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Physiological and sensorial quality of Arabica coffee subjected to different temperatures and drying airflows

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ABSTRACT. The objective of this study was to evaluate the correlation between a group of physiological variables (electrical conductivity, potassium leaching, and germination percentage) and a group of drying kinetics variables (drying time and drying rate) in addition to verifying the relation between drying kinetics variables and coffee quality as a function of processing type, temperature, and drying airflow. Coffee drying was conducted in a fixed-layer dryer at two temperatures and two airflows. After drying, an evaluation of the physiological and sensorial quality was conducted. Based on the results obtained, the following conclusions were drawn: coffee that is processed via a dry method is more sensitive to mechanical drying with heated air than coffee processed via a wet method, resulting in poor physiological performance; airflow does not interfere with the physiological quality of pulped and natural coffees; a temperature increase from 40 to 45°C resulted in a decrease in the physiological quality only for pulped coffee; and an increase in the drying rate as a result of an increase in the drying temperature to 40°C had a negative effect on the sensorial quality of pulped coffee.

Keywords: drying kinetics, processing, drying rate.

Qualidade fisiológica e sensorial do café arábica submetido a diferentes temperaturas e fluxos de ar de secagem

RESUMO. Este trabalho foi realizado com o objetivo de avaliar a correlação entre um grupo de variáveis fisiológicas (condutividade elétrica, lixiviação de potássio e porcentagem de germinação) e um grupo de variáveis de cinética de secagem (tempo e taxa de secagem), bem como verificar a relação entre as variáveis de cinética de secagem e a qualidade sensorial do café, em função do tipo de processamento, da temperatura e do fluxo de ar de secagem. A secagem do café foi realizada em secador de leito fixo com duas temperaturas e dois fluxos de ar. Após a secagem, foi avaliada a qualidade fisiológica e sensorial. A partir dos resultados obtidos, conclui-se que: o café processado via seca é mais sensível à secagem mecânica com ar aquecido do que o processado via úmida, apresentando pior desempenho fisiológico; o fluxo de ar não interfere na qualidade fisiológica do café despolpado e natural; a elevação da temperatura de 40 para 45°C resultou em queda da qualidade fisiológica apenas para o café despolpado e a elevação da taxa de secagem, por meio da elevação do fluxo de ar de secagem, para a temperatura de 40°C teve efeito negativo na qualidade sensorial do café despolpado.

Palavras-chave: cinética de secagem, processamento, taxa de secagem.

Introduction

Coffee quality depends on many factors, which range from species choice and crop variety to the method of preparation of coffee for consumption. Among these factors, processing, drying, storage, milling, and transportation are fundamental for obtaining and maintaining a differentiated final product.

Of all the post-harvest stages, drying is the most relevant from an energy consumption and a processing cost formation perspective, as well as from a quality preservation point of view (Borém, 2008). If the drying is not conducted correctly, it will impair the quality due to undesirable physical, chemical, and sensorial alterations, causing degradation of chemical components that may come in contact with hydrolytic and oxidative enzymes, thereby affecting the characteristic color, flavor, and aroma of the beverage (Borém, 2008; Bytof et al., 2007; Marques, Borém, Pereira, & Biaggioni, 2008).

Sensorial analyses are the most common method employed to determine coffee beverage quality, which is determined by the flavor and aroma that are formed from chemicals components present in the raw beans during roasting (Borém, Coradi, Saath, & Oliveira, 2008a; Farah, Monteiro, Calado, Franca, & Trugo, 2006).

Potassium leaching and electrical conductivity tests have frequently been used in studies as consistent indicators of the integrity of cell membranes (Angélico et al., 2011; Borém, Coradi, Saath, & Oliveira, 2008b; Coradi, Borém, Saath, & Marques, 2007; Isquierdo et al., 2011; Isquierdo, Borém, Oliveira, Siqueira, & Alves, 2012; Marques et al., 2008; Nobre, Borém, Isquierdo, Pereira, & Oliveira, 2011; Reinato, Borém, Cirillo, & Oliveira, 2012; Ribeiro et al., 2011; Saath, Biaggioni, Borém, Broetto, & Fortunato, 2012; Santos, Chalfoun, & Pimenta, 2009). Beans with poorly structured membranes leach a greater quantity of solutes when immersed in water (Prete & Abrahão, 1995). Many studies have demonstrated that beans of lower quality show higher levels of potassium leaching and electrical conductivity (Borém et al., 2008b; Marques et al., 2008; Santos et al., 2009).

