academicJournals

Vol. 10(12), pp. 1457-1466, 19 March, 2015
DOI: 10.5897/AJAR2014.9263
Article Number: 2E6001E51866
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Post-harvest effects on beverage quality and physiological performance of coffee beans

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Received 21 October, 2014; Accepted 11 March, 2015

During coffee drying, different temperatures applied to the beans with varied humidity content levels can interfere in the membranes integrity, germination, organic acid and carbohydrate content resulting in coffees with distinct flavors. The quality control of the beans will be much more effective the earlier the alterations provoked in the postharvest are detected. This work has an objective to study alternative methods for the dehydration of the coffee beans using ultra-drying followed by slow drying and its impact on the sensorial quality, chemical composition and physiology. For that purpose, coffee lots were processed by the methods, dry (natural coffee) and wet (fully washed coffee); and sun-dried and machine-dried at a constant 60°C temperature and alternating 60/40°C. The sensory quality of the samples was assessed by the Specialty Coffee Association of America (SCAA) analysis protocol. The sugar, total titratable acidity and the phenolic compound content was also analyzed. The physiological alterations of the coffee beans were analyzed by germination tests, emergence speed index, electrical conductivity and potassium leaching. The temperature of the drying air significantly altered the sensorial quality of the coffee beans. The processing way associated to drying methods causes many physiological alterations with the highest damage observed in the natural coffees. For the first time, we are showing that drying with heated air at 60/40ºC is promising for the fully washed coffee beans, which are more tolerant to dehydration than the natural coffee beans. Conversely, the natural coffee beans were much more sensitive to drying regardless the temperature, with very low performance in the physiological analyses. The drying at the constant 60ºC temperature is inappropriate for the natural coffee as well as for the fully washed coffee beans. In addition, the physiological tests used were shown effective for the early evaluation of coffee beans quality.

Key words: *Coffea arabica* L., processing, drying, sensory analysis, chemical composition, germination.

INTRODUCTION

The quality of coffee is determined mainly by the flavor and aroma formed during the roasting of the beans. Approximately 300 chemical compounds present in green coffee beans originate about 850 compounds after the roasting (Flament, 2001). Many of those compounds act as precursors of coffee flavor and aroma, their presence being dependent on the combination of genetic, environmental and technological factors (Bertrand et al., 2006; Farah et al., 2006). Other factors, such as post-harvest procedures also interfere in the coffee quality, especially processing and drying (Borém et al., 2008a, 2014; Saath et al., 2010, 2014; Taveira et al., 2012).

There are two processing methods used for the preparation of the coffee: the dry and the wet. In the dry processing, the whole or intact fruits are submitted to drying, without the removal of the exocarp (outer skin), resulting in the natural coffees. In the wet processing, the exocarp of the fruit is removed, creating three types of coffee: the peeled cherry coffee obtained after the peeling and drying of the beans, the remaining mucilage staying adhered to the parchment; the fully washed coffee, produced from the peeling of the fruits and removal of the mucilage by fermentation; and the demucilaged coffee, whose mucilage is removed mechanically.

The chemical composition of the raw coffee beans depends on the processing manner used (Bytof et al., 2004; Knopp et al., 2005; Borém et al., 2008b), effects of which determine distinct quality characteristics. Natural and fully washed coffee beans originate beverage with very distinct profile but with very similar final total score. Usually, the natural coffee beans have denser body and sweet drink compared to the fully washed coffees, which have a more acidy drink. The sugars contribute to the sweetness of the drink, being considered one of the most desirable flavor attributes in the special coffees. The sugars participate in important chemical reactions such as the Maillard reaction giving rise to compounds responsible for the formation of the color, flavor and the peculiar aroma of the drink (Arruda et al., 2012; Liu and Kitts, 2011; Murkovic and Derler, 2006). Several studies indicate that the postharvest operations also exercise influence on the sugar levels (Joët et al., 2010; Knopp et al., 2005).

The main phenolic compounds of coffee are in the form of chlorogenic acids (Farah and Donangelo, 2006; Monteiro and Farah, 2012). Besides contributing to the flavor and aroma of the drink, those acids can present benefits to human health. However, the presence of high amounts of chlorogenic acids increases the astringency of the coffee flavor, contributing to the devaluation of the product (Clifford, 2000).

