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Drying of hulled naturally processed coffee with high moisture content and its impacts on quality

Valdiney Cambuy Siqueira¹, Flavio Meira Borem², Eder Pedroza Isquierdo³, Guilherme Euripedes Alves⁴, Diego Egidio Ribeiro^{5*}, Afonso Celso Ferreira Pinto⁶, and Jose Henrique da Silva Taveira⁷

¹Faculty of Agricultural Sciences, Federal University of Grande Dourados – S/N, Cx. P. 533, 79.804-970, Dourados, MS, Brazil.

²Department of Agricultural Engineering, Federal University of Lavras – S/N, Cx. P. 3037, 37.200-000, Lavras, MG, Brazil.

³University of the State of Mato Grosso – Av. São João, S/N, 78.200-000, Cáceres, MT, Brazil.

⁴Department of Agricultural Engineering, Federal University of Lavras – S/N, Cx. P. 3037, 37.200-000, Lavras, MG, Brazil.

⁵Department of Agricultural Engineering, Federal University of Lavras – S/N, Cx. P. 3037, 37.200-000, Lavras, MG, Brazil.

⁶Department of Agricultural Engineering, Federal University of Lavras – S/N, Cx. P. 3037, 37.200-000, Lavras, MG, Brazil.

⁷Department of Agricultural Engineering, University of the State of Goiás – Av. Protestato Joaquim Bueno, 945, 75920-000, Santa Helena de Goiás, GO, Brazil.

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This study aimed to propose a new method to reduce the time needed for coffee processing and drying and to verify this method's possible impact on both the sensorial and physiological qualities of coffee. The method, which entails hulling coffee with different moisture contents by removing the entire pericarp before completing the drying, reduced the operating time by more than 50% as compared to the normal drying of natural process coffees. The temperatures used for drying the hulled coffee did not compromise its quality; coffee hulled with $36 \pm 2\%$ (w.b.) resulted in higher sensory analysis scores; and coffee hulled with higher moisture content yielded a better physical appearance.

Key words: Mechanical drying, *Coffea arabica* L., processing, physiological and sensory quality.

INTRODUCTION

In recent decades, coffee production has gone through several transformations such as the introduction of varieties that are more productive, have greater resistance to pests and diseases, and have greater tolerance to

drought as well as the implementation of modern production systems with a high standard of crop protection. In addition, there have been important technological advances such as the introduction of irrigation

*Corresponding author. E-mail: diegoerib@gmail.com.

systems, crop management and mechanical harvesting. Thus, in Brazil, coffee farming is becoming a growing business, which occupies extensive agricultural areas of high productivity (Carvalho et al., 2010; Faria and Siqueira, 2005; Lanna and Reis, 2012; Silva et al., 2008, 2013).

However, advances in the field have not been accompanied by comparable technological innovations in the post-harvest to allow for the assimilation of the increased yields and efficiencies. In fact, increased harvest yields combined with the introduction of mechanical harvesting have turned the post-harvest stage into the main bottleneck of the coffee production chain, with drying being the main limitation in the flow between harvest and storage (Borém et al., 2008b).

When compared with other commodities such as corn, soy, and wheat, coffee is the only agricultural grain with drying times that exceed 40 h. In the case of naturally processed coffees, drying times may even exceed 200 h in order to ensure a moisture content that is suitable for storage (Donzeles et al., 2007; Lacerda Filho and Silva, 2006; Resende et al., 2007, 2011a; Simões et al., 2008).

The longer drying times are due both to the high initial moisture content of the coffee upon harvesting and slower drying given the presence of the thick, fleshy and moist pericarp. Besides exposing the coffee to various risks that may alter its quality, these long drying times result in higher energy and labor consumption and thus a higher processing cost (Berbert et al., 2001; Borém et al., 2008b; Finzer et al., 1997; Ghosh and Venkatachalapathy, 2014; Palacin et al., 2009; Resende et al., 2007).

