ORIGINAL PAPER

EFFECT OF GROUND AND ROASTED PARAMETERS ON BOTH THE MICROSTRUCTURE OF ARABICA COFFEE BEANS AND COFFEE INFUSION – AN IMAGISTIC STUDY

ALINA MIHAELA CANTARAGIU[1], ANGELA STELA IVAN[1*], PETRU ALEXE[2], CARMELIA MARIANA DRAGOMIR BALANICA[1], MARICICA STOICA[1*]

Manuscript received: 14.09.2020; Accepted paper: 02.11.2020;
Published online: 30.12.2020.

Abstract. *Coffee is one of the most widely consumed beverages. Roasting is a baseline step in coffee processing, being involved in the development of color, flavor and taste for which coffee is appreciated. In addition, the roasting treatment triggers several complex physical changes inside the coffee bean, resulting in density decrease owing to volume increase, increase of beans brittleness, changes in coffee color, loss of bean mass and water, porosity increase, and governs coffee bean behavior during storage, grinding, and brewing. It is essential to examine physical changes, as coffee production is seasonal, and a long-term coffee storage is required. In the present study, the visual and microstructural differences between green and roasted Arabica coffee beans were investigated. The study of microstructural differences was performed using scanning electron microscopy, and clearly showed significant structural differences between green Arabica coffee beans and roasted Arabica coffee beans. The physical and structural modifications of infused coffee with water were explained through chromatic evaluation and microscopic analysis, respectively as function of ground size of roasted coffee beans and infusion time.*

Keywords: *Arabica coffee; roasting process; physical changes; Scanning Electron Microscopy; ground coffee.*

1. INTRODUCTION

Coffee is one of the most widely consumed drinks in the world, owing to its refreshing and stimulating effects, which are determined by the composition of green beans and the changes occurring during the postharvest processing, such as drying, storage, roasting and grinding [1-10]. Roasting, probably the most significant step in coffee processing [8, 11], is generally performed by heating the raw beans at high temperatures (around 200 – 240 °C) for as long as 4 min. to almost 15 min., the roasting temperature and time having an important influence on the sensory quality of the coffee drink [1, 5, 7-19]. The roasting process produces physicochemical, structural and sensory changes, several parameters being used as indicators to determine the degree of the roasting process, such as: aroma, color, flavor, chemical composition, pH, mass loss, and volume [1, 8-12, 15, 17, 20, 21]. The physical changes which occur in the roasting process include weight loss (about 15 - 22 %, due to the water loss and loss of volatile compounds); volume increase (around 50 % to almost 100 %); density decrease (from about 1.3 kg m^{-3} to 0.7 kg m^{-3}); color change and oil migration

[1] Dunarea de Jos University of Galati, Cross-Border Faculty, 80000 Galati, Romania. E-mail: Alina.Cantaragiu@ugal.ro; Angela.Ivan@ugal.ro; Carmelia.Dragomir@ugal.ro; Maricica.Stoica@ugal.ro.
[2] Dunarea de Jos University of Galati, Faculty of Food Science, 800001 Galati, Romania. E-mail: Petru.Alexe@ugal.ro.
**Corresponding authors:* Angela.Ivan@ugal.ro, Maricica.Stoica@ugal.ro.

towards the surface of the coffee bean; strength and toughness loss, coffee beans becoming more brittle (brittleness has a high impact on bean grinding); and organizing a typical porous structure of the roasted coffee bean, porosity increasing to about 0.5 for dark roasted coffee [1, 7-11, 16-18, 20-24]. Coffee production is seasonal, a long-term storage of coffee is necessary, so that exploring its physical characteristics is very important [7]. Even though the structural changes occurring during the roasting process have an important effect on the roasted coffee quality, the structural changes have been scarcely investigated so far.

Liquid coffee is a product obtained from coffee, being intensively used for a long time. In general, composition of the infusion ground coffee is determined by the grain size, infusion time, water pressure, color, high temperature extraction, and structure. The final coffee drink is affected by the chemical reactions which take place during the grinding and infusion processes [25]. Grinding the roasted coffee beans into fine particles enables to extract the coffee oils [26-27] and flavors. The larger the contact surface, the higher the coffee's quality and taste. Coffee contains above 11-20 % lipids related to the dried weight, which are extracted using hot water and defined the final brew taste [28].

One of the objectives of this study was to assess visually and objectively the differences between green and roasted *Coffea arabica* L. (Arabica coffee) beans. The evaluation of structural changes in the roasting process is relevant for packaging, storing, and transporting coffee beans. Further, some physical aspects (*i.e.*, color and morphology) of ground roasted Arabica coffee infusion are investigated. The grinding process of roasted coffee beans affects the chromatic aspect, the sensory taste, and the quality of infused coffee.

2. MATERIALS AND METHODS

2.1. MATERIALS

Two different types of Arabica coffee samples (*i.e.*, green unroasted and roasted beans) were used for visual assessment and Scanning Electron Microscopy (SEM) analysis. Green and roasted beans, produced from the same coffee beans, were acquired from a local coffee commercial distributor (Galati, Romania).