A soft, fruity or citric acidity, perceived by the tasters in the sensory analysis, has been pointed as a good indicator of the coffee quality. However, acetic or very intense acidity is related to some type of fermentation which occurs in the postharvest and it represents a negative aspect in the sensory evaluation of the coffee. In the literature, it is possible to find works that describe significantly higher total titratable acidity values for coffee processed by the dry method when compared to the values obtained for the fully washed coffees (Leite et al., 1996). However, the total titratable acidity values are not always directly related to the sensorial perceptions, because it involves the analysis of a very large group of organic acids and other chemical compounds.

The Specialty Coffee Association of America (SCAA) sensory evaluation method has stood out for its quality evaluation of the special coffee drinks. That method is based on a quantitative descriptive analysis of the drink, conducted by a team of selected tasters and, making use of a non-structured scale from 6 to 10 points for the evaluation of the fragrance, aroma, flavor, aftertaste, acidity, body, balance, sweetness, absence of defects and drink uniformity, with evaluation of the global quality of the coffee according to the terminology presented by Lingle (2011).

Physiological analyses have been used to evaluate the quality of the coffee beans and can be a valuable tool to evaluate the drink quality indirectly. Important biochemical alterations in the coffee beans during the processing, related to the metabolism of germination, whose extension depends on the preparation means, be it wet or dry (Bytof et al., 2007; Selmar et al., 2006). However, a correlation between the physiological performance and alterations with the drying methods is still missing in the literature.

The drying of coffee, if poorly conducted, can intensify the degradation of cell membranes which can be consistently indicated by potassium leaching and electrical conductivity tests (Prete, 1992). The coffee beans with badly structured, disorganized and damaged membranes leach higher amounts of solutes, presenting higher electrical conductivity and potassium leaching values (Krzyzanowski et al., 1991), indicating loss of quality (Prete, 1992).

In drying studies, the highest damage in coffee bean cell membrane systems occur due to the increase of the drying temperature and the high drying rates provoked by high temperatures can cause damage to the coffee quality due to the damage caused to the cell membranes (Borém et al., 2008b; Marques et al., 2008; Saath et al., 2010). In addition, the cell membranes of the coffee beans are damaged only between the 30 and 20% (w.b.) humidity levels (Borém et al., 2008b), when the natural and fully washed coffees were dried at the 60ºC temperature. Thus, a drying method that uses high temperatures at the beginning of the process, followed by lower temperatures at the end, could become promising, highlighting the lower exposure time of the beans to the drying conditions, contributing to the quality maintenance of the coffee.

The physiological analyses of the coffee during the postharvest can also aid in the elucidation of the

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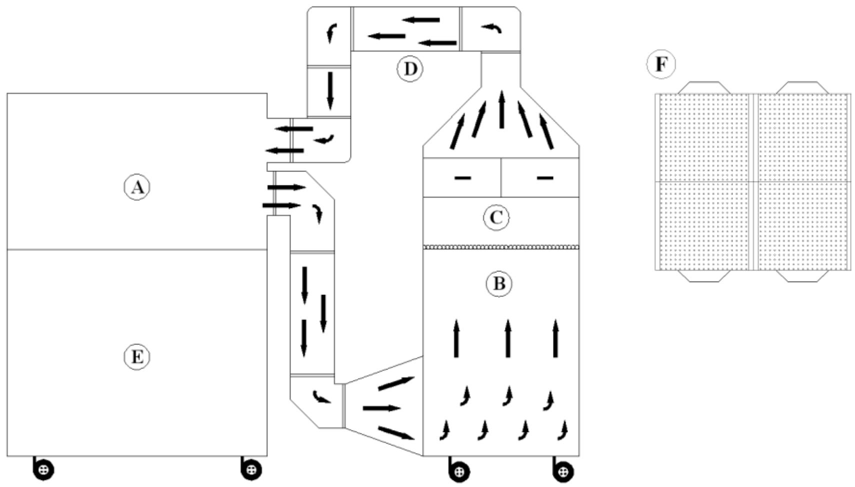

Figure 1. Scheme of the apparatus used in the mechanic drying: (A) compartment of air conditioning (B) plenum; (C) drying compartment; (D) recirculation system of air; (E) electrical system, motor and fan, and (F) removable drawer of the drying compartment.

biochemical events that occur in the beans during the processing and drying, which will result in different chemical compounds and, therefore, in different drink qualities.