The coffee drying rate can be increased by reducing relative humidity, increasing dry bulb temperature, or increasing the flow rate of the drying air (Alves, 2013; Isquierdo et al., 2011; Ribeiro et al., 2003). However, there are some limitations that impede the implementation of these techniques on a large scale.

Equipment used to reduce relative humidity is costly and, as of yet, has not been designed for use with commercial coffee dryers. The use of high air flow has a greater effect when the drying temperature is low and in the early stages of drying, when the product has a high moisture content. High drying air temperatures can cause thermal and physical damage to the product and compromise its quality (Borém et al., 2006; Isquierdo et al., 2011, 2013; Ribeiro et al., 2003).

Basically, coffee can be processed by two methods: dry and wet. The dry method consists of drying the whole fruit with all anatomical components intact. This results in a dried fruit also known as dried coffee pods or natural coffee. In wet processing, the fruit is pulped, that is, the epicarp and part of the mesocarp are removed, leaving just the seed, endocarp and potentially some of the remaining mucilage that adheres to the endocarp. This coffee is commonly known as parchment coffee (Borém et al., 2008b; Esquivel and Jiménez, 2012; Selmar et al.,

2006).

The greatest reduction in drying time is reported from wet processing which can be up to 6.8 times faster than dry process coffee, depending on the temperature and air flow used (Alves, 2013). Nonetheless, in Brazil most farmers still process their coffee using the dry process.

Drying efficiency is not solely related to time, costs, equipment, use of renewable and nonrenewable resources, etc., but it is also tied to product quality since quality is a key factor at the time of sale. Several studies show that drying has a direct influence on the final coffee quality (Borém et al., 2008a; Coradi et al., 2008; Isquierdo, 2011; Isquierdo et al., 2013, 2012; Kleinwächter and Selmar, 2010; Reinato et al., 2011b, 2012; Rosa et al., 2005). It is therefore necessary to develop new technologies for processing and drying natural coffees in order to meet increasing post-harvest demands, improve drying efficiencies and do so without compromising the quality of the final product. This study analyzed the technical feasibility of drying natural coffees with full removal of the pericarp at higher moisture contents. The reduction of the total drying time and possible impacts on the physiological and sensory quality of coffee was analyzed.

MATERIALS AND METHODS

Characterization of the experiment

Coffee fruits (*Coffea arabica* L. cv. Bourbon Amarelo) were harvested in commercial crops at 1,246 m asl (S22° 06' 7.6" and W45° 12' 15.5") in the municipality of Carmo de Minas, Minas Gerais, Brazil. The harvest was performed manually, by collecting only fruit at maximum maturity. After the harvest, fruits were subjected to hydraulic separation to remove those with lower density, such as overripe, underdeveloped and insect-damaged fruit. After this step, a new manual selection removed any remaining immature and overripe fruits that were harvested but not removed in the hydraulic separation process.

The material was then separated into two groups. The first group, consisting of fruits with initial moisture content of 70.6% (w.b.), was dried at 40°C until reaching a final moisture content of $11 \pm 0.5\%$ (w.b.). The second group was dried at 40°C for periods of 36, 48, 60 and 72 h, corresponding respectively to moisture contents of 36 ± 2 ; 29 ± 2 ; 22 ± 2 and $17 \pm 2\%$ (w.b.). Fruits were then hulled at these respective periods and after hulling subject to continuous drying at $35 \pm 1^\circ\text{C}$ and $40 \pm 1^\circ\text{C}$, until reaching a final moisture content of $11 \pm 0.5\%$ (w.b.) as described in Figure 1. Drying was carried out by forced convection in fixed bed dryers, composed of six square perforated trays, each with 0.35 m sides and a depth of 0.4 m, located over a plenum in order to ensure a uniform airflow. Throughout the drying process of both the natural and hulled coffees, airflow was monitored using a vane anemometer set and kept at $24 \text{ m}^3\text{min}^{-1}\text{m}^{-2}$. Temperature adjustment and control were performed by means of an electronic controller and constant monitoring, with the aid of mercury thermometers inside the coffee mass.