The experimental study continued with the preparation and analysis of coffee infusion. The whole roasted beans were ground at a local coffee point, ensuring a uniform grinding of beans necessary to further obtaining of infused coffee. Three different grain sizes (*i.e.*, 4.0, 5.2 and 9.5 μm) were obtained using an automatic grinding machine of roasted coffee beans. Coffee infusions were prepared through pouring hot water over the ground coffee. The infusion process held 5 min. and 10 min., respectively, thus obtaining six samples for study.

2.2. METHODS

2.2.1. Colorimetric Analysis

Color changing of coffee drops prepared as infusion from three types of ground coffee beans was studied through colorimetry. The concentration of colored compounds into infusion was indicated by three parameters such as, L*, a* and b*, which are measured using the portable colorimeter Chroma Meter CR-400 (Konica Minolta Sensing, Osaka, Japan). The significance of color parameters is: L* shows the brightness component from solution ranged between 0 (black) and +100 (white); a* indicates the green-red component ranging from −120 (green) to +120 (red), and b* corresponds to blue-yellow component from −120 (blue) to +120 (yellow) [29]. The device was calibrated on white.

2.2.2. Scanning Electron Microscopy

The surface and the section of green and roasted Arabica coffee beans were analyzed. The coffee beans were cut by hand with a razor blade [30], and the pieces of coffee beans were mounted on carbon tape placed onto support stubs, then sputter covered with a layer of gold for better conductivity, allowing surface and section imaging with a Quanta 200 system (FEI Company-Thermo Fisher Scientific, Oregon, USA; 30 nm as resolution) with secondary electron detector. All samples were examined in Low-Vacuum mode using an accelerating voltage (HV) of 15 kV [31] and 10 nm as working distance (WD). Several microphotographs were obtained at different magnifications, but only the images at a 2000x magnification were analyzed for structural differences between the green and roasted Arabica coffee beans.

The six samples as drops prepared from infused Arabica coffee were analyzed using the same microscope (Quanta 200) by placing them on a metal support and dried at room temperature. The microstructural evaluation of the infused coffee drops was analyzed at 1000x magnification.

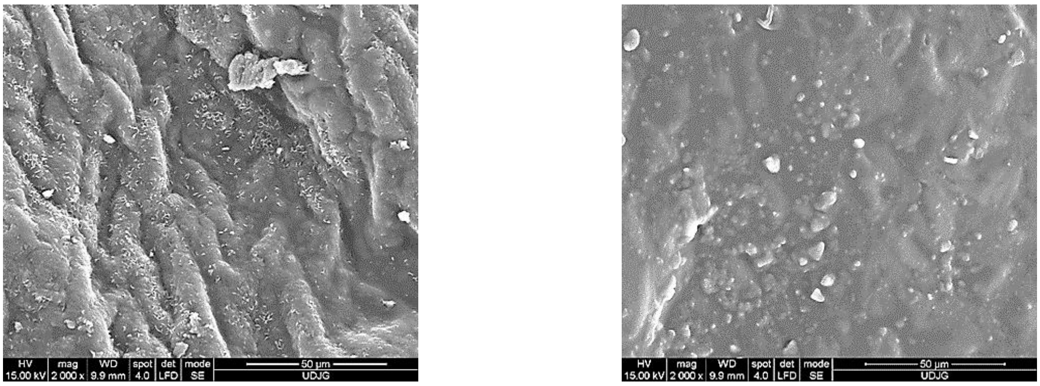
3. RESULTS AND DISCUSSION

3.1. RESULTS

Visual examination correlated with microscopy method was performed on the surface area and the section of green Arabica coffee beans, which were subsequently compared with roasted Arabica coffee beans. The physical differences observed between green and roasted coffee beans are summarized in Table 1. Figs. 1 (a, b) show the micrographs on the surfaces area of green (a) and roasted (b) Arabica coffee beans. Figs. 2 (a, b) show the micrographs of the sections of unroasted (a) and roasted (b) Arabica coffee beans. Fig. 3 shows the chromatic of roasted Arabica coffee prepared by infusion of the grind period. The numbers (17÷22) marked on the metal plates represent the code of the six studied samples.

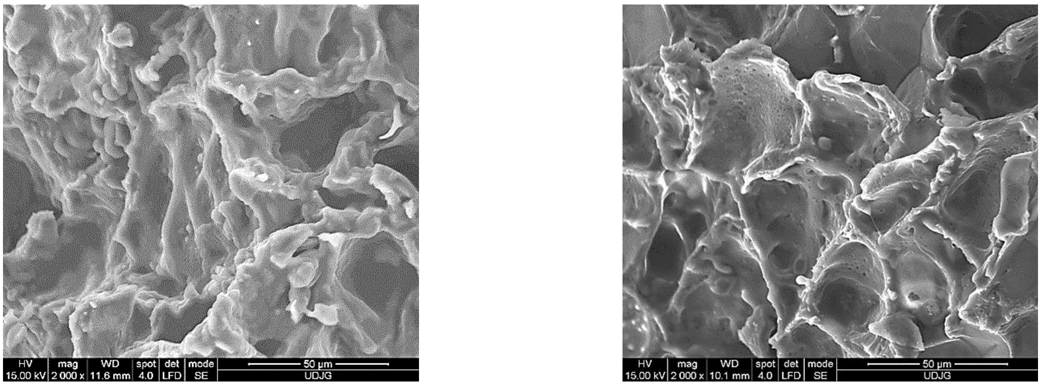
Table 1. Physical differences between green and roasted Arabica coffee beans.