The objective of the present research was to assess the effects of different processing and drying methods on the physiological quality and chemical composition of coffee beans, analyzing their interrelation with the quality of the drink.

MATERIALS AND METHODS

Experimental design

The experiment was conducted with handpicked ripe coffee fruits of Catuaí Vermelho IAC 99 (*Arabic Coffea* L. cv.). The fruits were washed and separated by density, eliminating the float portion formed by light, hollow, bored or poorly grained fruit. To guarantee the uniformity of the raw material, new manual selection was carried out in the portion of ripe fruits, eliminating all of the immature and over-ripe fruits still present, remaining only the fruits at the cherry stage. The cherry coffee was processed by dry and wet methods and dried under three different conditions: on an asphalt patio, in a hot air dryer at a constant 60°C temperature and in dryer with air heated to an alternating 60/40°C temperature.

In the dry processing of the coffee samples, the ripe fruits were dried with the exocarp intact, obtaining the natural coffee. In the wet processing, the coffee was mechanically peeled and depulped by natural fermentation in water for approximately 20 h, under ambient conditions at an average temperature of 22°C.

The experiment was conducted in a randomized block design with three repetitions represented by the harvest times and in a 2 × 3 factorial outline (two processing methods and three drying methods):

i. Patio drying: After the processing, the coffee was taken for drying on the patio, where it remained under ambient conditions and was managed according to the procedures proposed by (Borém, 2008). The control treatment portions remained on the patio until they reach a moisture content of 11% (w.b.), for the natural coffee as well as for the fully washed coffee samples.

ii. Drying in mechanical dryer: To minimize the differences in the initial moisture level in the hot air drying, the portions destined for mechanical drying passed through a two day pre-drying period on the patio for the natural coffee, and one day for the fully washed coffee samples. After the pre-drying period, the portions were taken to the 0.15 m fixed bed dryer (Figure 1) coupled to a high-precision air conditioner, according to the model proposed by Fortes et al. (2006), which allows for the precise control of the air flow, temperature (T) and relative humidity (RH) of the drying air.

The air flow was maintained at 20 $m^3.min^{-1}.m^{-2}$, normal values for the commercial coffee dryer models. To maintain the same drying conditions during the whole experiment, independently of the climatic variations, the temperature and relative humidity values of the air were controlled and maintained constant, observing a relative humidity of 7% for the hot air at 60°C and 21% for the hot air at 40°C. Those drying conditions were established based on the thermodynamic studies of the ambient air warming, considering the climatic averages of 20°C and 60% RH during the coffee harvest months.

The portion that received the 60°C hot air treatment remained in the dryer until the coffee reached a moisture content of 11% ± 0.5% (wb). The portion that received the 60/40°C hot air treatment was dried at 60°C until the beans reach 30% (wb) moisture followed by drying with 40°C air until reaching 11% (wb).

The control of the bean moisture level during drying was handled by successive weighing knowing the mass and the initial moisture content of each coffee sample (Equations 1 and 2). The coffee moisture content was determined by the standard (ISO, 6673, 2003) method. To determine the air temperature transition point from 60 to 40°C, each drawer, containing the experimental portion, was weighed every 30 min. When each drawer reached the mass relative to a 30% ± 2% (wb) moisture content, the temperature was changed from 60 to 40°C, remaining at 40°C until the coffee reached 11% (wb).

$$PML = \left[\frac{(MC_i - MC_f)}{100 - MC_f}\right] \times 100 \qquad (1)$$

$$M_f = M_i - \left(M_i \times \frac{PML}{100}\right) \quad (2)$$

in which PML: percentage of mass loss (%); MC_i: initial moisture content (% wb); MC_f: final moisture content (% wb); M_f: final mass (kg) and M_i: initial mass (kg).
The moisture reduction rate was obtained by means of Equation 3.

$$MRR = \left(\frac{MC_0 - MC_c}{t_c - t_p}\right) \quad (3)$$

in which MRR: moisture reduction rate (kg H_2O.kg coffee^{-1}.hour^{-1}); MC_0: previous moisture content (kg H_2O.kg coffee^{-1}); MC_c: current moisture content (kg H_2O.kg coffee^{-1}); t_c: total current drying time (hours); t_p: total previous drying time (hours).

