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Roasting optimization of peaberry coffee beans from cherry fruits

Otimização do processo de torração de grãos moca provenientes de frutos cereja

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Resumo
O objetivo desse estudo foi determinar a melhor interação entre tempo e temperatura de torração de grãos moca provenientes de frutos cereja combinado com três diferentes graus de torração com o intuito de alcançar os melhores resultados de atributos sensoriais assim como verificar as mudanças nos parâmetros físicos. As curvas de torração mostraram similaridade dos perfis de temperatura indicando apropriada condução do processo de torração. De acordo com as diferentes formas de torração, diferenças significativas a nível de 5% de probabilidade foram observadas para densidade a granel, umidade, expansão enquanto a tonalidade e perda de massa foram iguais. A condição ótima de torração de grãos moca foi alta temperatura todo o tempo (T1) na coloração escura que obteve maiores valores para os atributos sensoriais.
Palavras-chave: Grãos moca. Café cereja. Análise sensorial. Propriedades físicas

Abstract
The aim of this study was to determine the best interaction between roasting time and temperature of peaberry beans from cherry fruits combined with three different degrees of roast in order to archive the best results for sensorial attributes as well as verify changes in physical parameters. The roasting curves showed similarity of temperature profiles, indicating proper conduction of the roasting process. According to the different ways of roasting, significant differences at 5% probability level were observed for the bulk density, moisture content, swelling while shade and weight loss was the same. The optimum roasting condition for peaberry beans was high temperature all the time (T1) in dark color, which obtained higher values for sensorial attributes.
Keywords: Peaberry beans. Cherry coffee. Sensorial analysis. Physical properties

1. Introduction

Among the different classifications used in Brazil for processed crude coffee beans, there is one regarding the shape and size of the beans, which can be classified in flat or peaberry subcategory (Brazil, 2003). Peaberries is the term used when only one of the flower's two ovaries is pollinated. This gives rise to a single oval grain instead of the usual two pairs of flat-sided grains. Typically, around 5% of all coffee beans harvested are this way (Garuma *et al.*, 2015). Demanding markets tolerate up to 10% peaberry beans in coffees classified as flat (Laviola *et al.*, 2006). Currently, in the market for roasted coffee beans, peaberry has a higher price when compared to flat beans, due to its supposed flavor being more concentrated compared to the normal bean (Suhandy and Yulia, 2017).

Roasting is responsible for changes in physical and sensorial characteristics of crude beans. The major changes in physical characteristics are the change in color, wight loss, bulk density, swelling and reduction on water content. These parameters are influenced by the degree of roast in the process. The roasting process is complex and several parameters and processes influence the final quality of the product. The roasting process can be divided into three stages: drying, roasting or pyrolysis and cooling. (Dutra *et al.*, 2001; França *et al.*, 2009; Nebesny and Budryn, 2006; Rodrigues *et al.,* 2003; Schenker and Rothgeb, 2017; Wang and Lim, 2017).

Although many studies have been carried out on the subject of coffee and roasting, there is no published study regarding the roasting of mocha beans, so the aim of this study was to determine the best interaction between roasting time and temperature of peaberry beans from cherry fruits with three different degrees of roast (light, medium and dark) in order to obtain the best results for the sensorial parameters as well as to verify the changes in the physical attributes given the importance in the industrialization, mainly in the packaging process of these roasted coffees.

2. Material and Methods

2.1 Raw material

The beans used in this study are all from the same planting area and the same variety. The fruits were processed on the same day and had an initial moisture content of around 11 to 12% (w.b.). Raw peaberry beans from cherry fruits were manually separated according to the size of the beans with the aid of sieves used for coffee classification, according to the Ministry of Agriculture, Livestock and Supply (MAPA) (Brasil, 2003). In this Normative Instruction, the sieves are numbered from 8 to 13 for peaberry beans. The samples used in this study were the sets of mixed peaberry beans retained on sieves 13, 12 and 11. Defective beans (immature, black, sour) were manually removed.

2.2 Roasting curves

Samples of 140 g of coffee are roasted in a Probat roaster, model BRZ-6 (Germany). During the roasting process, a digital stopwatch (±0.001s, Quartz, model BVQI, Brazil) and a digital pen thermometer (± 1oC, Incoterm, model 97900, Brazil) were used to measure time and temperature. The beans used in this study are all from the same planting area and the same variety.