Characteristics	Green Arabica coffee bean	Roasted Arabica coffee bean
Color	Gray-green tones	Dark brownish
Size	Smaller	Larger
Volume	Smaller	Larger
Cracking	Without cracks	Cracks
Brittleness	Not brittle	More brittle
Porosity	Smaller	Larger



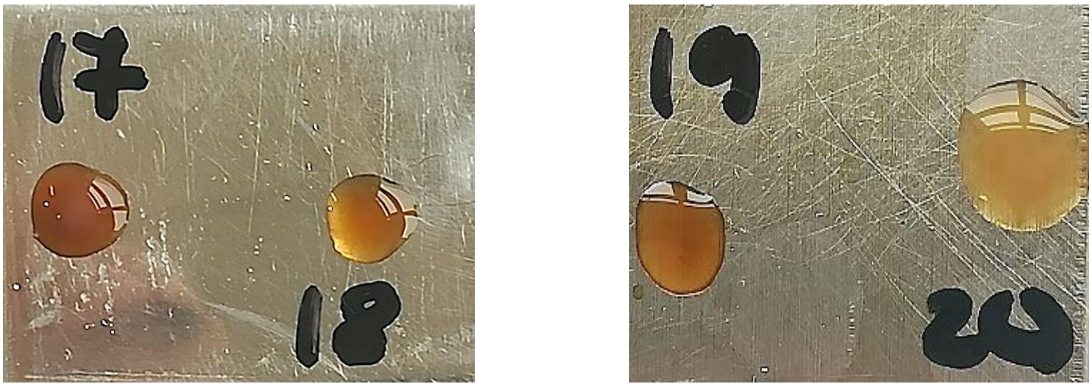
a **b**

Figure 1. SEM images on the surfaces of green bean (a) and roasted bean (b) of Arabica coffee.



a **b**

Figure 2. SEM images of the section of green Arabica coffee bean (a), and the roasted Arabica coffee bean (b).



a **b**

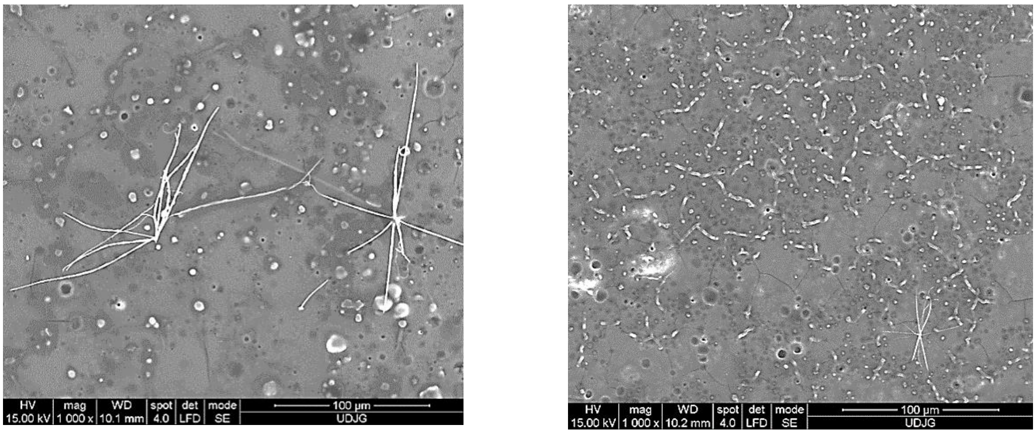
c

Figure 3. Color intensity of the infused coffee obtained from ground roasted Arabica coffee with different granulation: a) 4 µm; b) 5.2 µm; c) 9.5 µm after 5 min. (drop on the left side) and 10 min. (drop on the right side) infusion time.

Table 2. Mean values of color parameters (L*, a* and b*) corresponding to the infused coffee in different conditions.

Color parameters	Code sample: 17 (4 µm, 5 min)	Code sample: 18 (4 µm, 10 min)	Code sample: 19 (5.2 µm, 5 min)	Code sample: 20 (5.2 µm, 10 min)	Code sample: 21 (9.5 µm, 5 min)	Code sample: 22 (9.5 µm, 10 min)
L*	40.42±0.01	46.24±0.02	35.22±0.02	66.36±0.02	53.90±0.04	72.04±0.02
a*	21.48±0.03	20.30±0.01	20.45±0.03	9.20±0.01	17.45±0.01	6.35±0.02
b*	26.71±0.01	35.45±0.04	20.10±0.01	42.22±0.01	43.64±0.01	41.30±0.01

