

CHANGES OF PHYSICAL PROPERTIES OF COFFEE BEANS DURING ROASTING

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The effects of heating time on physical changes (weight, volume, texture and colour) of coffee beans (Outspan and Guaxupe coffee) were investigated. The roasting temperature of both samples was 170°C and samples for analysis were taken at the intervals of 7 minutes during 40 minutes of roasting. Total weight loss at the end of the roasting process was 14.43 % (light roasted) and 17.15 % (medium to dark roasted) for Outspan and Guaxupe coffee beans, respectively. Significant ($P < 0.05$) changes in the coffee bean breaking force values were noted between the 7th and 14th minutes, and statistically not significant ($P > 0.05$) between the 35th and 40th minutes of the roasting. According to the L^ colour parameter as a criterion for the classification of roasted coffee colour (light, medium, dark), the Outspan sample was medium and Guaxupe sample was dark roasted.*

KEY WORDS: coffee bean, roasting, texture, colour

INTRODUCTION

Coffee is one of the most widely consumed beverages in the world. The high acceptability of coffee is due to many factors, one of the most contributory factors being its flavour (1). Commercial coffee beverage is made from arabica or robusta beans or blends of them (2). The quality of coffee used for beverages 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) (3).

Green coffee is devoid of the pleasant aroma and flavour appreciated worldwide in roasted coffee. The desired aroma and flavour of coffee beans used for beverage preparation are developed during the roasting process, where the beans undergo a series of reactions leading to the desired changes in the chemical and physical composition (4). So, in order to obtain a good quality cup of coffee with specific organoleptic properties (flavour,

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aroma and colour), the step of roasting is very important (5). The characteristic flavour and aroma of coffee result from a combination of hundreds of chemical compounds produced by the reactions that occur during the roasting (3). This implies controlling the roasting time and temperature so that they are sufficient for the required chemical reactions to occur, without burning the beans and compromising the flavour of the final beverage. In general, in conventional roasting process the temperature is in the range from 200 to 230°C, and the process time is ranging from 12 to 20 minutes. However, these values can vary greatly, depending on the degree of roast required (light, medium or dark), on the type of roaster used, and also on the variety, age, moisture content, etc. of the coffee beans (6). The roasting process can be divided into three consecutive stages: drying, roasting or pyrolysis and cooling (3).

The degree of roast can be monitored by the colour of the beans, the loss of mass, the developed flavour and aroma or by the chemical changes of certain components (5, 6). Control of temperatures and duration of roasting, in industry, are only effective if the quality of the raw material does not vary (5).

Therefore, the objective of this study was to evaluate the changes of different physical characteristics such as total weight loss, breaking force, and colour of Outspan and Guaxupe coffee beans during roasting.

EKSPERIMENTAL

Sample preparation

Two green (crude) coffee samples of Rio Minas, Outspan and Guaxupe, used for the production of commercial blends, were provided by a local industrial coffee roaster. Beans of each variety (20 kg/batch) were roasted separately using an oven with direct heating. The roasting conditions were the same; the highest roasting temperature was 170°C, and roasting time was 40 min. For each sampling step (0, 7, 14, 21, 28, 35, 40 min) the coffee beans (100 g) were taken from the oven, and the following determinations were carried out:

Determination of moisture, protein, carbohydrate and ash content

Moisture content was measured based on the sample weight-loss after oven-drying at 105°C for 16 h (3). The nitrogen (N₂) content of the coffee sample was determined on a Kjeldahl Digestion System. Protein content was calculated as nitrogen x 6.25 (3). Ash content was calculated from the weight of the sample after burning at 580°C for 17 h (3). Carbohydrate content was estimated by volumetric method of Luff-Schoorl, which is based on the reduction of alkaline Cu²⁺-complex (7). Results are expressed as the mean value of three measurements.

Total weight loss (WT)

Total weight loss is expressed as g/100 g, and is calculated by weighing coffee samples before (WI) and after roasting (W), as follows: $WT=100 (WI-W)/WI$ (8). The results are expressed as the mean value of three measurements.

Mass, volume and bulk density

Mass was measured for 100 beans. Volume was measured for 100 beans in a 50 mL graduated recipient.

Bulk density was evaluated as the ratio between the weight and volume of the 100 beans sample in a 50 mL graduated recipient (8). The results are expressed as the mean value of three measurements.