For initial drying, 20 L of fruits were placed in each tray, corresponding to approximately 13 kg. The thickness of the drying fruit layer at the beginning of this process was 16 ± 1 cm. For drying the second group, a portion of fruit was hulled by a sample huller machine CARMOMA[®] DC1. Afterwards, the hulled coffee (beans)

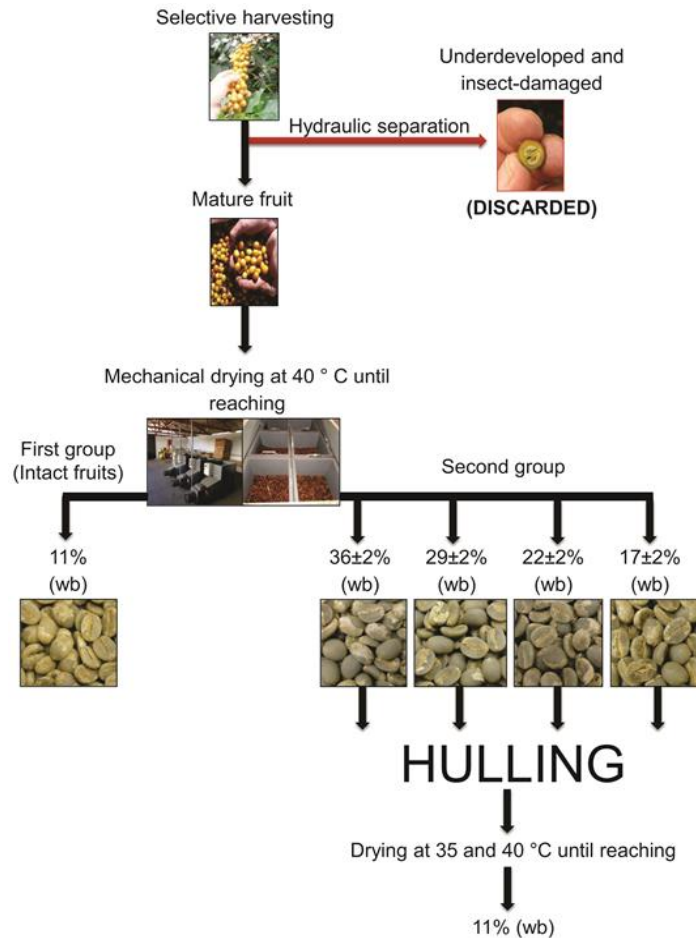


Figure 1. Flowchart of coffee processing and drying.

was subjected to continuous drying according to the treatments. After hulling, the height of the coffee layer was approximately 4 cm.

Determination of moisture content and preparation of the samples

The moisture content of the natural coffee was determined using an oven at $105 \pm 3^\circ\text{C}$ for 24 h in three replicates (Brasil, 2009). The moisture content of the hulled coffee was determined by the oven method at $105 \pm 1^\circ\text{C}$ for 16 h, according to international standard ISO 6673 (ISO, 2003). The results were expressed as a wet basis percentage (w.b.).

After drying, coffee beans were classified according to size and shape. For analysis, only undamaged plano-convex shaped beans that were retained by sieves with 16 to 18/64 inch diameter holes were used. This was done to standardize the samples and minimize interference unrelated to treatments.

Characterization of coffee quality

In order to evaluate the physiological quality of the bean and the sensory quality of the coffee beverage, physiological tests, color evaluations and sensory analysis was performed on each prepared sample.

Electrical conductivity and potassium leaching

Electrical conductivity of the coffee beans was determined using two replicates of 50 beans per sample. Each replicate was weighed to the nearest 0.001 g and then immersed in 75 mL distilled water, inside plastic cups with a 200 mL capacity. These cups were placed in a BOD incubator with forced air ventilation and a temperature of 25°C for five hours. After incubation, the electrical conductivity of the imbibition water was determined using a benchtop conductivity meter – BEL brand, model W12D – (Krzyzanowski et al., 1991).