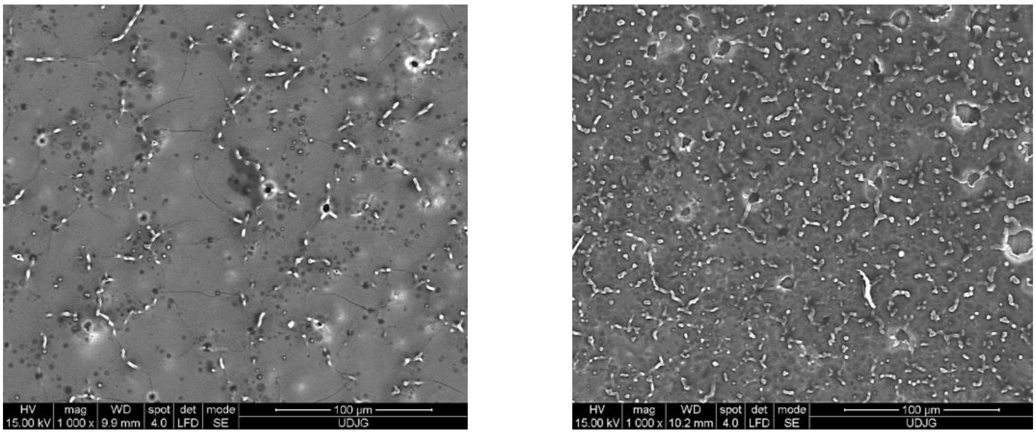
Figs. 4 (a, b) show the microstructure of the Arabica coffee drops prepared by infusion of the ground roasted beans with grain size of 4 µm for 5 min. (a) and 10 min. (b), respectively.



a b

Figure 4. SEM images of the drops obtained from Arabica coffee bean with 4 µm granulation after 5 min. (a), and 10 min. infusion time (b).

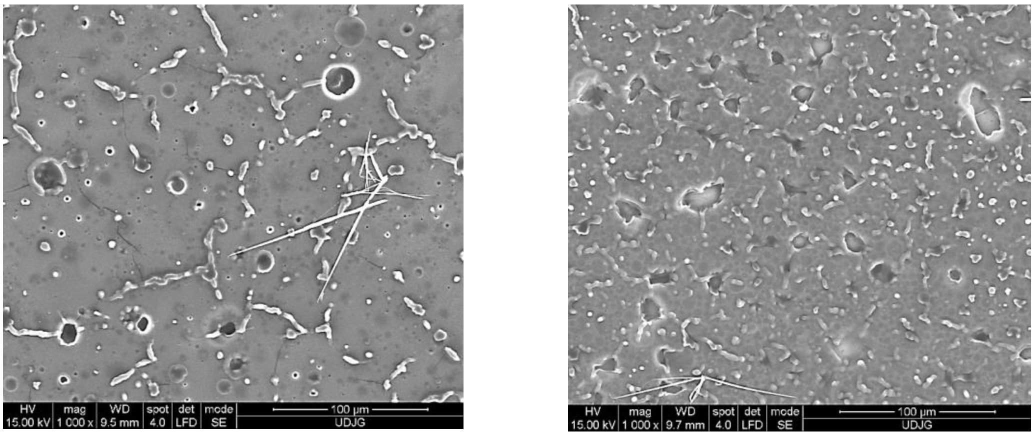
Figs. 5a and b show the microstructure of the Arabica coffee drops prepared by infusion of the ground roasted beans with grain size of 5.2 µm for 5 min. (a) and 10 min. (b), respectively.



a b

Figure 5. SEM images of the drops obtained from Arabica coffee bean with 5.2 µm granulation after 5 min. (a), and 10 min. infusion time (b).

Figs. 6a and b show the microstructure of the Arabica coffee drops prepared by infusion of the ground roasted beans with grain size of 9.5 μm for 5 min. (a) and 10 min. (b), respectively.



a b

Figure 6. SEM images of the drops obtained from Arabica coffee bean with 9.5 μm granulation after 5 min. (a) and 10 min. infusion time (b).

3.2. DISCUSSION

3.2.1. Visual investigation of physical changes of coffee beans

During roasting, a series of complex physical changes take place to transform the green coffee beans into the roasted beans, and some changes can occur [1, 11, 20, 23]. Regarding physical changes, the color, roast volume, and roast loss are among the important features [12].

The results of the visual evaluation reveal a significant difference of physical properties between the green and the roasted Arabica coffee beans, such as: visual appearance, color change, size expansion, volume increase, and mass decrease. The modifications are shown systematically in Table 1.

Generally, color is an attribute, which significantly influences the consumers' preferences and their choice in point of acquisition [32-36]. Chromatic characteristics are used to evaluate the product quality and are an indicator of the storage time and age of coffee, and a point of reference coffee pricing [12, 37]. A distinctive coffee bean color is related with the roasting treatment [1, 7], the roasting treatment parameters (time and temperature) being adapted to the type of coffee being roasted [1]. Before roasting, the coffee beans had good appearance and typical gray-green tones, which turns to a dark brownish color. The Maillard Reaction and the production of melanoidin compounds can explain the emergence of the dark brownish color [11, 38]. Even though the color is not a main criterion in categorizing the roasting level, at least it can illustrate the roasted coffee beans taste [11], dark brownish roasted coffee having notes of dark chocolate [39], while green coffee has a bean-like aroma [3, 40].

From Table 1 data it can be noticed that the coffee bean has a larger roast volume. Roast volume generally increases during roasting owing to the softening of cellulose and the release of gases and pyrolysis products [12, 24, 41]. In the roasting treatment, the transformation of water into water vapor created high pressure inside the coffee bean, which changed the structure of the cell walls from rigid to rubbery. This can be explained by the findings of Indriati, 2020 [11], the internal matter pushed out toward the cell wall, leaving a gas-filled void in the center, meaning that the coffee bean expanded in volume, and decreased in mass (roast loss). Roast loss exhibits two trends: less weight loss (due to dehydration and slow release of volatiles) occurs during the first stages of roasting processing, while more weight loss (attributed to intensive volatile and CO_2 loss due to pyrolysis) is noted in the later roasting treatment stages [12]. During roasting, an important decrease of density can take place owing to the volume increase of the beans [7, 12], the coffee beans density being a very important factor for processing, packaging, storage and transport [42, 43]. Whilst the green coffee beans are desired for the smaller packages and transit costs for long distance transport, the dark roasted coffee beans are desired due to their lower oxidation risks [7]. During roasting, since the concomitant volume increase, the density of coffee beans decreases and a porous structure develops [7, 17, 43, 44].

