS' CONTRIBUTION

Conceptual Idea: Borem, F. M.; Methodology design: Borem, F. M; Silva, L. O.; Data collection: Silva, L. O.; Heinerici, G. C.; Alves, A. P. C.; Haeberlin, L.; Data analysis and interpretation: Silva, L. O.; Alves, A. P. C.; Haeberlin, L.; and Writing and editing: Silva, L. O.; Alves, A. P. C.; Haeberlin, L.; Santos, C. M.

8 REFERENCES

- ALCANTARA, G. M. R. N.; DRESCH, D.; MELCHERT, W. R. Use of non-volatile compounds for the classification of specialty and traditional Brazilian coffees using principal component analysis. **Food Chemistry**, 360:130088, 2021.
- ALVES, R. M. V et al. Roasted and ground coffee in nitrogen gas flushing packages. **Food Science and Technology**, 23:22 -27, 2003.
- ANESE, M.; MANZOCCO, L.; NICOLI, M. C. Modelling the secondary shelf life of ground roasted coffee. **Journal of Agricultural and Food Chemistry**, 54:5571-5576, 2006.
- ANGELONI, G. et al. What kind of coffee do you drink? An investigation on effects of eight different extraction methods. **Food Research International**, 116:1327-1335, 2019.
- ANISA, A.; SOLOMON, W. K.; SOLOMON, A. Optimization of roasting time and temperature for brewed hararghe coffee (*Coffea Arabica* L.) using central composite design. **International Food Research Journal**, 24:2285-2294, 2017.

- AUGUSTINI, S.; YUSYA, M. K. The effect of packaging materials on the physicochemical stability of ground roasted coffee. **Current Research on Biosciences and Biotechnology**, 1(2):66-70, 2020.
- BEKEDAM, E. K. et al. Roasting effects on formation mechanisms of coffee brew melanoidins. **Journal of Agricultural and Food Chemistry**, 56(16):7138-7145, 2008.
- BENKOVIĆ, M.; TUŠEK, A. J. Regression models for description of roasted ground coffee powder color change during secondary shelf-life as related to storage conditions and packaging material. **Beverages**, 4(1):1-16, 2018.
- BORÉM, F. M. et al. Avaliação sensorial do café cereja descascado, armazenado sob atmosfera artificial e convencional. **Ciência e Agrotecnologia** 32(6):1724-1729, 2008.
- BORÉM, F. M. et al. Evaluation of the sensory and color quality of coffee beans stored in hermetic packaging. **Journal of Stored Products Research**, 52:1-6, 2013.
- BORÉM, F. M. et al. Volatile compounds indicating latent damage to sensory attributes in coffee stored in permeable and hermetic packaging. **Food Packag Shelf Life**, 29:100705, 2021.
- BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. **Instrução normativa nº 16, de 24 de maio de 2010**. Sistema Integrado de Legislação. Brasília, DF, Brasil. 2010.
- DOS SANTOS SCHOLZ, M. B. et al. From the field to coffee cup: Impact of planting design on chlorogenic acid isomers and other compounds in coffee beans and sensory attributes of coffee beverage. **European Food Research and Technology**, 244(10):1-10, 2018.
- ESTEBAN-DIEZ, I.; GONZALEZ-SAIZ, J. M.; PIZZARO, C. Prediction of sensory properties of espresso from roasted coffee samples by near-infrared spectroscopy. **Analytica Chimica Acta**, 525:171-182, 2004.
- FERREIRA, D. F. Sisvar: A computer statistical analysis system. **Ciência e Agrotecnologia**, 35(6):1039-1042, 2011.
- FERREIRA, M. D.; SPRICIGO, P. C. Colorimetria - princípios e aplicações na agricultura. In: FERREIRA M. D. (Ed. técnico). **Instrumentação pós-colheita em frutas e hortaliças**, São Carlos: Embrapa Instrumentação, p. 209-220, 2017.
- FERREIRA, J. B.; BASSOTTO, L. C.; CASTRO JUNIOR, L. G. Attributes, values and traditional coffee consumption behavior in Brazil. **Espacio Abierto**, 29(4):294-313, 2020.
- FOLEY, J. D. **Computer graphics: Principles and practice**. 2.ed. Washington: Wesley, 1175p, 1990.
- GIRARDI, L. H.; CARGNELUTTI FILHO, A.; STORCK, L. Type I error and power of five multiple comparison procedures for means. **Revista Brasileira de Biometria**, 27(1):23-36, 2009.
- GLÖSS, A. N. et al. Freshness indices of roasted coffee: Monitoring the loss of freshness for single serve capsules and roasted whole beans in different packaging. **Chimia**, 68(3):179-182, 2014.
- HELOU, C. et al. Maillard reaction products in bread: A novel semi-quantitative method for evaluating melanoidins in bread. **Food Chemistry**, 190:904-911, 2016.
- ILLY, A.; VIANI, R. **Espresso coffee: The science of quality**. 2 ed., Amsterdam: Elsevier Academic Press, 2005. 398p.
- IRIONDO-DEHOND, A. et al. Assessment of healthy and harmful maillard reaction products in a novel coffee cascara beverage: Melanoidins and acrylamide. **Foods**, 9(5):620, 2020.
- KALLIO, H. et al. Headspace of roasted coffee as an indicator of storage time. **Food Chemistry**, 36:135-148, 1990.
- KALSCHNE, D. L. et al. Sensory characterization and acceptance of coffee brews of C. arabica and C. canephora blended with steamed defective coffee. **Food Research International**, 124:234-238, 2019.
- LA MANTIA, A. et al. Effect of cocoa roasting on chocolate polyphenols evolution. **Antioxidants**, 12(2):469, 2023.
- LAUKALEJA, I.; KRUMA, Z. Influence of the roasting process on bioactive compounds and aroma profile in specialty coffee: A review. **Foodbalt**, 7-12, 2019.
- LAWLESS, H. T.; HEYMANN, H. Principles of good practice. In: _____. **Sensory evaluation of food**. Food Science Text Series. Springer, p. 55-77, 2010.
- LEE, D. S. et al. Active food packaging to control carbon dioxide. **Packaging Technology and Science**, 35:213-227, 2022.
- LIMA, G. V. S. et al. Impact of post-harvest processing and roasting conditions on the physicochemical properties, phenolic compounds, and antioxidant capacity of cocoa beans from the Brazilian Amazon, **LWT**, 210:116825, 2024.