Mechanical testing

An Instron Universal Testing Machine, equipped with a 25 kN load cell was used. The uniaxial compression was carried out at a rate of 50 mm/min. For the measurements, 20 beans of each sample were taken at random. Each bean was positioned on its longest side and with the flat side up between two parallel metal plates. A compression force was applied until failure occurred; the working temperature was 23°C. The breaking force (N) corresponded to the force at the major failure event. It was considered as an empirical measure of the strength (8). The results are expressed as the mean value.

Colour analysis

Colour was analysed by using a tristimulus colorimeter MINOLTA CP410. Standard CIE conditions with illuminate were used. The configuration included the illuminant D65 and an angle of 10. The readings were made using the CIELAB system (L^* , a^* , b^*), and presented as L^* value (colour brightness).

Colour was evaluated for ground coffee beans placed in a suitable tank. The results are expressed as the mean value of five measurements.

Statistical analyses

Analysis of variance (one-way ANOVA) was used to test the hypothesis about the differences among the mean values. The software package STATISTICA 8.0 (9) was used for the analysis.

RESULTS AND DISCUSSION

Table 1 presents the composition of raw Outspan and Guaxupe coffee beans. The data show that the raw Outspan and Guaxupe coffee beans, according to their chemical composition, are of the same quality category.

Table 1. Chemical composition of raw Outspan and Guaxupe coffee beans

| Parameters | Outspan | Guaxupe |
|---------------------------|------------|------------|
| Moisture (%) | 10.43±0.02 | 9.59±0.06 |
| Protein (%) | 13.66±0.07 | 13.41±0.06 |
| Mono and disaccharide (%) | 7.45±0.09 | 5.16±0.11 |
| Total ash (%) | 4.06±0.12 | 3.92±0.07 |

The contents of moisture and total ash of both samples are in agreement with Serbian national legislation (10). The protein contents of the analysed coffee samples (13.66 % for Outspan and 13.41 % for Guaxupe) are in the range for green coffee reported in the literature: 11.0–16.5 g/100 g (11). Franca et al. (11) reported that the higher quality coffee samples have higher protein levels, but there is no evidence suggesting that the protein contents in the varieties of different quality or even of different species (arabica vs. robusta) should be noticeably different.

The changes in the weight, volume, bulk density and total weight loss (measured for 100 beans) of Outspan and Guaxupe coffee beans during roasting are presented in Tables 2 and 3, respectively.

Table 2. Changes in weight, volume, density and total weight loss of Outspan coffee beans during roasting (100 beans)

| Heating time (min) | Weight (g) | Volume (mL) | Bulk density (g/mL) | Weight loss (%) |
|--------------------|------------|-------------|---------------------|-----------------|
| 0 | 14.86±0.04 | 23.03±0.06 | | |
| 7 | 14.43±0.07 | 27.10±0.36 | 0.53±0.009 | 2.88 |
| 14 | 13.81±0.07 | 28.13±0.15 | 0.49±0.000 | 7.09 |
| 21 | 13.64±0.04 | 28.10±0.17 | 0.49±0.002 | 8.23 |
| 28 | 13.63±0.04 | 29.10±0.10 | 0.47±0.000 | 8.29 |
| 35 | 12.98±0.04 | 31.07±0.12 | 0.42±0.000 | 12.64 |
| 40 | 12.71±0.04 | 34.10±0.10 | 0.37±0.002 | 14.43 |

Table 3. Changes in weight, volume, density and total weight loss of Guaxupe coffee beans during roasting (100 beans)

| Heating time (min) | Weight (g) | Volume (mL) | Bulk density (g/mL) | Weight loss (%) |
|--------------------|------------|-------------|---------------------|-----------------|
| 0 | 12.62±0.04 | 19.13±0.12 | 0.66±0.006 | |
| 7 | 12.10±0.09 | 20.47±0.06 | 0.59±0.003 | 4.11 |
| 14 | 11.69±0.03 | 21.07±0.12 | 0.56±0.004 | 7.32 |
| 21 | 11.46±0.04 | 22.10±0.10 | 0.52±0.001 | 9.16 |
| 28 | 11.35±0.03 | 24.13±0.15 | 0.47±0.002 | 9.90 |
| 35 | 11.37±0.03 | 25.10±0.10 | 0.45±0.003 | 10.03 |
| 40 | 10.45±0.03 | 28.57±0.12 | 0.37±0.001 | 17.15 |

Protein contents of analysed coffee samples (13.66 % for Outspan and 13.41 % for Guaxupe) are in the range for green coffee reported in the literature: 11-16.5 g/100 g (11). Franca et al. (11) reported that the higher quality coffee samples present higher protein levels, but there is no evidence suggesting that the protein contents in varieties of different qualities or even of different species (arabica vs. robusta) should be noticeably different.