After roasting the roasted coffee beans show some cracks compared to green beans. This is a sign of textural changes, the roast coffee beans having a tough and brittle texture. The roasted coffee bean was more brittle than a green coffee bean, due to the loss of water [11]. The dehydration of coffee beans is one of the essential reasons behind the brittleness, a higher water level leading to the toughness and stiffness of beans until a glassy standing is reached. After the glassy condition, a fracture point can occur in the roasting time, which contributes to a drop in overall bean integrity, allowing extensive textural changes in the coffee bean [12, 16].

Among the textural changes, the porous texture also has a significant influence on final product quality [12]. The visual evaluation reveals a more porous texture in the case of roasted coffee beans. Porosity becomes more obvious after roasting and storage, owing to its controllability over mass transfer, gas desorption and degassing. Migration of oil droplets toward the coffee bean surface, loss of volatiles, and O_2 accessibility in the storage time also relate to porosity [12]. The expansion of the porous texture of the bean was determined by high pressure due to temperature increase during the roasting treatment, resulting in not only the increase of individual coffee bean volume but also the expansion of bean porosity [11, 45].

Finally, the significant difference between green and roasted Arabica coffee beans is revealed in the SEM micrographs in Figs. 1a, b, and Figs. 2a, b, respectively. The SEM image of the surface of the green coffee bean is shown in Fig. 1a, while the SEM image of the surface of the roast coffee bean is shown in Fig. 1b. The image taken on the surface of the green coffee bean reveals longitudinal fibers with relatively smooth surface. A thin waxy layer covers the rough surface of the green coffee bean (Fig. 1a). Coffee cultures with less wax on their beans generate a more easily digested drink with improved flavor and quality attributes [46]. The roasting treatment had a significant effect on the surface of coffee bean (Fig. 1b). Fig. 1b reveals a surface that is covered with particulate material, visibly deposited on the entire surface, some of this being in irregularly shape and rough. The cells are no longer so obvious, and the wax is unnoticed. Numerous small oil spherules are observed. Small sized oil spherules overlap the roasted coffee bean surface, suggesting the existence of a large pore network through which the very small oil droplets start to migrate toward the outer layer of the roasted bean. Schenker et al. [17] reported similar results. These findings may support the model of a 3-dimensional permeable network of polysaccharides, where the latter have been partially degraded and removed in the roasting treatment time [17, 47].

SEM images of the microstructure of green coffee beans and roasted Arabica coffee beans are shown in Figs. 2a, b. The transversal section of the green coffee bean reveals broken cell walls and irregular dark regions which represent cavities or pores (Fig. 2a). Probably, the cavities/pores arise from the dehydration treatment in the post-harvest time processing of the coffee beans. Fig. 2b shows a highly porous structure in the roasted coffee bean. A significantly greater macropore/cavities area may be noted, as well as numerous fine micropores which are generated owing to both degradation of the intercellular matrix, and the destruction of the cells during roasting [7]. The internal surface of the cavities is rough and broken. The cause for the micropores could be the increased polysaccharide degradation at higher temperatures during roasting [17]. Variation in pore size may be dependent upon fluctuations in volatiles/gas pressure and water evaporation rate [12, 16, 41]. Pore structure controls the mass transfer in the storage time of coffee, having an important influence on the final product quality.

3.2.2. Visual evaluation

Fig. 3 shows the variation of colors and color intensity of the infused coffee with increasing both the grinding degree and infusion time. The brown-red color of coffee prepared after 5 min. of infusion (the darkest color) is due to nitrogen-based compounds released after Maillard Reactions (non-enzymatic browning) [48]. The brown-red color intensity decreased with increasing the grinding degree (colors varied from dark to lighter and brighter shades) (drops on the left side of Figs. 3a, 3b and 3c). The longer infusion time increases to 10 min. the more yellow color intensifies, proportional to the grain size (from the fine-grained, 4 µm, to the coarse-grained, 9.5 µm). Thus, the color changing indicated a decrease in caffeine (the drops on the right side of Figs. 3a, 3b and 3c).

3.2.3. Color assessment by means of chromatic parameters

Color is an important sensory attribute, being the determining characteristic from the point of view of the acceptability of food products by the consumer. The color of infused coffee was evaluated using the Konica Minolta device, and the parameter (L*, a* and b*) values are presented in Table 2. The parameters L*, a* and b* have an important contribution to the total color impression. All measured chromatic parameters have indicated only positive values from the specific chromatic range. The analysis of color parameters (Table 2) has indicated that brightness (L*) and luminosity (b*) significantly increase with the infusion time for all granulation types; on the other hand, the red component (a*) drastic decreases with increasing both the infusion time and grain size.