The leaching of potassium ions was performed on raw beans using the imbibition water obtained in the prior electrical conductivity test. Levels of leached potassium were determined using a flame photometer – Digimed brand, model NK-2002 (Prete and Abrahão, 1995).

Lercaf  test

A Lercaf  test was conducted in three replicates of 25 beans each sample. Coffee beans were submerged in 100 mL of a 5% sodium hypochlorite solution for one hour (Reis et al., 2010). A plastic screen from a germination box was used to ensure that all beans were submerged and in contact with the solution. Subsequently, the germination boxes were capped and kept in a BOD incubator under a constant temperature of 25°C for 6 h. The beans were then

Table 1. Drying time (hours) of coffee beans submitted to the new method of processing.

Temperature (°C)	Moisture contents at hulling (% w.b.)			
	36±2	29±2	22±2	17±2
40±1	47.5	57.25	67.25	76.5
35±1	58	67	72.5	81

washed to remove excess solution, immersed in distilled water for 40 min and then arranged on a counter for counting, characterization and visual evaluation. This evaluation was performed by comparing the endosperm color to the total surface area of the beans.

Color evaluation

The color of the raw coffee beans was determined using a Minolta colorimeter CR 300 to directly measure "L", "a", "b" dimensions using the Hunter lab color scale (Nobre, 2005). The samples were placed in Petri dishes and, for each replicate, five readings were taken at the four cardinal points of the plate and at the center point.

Sensory analysis

Sensory analysis was performed by certified specialty coffee judges, using the methodology proposed by the Specialty Coffee American Association – SCAA – (Lingle, 2011). The SCAA sensory analysis protocol was used for coffee brewing and roasting. The coffee was roasted to a level corresponding to 58 points for whole beans and 63 points for ground beans, with a tolerance of ± 1 point. 100 g of beans were roasted from each sample.

For the sensory evaluation, five cups of each sample were tasted, with one session of sensory analysis for each replicate and three replicates for each treatment. The evaluated sensory attributes were grouped into "subjective" and "objective" categories. "Subjective" attributes were fragrance/aroma, flavor, acidity, body, balance, aftertaste and overall impression. They were scored according to their quality on a scale of 6 to 10 points in intervals of 0.25 points. The "objective" category included uniformity, sweetness and clean cup (absence of defects). The objective attributes were scored on a scale from 0 to 10 points, with 2 points awarded for each cup that presented satisfactory levels of each attribute. For the purposes of this study, the final score, obtained from the sum of the scores for each attribute in both categories were only considered.

Experimental design and statistical analysis

The experiment was a completely randomized design with a 4 x 2 + 1 factorial arrangement with four moisture content hulling levels (36 \pm 2; 29 \pm 2; 22 \pm 2 and 17 \pm 2% w.b.), two drying temperatures of the hulled coffee (35 \pm 1 and 40 \pm 1°C) and a control treatment (complete drying of natural coffee at 40 \pm 1°C, without hulling), in three replicates. Data was subjected to analysis of variance and the mean values were compared by Scott-Knott test at a 5% significance level. The hulled coffees were compared with the control coffee using Dunnett's test.

RESULTS AND DISCUSSION

The drying time of coffee fruits prior hulling were 36, 48,

60 and 72 h, which correspond to the moisture content 36 \pm 2, 29 \pm 2, 22 \pm 2 and 17 \pm 2% w.b. in the beans, respectively. The drying time of the hulled coffee beans was calculated by the difference between the total drying time (Table 1) and the drying time before hulling. Considering the initial moisture content of the coffee beans at 36 \pm 2, 29 \pm 2, 22 \pm 2 and 17 \pm 2% w.b. at the moment of hulling, the drying time of the hulled coffee beans was 11.5, 9.25, 7.25, and 4.25 h for the air temperature set at 40 \pm 1°C. For the air temperature set at 35 \pm 1°C, the drying time of the hulled coffee beans was 22, 19, 12.5, and 9 h. Conversely, the total drying time of the natural coffee (control) with initial moisture content at 70.6% (w.b.) was 108 h.