Despite the technological evolution of the Brazilian coffee sector in recent years, drying technologies have not evolved sufficiently to contend with the flow of coffee coming from mechanical harvests. Hence, the drying infrastructure is frequently inadequate to receive the volume of coffee picked daily. Given this scenario, the solution used by some coffee growers who dry beans on patios is to spread out the coffee in thicker layers than is recommended. As for mechanical drying, the use of drying temperatures higher than the limit tolerated by coffee has been observed with the objective of accelerating the process and increasing the drying capacity. However, these practices could compromise the quality of the coffee due to fermentation on the patio and thermal damage in the mechanical dryers.

Available coffee drying technologies only allow an increase in the drying rate via an increase in temperature or airflow. Nevertheless, coffee mass temperatures higher than 40°C cause thermal damage that depreciates its quality (Borém et al., 2013; Isquierdo et al., 2013; Oliveira et al., 2013). The use of airflows significantly higher than those commercially used is an alternative for increasing the drying rate without exceeding the maximum temperature threshold tolerated by coffee. However, little is known about the effect of these flows on coffee quality and drying kinetics.

Therefore, the objective of the present study was to evaluate the correlation between a group of physiological variables (electrical conductivity, potassium leaching, and germination percentage) and a group of drying kinetics variables (drying time and percentage) in addition to verifying the relation between drying kinetics variables and coffee quality as a function of the processing type, temperature, and drying airflow.

Material and methods

Coffee harvesting and processing

Manually harvested ripe coffee fruits (*Coffea arabica* L. cv. Bourbon Amarelo) were used for this experiment. After harvesting, the fruits were separated in water by density differences, and those with a lower specific mass (dry, underdeveloped, damaged by coffee berry borers, and malformed coffee fruits) were removed. A subsequent manual selection was conducted to remove any remaining immature or overripe fruits. Mature, selected fruits were then divided into two groups: one group was taken directly to the dryers, representing “natural” coffee (dry processing), whereas the other group was pulped and placed in water tanks at room temperature for fermentation for 20 hours. Following fermentation, the coffee was washed in running water until the remaining mucilage was fully removed. The resulting parchment coffee was then taken to the dryer, representing pulped coffee (wet processing). All harvesting and processing procedures were conducted according to Borém (2008).

Drying system

The drying system consisted of three fixed-layer dryers (Figure 1). In these dryers, the drying airflow and the temperature (T) were precisely electronically controlled.

Figure 1. Dryers used for coffee drying.

Each dryer contained three removable trays. Each tray measured 0.3 m on a side and had a square perforated bottom. The trays were placed above a plenum to ensure uniform airflow. Samples of natural (5.7 kg) and pulped (2.3 kg) coffees were placed in the trays, resulting in coffee layers of 0.106 and 0.046 m, respectively.

The drying air speed was monitored using a blade anemometer that was constantly regulated and maintained between 0.4 and 1.6 m s^{-1}, corresponding to flow rates of 24 and 96 m^3 $min.^{-1}$ m^{-2}, respectively.

These flow rates were chosen based on preliminary tests. An airflow of 24 $m^3 min.^{-1} m^{-2}$ is the rate most commonly used by producers. Preliminary tests showed no differences in drying time for either natural or pulped coffees when flow rates of 96 and 132 m^3 $min.^{-1}$ m^{-2} were used. Therefore, the lowest flow that provided the lowest drying time was chosen.

Two air drying temperatures were used (40 and 45°C). These temperatures were monitored through the use of mercury thermometers placed in the coffee mass.

Experimental design

The experimental design was a fully randomized 2 x 2 x 2 factorial scheme using two processing types (natural and pulped), two drying temperatures (40 and 45°C), and two drying airflows (Table 1). Three replicates were conducted for each treatment.

Table 1. Processing type (natural and pulped), temperature, and drying airflow.

Processing	Temperature (°C)	Flow (m^3 $min.^{-1} m^{-2}$)
Natural	40	24
		96
	45	24
		96
Pulped	40	24
		96
	45	24
		96

Description of the drying process

The mean coffee moisture content at the onset of drying was 2.18 kg of water kg^{-1} of dry matter on dry base (d.b.) and 0.87 kg of water kg^{-1} of dry matter (d.b.) for natural and pulped coffees, respectively. The coffee was dried continuously until it reached 0.145 ± 0.005 (d.b.) in the fruit and 0.125 ± 0.005 (d.b.) in the parchment coffee, which corresponded to a 0.125 ± 0.005 kg kg^{-1} (d.b.) moisture content for the milled coffee. The trays holding the samples were removed from the dryer and weighed each hour on an analytical scale with a resolution of 0.01 g until the desired moisture level was reached. Each time the trays were weighed, their positions in the dryers were rotated to minimize possible positional differences in temperature and airflow.