The values of L* parameter show an increasing from 40.42 to 53.90 with increasing granulation for 5 min. as infusion time. At the same time, the increasing infusion time from 5 to 10 min. led to a significantly enhancing of L* parameter (the highest L* values) ranged between 46.24 and 72.04. The darkest color of infused coffee drops corresponds to the higher value of L* parameter. Therefore, the brightness (L* parameter) evolution are in accordance with the visual aspect showed in Figs. 4a, 4b and 4c, in terms of dark-brownish.

On the other hand, positive and slightly enhanced values were recorded for b* parameter with increasing both the grain size and infusion time. An increasing of b* values up to 43.64 was measured for 5 min. for coarse-grained of 9.5 µm; while, after 10 min., b* value indicated 42.22. The increasing of b* parameter values with the infusion time suggests an intensification of the yellow color of the infused coffee.

The highest value of a* parameter (21.48) was detected for 4 µm ground coffee infusion during 5 min., while the smallest value (6.35) was recorded after 10 min. of infusion of 9.5 µm grain size bean. Therefore, the red color of infused coffee is more intensive for a coffee prepared from the coarse-grained beans for a short period of time.

After 10 min., the infused coffee obtained from the fine-grained with a granulation of 4 µm has the darkest color, and the chromatic parameters register the smallest variations, compared to that obtained from the ground coffee with the granulation of 5.2 and 9.5 µm, respectively. The fine degree of coffee grinding is of great importance because it influences the sensory quality of infused coffee. In order to prepare the coffee, the beans which are finely ground have a larger surface area exposed to the hot water, producing a more intensive color, a richer and more delicate taste. Instead, too coarse grinding of roasted coffee beans will produce a coffee with less intensity taste. A short infusion time (5 min.) may be indicated to prepare a fine-grained coffee resulting a coffee with an equal aroma. A fine grinding allows the most efficient extraction, but a very fine ground coffee will slow down the filtration process. In fact, it is the consumer who identifies the key attributes that could have an impact on its acceptability.

3.2.4. Morphological properties

Imagistic analysis (Figs. 4-6) reveals the behavior of the component particles similar to that of the suspended particles as in a colloidal system.

SEM image (100 µm scale bar) of coffee drop obtained by infusing for 5 min. of fine-grained roasted coffee (4 µm grain size) shows a micro-heterogeneous appearance (Fig. 4a) with a large number of oil particles as shown in Fig. 1b. Two stranded caffeine crystals – as white, fibrous filament clusters were captured. The formation of irregular circular structures (voids with different diameter) can be observed on the entire analyzed area. Thus, a spatial lattice structure is initiated. The infused coffee is however prepared in much less energetic way (less energetic conditions compared to the high pressure used in the professional coffee machine), the hot water vapor will determine the emulsion of oil from the coffee grounds [49].

Prior to microscope evaluation (dehydration of water from the coffee drops, fixed on the metal support, at room temperature with low rate of evaporation), some cracks are clearly highlighted (Fig. 4a) (5 min. and fine-grained of 4 µm). Further, increasing infusion time up to 10 min. will determine the formation of a cross-linked network against a background of the existence of the initial cracks (Fig. 4b). At the same time, there is a tendency for a quasi-homogeneous distribution of ruptured circular structures. The number of caffeine crystals is reduced (to a single caffeine crystal in the scanned area) until they will completely disappear if the infusion time were longer than 10 min. This result is in accordance with the analysis of a* parameter, the red component (Table 2).

Figs. 5a and 5b show the morpho-structural aspects of the coffee drops obtained by infusion of ground roasted coffee, having an average granulation of 5.2 µm. As in the previous case, a cross-linked spatial network (particles arc-wise arrangement) is formed (Fig. 5a) against a background of the cracks generated by the slow drying process of the coffee drop. High density of ruptured circular structures can be noticed on the entire analyzed surface leading to the network generation and branches spreading. Fig. 5b indicated a discontinuous microstructure due to the quasi-homogeneous distribution of ruptured circles, whose diameters are larger than in the case of fine-grained beans. It can be estimated that the intensification of the spatial network is similar to the behavior of particles into a stable suspension.

The infusion obtained from coarse-grained roasted coffee (9.5 µm) showed a heterogeneous cross-linked spatial structure due to the reduction of packing degree between particles (Fig. 6a). Figs. 6a and 6b indicate a reduction in the caffeine (as thin, bright and sporadic filaments) concentration in the liquid phase. This aspect is in accordance with the results obtained and previously presented by evaluating the color of coffee drink (Fig. 3 and Table 2).

The highest content in lipids as light spots on the surface with increasing grain size up to 9.5 µm was observed (Fig. 6a). Thus, after only 5 min. of infusion time, the brownish color intensity (Fig. 3c, left side) could be explained by the increasing of the concentration of coffee oil [50]. Also, the higher the granulation, the net-shaped aspect is inhibited. Therefore, the discontinuous character is all around the surface, and the density of voids (larger diameters) is enhanced (Fig. 6b). The appearance of large voids could be related to the oil particles removal during the infusion process. So, this aspect is confirmed by the yellow color of the coffee (Fig. 3c, right side). This behavior can be associated with the structure of an unstable colloidal suspension. According to the results published in the literature, it is known that higher caffeine content (and other particles) significantly contributes to the reducing of surface tension from oils [51-54].