Changes in weight, volume, bulk density and total weight loss (measured for 100 beans) of Outspan and Guaxupe coffee beans during roasting are presented in Tables 2 and 3, respectively.

At the beginning of the heating process, the total mass of the 100 beans was 14.86 g for Outspan sample, and 12.62 g for Guaxupe coffee. During the heating, the processed coffee beans lose mass due to the water loss and loss of volatile materials (11). The total weight loss at the end of the roasting process was 14.43 % and 17.15 % for Outspan and Guaxupe coffee beans, respectively. The total weight loss of green coffee beans after roasting can be one of the criteria for determining the degree of roasting. According to Oosterveld et al. (12), the weight losses of 11 %, 15 % and 22 % represent light, medium, and dark roasted coffee beans, respectively.

The increase in the beans volume at the end of the heating process was 48 % for Outspan coffee beans, and 50 % for Guaxupe beans. The results of Franca and co-workers (11) for the volume increase of samples of different quality were 40 – 65 %, where the volume increase of non-defective beans was higher than for black beans. Also, these authors reported that the beans which swell less should be roasted more slowly.

Further, the changes in the density are noticeable during the roasting. These changes are caused by the simultaneous increase of the volume and internal gas formation, products of the heat-induced reactions (mainly water vapour and carbon dioxide, and pyrolysis reaction products), and the decrease in the mass (due to the loss of volatiles) (8). Bulk density changes are implied in bean expansion and in the formation of a characteristic porous structure of the roasted coffee bean (13). The variations in the bean density and volume probably reflect the bean porosity and compressibility of ground coffee, thus being a consequence of commercial percolation (11). If the changes of density are detected, they can determine eligible roasting degree. An adequate roasting degree is needed for coffee beans to be fragile and breakable, and as such proper for grinding and making coffee beverages with pleasant sensory properties (8).

The results of breaking force for Outspan and Guaxupe coffee beans after different heating time are presented in Table 4.

Table 4. Breaking force of Outspan and Guaxupe coffee beans during roasting (n=20)

| Heating time (min) | Outspan ^{ns} | Guaxupe ^{ns} |
|-----------------------|----------------------------|--------------------------|
| | Breaking force (N) | Breaking force (N) |
| 7 | 96.76±18.86 ^a | 94.75±15.87 ^a |
| 14 | 69.58±15.49 ^b | 69.30±18.00 ^b |
| 21 | 64.13±18.75 ^b | 68.43±17.79 ^b |
| 28 | 63.03±16.99 ^b | 66.10±15.66 ^b |
| 35 | 52.12±15.14 ^{b,c} | 52.78±15.61 ^b |
| 40 | 37.82± 5.67 ^c | 35.39±9.50 ^b |

^{a,b,c} Means within a column with different superscripts differ ($P < 0.05$)

^{ns} Means within a row no significant difference ($P > 0.05$)

The textural characteristics of roasted beans could be related to the effects of some chemical changes induced on the raw bean components by the severe thermal process (13). The braking force values after 7 minutes of heating were similar ($P > 0.05$) for both samples, 96.76 N for Outspan and 94.75 N for Guaxupe. According to Pittia et al. (13), a higher breaking force value for raw coffee beans could be attributed, partly, to the presence of a certain amount of some structural polysaccharides. Also, the force needed to break the bean depends on the content of water in the bean. When the content of water is low, the bean has more fragile and breakable structure, and when the content of water is high, the bean is no longer crunchy, and becomes viscose and plastic (8). In both cases, for Outspan and Guaxupe coffee, as the heating time went by, the force at failure tended to decrease, reaching, again, similar values (37.82 N and 35.39 N) at the end of the process. The reduction of the breaking force indicates a progressive reduction in the strength of the bean.