Characterization of coffee quality

Sensorial analysis and chemical analyses: The sensorial analysis and the chemical analyses were conducted in the Pólo de Tecnologia em Qualidade do Café da Universidade Federal de Lavras. For the chemical analyses, three subsamples of each experimental portion were used, corresponding to the respective treatments. The chemical and sensorial analyses were conducted in the portions of the bean samples classified above sieve 16, discarding the peaberry and defective beans.

Sensory analysis: The sensorial analysis was carried out according to the protocol established by the Specialty Coffee Association of America (SCAA), (Lingle, 2011). For presenting different sensory characteristics, the sensorial analysis of the natural and fully washed coffees was conducted separately, aiming to minimize possible negatives or positive interferences. The final results of the sensorial evaluation were made up of the sum of the scores of all of the attributes.

Reducing and non-reducing sugars: The total and reducing sugars were extracted by the Lane-Enyon method, cited by (AOAC, 1990) and determined by the Somogy adapted technique (Nelson, 1944). The non-reducing sugars were determined by the difference between the total and reducing sugars.

Total titratable acidity: The total titratable acidity was determined by titration with NaOH 0,1N, adapting the methodology (AOAC, 1990). Two grams of the ground coffee sample were weighed, and added to 50 mL of distilled water, agitating for one hour. Soon afterwards, filtering took place in filter paper and 5 mL of the filtered solution removed, placed in an Erlenmeyer flask with about 50 mL of distilled water. Three drops of phenolphthalein were added and, soon afterwards, it was titrated to turning with NaOH 0,1 N. The result was expressed in mL of NaOH 0,1 N for 100 g of sample.

Polyphenols: The polyphenols were extracted using 80% methanol (U/V) as extractor (Goldstein and Swain, 1963) and identified according to the Folin Denis method (AOAC, 1990). The results were expressed as percentage of dry matter.

Physiological analyses: For the physiological analyses; four seed subsamples were used without visible defects for each repetition of the respective treatments.

Germination test: The germination test was conducted with four subsamples of 50 seeds without parchment, distributed on a paper towel moistened with an amount of water equal to two and a half times the substrate dry mass, and placed to germinate at a temperature of 30ºC. The evaluations were made at thirty days after the sowing (Brasil, 2009) and the results expressed in percentage.

First germination and root protrusion count: The first germination count was carried out together with the germination test; fifteen days after the beginning of the test. The seeds that presented a principle root and at least two lateral roots were considered as normal seedlings (Brasil, 2009) with the results expressed in percentage. Also, at fifteen days from the beginning of the germination test; the counting of root protrusion was done with the results expressed in percentage.

Emergence velocity index test (EVI): Four subsamples of 50 seeds were sowed in plastic trays containing a 2:1 mixture of sand and soil. The trays were maintained in a growth chamber, previously regulated to a temperature of 30°C, under an alternating regime of light and darkness (12 h). The trays were irrigated when necessary and, at the onset of the emergence, the emerged seedlings were computed daily, until stabilization, with the results expressed in percentage of final emergence. ESI was calculated according to the formula proposed by Maguire (1962), using the following equation:

$$EVI = \left(\frac{E1}{T1}\right) + \left(\frac{E2}{T2}\right) + \cdots + \left(\frac{En}{Tn}\right) \quad (4)$$

In which EVI: emergence velocity index; E: number of emerged seedlings per day; T: time from sowing to the respective counting (day).

Open cotyledonary leaves: At the end of the emergence test, the seedlings that presented totally expanded cotyledonary leaves were counted and the results were expressed in percentage.

Electrical conductivity: The electrical conductivity of the raw beans was determined adapting the methodology proposed by Krzyzanowski et al. (1991). Four repetitions of 50 beans of each portion were used, which were weighed to a precision of 0.001 g and immersed in 75 mL of deionized water inside 180 mL plastic cups. Soon afterwards, these containers were taken to a forced ventilation greenhouse at a temperature of 25°C, for five hours, proceeding with the electrical conductivity reading of the soaking water in a Digimed CD-20 apparatus. With the obtained data, the electrical conductivity calculations were made, the result being expressed as μS.cm^{-1}.g^{-1} of beans.