The total time for drying the hulled coffee beans was 56% lower [(108-47.5)/108 = 56%] than for drying the natural coffees (whole fruits), when the coffee fruits were hulled at 36 \pm 2% (w.b.) and submitted to air temperature to 40 \pm 1°C. Such behavior is due to the shorter time (36 h) until the hulling moment plus the 11.5 h for drying the hulled coffee beans at this temperature.

The higher drying rates are for the hulled coffees dried at 40 \pm 1°C as compared to the ones dried at 35 \pm 1°C (Figure 2), regardless of the moisture content at the moment of hulling. It is clear that the lower temperature of drying is the higher in the time needed for drying. The higher decrease in moisture content when air drying temperature was 40 \pm 1°C can be explained by the larger difference in the partial vapor pressure of air and inside de coffee beans. These results in higher drying rate (Table 2), which makes the water molecules removed easily and quickly. By hulling the coffee in this manner, its morphological and/or physical characteristics become more similar to other agricultural products such as soy, beans, wheat, etc. This opens up the possibility of using other types of dryers used for drying these products and not restricting coffee drying solely to traditional coffee dryers, such as fixed bed, rotary and cross flow dryers. Table 3 presents a summary of the analysis of variance for all variables. The drying temperature by itself did not change any of the variables studied. However, the moisture content at the time of hulling resulted in both different sensory perceptions of the coffee beverage, as well as in the color evaluation (coordinates "a" and "b" and brightness). The interaction between drying temperature and the moisture content of the hulled coffee is significant only for color evaluations, as well as the effect of this interaction, together with the control

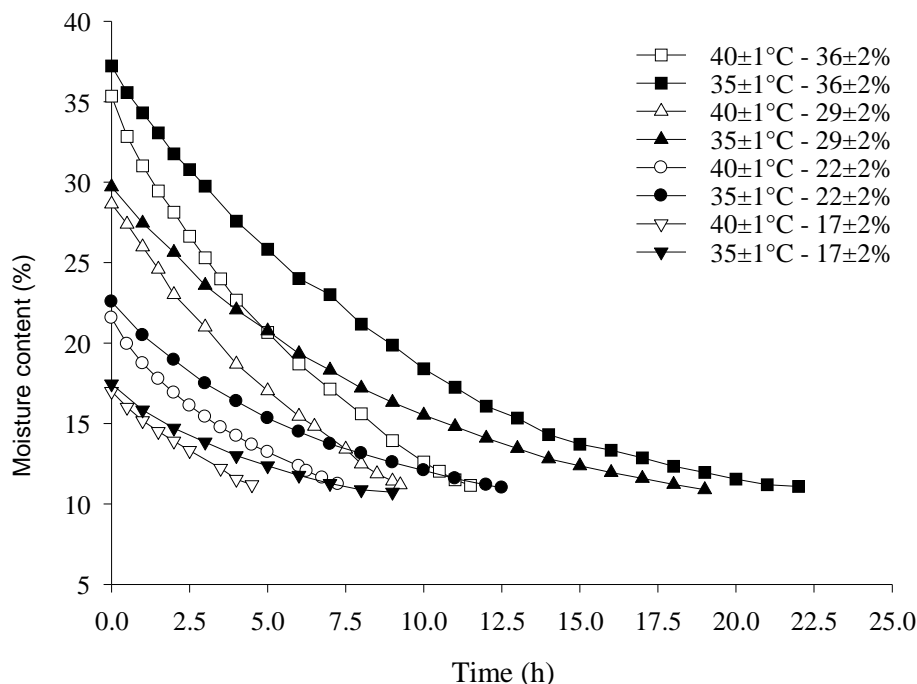


Figure 2. Moisture content of hulled coffee beans during drying with air temperature set at $40 \pm 1^\circ\text{C}$ and $35 \pm 1^\circ\text{C}$ (drying curves).