The moisture content of the coffee fruit and parchment coffee, both at the beginning and the end of drying, were determined using the standard oven method of 105 ± 3°C for 24 hours based on the *Regras para Análise de Sementes* (Brasil, 2009). The moisture content of the raw coffee beans was determined using the ISO 6673 (2003) standard method. Knowing the initial fruit and parchment coffee mass and the moisture content and using an analytical scale with a resolution of 0.01 g, the drying was monitored using the gravimetric method (mass loss) until the coffee reached the desired moisture content, based on the following equation:

$$MC_t = \frac{Wm_i - (Tm_i - Tm_t)}{Mms} \tag{1}$$

where:

MC_t: moisture content at time t (kg of water kg^{-1} dry matter (d.b.));

Wm_i: initial water mass (kg);

Tm_i: initial total mass (kg);

Tm_t: total mass at time t (kg);

Mms: dry matter mass (kg).

The product drying rate was determined to evaluate the speed of water evaporation based on the following equation:

$$Dry.Rate = \frac{MC_{prev} - MC_{curr}}{\Delta t} \tag{2}$$

where:

Dry.Rate: drying rate (g of water kg^{-1} dry matter h^{-1});

MC_{prev}: moisture content at the previous time (g of water kg^{-1} dry matter (d.b.));

MC_{curr}: current moisture content (g of water kg^{-1} dry matter (d.b.));

Δt: time interval between weights (h).

Sample storage and milling

After drying, the samples were packaged in single layer kraft brown paper bags, which were placed in clear polyethylene plastic bags. The samples were then stored in a climate-controlled room at 10°C and 60% relative humidity for a period of 30 days.

The coffee was subsequently milled, and the beans were separated by shape and size using only flat beans that were retained in screens with circular perforations 16/64 to 18/64 inches in diameter. Flat beans that were retained in screens with 19/64 inch perforations and rounded "peaberry" beans that were retained in screens with oblong 11/64 x ¾ inch perforations were removed. Following screening, all defective beans were manually removed to maintain product uniformity for both the sensorial and the chemical analyses.

Sensorial analysis

The sensorial analysis was conducted by three SCAA (Specialty Coffee American Association) certified cupping judges.

The SCAA sensorial analysis protocol, based on the specialty coffee sensorial evaluation methodology proposed by Lingle (2011), was used.

Physiological analyses

Germination test

The germination test was conducted with four subsamples of 50 seeds distributed in germination paper that was dampened with a quantity of water equal to two and a half times the mass of the dry substrate and germinated at 30ºC. Evaluations were conducted 30 days after sowing based on the *Regras para Análise de Sementes* (Brasil, 2009), and the results were expressed as a percentage of seeds sown.

Electrical conductivity

The electrical conductivity of raw beans was determined using the proposed methodology of Krzyzanowski, França Neto, and Henning (1991). Two replicates of 50 beans of each sample were accurately weighed to the nearest 0.001 g and immersed in 75 mL of distilled water in 200 mL plastic cups. These replicates were subsequently placed in BOD refrigerators with forced ventilation and maintained at 25°C for five hours; the electrical conductivity reading of the soaking water was conducted with a BEL W12D conductivity microprocessor. The electrical conductivity was calculated from these readings using equation 3, and the result was expressed in μS cm^{-1} g^{-1} of beans.

$$EC = \frac{Reading(\mu S / cm)}{Weigh(g)} \tag{3}$$

Potassium leaching

The leaching of potassium ions was measured on raw beans using the methodology of Prete and Abrahão (1995). After determining the electrical conductivity, the solutions were analyzed to determine the quantity of potassium that had been leached. This analysis was conducted using a flame photometer (Digimed NK-2002). The quantity of leached potassium was determined using equation 4, and the result was expressed in ppm.

$$LK = \frac{Reading \times Dilution \times 1.56}{Weigh(g)} \tag{4}$$

Statistical analysis

The results of the physiological analyses and coffee drying rates and times were subjected to a canonical correlation analysis using the statistical software R (Team, 2014). The sensorial analysis was related to drying kinetics variables using correlation matrices in R (Team, 2014).

Results and discussion

Table 2 shows the mean time elapsed for the coffee to reach a mid-dry (MD) and a completely dry state, as well as the mean drying rate. The moisture content at the onset of drying, at mid-dry and at the end of drying are also presented as a function of the processing type, temperature, and drying airflow.