4. CONCLUSIONS

The present study evaluates the visual and microstructural differences between green and roasted *Coffea arabica* L.. In general, roasting as a processing method caused the change of the physical properties (color, size, volume, cracking, brittleness, porosity) of the green coffee bean. The microscopic study showed significant structural differences between the green and the roasted Arabica coffee bean. The results of the imagistic study clearly showed that roasting mainly influences the porous structure of the coffee bean. The development of the porous structure and the increase in volume are important factors for packaging, storage and transport of the roasted coffee beans.

The visual and microscopic features of the infused ground roasted Arabica coffee are analyzed. The study of color changing during infusion process through the analyses of chromatic parameters allows a coffee quality assessment. By grinding process, the color intensity is modified with increasing both the grinding degree and infusion time. Variation from dark-brownish to yellow color indicated a decrease in caffeine concentration. Finest ground coffee having a large active surface produced more flavorful taste and intense color for no longer than 5 min. infusion time.

Morphological characteristics indicated significant structural differences through the particle content such as caffeine, lipids etc. If the ground is too coarse, the coffee could be under-extracted and weak aroma. The ability to extract the water-soluble components is enhanced with the infusion time and water pressure.

Based on some physical characteristics (chromatic, volume, size, microscopic structure, porosity) the roasting and grinding processes and the extraction time have a great influence on the color of brew coffee.

REFERENCES

[1] Jokanović, R. M., Džinić, R.N., Biljana, C., Grujic, S., Odžaković, B., *Acta Periodica Technologica*, **342**(43), 21, 2012.
[2] Ballesteros, L.F., Teixeira, J.A., Mussatto, S. I., *Food and Bioprocess Technology*, **7**(12), 3493, 2014.
[3] Klingel, T., Kremer, J.I., Gottstein, V., de Rezende, T.R., Schwarz, S., Lachenmeier, D.W., *Foods*, **9**, 665, 2020.
[4] Lachenmeier, D.W., Teipel, J., Scharinger, A., Kuballa, T., Walch, S.G., Grosch, F., Bunzel, M., Okaru, A.O., Schwarz, S., *Journal of AOAC International*, **103**(2), 306, 2020.
[5] Münchow, M., Alstrup, J., Steen, I., Giacalone, D., *Beverages*, **6**(2), 29, 2020.
[6] Mussatto, S.I., Ballesteros, L.F., Martins, S., Teixeira, J.A., *Separation and Purification Technology*, **83**, 173, 2011.

[7] Nakilcioğlu-Taş, E., Ötleş, S., *Anais da Academia Brasileira de Ciências*, **91**(2), e20180191, 2019.
[8] Noor Aliah, A.M., Fareez Edzuan, A.M. Noor Diana, A.M., *Journal of Applied Science and Agriculture*, **10**(7), 18, 2015.
[9] Nilsson, G., *Microstructure of Instant Coffee Foam. Confocal Microscopy Method Development and Production Related Parameters Affecting Foam Kinetics*, Master of Science Thesis, Chalmers University of Technology, Gothenburg, Sweden, 2015.
[10] Bertrand, B., Vaast, P., Alpizar, E., Etienne, H., Davrieux, F., Charmetant, P., *Tree Physiology*, **26**(9), 1239, 2006.
[11] Indriati, A., Hidayat, D.D., Andriansyah, C.E., Rahayuningtyas, A., Sudaryanto, A., *Asian Journal of Applied Sciences*, **8**(01), 12, 2020.
[12] Hameed, A., Hussain, S.A., Ijaz, M.U., Ullah, S., Pasha, I., Suleria, H.A.R., *Comprehensive Reviews in Food Scienceand Food Safety*, **17**(5), 1184, 2018.
[13] Baggenstoss, J., Poisson, L., Kaegi, R., Perren, R., Escher, F., *Journal of Agricultural and Food Chemistry*, **56**(14), 5836, 2008.
[14] Giacalone, D., Degn, T.K., Yang, N., Liu, C., Fisk, I., Münchow, M., *Food Quality and Preference*, **71**, 463, 2019.
[15] Kamal, I.M., Sobolik, V., Kristiawan, M., Mounir, S.M., Allaf, K., *Innovative Food Science and Emerging Technologies*, **9**(4), 534, 2008.
[16] Pittia, P., Dalla Rosa, M., Lerici, C.R., *LWT- Food Science and Technology*, **34**(3), 168, 2001.
[17] Schenker, S., Handschin, S., Frey, B., Perren, R., Escher, F., *Journal of Food Science*, **65**(3), 452, 2000.
[18] Schenker, S., Heinemann, C., Huber, M., Pompizzi, R., Perren, R., Escher, R., *Journal of Food Science*, **67**(1), 60, 2002.
[19] Yang, N., Liu, C., Liu, X., Degn, T.K., Munchow, M., Fisk, I., *Food Chemistry*, **211**(15), 206, 2016.
[20] Dutra, E.R., Oliveira, L.S., Franca, A.S., Ferrez, V.P., Afonso, R.J., *Journal of Food Engineering*, **47**(3), 241, 2001.
[21] Hernández, J.A., Heyd, B., Irles, C., Valdovinos, B., Trystram, G., *Journal of Food Engineering*, **78**(4), 1141, 2007.
[22] Pittia, P., Nicoli, M.C., Sacchetti, G., *Journal of Texture Studies*, **38**(1), 116, 2007.
[23] Nedomova, S., Trnka, J., Stoklasova, P., Buchar, J., *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, **LXI 82**(3), 743, 2013.
[24] Smrke, S., Wellinger, M., Suzuki, T., Balsiger, F., Opitz, S.E.W., Yeretzian, C., *Journal of Agricultural and Food Chemistry*, **66**, 5293, 2018.
[25] López, J. A. S., *Direct analysis of volatile compounds during coffee and tea brewing with Proton Transfer Reaction Time of Flight Mass Spectrometr*y, PhD Thesis, Rostock, 130, 2016.
[26] Caporaso, N., Genovese, A., Canela, M.D., Civitella, A., Sacchi, R., *Food Research International*, **61**, 152, 2014.
[27] Gloess, A.N., Schönbächler, B., Klopprogge, B., D`Ambrosio, L., Chatelain, K., Bongartz, A., Strittmatter, A., Rast, M., Yeretzian, C., *European Food Research and Technology*, **236**, 607, 2013.
[28] Hussein, A., Ali, H., Bareh, G., Farouk, A., *Pakistan Journal of Biological Sciences*, **22** (6), 273, 2019.
[29] Chen, Z., Zhu, C., Zhang, Y., Niu, D., Du, J., *Postharvest Biology and Technology*, **58**, 232, 2010.
[30] Mutarutwa, D., Navarini, L., Lonzarich, V., Compagnone, D., Pittia, P., *Journal of Agricultural and Food Chemistry*, **68**(17), 4743, 2020.