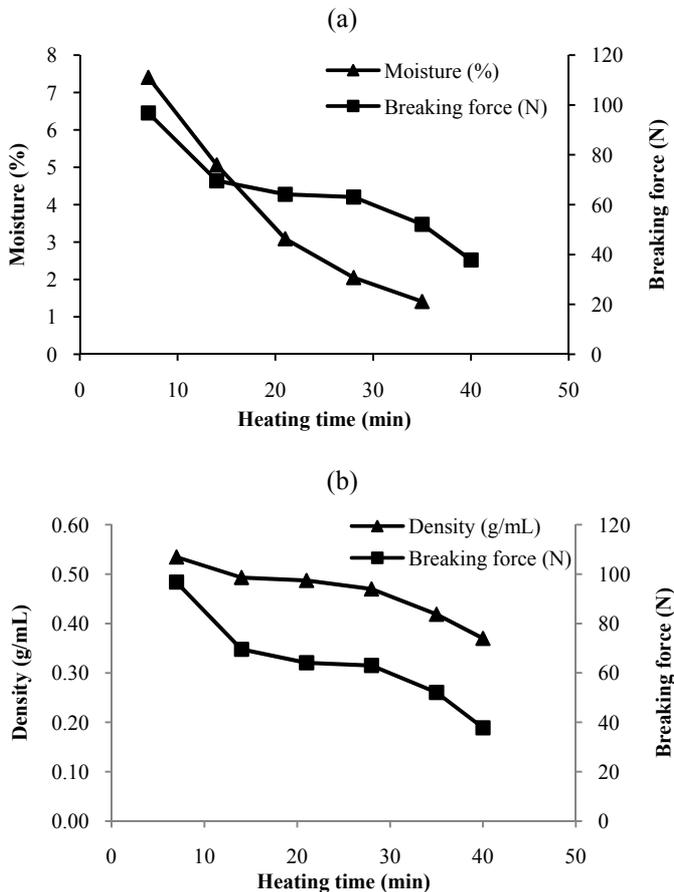


Figure 1. Changes in moisture (a), bulk density (b) and breaking force value of Outspan coffee beans during roasting

The breaking force can also show the degree of roasting, but to a lesser extent than the water content can (13). The characteristic brittleness and fragility induced by roasting is the primary attribute of roasted coffee beans. The reaching of a certain degree of brittleness is very important in the grinding process, which is carried out on roasted coffee beans before the extraction of coffee brew (8).

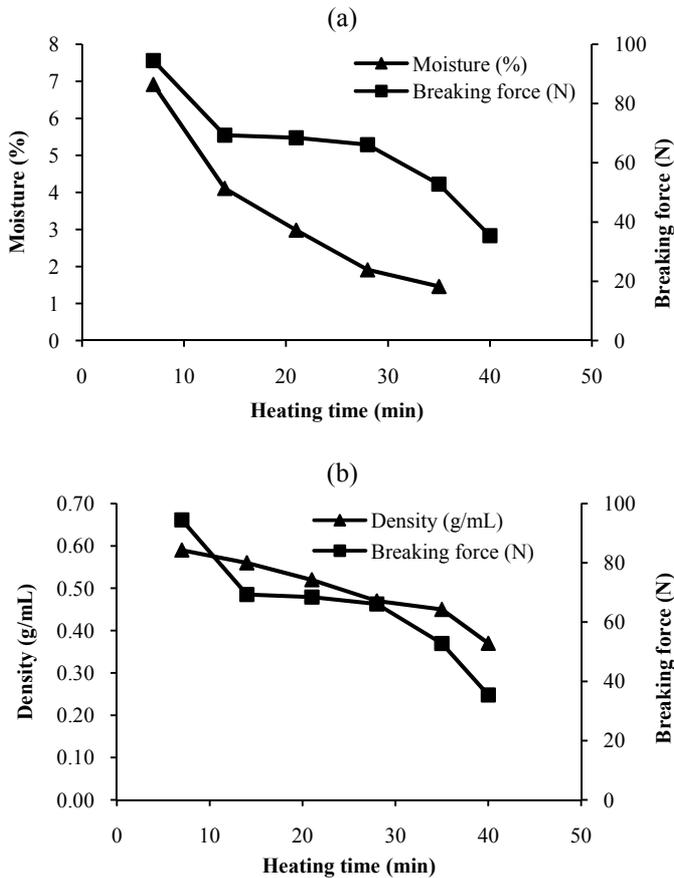


Figure 2. Changes in moisture (a), bulk density (b) and breaking force value of Guaxupe coffee beans during roasting