The mid-dry state had a moisture content of 0.50 ± 0.005 and 0.33 ± 0.005 kg of water kg^{-1} dry matter (d.b.) for natural and pulped coffees, respectively. When completely dry, the moisture content of the natural coffee was 0.145 ± 0.005 kg of water kg^{-1} dry matter (d.b.), and the moisture content of the parchment coffee was 0.125 ± 0.005 kg of water kg^{-1} dry matter (d.b.).

Table 2. Mean time and drying rates for mid-dry (MD) and complete drying (End), and initial moisture content and moisture content at mid-dry and complete drying as a function of processing, (natural and pulped), temperature, and drying airflow.

Processing	Temperature (°C)	Airflow (m^3 min^{-1} m^{-2})	Drying time (h)		Moisture content (d.b.)			Drying rate (g kg^{-1} h^{-1})	
			MD	End	Initial	MD	End	MD	Mean
Natural	40	24	28.25	87.65	2.21	0.50	0.145	72.9	37.3
		96	25.55	82.63	2.18	0.50	0.145	79.5	39.3
	45	24	20.58	56.18	2.19	0.50	0.145	96.9	46.1
		96	16.68	49.81	2.14	0.50	0.145	117.9	51.4
Pulped	40	24	9.46	18.75	0.86	0.33	0.125	56.4	42.4
		96	7.09	14.70	0.85	0.33	0.125	73.8	49.8
	45	24	5.15	10.60	0.89	0.33	0.125	109.5	72.4
		96	4.62	9.32	0.88	0.33	0.125	117.1	82.0

At an airflow of 24 $m^3 min.^{-1} m^{-2}$, the increase in temperature (from 40 to 45°C) resulted in a decreased drying time of 36% (87.65 to 56.18 hours) and 43% (18.75 to 10.60 hours) for the natural and pulped coffees, respectively (Table 2). When the airflow was increased from 24 to 96 m^3 $min.^{-1}$ m^{-2} during the natural coffee drying, the drying time decreased by 6% (87.65 to 82.63 hours) and 11% (56.18 to 49.81 hours) at 40 and 45°C, respectively. The same increase in airflow for pulped coffee resulted in a decrease of 22% (18.75 to 14.70 hours) and 12% (10.60 to 9.32 hours) at 40 and 45°C, respectively.

The increase in air temperature results in a greater difference between the steam pressure of the drying air and the product, which makes water removal easier and quicker (Siqueira, Resende, & Chaves, 2012). In addition, there are other reported causes for the reduction in drying time associated with a temperature increase. The increase in temperature decreases water viscosity, which directly influences the fluid runoff. The decrease in viscosity facilitates the diffusion of water molecules through the product, in addition to increasing the kinetic energy of the water molecules, which also contributes to an increase in the drying rate (Corrêa, Oliveira, Botelho, Goneli, & Carvalho, 2010).

Figure 2 shows the drying rates as a function of the moisture content in the fruits of natural and parchment (pulped) coffees subjected to complete drying in a mechanical dryer.

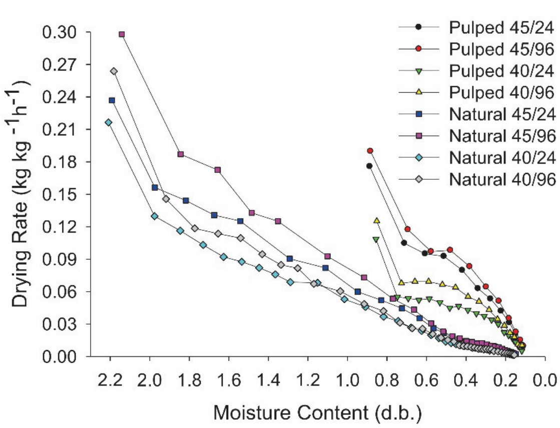

Figure 2. Drying rate as a function of mean moisture content of the coffee.

For the same moisture content, pulped coffee showed a faster drying rate than natural coffee. Additionally, for a given moisture content and processing type, the higher temperature resulted in a faster drying rate. Faster drying rates were observed at the beginning of drying, and as drying progressed, the differences in drying rates between natural and parchment coffee decreased considerably. The effect of airflow for the same processing type and temperature was more evident at the beginning of drying. Over the course of the drying process, coffee water removal becomes more difficult due to the strong adsorptive forces between the water and the other constituents of the bean. Thus, the drying rates for the two airflows and the two temperatures tend to converge at the end of the process for the same processing type. These results are consistent with the literature describing the general theory of drying agricultural products (Borém, 2008; Brooke, Bakker-Arkema, & Hall, 1992; Pabis, Jayas, & Cenkowski, 1998; Silva, 2008).