Potassium leaching: The leaching of potassium ions was conducted in the raw beans, according to the methodology proposed by Prete (1992). After the electrical conductivity reading, the solutions were submitted to the determination of the amount of leached potassium. The reading was conducted in a Digimed NK-2002 flame photometer. With the obtained data, the calculation of the amount of leached potassium was made and the result was expressed in ppm.

Statistical analysis

The data obtained in the chemical, sensorial and physiological analyses were submitted to the ANOVA using the Sisvar 4.0 computational program (Ferreira, 2011) and the means were compared by the Scott-Knott test (Scott and Knott, 1974) at 5% level of significance.

RESULTS

Drying conditions

During the drying on the patio, the air temperature varied

Table 1. Average final score of the sensorial analyses of coffees submitted to processing and drying.

Processing	Final score	Drying	Final score
Natural	79.04^{A}	Patio	80.35^{A}
Fully washed	78.98^{A}	60/40ºC	79.05^{B}
		60ºC	77.64^{C}

Averages followed by the same capital letters on the columns do not differ statistically for the Scott-Knott test at 5% probability.

Table 2. Average of total sugars, reducing sugars, non-reducing sugars and total titrable acidity (TTA) of the natural and fully washed coffees.

Processing	Total sugars (%)	Reducing Sugar (%)	Non-reducing Sugars (%)	TTA (NaOH 0.1N/100 g)
Natural	6.47^{A}	0.38^{A}	6.09^{A}	162.16^{A}
Fully washed	5.64^{B}	0.35^{A}	5.29^{B}	132.17^{B}

Averages followed by the same capital letters on the columns do not differ statistically for the Scott-Knott test at 5% probability.

Table 3. Percentage averages of the phenolic compounds of coffee beans.

Processing	Phenolics (%)	Drying	Phenolics (%)
Natural	6.21^{A}	Patio	6.23^{A}
Fully washed	6.31^{A}	60/40ºC	6.59^{A}
		60ºC	5.97^{A}

Averages followed by the same capital letters on the columns do not differ statistically for the Scott-Knott test at 5% probability.

between 10 and 28°C and the relative humidity between 34.5 and 61.2%. Those environmental conditions provided an average drying rate of 0.0020 kg $H_2O.kg^{-1}.hora^{-1}$ for the fully washed coffee and 0.0017 kg $H_2O.kg^{-1}.hora^{-1}$ for the natural coffee. It should be emphasized that those values were very inferior to those obtained in the drying with hot air at 60/40°C and 60°C. In this case, the highest drying rates were observed in the hot air treatment at 60°C, being 0.0324 kg $H_2O.kg^{-1}.hora^{-1}$ for the fully washed coffee and 0.0213 kg $H_2O.kg^{-1}.hora^{-1}$ for the natural coffee. In the 60/40°C treatment, in which the hot air used was 40ºC starting from a 30% moisture level (wb), the drying rate was 0.0205 kg $H_2O.kg^{-1}.hora^{-1}$ for the fully washed coffee and 0.0098 kg $H_2O.kg^{-1}.hora^{-1}$ for the natural.

Sensory analyses

Sensory analysis

The highest sensorial analysis scores were observed in t he sun-dried coffees, indicative of the best quality of those coffees (Table 1). Compared to the hot air drying at 60°C, the drying treatment with the 60/40°C temperature resulted in better drinks, for the natural coffee as well as for the fully washed coffee. Although, the natural and fully washed coffees can present different sensorial profiles for some isolated attributes, the final score of the coffee drink was not affected significantly by the processing type.

Chemical analyses

The average total sugars, non-reducing sugars and total titratable acidity (TTA) values were different ($\alpha<0.05$) for the natural coffee and the fully washed coffee (Table 2). However, significant differences were not observed for the reducing sugar values (Table 2) or for the final the phenolic compound levels (Table 3).

Physiological analysis

The physiological performance of the coffee seeds (Table

Table 4. Physiological quality evaluations of the coffee beans submitted to drying on patio and heated air at 60/40ºC and 60ºC.