The peaberry beans were subjected to light, medium and dark roasting. In roasting, three types of development of roasting process conduction were evaluated: high roaster chamber temperature all the time (T1); roaster chamber temperature increasing with time (T2) and low roaster chamber temperature all the time (T3) (Pimenta *et al.,* 2009). The initial roaster temperature measured by convection inside the roasting chamber was 150°C, which is the temperature recommended by the roaster manufacturer.

The grain heating rate was calculated by the ratio between grain temperature variation and time variation. These different roasting curves were applied in order to identify the degree of roast and the curve that reach the maximum quality potential, i.e., higher values of sensory attributes and appropriate physical characteristics for the packaging process of roasted beans.

2.3 Physical parameters

The physical analyzes carried out on the raw and roasted grains were: bulk density, with a graduated cylinder of 1000 mL± 10 mL (Merck, Germany); measurement of the dimensions of the grains, with a digital caliper (Digimess, China) in the dimensions of length, width and thickness using 50 grains; swelling was obtained by the difference between the dimensions of roasted and raw grains; weight loss was assessed as percentage of sample weight, before and after roasting, and moisture content according to Association of Official Analytical Chemists (AOAC, 2005) procedures. The color analysis parameter used in this study was hue (h). This parameter was obtained using the COLORPRO software (USA) (Rodrigues *et al.*, 2003). The shade was obtained with ground coffee and was performed with a colorimeter (Minolta, model CR 300, Japan).

2.4 Experimental design

In order to obtain the results of the analysis of the raw grains, four repetitions were used.

The experimental design was completely randomized, with three replications in a 3x3 factorial scheme for the roasting curves and physical analysis of the roasted grain.

The factors in this study consisted of different degrees of roast, i.e., light, medium and dark and roasting conditions denominated T1 for fast roasting, T2 for medium roasting and T3 for slow roasting. For sensory analysis, the experimental design was in complete blocks, consisting of two blocks, where each block represented a trained taster (Mason *et al.*, 2003). To compare the averages of the physical and sensory parameters, Tukey's test was used, with a 5% probability level. All data obtained were analyzed using Sisvar 5.6 software (Ferreira, 2011).

2.5 Sensory analysis

Sensory analysis was performed following the SCAA protocol (2007) by two tasters trained in this methodology. All roasted samples were subjected to a resting period of approximately 12 hours before the sensory analysis. Weighed on an analytical scale with 0.001g precision, 8.5 g of coffee for each cup. 5 cups were prepared for each type of sample, resulting from the applied treatments. The cups containing coarsely ground coffee were covered until the sensory analysis was carried out. The time elapsed between milling and the beginning of the sensory analysis did not exceed 15 minutes.

The first stage of the analysis constituted the evaluation of the attribute fragrance/aroma, the first being evaluated with the coffee powder still dry and the second after three minutes of adding water at the time of breaking the crust formed on the surface of the infusion. Tasters attributed grades from 0 to 10 according to their evaluation criteria. Mineral water at a temperature of 90ºC was used.

In the second stage, the evaluation of the attributes flavor, acidity, aftertaste, body and balance was carried out. Each attribute received scores from 0 to 10. The beginning of this stage occurred with the temperature of the solution between 45ºC and 50ºC, verified with a thermometer.

In the third stage, the attributes sweetness, clean cup, uniformity and overall impression. For the first three questions, the evaluation was carried out individually for each cup, which receives two points if the evaluation is positive and zero points if the evaluation is negative. The final result of these attributes was computed with the sum of the scores assigned to the 5 cups; the general impression attribute was assigned scores from 0 to 10.

In the fourth and last step, the final score was calculated by adding all the attributes.

3. Results and Discussion

3.1 Physical attributes of crude peaberry beans

The physical attributes of raw peaberry beans are presented in Table 1 and are in accordance with those specified for Arabica coffee (Brasil, 2003). The physical parameters bulk density, length, width and thickness were different from those found by Belay *et al.*, (2014), France *et al.*, (2005a), France *et al.*, (2005b) and Mendonça *et al.*, (2009) for flat beans confirming the different grain shape. Knowing these attributes is important for monitoring the physical changes that occur during roasting.

Table 1 – Physical attributes of crude peaberry beans.

Attributes	Crude peaberry beans
Bulk density (kg m^{-3})	682±3.2
Length (x 10^{-3} m)	8.6±0.1
Width (x 10^{-3} m)	5.6±0.1
Thickness (x 10^{-3} m)	4.8±0.1
Moisture content (w.b.)	11.5±0.1

3.2 Roasting curves

Figures 1 and 2 show examples of roasting curves obtained in this study. These roasting curves showed the best sensory merits (Table 3). The fast roasting curve (T1) showed an average heating rate of 14ºC/min, temperature increase with time (T2) of 11ºC/min and slow roasting curve (T3), 9ºC/min. Roasting time ranged from 11 minutes for T1 in light roasting to 17 minutes for T3 in dark roasting. The final temperature of the beans varied between 210ºC (light roasting) and 235ºC (dark roasting).