Table 2. Average drying rate ($\text{kg kg}^{-1} \text{h}^{-1}$) of coffee beans early hulled at high moisture content and submitted to air drying temperature set at 40 ± 1 and $35 \pm 1^\circ\text{C}$.

Temperature ($^\circ\text{C}$)	Moisture content (% w.b.)			
	36 \pm 2	29 \pm 2	22 \pm 2	17 \pm 2
40 \pm 1	0.035	0.030	0.021	0.018
35 \pm 1	0.021	0.016	0.013	0.010

Table 3. Summary of analysis of variance for electrical conductivity, potassium leaching, Lercaf , sensory score (sensory), coordinate "a", coordinate "b" and brightness of coffee beans after different methods for hulling and drying.

Source of variation	EC	KL	Lercaf�	Sensory	Coord" a"	Coord" b"	B's
	F _{calc}	F _{calc}	F _{calc}	F _{calc}	F _{calc}	F _{calc}	F _{calc}
Temperature	0.013 ^{ns}	0.025 ^{ns}	1.066 ^{ns}	1.933 ^{ns}	1.623 ^{ns}	3.034 ^{ns}	3.522 ^{ns}
Moisture content upon hulling	0.354 ^{ns}	1.710 ^{ns}	0.643 ^{ns}	5.694*	98.99*	25.611*	87.692*
Factorial (temperature x moisture content)	0.248 ^{ns}	1.058 ^{ns}	1.806 ^{ns}	2.190 ^{ns}	4.289*	3.957*	3.364*
Factorial x control	4.249 ^{ns}	2.376 ^{ns}	1.415 ^{ns}	0.024 ^{ns}	75.241*	9.224*	149.361*
CV (%)	19.2	19.7	15.8	0.8	9.9	4.9	6.4

*Significant at 5%, by F-test. ^{ns} Non-significant. Control: complete drying of natural coffee at 40°C , without hulling.

(complete drying of the natural coffee).

Table 4 shows the average values of the physiological tests, color evaluation and sensory analysis performed on

coffee hulled with high moisture content and subjected to drying at different temperatures, as compared to natural coffee (control). With respect to physiological testing and

Table 4. Electrical conductivity, potassium leaching, Lercafé, sensory score (Sensory), coordinate “a”, coordinate “b” and brightness of coffee beans subjected to drying after hulling as compared to drying of control.

Treatments	EC ($\mu\text{S.cm}^{-1}.\text{g}^{-1}$)	KL (ppm)	Lercafé (%)	Sensory	Coord“a”	Coord“b”	B's
35±1/36±2	12.039	23.103	75.407	85.611	2.396*	24.679*	19.049*
35±1/29±2	11.390	23.368	71.414	84.555	1.444*	19.461	27.553*
35±1/22±2	11.861	20.214	66.370	85.833	1.091	19.460	29.016*
35±1/17±2	12.944	22.147	60.559	84.611	0.834	18.674	40.472
40±1/36±2	13.242	26.926	66.734	86.111	1.684*	22.702*	22.355*
40±1/29±2	11.216	18.462	55.852	84.472	2.007*	23.908*	20.589*
40±1/22±2	12.362	18.886	62.068	84.333	1.085	20.782	30.600
40±1/17±2	11.860	23.403	71.703	84.111	0.783	20.002	33.304
Control	15.140	26.253	58.748	84.889	0.673	19.320	43.046

Control: complete drying of natural coffee at 40°C, without hulling.

Table 5. Coordinates “a” and “b” and brightness of coffees hulled with high moisture content and subjected to drying at different temperatures.