The influence of moisture content and bulk density on the breaking force values of Outspan and Guaxupe coffee beans are shown in Fig. 1 and 2. The coffee beans with the lowest moisture content and the lowest bulk density had the lowest breaking force values. The water content has a great influence on the texture of roasted beans, and therefore influence the work applied during the grinding process (13). According to the results of Pittia et al. (13) the lowest breaking force values are reached by the samples of coffee

beans having very low moisture content. Water, acting as plasticizer, is expected to decrease the bean's stiffness. Therefore, decreasing the moisture content should increase the stiffness of the material up to the glassy state. When the moisture of coffee bean is very low (1.5 - 2 g/100g), it permits a glassy-like structure to form, which is very easy to break (13). As can be seen from Figs. 1 and 2, there is an initial (between 7th and 14th minutes of roasting) significant ($P < 0.05$) decrease in the breaking force that could be attributed to the higher water loss and higher density decrease caused at high temperatures. This can be explained by the finding of Massini et al (14), who analysed coffee beans under industrial roasting conditions (200 - 210°C), and found formation of cavities and cracks after 4 minutes of roasting in the internal and external bean surface due to the relevant increase in the internal pressure and volume of coffee bean. Pittia et al. (13) reported the relation of texture changes of coffee beans roasted at 170 and 200°C to the changes of density.

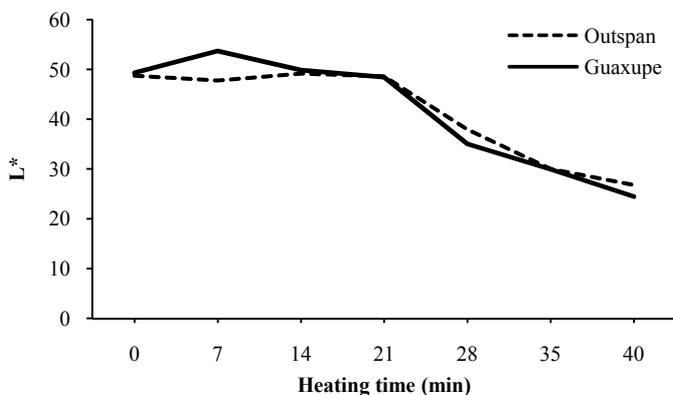


Figure 3. Changes in L^* value of Outspan and Guaxupe coffee beans during roasting

In coffee, the characteristic colour, aroma and flavour are developed during roasting, and thus it is necessary to adapt the roasting process to the type of coffee being roasted. This implies controlling the roasting time and temperature so that they are sufficient for the required chemical reactions to occur, without burning the beans and compromising the flavour of the beverage (6). During roasting, due to the non-enzymatic browning and pyrolysis reactions, changes in the coffee bean colour take place. So, beside the loss of mass and the chemical changes of certain components which could serve as tools in the control of the process, the effects of heating and the degree of roast can also be monitored by the colour of the beans (5). Yellow-green colour of the raw bean changes to a brown-black roasted colour (13). Browning is, in turn, described by a decrease of L^* as well as of a^* and b^* parameters. These colour changes for samples of Outspan and Guaxupe coffee beans are shown by the decrease of the L^* value in Fig. 3. The initial L^* value of 48.72 and 49.32 for raw coffee beans decreased during roasting to the final values of 26.77 and 24.45 for Outspan and Guaxupe, respectively. In their paper Pittia et al. (8) stated the criteria for the classification of differently roasted coffee samples on the basis

of the L^* colour parameter: the samples are classified as light, medium or dark roasted when L^* value is 31.1, 26.0 and 24.3 respectively. According to these criteria, it can be concluded that Outspan sample was medium and Guaxupe was dark roasted.

CONCLUSION

On the basis of obtained the results, it is possible to summarise that the moisture content, and density changes, mainly affect the mechanical properties of coffee beans during roasting. Bulk density values at the end of the heating process were the same for both coffee samples, 0.37g/mL, and the mean values of bean's breaking force were also very similar ($P > 0.05$), 37.82 N for Outspan and 35.39 N for Guaxupe. According to the total weight loss of green coffee beans after roasting the Outspan coffee was medium roasted, and Guaxupe coffee was between medium and dark roasted. According to the values of L^* colour parameter at the end of roasting process it can be concluded that the Outspan sample was medium and Guaxupe dark roasted.

It is possible to control and standardize the quality of ground roasted coffee as the final product by way of applying an adequate roasting procedure. In conventional roasting, the temperature range and the time can vary greatly, depending on the degree of roast required (light, medium or dark), on the type of used roaster, and also depend on the variety, age, moisture content, and other quality characteristics of the coffee.