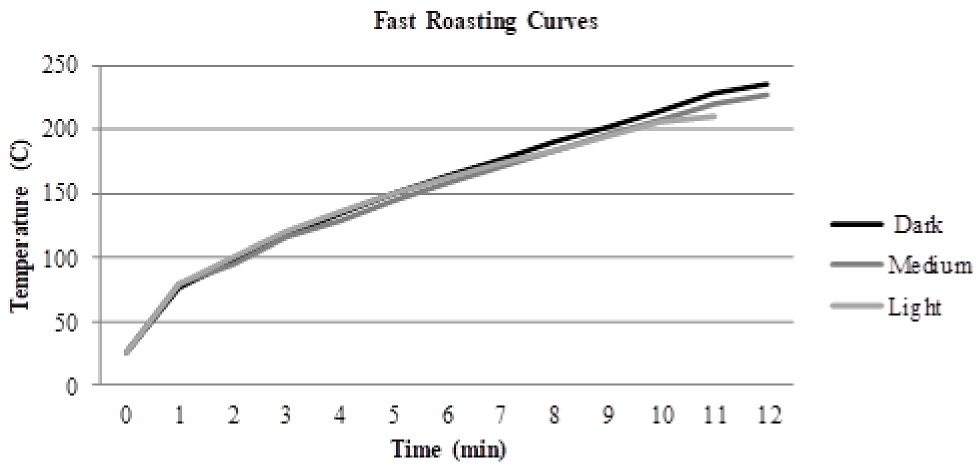

Figure 1 - Roasting curves of peaberry beans roasted in different degrees of roast.

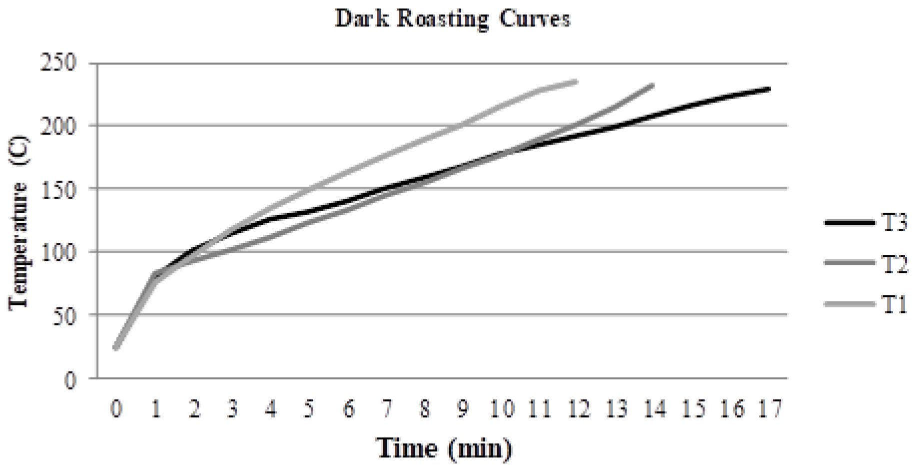

Figure 2 - Roasting curves of peaberry beans roasted in different conditions.

The similarity of the temperature profile shown in Figure 1 is indicative of the adequate conduction of the roasting process with the roaster used in this study; the same can be observed for the T2 and T3 roasting curves (data not shown). Differential thermal analysis showed that exothermic reactions start at 160ºC and peak at 210ºC for arabica coffee (Eggers and Pietsch, 2001). The roasting curve in the dark degree in the T1 condition, the times that correspond to these temperatures were 6 and 10 minutes respectively. Dutra *et al.*, (2001) obtained similar initial times for the final drying step (6 min) and 6 to 8 minutes for the beginning of the pyrolysis reactions, in the condition of the process used in the roasting of flat beans. With the different forms of heat conduction, the roasting curves (Figure 2) showed a different behavior, which is in line with the study by Pimenta *et al.*, (2009) who concluded that the temperature profiles of roasted beans depend on the form of heat increase and not on the shape of the bean.