Variables analyzed	Temperature (°C)	Moisture content (% w.b.)			
		36±2	29±2	22±2	17±2
Coordinate “a”	35±1	2.39 aA	1.44 aB	1.09 aB	0.83 aB
	40±1	1.68 bA	2.01 aA	1.08 aB	0.78 aB
Coordinate “b”	35±1	24.68 aA	19.46 bB	19.99 aB	18.67 aB
	40±1	22.70 aA	23.91 aA	20.78 aB	20.00 aB
Brightness	35±1	19.05 aC	27.55 aB	29.01 aB	40.47 aA
	40±1	22.35 aB	20.59 bB	30.60 aA	33.30 bA

Means followed by different lowercase letters in the same column and uppercase letters in the same row are significantly different ($P < 0.05$) by Scott-Knott test.

sensory analysis, none of the treatments were significantly different from the control.

In the color evaluation, some of the hulled coffees presented different color tones than the control. Coffees dried at $40 \pm 1^\circ\text{C}$ and hulled at moisture contents of 36 ± 2 and $29 \pm 2\%$ (w.b.) had different “a” and “b” coordinates and brightness levels as compared to the control coffee. For the drying temperature of $35 \pm 1^\circ\text{C}$ similar results were found as well as a difference in the brightness observed in the coffee hulled with a moisture content of $22 \pm 2\%$ (w.b.). However, unlike the coffee dried at $40 \pm 1^\circ\text{C}$, the coffee hulled at $29 \pm 2\%$ (w.b.) did not present changes in bluish and yellowish colors (coordinate “b”) as compared to the control. Higher values of the coordinates “a” and “b” represent higher saturation of the colors, red and yellow, respectively, and lower values of these coordinates indicate greater saturation of green and blue, respectively.

Differences in brightness were found between coffees hulled with high moisture content and coffee processed by the standard dry method with $11 \pm 0.5\%$ (w.b.). The

higher the moisture content upon hulling, the greater the difference in tonality. It is interesting to also note that coffees hulled with high moisture content presented, at the end of the drying process, a darker tone that is common to wet processed coffees. Coffee beans processed in the wet way have higher activity of polyphenol oxidase (Saath et al., 2014) and these coffee beans are darker than the coffee beans processed using the natural method (Abreu et al., 2015). It suggests that the high activity of polyphenol oxidase is a possible cause of the darker color of the coffee beans hulled with high moisture content.

Results of the interaction between moisture content and drying temperature for the color analysis are shown in Table 5. It was not possible to observe a clear behavior for the same moisture contents in function of the two drying temperatures used. The higher the drying temperature, the lower the intensity of the color green for coffees processed by dry and wet methods (Corrêa et al., 2002). However, for the temperature range used in this experiment, this behavior was only observed when the

Table 6. Average values of electrical conductivity, potassium leaching, Lercafé, sensory score (Sensory), coordinate “a”, coordinate “b” and brightness for the coffee hulled and dried at temperatures of 35 ± 1 and $40 \pm 1^\circ\text{C}$.

Temperature	EC ($\mu\text{S cm}^{-1} \text{g}^{-1}$)	KL (ppm)	Lercafé (%)	Sensory	Coord“a”	Coord“b”	B's
$35 \pm 1^\circ\text{C}$	12.06	22.21	68.44	85.15	1.44	20.7	29.02
$40 \pm 1^\circ\text{C}$	12.17	21.92	64.09	84.75	1.39	21.85	26.71

Table 7. Electrical conductivity, potassium leaching, Lercafé and sensory score (Sensory) for the coffee hulled and dried at temperatures of 35 ± 1 and $40 \pm 1^\circ\text{C}$.

Moisture content (% w.b.)	EC ($\mu\text{S cm}^{-1} \text{g}^{-1}$)	KL (ppm)	Lercafé (%)	Sensory
36 ± 2	12.64	25.01	71.07	85.86a
29 ± 2	11.30	20.91	63.63	84.51b
22 ± 2	12.11	19.55	64.22	85.08b
17 ± 2	12.40	22.77	66.13	84.36b

Means followed by different lowercase letters in the same column are significantly different ($P < 0.05$) by Scott-Knott test.

coffee was processed with a moisture content of $36 \pm 2\%$ (w.b.).