- LLOYD, K.; MIROSA, M.; BIRCH, J. Active and intelligent packaging. **Encyclopedia of Food Chemistry**, 3:177-182, 2019.
- LU, T. et al. Effects of roasting on the chemical compositions, color, aroma, microstructure, and the kinetics of changes in coffee pulp. **Journal of Food Science**, 88:1430-1444, 2023.
- MACHADO, F. et al. Mechanisms of action of coffee bioactive compounds - a key to unveil the coffee paradox. **Critical Reviews in Food Science and Nutrition**, 20:1-23, 2023.
- MAZZAFERA, P.; GUERREIRO, O.; CARVALHO, A. A cor verde do endosperma do café. **Bragantia**, 47(2):159-170, 1988.
- MOREIRA, A. S. et al. Coffee melanoidins: Structures, mechanisms of formation and potential health impacts. **Food and Function**, 3(9):903-915, 2012.
- MOHSIN, G. F. et al. Structural characterization of melanoidin formed from d-glucose and l-alanine at different temperatures applying FTIR, NMR, EPR, and MALDI-TOF-MS. **Food Chemistry**, 245:761-767, 2018.
- MURATA, M. Browning and pigmentation in food through the Maillard reaction. **Glycoconjugate Journal**, 38:283-292, 2021.
- NUNES, F. M.; COIMBRA, M. A. Role of hydroxycinnamates in coffee melanoidin formation. **Phytochemistry Reviews**, 9(1):171-185, 2010.
- PASTORIZA, S.; RUFIÁN-HENARES, J.A. Contribution of melanoidins to the antioxidant capacity of the Spanish diet. **Food Chemistry**, 164:438-445, 2014.
- OLENNIKOV, D. N.; KIRILLINA, C. S.; CHIRIKOVA, N. K. Water-soluble melanoidin pigment as a new antioxidant component of fermented willowherb leaves (*Epilobium angustifolium*). **Antioxidants**, 10(8):1300, 2021.
- PATRIGNANI, M.; GONZÁLEZ-FORTE, L. D. S. Characterization of melanoidins derived from Brewers' spent grain: New insights into their structure and antioxidant activity. **International Journal of Food Science & Technology**, 56(1):384-391, 2020.
- PÉREZ-BURILLO, S. et al. Bioactivity of food melanoidins is mediated by gut microbiota. **Food Chemistry**, 316:126309, 2020.
- PORTELA, C. S. et al. Brewing conditions impact on the composition and characteristics of cold brew Arabica and Robusta coffee beverages. **LWT - Food Science and Technology**, 143:111090, 2021.
- RODRÍGUEZ, A. et al. Isolation and characterization of melanoidins from dulce de leche, a confectionary dairy product. **Molecules**, 24(22):4163, 2019.
- RUFIÁN-HENARES J. Á.; PASTORIZA, S. Maillard reaction. In: CABALLERO, B.; FINGLAS, P.; TOLDRÁ, F. (Vol. Eds.). **The encyclopedia of food and health**. Oxford: Academic Press, p. 593- 600, 2016.
- SHAHEEN, S. et al. Dissecting dietary melanoidins: Formation mechanisms, gut interactions and functional properties. **Critical Reviews in Food Science and Nutrition**, 62(32):8954-8971, 2022.
- SMRKE, S. et al. Effects of different coffee storage methods on coffee freshness after opening of packages. **Food Packag Shelf Life**, 33:100893, 2022.
- TOLEDO, P. R. A. B. et al. Relationship between the different aspects related to coffee quality and their volatile compounds. **Comprehensive Reviews in Food Science and Food Safety**, 15(4):705-719, 2016.
- TYAGI, P. et al. Advances in barrier coatings and film technologies for achieving sustainable packaging of food products: A review. **Trends in Food Science & Technology**, 115:461-485, 2021.
- WANG, Z. et al. Formation mechanisms and characterisation of the typical polymers in melanoidins from vinegar, coffee and model experiments. **Food Chemistry**, 355:129444, 2021.
- YANG, S.; FAN, W.; XU, Y. Melanoidins present in traditional fermented foods and beverages. **Comprehensive Reviews in Food Science and Food Safety**, 21(5):4164-4188, 2022.
- YEAGER S. E. et al. Roast level and brew temperature significantly affect the color of brewed coffee. **Journal of Food Science**, 87:1837-1850, 2022.
- ZHANG, D. et al. Profiling flavor characteristics of cold brew coffee with GC-MS, electronic nose and tongue: Effect of roasting degrees and freeze-drying. **Journal of the Science of Food and Agriculture**, 104:6139-6148, 2024.