3.3 Physical attributes of roasted peaberry beans

Table 2 presents the physical characteristics of roasted beans under different conditions of temperature, time and degree of roast. The hue (h) did not show significant differences after the end of the process, as it had the same color as the beans, confirming proper roasting, as the end of the process was evaluated by visual inspection of the color. Obtaining the standard degree of roast is important for later comparison of physical characteristics, since such characteristics are dependent on the final color of the beans. Significant differences were observed between the different degrees of roast, the light roasting presents more shade than the medium and dark ones. These results are in agreement with Borges *et al.*, (2004) and Rodrigues *et al.*, (2003) who verified the decrease of the shade with the increase of the degree of roast. In this study, the luminosity averages for grains of each color were 29.5, 21.5 and 19.2 for light, medium and dark roasting, respectively.

The final moisture content (M_C) of the roasted beans is shown in Table 2. Only in the light roasting under T3 condition the percentage of water was minor than in the roasting T1 and T2, in the longer roasting time there is more water vaporization and degradation and volatilization of organic compounds. Coffees roasted in light roasting have 2.4% moisture content, differing significantly from the other roasting grades. Light roasting had a shorter time and temperature when compared to the others. Vasconcelos *et al.*, (2007) obtained lower values for water in non-defective grains when compared to this study of 0.9; 0.9 and 1.0 for light, medium and dark roasting due to longer roasting time (30, 60 and 120 minutes). The Industrial Brazilian Coffee Association (ABIC) allows roasted coffee beans for sale in Brazil to have a maximum moisture content of 5%.

Table 2 -Physical attributes of coffee beans submitted to different degree and ways of roasting.

Degree of Roast	Roasting	H	M_C %	W_L %	ρ_B kg m^{-3}	Length x 10^{-3} m	Width x 10^{-3} m	Thicknes x 10^{-3}m
	T1	66±0.1[a]	2.5±0.2[a]	15.7±0.4[a]	370±4[b]	13±0.3[a]	23±1.1[a]	21±3[a]
Light	T2	67±0.1[a]	2.5±0.0[a]	15.3±0.1[a]	367±3[b]	7±0.6[c]	22±1.5[a]	15±2[b]
	T3	66±0.1[a]	2.1±0.0[b]	15.5±0.5[a]	384±4[a]	8±0.7[b]	21±0.7[a]	17±2[b]
Average		66A	2.4A	15.5C	374A	9.6C	22A	17±B
	T1	63±0.1[a]	1.5±0.1[a]	18.7±0.2[a]	343±1[b]	13±0.8[a]	23±0.6[a]	23±1[a]
Medium	T2	64±0.5[a]	1.8±0.1[a]	17.9±0.1[a]	347±3[ab]	10±0.3[b]	22±0.6[b]	18±1[b]
	T3	64±0.1[a]	1.5±0.1[a]	18.4±0.2[a]	352±6[a]	11±0.3[b]	22±0.6[b]	22±1[a]
Average		64B	1.6B	18.4B	347B	11B	22A	21±A
	T1	61±0.1[a]	1.6±0.2[a]	21±0.9[a]	328±1[b]	14±0.3[b]	22±0.5[a]	25±1[a]
Dark	T2	62±0.1[a]	1.6±0.1[a]	20±0.5[a]	330±1[ab]	15±0.3[a]	23±0.4[a]	19±1[b]
	T3	62±0.1[a]	1.4±0.1[a]	20±0.5[a]	335±4[a]	14±0.5[ab]	22±0.6[a]	20±1[b]
Average		62C	1.5B	20.3A	331C	14A	22A	21A

Average value±standard deviation. Values followed by the lowercase and uppercase column do not differ significantly using the Tukey test at 5% probability.

Weight loss (W_L) of roasted beans did not range with the different roasting conditions, presenting significant differences with the degree of roast. Roasted coffee in dark roasting present weight loss of 20.3%, medium roasting, 18.4% and light roasting, 15.5%. This is due to the difference in roasting time, darker coffees present greater roasting time leading to higher release of CO_2, steam and organic compounds during the pyrolysis. França *et al.*, (2009) obtained weight loss values of 19, 15 and 14% corresponding to dark, medium and light roasting, and the weight loss obtained by Silva (2008) was smaller, varying of 17 a 13% for light and dark roasting, respectively.