REFERENCES

1. Kumazawa, K., Masuda, H.: Investigation of the Change in the Flavor of a Coffee Drink during Heat Processing. *J. Agric. Food Chem.* **51**, (2003) 2674-2678.
2. Martin, M.J., Pablos, F., Gonzalez, A.G.: Discrimination between arabica and robusta green coffee varieties according to their chemical composition. *Talanta.* **46**, (1998) 1259-1264.
3. Franca, A. S., Mendonca, J. C. F., Oliveira, S. D.: Composition of green and roasted coffees of different cup qualities. *LWT.* **38**, (2005) 709-715.
4. Dutra, E. R., Oliveira, S., Franca, A. S., Ferraz, V. P., Afonso, R. J. C. F.: A preliminary study on the feasibility of using the composition of coffee roasting exhaust gas for the determination of the degree of roast. *Journal of Food Engineering.* **47**, (2001) 241-246.
5. Hernandez, J. A., Heyd, B., Irlles, C., Valdovinos, B., Trystram, G.: Analysis of the heat and mass transfer during coffee batch roasting. *Journal of Food Engineering.* **78**, (2007) 1141-1148.
6. Mendes, C. L., De Menezes, C. H., Aparecida, M., da Silva, A. P.: Optimization of the roasting of robusta coffee (*C. canephora conillon*) using acceptability tests and RSM. *Food Quality and Preference.* **12**, (2001) 153-162.
7. Pravilnik o metodama uzimanja uzoraka i vršenja hemijskih i fizičkih analiza radi kontrole kvaliteta proizvoda od voća i povrća, Službeni list SFRJ 29/1983.

8. Pittia, P., Nicoli, M. C., Sacchetti, G.: Effect of moisture and water activity on textural properties of raw and roasted coffee beans. *Journal of Texture Studies*. **38**, (2007) 116-134.
9. StatSoft, Inc.: STATISTICA (data analysis software system), version 8.0, 2008. Available from: <http://www.statsoft.com/>.
10. Pravilnik o kvalitetu i drugim zahtevima za sirovu kafu, proizvode od kafe i surogat kafe, („Sl.list SRJ“, br.35/2001 i 49/2001-ispr.i „Sl.list SCG“,br.56/2003 - dr.pravilnik i 4/2004 -dr.pravilnik).
11. Franca, A. S., Oliveira, S. L., Mendonca, C. F. J., Silva, A. X.: Physical and chemical attributes of defective crude and roasted coffee beans. *Food Chemistry*. **90**, (2005) 89-94.
12. Oosterveld, A., Harmsen, J. S., Voragen, H. A.: Extraction and characterization of polysaccharides from green and roasted Coffee arabica beans. *Carbohydrate Polymers*. **52**, (2003) 258-296.
13. Pittia, P., Dalla Rosa, M., Lerici, C. R.: Textural changes of coffee beans as affected by roasting conditions. *Lebensm.-Wiss.Techinol*. **34**, (3) (2001) 168-175.
14. Massini, R., Nikoli, M. C., Cassara, A., Lerici, C. R.: Study on physical and physico-chemical changes of coffee beans during roasting. *Italian Journal of Food Science* **2**, (1) (1990) 123-130.

ПРОМЕНЕ ФИЗИЧКИХ СВОЈСТАВА ЗРНА КАФЕ ТОКОМ ПЕЧЕЊА

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У овом раду испитане су промене физичких својстава (маса, запремина, текстура и боја) зрна кафе сорти Outsran и Guaхуре, које се користе за производњу комерцијалних мешавина, у различитим временским интервалима топлотне обраде. Топлотна обрада обе соре била је индентична, примењена је максимална температура од 170°C у току 40 минута. Узорци за анализе узиману су током просеца топлотне обраде у временским интервалима од 7 минута.

Укупан губитак масе зрна на крају процеса печења био је 14,43% и 17,15% за Outsran и Guaхуре, редом и према том критеријуму узорак Outsran кафе био је средње печен, док је узорак Guaхуре кафе био средње до тамно печен. Током топлотне обраде смањивала се и просечна вредност силе лома зрна кафе. Највеће, статистички значајне ($P < 0,05$) разлике вредности силе лома за оба узорка уочене су

имеђу 7. и 14., као и нумеричке, али не и статистички значајне ($P > 0,05$) разлике између 35. и 40. минута топлотне обраде.

L^* вредност, као један од параметара за дефинисање степена печености зрна кафе, током процеса печења се смањује, односно зрно постаје тамније. Према критеријумима за дефинисање степена печења на основу L^* вредности може се закључити да је узорак Outspan (26,77) кафе средње, а узорак Guahure (24,45) кафе тамно печен.

Кључне речи: зрно кафе, печење, текстура, боја

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