Parameter	Drying	Processing (%)	
		Natural	Fully washed
Root protrusion	Patio	76^{bA}	97^{aA}
	60/40ºC	2^{bB}	85^{aA}
	60ºC	9^{bB}	51^{aB}
Germination	Patio	80^{bA}	97^{aA}
	60/40ºC	0^{bB}	85^{aB}
	60ºC	0^{bB}	61^{aC}
Emergence	Patio	67^{bA}	92^{aA}
	60/40ºC	0^{bB}	60^{aB}
	60ºC	0^{bB}	30^{aC}
Emergence velocity index	Patio	1.2^{bA}	1.5^{aA}
	60/40ºC	0^{bB}	1.1^{aA}
	60ºC	0^{bB}	0.5^{aB}
Open cotiledonary leaves	Patio	56^{bA}	80^{aA}
	60/40ºC	0^{bB}	47^{aB}
	60ºC	0^{aB}	16^{aC}

Averages followed by the same capital letters on the columns and the same lower case letter on the rows do not differ statistically for the Scott-Knott test at 5% probability.

4) depends on the interaction between the drying method and the processing type. Significantly lower values for root protrusion, germination, emergence, ESI and open cotiledonary leaves were observed in the natural coffee, indicating that the processing form exposes the beans to more intense physiological damage than the fully washed coffees during the drying. In spite of there being a small percentage of root protrusion in the natural coffee drying treatments at 60/40°C and 60°C, the germination, emergence, ESI and open cotiledonary leaves had drastic reduction indicating that the seeds were already dead or in an advanced deterioration process. The lower root protrusion and germination values in the natural coffee compared to the fully washed coffees, sun-dried, show that more intense physical and physiological damage occurred to the beans in the processing through drying. Conversely, the root protrusion and ESI results for the fully washed coffee dried at 60/40°C did not differ significantly from the sun-dried fully washed coffee. Furthermore, the germination, emergence and open cotiledonary leaf values were significantly superior to the values observed in the coffees dried with hot air at 60°C.

The lowest electrical conductivity values were observed for the sun-drying, while the highest values were observed for the natural coffee hot air drying (Table 5). It is noticed that the electrical conductivity values depend on the interaction between the drying method and processing. In the dry processing method, it is observed that the electrical conductivity values of the coffee dried at 60/40°C did not statistically differ from that dried at 60°C. On the other hand, the drying of the depulped coffee with temperatures of 60/40ºC resulted in an intermediate value, statistically differing from the sun-drying as well as the drying at the temperature of 60°C. As for the processing effect, it was observed that independent of the manner of heating the air, the electrical conductivity values were significantly lower in the coffees processed by the wet method, there was no significant differences for the sun-dried coffees.

The potassium leaching of the coffee beans (Table 6) was significantly lower for the depulped coffee, independent of the drying method. Furthermore, the use of an elevated temperature followed by a low temperature (60/40°C) made possible a significant reduction in the potassium leaching values compared to the continuous drying with warm air at 60°C.

DISCUSSION

The coffee cell membrane integrity can be affected by the seed moisture removal rate. The higher the stress

Table 5. Electrical conductivity averages of the coffee beans submitted to drying on patio and heated air at 60/40ºC and 60ºC.

Drying	Processing	
	Natural (μS/cm/g)	Fully washed (μS/cm/g)
Patio	59.59^{aA}	48.22^{aA}
60/40ºC	114.7^{bB}	72.98^{aB}
60ºC	117.5^{bB}	95.67^{aC}

Averages followed by the same capital letters on the columns and the same lower case letter on the rows do not differ statistically for the Scott-Knott test at 5% probability.

Table 6. Potassium leaching (KL) averages of the coffee beans submitted to drying on patio and heated air at 60/40ºC and 60ºC.

Processing	KL (g/kg)	Drying	KL (g/kg)
Natural	67.52^{A}	Patio	47.63^{A}
Fully washed	57.52^{B}	60/40ºC	62.25^{B}
		60ºC	77.67^{C}

Averages followed by the same capital letters on the columns do not differ statistically for the Scott-Knott test at 5% probability.

provoked by the drying in the seeds, the higher the damage in the membranes (Borém et al., 2008b, 2008a; Saath et al., 2010) and the worse will be its physiological quality. The sun-drying made a slow and continuous drying of the coffee possible, while the drying with hot air at 60°C exposed the seeds to the highest drying rates. On the other hand, the use of high temperatures, when the beans had a humidity level above 30%, followed by the reduction of the air drying temperature to 40°C, resulted in less intense moisture removal rates, favoring the coffee quality compared to the continuous use of high temperatures.