The bulk density (ρ_B) enables the comparison of roasted coffees obtained in different curves. In the industrialization of roasted coffee, this parameter is the most important one, as it influences the quality of the packaging process for whole, roasted and ground roasted beans, as roasted beans with lower density generate a greater number of particles during grinding (grains with higher swelling). This fact can make the packaging stage more difficult, if the packages are not sized correctly or, even if the company does not have densification systems (Silva, 2008). In this study, there was significant decrease in bulk density (682 kg m^{-3} – Table 1) after roasting due to simultaneous increase in volume (due to increase in internal pressure) and decrease in mass (due to loss of volatiles). Coffee roasting in T3 conditions presented greater bulk density than those roasting in T1 conditions for the three degrees of roast, indicative of smaller final volume of beans in roasting with slow temperature and greater roasting time. This fact is related to slow liberation of steam, CO_2 and volatile compounds, resulting in lower pressure on cellular structure during roasting T3. Similar results were obtained by Pimenta *et al.*, (2009). This corroborates the study by Schenker *et al.*, (2000) who observed that the volumetric expansion and opening of cell wall micropores were greater in fast roasting than in slow roasting. Regarding the degree of roast, light roasting has a higher bulk density when compared to medium and dark roasting, only due to the shorter process time with consequent interruption of the product of pyrolytic reactions responsible for the simultaneous increase in swelling and mass loss (Table 2). Dutra *et al.*, (2001) and Rodrigues *et al.*, (2003) cite that for an adequate roasting process the bulk density varies between 315 and 370 kg m^{-3} for light-medium degree of roast and 250 – 290 kg m^{-3} for dark roasting. In this study, similar values were obtained for light and medium roasted, and the dark roasting has obtained greater values.

Regarding swelling, no significant differences were found between the different forms and degrees of roast for the width. Regarding the length and thickness, there was a tendency for greater swelling for T1, indicative of greater pressure produced by volatile compounds during roasting with high temperatures. The different degrees of roast influenced swelling in the length and thickness, with higher values obtained in dark roasting, due to the longer process time. Flat beans, due to the convex shape plane, have less resistance in the thickness, providing greater swelling during roasting (Silva, 2008). Peaberry beans, there is greater swelling on the width and values close to the thickness, due to the oval shape.

3.3 Sensorial attributes of roasted peaberry beans

Tables 3 and 4 shows the merits obtained by roasting coffees, according to an evaluation by trained taster based on SCAA recommendations (SCAA, 2007). In relationship to aroma/fragrance, the different degrees of roast do not have influence in this attribute. Light roasting in T1 condition has presented a slight fragrance and flavor of past crop or bag taste that damaged the development of coffee whereas in T3 condition, slight fragrance of chocolate and after cooling, slight flavor of past crop. Roasting T2 and T3 in medium degree of roast and T3 in dark roast presented a slight fragrance of chocolate and vanilla. Dark degree of roast in T1 condition presented chocolate fragrance. The aroma was not influenced according to the degrees of roast.

Table 3 – Sensorial attributes of coffee beans submitted of different degree and way of roasting.

Degree of Roast	Roasting	Aroma	Uniformity	Clean Cup	Sweetness	Flavor
	T1	7.1±0.2[a]	10±0 [a]	8±0.2 [a]	8±0.2 [a]	6.5±0.2 [a]
Light	T2	7.2±0.2 [a]	10±0[a]	8±0.2 [a]	8±0 [a]	6.7±0.2 [a]
	T3	7.2±0.1 [a]	10±0 [a]	8±0.2 [a]	8±0.2 [a]	6.5±0.1 [a]
Average		7.2A	10A	8B	8A	6.6A
	T1	7.2±0.2 [a]	10±0 [a]	8±0.1[b]	8±0.1 [b]	6d.7±0.1 [a]
Medium	T2	7.2±0.2 [a]	10±0 [a]	8±0.2 [b]	8±0.1 [b]	6.7±0.1 [a]
	T3	7.2±0.1 [a]	10±0 [a]	10±0 [a]	10±0 [a]	7±0.2 [a]
Average		7.2A	10A	8.7AB	8.7A	6.8A
	T1	7.5±0.1 [a]	10±0 [a]	10±0 [a]	10±0 [a]	7±0 [a]
Dark	T2	7.0±0.3 [a]	10±0 [a]	10±0 [a]	8±0.2 [b]	6.7±0.3 [a]
	T3	7.5±0.2 [a]	10±0 [a]	10±0 [a]	8±0.2 [b]	6.7±0.2 [a]
Average		7.3A	10A	10A	8.7A	6.8±A

Average value±standard deviation. Values followed by the lowercase and uppercase column do not differ significantly using the Tukey test at 5% probability.