In general, values of the coordinates “a” and “b” decrease and brightness values increase when the hulling was carried out with drier coffee. This implies a blue-green color with light shading, an aspect that is usually related to good quality coffee (Afonso Júnior and Corrêa, 2003; Selmar et al., 2007). Increased brightness is more evident in the temperature of $35 \pm 1^\circ\text{C}$, perhaps favored by the longer drying time after hulling. The quality of coffee showed no significant differences for the two temperatures used in drying the coffee hulled with high moisture contents (Table 3). The average values of the analyses performed to characterize the physiological quality of the bean and sensory quality of the beverage are shown in Table 6.

For artificial drying with forced ventilation, the maximum temperature that can be used without compromising quality is $40 \pm 1^\circ\text{C}$ (Isquierdo, 2011). The same was observed in the present study, in which the temperature of $40 \pm 1^\circ\text{C}$ applied in drying coffee hulled with high moisture content had no negative effects on the final product quality. This information is relevant, since the drying times are significantly reduced when the drying is performed at $40 \pm 1^\circ\text{C}$ when compared with the temperature of $35 \pm 1^\circ\text{C}$.

Table 7 lists the average values of the analyses used to determine the quality of coffee subjected to two drying temperatures after hulling with different moisture contents. The moisture content of the coffee upon hulling did not influence the values of electrical conductivity, potassium leaching and Lercafé. These analyses indicate the physical integrity of the bean and indicate its physiological potential. Thus, for these ranges of moisture content upon

hulling, there was no great physical or thermal damages to the beans during the drying process.

It was expected that the higher moisture content would cause greater damage since the bean would be more sensitive to hulling and, in fact, mechanical damage to the beans was observed during this operation. Moreover, hulling promotes an increased drying rate, since by removing the pericarp (skin, mucilage and parchment), a barrier to the water removal is also removed. This fact, coupled with high moisture content of the bean, favors a significant increase in the drying rate (Burmester and Eggers, 2010; Guida and Vilela, 1996; Isquierdo et al., 2013; Resende et al., 2009; Sfredo et al., 2005), which may cause internal cracks or microscopic fissures in the bean (Kirleis and Strohshine, 1990; Yang et al., 2003b; 2003a). Nevertheless, this hypothesis was not confirmed in this study as no immediate damage was found. Contrary to the main hypothesis, coffee gulled with the highest moisture content ($36 \pm 2\%$ w.b.) showed more pleasant sensory characteristics, resulting in a higher final score, as compared to the other treatments (Table 7). In fact, tasters found the sensory attributes of this coffee were similar to those of pulped coffee, describing it as having a more pleasant acidity with better aftertaste and balance.

The highest score in the sensory analysis was for the coffee hulled with a moisture content of $36 \pm 2\%$ (w.b.), which was also the treatment with the lowest total drying time (47.5 and 58 h for temperatures of 40 and 35°C , respectively). Therefore, early removal of parts of the fruit reduces the total drying time without changing the sensory quality of the beverage as compared to the control treatment (Table 4).

Therefore, this drying technology causes no immediate

physiological and sensory damage while providing a reduction in coffee drying time of over 50% as compared to the traditional drying method for natural coffees.

Conclusions

The new technology proposed in this paper, which comprises the hulling of coffee fruits at high moisture content, decreased the total time of drying in more than 50% as compared to the traditional method currently used by farmers. In addition, this new method does not cause instant damages to the coffee beans, and does not decrease physiological and sensorial quality.

Another advantage of the early hulling of coffee fruits at high moisture content is that the dried coffee beans have better aspect, with typical color and luminosity of a high quality product.

Conflict of interests

The authors have not declared any conflict of interests.

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