The processing conditions and drying of the beans altered the chemical composition, the physiological and sensorial quality of the coffee. The coffee processed by the wet method presented lower total and non-reducing sugar levels, indicating that the hexose breakdown for the energy production due to the change of the aerobic respiration to alcoholic or lactic fermentation under the lack of oxygen during the depulping (Knopp et al., 2005) might have occurred. The consumption of sugars under anaerobic conditions is very high when compared to the normal aerobic conditions for the production of the same amount of energy. In contrast to the wet processing, the dry processing is maintained under aerated environmental conditions, allowing the normal breathing of the beans during drying, with smaller breakdown and lower sugar consumption.

On the other hand, it is known that the drying speed can exercise an influence on the amount and proportion of the several types of sugars in coffee beans. In general, the slow drying favors the accumulation of sugars of higher molecular weight, such as the oligosaccharides, to the detriment of the reducing sugars (Lima et al., 2004; Rosa et al., 2004). Marques et al. (2008) observed reduction in the levels of non-reducing sugar with the increase of the drying temperature from 40 to 60°C. Similar results showed higher non-reducing sugar levels in the samples that had lower moisture reduction rates (Borém et al., 2006). In that work, although the differences among the levels of sugar were small in the natural and fully washed coffees, it was observ ed that the slowest drying of the beans in the dry processing method favored the accumulation of total and sugars non-reducing sugars.

Higher total titratable acidity values (TTA) have been associated with deteriorative processes and, consequently, with worse drink quality (Franca et al., 2005). It has been verified in coffees processed by the dry manner when compared to the values obtained for the peeled, demucilaged and fully washed coffees. In the present work, although the natural coffee has presented a significantly higher TTA value in relation to the fully washed, this was not reflected in the drink quality of those coffees. Other chemical compounds, besides the organic acids, such as lactic, citric, malic, phosphoric, and acetic or butyric acid can also participate in the determination of TTA. In this case, it is important to distinguish the titratable acidity from that perceived by the cuppers at the occasion of the sensorial evaluation.

The phenolic compounds are responsible for the astringency of the drink, being found mainly when there is a presence of green or immature beans. In this work, due to the selective harvest and rigorous selection of the raw material for obtaining of cherry fruits, high astringency was not observed in the drink. In spite of the presence of those compounds being undesirable, they can inhibit the oxidation processes in certain systems, but that does not mean that they can protect the cells and the tissues from all types of oxidative damage.

For a precise diagnosis of the immediate and latent effects of the processing and drying on the coffee quality, the use of methods and/or equipment that allow the determination of the chemical composition of the beans is recommended, such as high performance liquid chromatography with (HPLC) and high resolution gas chromatography (HRGC) coupled to a mass spectrometer. However, it stands out that, since most of the time those determinations are accomplished with raw beans, it is not always possible to obtain a good correlation between the chemical composition and the beans quality, especially when dealing with the drink quality. This can occur because the sensorial analysis is conducted with roasted beans, while the determination of the chemical composition is made with raw beans, in other words, completely different beans are analyzed as to their chemical composition.

As an alternative to those more sophisticated and high cost analyses in the present work, unprecedented physiological evaluations in raw coffees beans destined for roasting and consumption took place with the objective of an early diagnosis of possible quality alterations.

The physiological analyses indicated that as the drying conditions became more severe, the damage to the beans also increased, showing that the processing by the wet method and sun-drying were the treatments that favored a better preservation of the beans integrity. The root protrusion and germination results for the fully washed coffee dried under alternate temperature of 60/40°C indicate that the beans were in good physiological conditions in way similar to the fully washed sun-dried coffee. The germination and emergence tests presented solid results and they proved that the combination of treatments that provides the best physiological quality is the wet processing and the sun-drying.

The use of high drying temperatures for the coffee allows a fast removal of moisture from the beans, however it can provoke very large differences between the moisture level of the external part and the centre of the bean, generating a high pressure gradient, which can cause ruptures and cracks within the beans, besides possible thermal damage. Tissues damaged during drying require energy expenses for the reorganization of membranes, with possible increases in the respiration rate and solute leaching, besides the formation of toxins by the non-recuperated parts, among other metabolic events, possibly resulting in the reduction of the seed energy or even total loss of its viability, depending on the extent of the damage and the metabolic activity of the beans.