Uniformity values were maximum for all coffee samples and this attribute was not influenced by the form and degree of roast. In relation to the clean cup, dark roast has presented major and maximum value than the other degrees of roast. Only in medium roast, T3 conditions have presented major values than T1 and T2. Dark roasting differed from light roasting for this attribute.

In relation of sweetness the obtained values for medium roasting in T3 condition were major than the others, whereas the same was noted in dark roasting in T1 condition. This attribute was not influenced by the degrees of roast. The flavor values were the same for the different treatments applied.

Acidity was major for light and medium roasting. According to tasters, dark roasting in T1 condition presented outstanding citric acidity. According to Silva (2008) light roasting accents the perception of this attribute while in slow roasting the opposite is noted. This are verified in this study.

In relationship to the body, light and dark roasting have presented the same values. The values obtained in T3 condition were minor than those in T1 and T2. Major prominence in this attribute was obtained for T2 condition in light roasting and T1 condition in dark roasting, according to the tasters.

Table 4 – Sensorial attributes of coffee beans submitted of different degree and way of roasting.

Degree of Roast	Roasting	Acidity	Body	Aftertaste	Balance	Overall	Final Score
	T1	7.5 ± 0.3^{a}	6.7 ± 0.1^{a}	7 ± 0^{a}	7 ± 0^{a}	7 ± 0^{a}	74 ± 0.5^{a}
Light	T2	7.5 ± 0.3^{a}	6.7 ± 0.7^{a}	7.2 ± 0.2^{a}	7 ± 0^{a}	7 ± 0^{a}	75 ± 1.3^{ab}
	T3	7.2 ± 0.2^{a}	6.5 ± 0.2^{a}	7.2 ± 0.2^{a}	7 ± 0^{a}	7.2 ± 0.3^{a}	75 ± 1.2^{a}
Average		7.4A	6.7AB	7.2A	7A	7.1A	75B
	T1	7.5 ± 0.3^{a}	6.7 ± 0.1^{a}	6.7 ± 0.3^{a}	6.7 ± 0.1^{a}	6.7 ± 0.2^{a}	74 ± 0.4^{b}
Medium	T2	7.5 ± 0.2^{a}	6.5 ± 0.3^{a}	6.5 ± 0.2^{a}	6.5 ± 0.1^{a}	6.5 ± 0.2^{a}	73 ± 0.6^{b}
	T3	7.2 ± 0.3^{a}	6.2 ± 0.4^{b}	6.5 ± 0.2^{a}	6.5 ± 0.1^{a}	6.5 ± 0.1^{a}	77 ± 0.3^{a}
Average		7.4A	6.5B	6.6B	6.6B	6.6B	75B
	T1	7 ± 0^{a}	7.2 ± 0.2^{a}	7 ± 0^{a}	7 ± 0^{a}	7 ± 0^{a}	79 ± 0.4^{a}
Dark	T2	6.5 ± 0.2^{b}	7 ± 0^{a}	6.7 ± 0.3^{a}	6.7 ± 0.2^{a}	6.7 ± 0.3^{a}	75 ± 0.5^{b}
	T3	6.7 ± 0.2^{ab}	6.7 ± 0.3^{ab}	6.7 ± 0.3^{a}	6.7 ± 0.2^{a}	7 ± 0^{a}	76 ± 0.7^{b}
Average		6.7B	7A	6.8AB	6.8AB	6.9AB	77A

Average *value* ± *standard* deviation. Values followed by the lowercase and uppercase column do not differ significantly using the Tukey test at 5% probability.

Better merits were obtained for light roasting for aftertaste when compared with medium and dark roasting. In relation to roasting condition high merits were obtained for T1 in medium and dark roasting, and minor for light roasting. Roasting T2 in medium degree of roast presented astringent aftertaste.

Dark roasting in T1 condition has presented the highest final score, which is the sum of all merits. These conditions of roasting and degree of roast are the optimum for peaberry beans from cherry fruits, obtaining the maximum quality potential in relation to sensorial attributes.

4. Conclusion

In this study it was not possible to note the stages of drying and pyrolysis of the roasting process. Evaluation of the temperature profiles (roasting curves) concludes that the roasting was conducted properly and this fact is confirmed by final shade of roasted and weight loss within each degree of roast.

Although peaberry have different shape, the physical parameters of this crude beans are according to literature values for flat beans, which variation only in width.

Peaberry roasted beans from cherry fruits were optimum in dark degree of roast and roasting in fast way. They have presented, in general, the best sensorial attributes in relation to other applied treatments, being classified as premium, according to the final score of the SCAA.

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