[31] Rattan, S., Parande, A.K., Ramalakshmi, K., Nagaraju, V.D., *Journal Food Science and Technology*, **52**(9), 5470, 2015.
[32] Bredahl, L., *Food Quality and Preference*, **15**(1), 65, 2004.
[33] Carpenter, C.E., Cornforth, D.P., Whittier, D., *Meat Science*, **57**(4), 359, 2001.
[34] Font-i-Furnols, M., Guerrero, L., *Meat Science*, **98**(3), 361, 2014.
[35] Krystallis. A., Chryssohoidis, G., *British Food Journal*, **107**(5), 320, 2005.
[36] Stoica, M., Alexe P., *Elemente de proiectare a produselor alimentare noi*. Ed. Academica, Galați, 224, 2016.
[37] Ramalho, J.C., Pais, I.P., Leitão, A.E., Guerra, M., Reboredo, F.H., Máguas, C.M., Carvalho, M.L., Scotti-Campos, P., Ribeiro-Barros, A.I., Lidon, F.J.C., DaMatta, F.M., *Frontiers in Plant Science*, **9**, 287, 2018.
[38] Nebesny, E., Budryn, G., *European Food Research and Technology*, **217**(2), 157, 2003.
[39] https://www.ticocoffee.com/en/blog/coffee-roasting/coffee-roasting-levels.html.
[40] Naidu, M., Sulochanamma, G., Sampathu, S.R., Srinivas, P., *Food Chemistry*, **107**, 377, 2008.
[41] Oliveros, N.O., Hernández, J.A., Sierra-Espinosa, F.Z., Guardián-Tapia, R., Pliego-Solórzano, R., *Journal of Food Engineering*, **199**, 100, 2017.
[42] Santana, A.A., De Oliveira, R.A., Kurozawa, L.E., Park, K.J., *Engenharia Agrícola*, **34**(5), 980, 2014.
[43] https://www.kickinghorsecoffee.com/en/blog/roasting-101.
[44] Frisullo, P., Barnaba, M., Navarini, L., Del Nobile, M.A., *Journal of Food Engineering*, **108**(1), 232, 2012.
[45] Frisullo, P., Barnaba, M., Navarini, L., Del Nobile, M.A., *Journal of Food Engineering*, **108**(1), 232, 2012.
[46] Wagemaker, T.A.L., Carvalho, C.R.L., Maia, N.B., Baggio, S.R., Filho, O.G., *Industrial Crops and Products*, **33**(2), 469, 2011.
[47] https://www.coffeesciencelab.com.au/blog/coffee-under-the-microscope-iii.
[48] Moreira, A.S., Nunes, F.M., Domingues, M.R., Coimbra, M.A., *Food & Function*, **3**(9), 903e915, 2012.
[49] Piazza, L., Gigli, J., Bulbarello, A., *Journal of Food Engineering*, **84**(3), 420, 2008.
[50] Somnuk, K., Eawlex, P., Prateepchaikul, G., *Agriculture and Natural Resources*, **51**, 181, 2017.
[51] Gmoser, R., *Instant coffee foam stability: Bulk and surface rheology approach*, MSc Thesis, Lund University, 2014.
[52] Buruleanu, L.C., Radulescu, C., Georgescu, A.A., Dulama, I.D., Nicolescu, C.M., Olteanu, R.L. Stanescu, S.G., *Analytical Letters*, **52**(8), 1195, 2019.
[53] Ernesto, I., Navarini, L., *Food Biophysics*, **6**(3), 335, 2011.
[54] Green, A.J., Littlejohn, K.A., Hooley, P., Cox, P.W., *Current Opinion in Colloid & Interface Science*, **18**(4), 292, 2013.