The increase of the drying temperature causes damage to coffee beans cell membrane system, increasing the electrical conductivity of the bean exudates (Borém et al., 2008a; Coradi et al., 2007). Those authors affirm that with the extravasations of fatty acids present in the cell interior due to the disorganization or breakdown of the cytoplasmic membranes, oxidative or catalytic reactions can occur, forming undesirable by-products and harmful to the sensorial quality of the coffee drink.

In this work, it can be observed that the depulped and machine-dried coffees presented lower electrical conductivity values than the natural coffees, allowing to infer that the damage in the cell membranes was less intense in the depulped coffees.

The potassium leaching test, as well as that of electrical conductivity, evaluates the integrity of the membrane systems. In this work, it is observed that the effects of the treatments are similar to those verified in the electrical conductivity test, and the drying method 60/40°C presented lower intermediate of potassium leaching values when compared to the sun-drying and the continuous drying at 60°C. This can be an indication that there was less membranes damage at the 60/40°C temperature, and that the damage might have happened before the beans reached the 30% ± 2% (wb) moisture level. It stands out that in the drying of the natural coffee at 60°C the exposure time of the beans to the drying conditions was longer than in the depulped coffees, which certainly favored the occurrence of more severe damage to the natural coffee cell membrane systems, similar to the observations found in the literature (Borém et al., 2006, 2008a; Marques et al., 2008; Prete, 1992).

The high moisture removal rate, provoked by the high temperature at the beginning of the drying in the 60/40°C treatment, might have been harmful to the physiological integrity of the beans. Besides, a seed defense mechanism against cell membrane degeneration is the accumulation of sugars, acting in the seed membrane and protein stabilization (Corbineau et al., 2007). However, when the drying is excessively fast, there is no enough time for that phenomenon to happen and, consequently, the maintenance of the physiological integrity of the bean is compromised. These results are coherent with those obtained in the chemical analyses and in the sensorial analyses, indicating that the physiological analyses constitute promising tools for evaluation of coffee quality.

According to the scale of scores for sensorial evaluation of special coffees proposed by the Specialty Coffee Association of America (SCAA), coffees with scores above 80 points are considered very good coffees and are placed in the category of special coffees. In the present work, only the sun-drying made possible the obtaining of coffees with average scores superior to 80 points, independent of the processing type. The machine-drying was unfavorable for the sensorial quality of the coffees, which were placed in the non-special coffee category, with scores between 75 and 79 points. Damage to the beans provoked by the drying conditions can result in alterations to the flavors and perceptible aromas in the sensorial analysis. Besides the objective evaluation, the SCAA protocol allows a descriptive analysis of the coffee flavor and aroma. Strange flavors of wood and oil were more frequently found in the coffees dried at 60°C. The result of this experiment corroborates the results obtained by several authors who associate the elevation of the temperature with the reduction of the quality of the drink (Borém et al., 2008a; Coradi et al., 2007; Marques et al., 2008).

In the present work, the sensorial and physiological analyses provided an early diagnosis of some of the transformations which occurred in the coffee beans during the processing and drying. Based on the obtained results, it can be affirmed that the coffee drying procedures that provided the best physiological quality of the beans also provided the best drink quality, indicating a close relationship between these two variables. This takes on great importance in the coffee postharvest technology context, with relevant contributions for the definition of coffee postharvest management strategies, be them sun or machine dried, seeking the obtaining of superior quality coffees.

Conclusions

The sun-drying provided coffee beans with the best physiological performance and the best drink quality. However, the fully washed coffees presented better physiological performance than the natural coffees, regardless the drying method. In addition, the innovative drying method with alternate temperature of 60/40°C was only adequate for the fully washed coffees, while the constant temperature of 60°C was inappropriate for the natural coffees as well as the fully washed coffees.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGMENTS

We thank the Fundação de Amparo à Pesquisa do Estado de Minas Gerais -FAPEMIG (CAG 1257/06) for financial support and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the fellowship provided to José Henrique da Silva Taveira (JHST).

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