The phenomenon of water migration in the interior of the bean is not entirely understood. Nonetheless, numerous thermal and physical mechanisms have been proposed to describe the transport of water in hygroscopic porous capillary products (Brooke et al., 1992). However, recent theories suggest that at a particular stage of the drying, water movement is largely determined by liquid diffusion (Borém, Marques, & Alves, 2008). Liquid diffusion should be facilitated by both a temperature increase and the removal of physical barriers, as occurs as a result of the coffee pulping process in comparison to the drying of natural coffee. The airflow effect on the drying rate is more evident when the product still has high moisture content, which is also consistent with general drying theory.

Table 3 shows the mean values for electrical conductivity, potassium leaching, and germination as well as for the sensorial analysis and the mean drying rate as a function of the experimental variables.

The canonical correlation analysis was applied with the objective of finding linear combinations that would preserve the relations between the physiological variables (electrical conductivity, potassium leaching, and germination percentage) and the drying kinetics variables (drying time and rates for mid-dry and complete drying).

The results of the Bartlett test are presented in Table 4 to validate the analysis and to justify the choice of these paired physiological and kinetics variables.

The results (Table 4) show that there is a strong correlation ($\rho < 0.05$) between the drying kinetics variables and the physiological variables represented by the first pair of canonical variables (U_1 and V_1) that may still be present in the second pair of canonical variables ($\rho < 0.05$). However, given the stronger correlation in the first pair of canonical variables (0.996), the components obtained are described in Equations 5 and 6.

Table 3. Mean drying rate (MxDR), electrical conductivity, potassium leaching, germination percentage, and sensorial analysis as a function of processing (natural and pulped), temperature, and drying airflow.

Processing	Temperature (°C)	Airflow (m^3 min.$^{-1}$ m^{-2})	MxDR (g kg^{-1} h^{-1})	Electrical conductivity (μS g^{-1})	Potassium leaching (ppm)	Germination percentage (%)	Sensorial
Natural	40	24	37.3	13.34	32.83	4.83	82.50
		96	39.3	12.65	31.63	4.00	80.75
	45	24	46.1	13.60	33.18	0.00	81.67
		96	51.4	12.94	31.67	0.00	81.33
Pulped	40	24	42.4	3.81	8.29	87.67	83.25
		96	49.8	3.24	7.11	84.67	81.50
	45	24	72.4	3.26	6.20	9.00	81.92
		96	82.0	3.19	6.18	11.67	81.83

Table 4. Bartlett test verifying the correlation between the physiological and drying kinetics variables.

Pairs of canonical variables	Canonical correlation ρ	Chi-square statistics	p-value
1	0.9965	65.057	$< 2.2.10^{-16}$
2	0.9561	17.302	$< 2.69.10^{-9}$
3	0.4756	-	-

$$U_1 = -0.0057 \times \%Germ + 0.15741 \times EC + 0.0051 \times KL \quad (5)$$

$$V_1 = -0.0336 \times TpT + 0.2119 \times TpMD - 16.841 \times TxT + 28.849 \times TxMD \quad (6)$$

where:

% Germ: germination percentage (%);

EC: electrical conductivity (μS g^{-1});

KL: potassium leaching (ppm);

TpT: total drying time (h);

TpMD: drying time to mid-dry (h);

TxT: mean drying rate at the end of drying (g of water kg of dry matter^{-1} h^{-1});

TxMD: mean drying rate at mid-dry (g of water kg of dry matter^{-1} h^{-1}).

The correlation of the original variables in each group with the canonical variables U_1 and V_1 obtained from equations 5 and 6 are described in Tables 5 and 6.

Table 5. Correlations of physiological variables with canonical variables.

Variables	U_1	U_2	U_3
	Pairs of canonical variables		
%Germ	-0.745	-0.666	0.024
EC	0.986	-0.161	0.008
KL	0.983	-0.180	-0.029

% Germ = germination percentage, EC = electrical conductivity, KL = potassium leaching, U_1 = first pair of canonical variables, U_2 = second pair of canonical variables, U_3 = third pair of canonical variables.

Based on the results presented in Table 5, the first canonical variable (U_1) showed a high correlation with electrical conductivity (EC) and potassium leaching (KL) (0.986 and 0.983, respectively). Therefore, U_1 is designated as EC/KL.

In contrast, the variables that were highly correlated with the first canonical variable V_1 (Table 6, kinetics variables) were the total drying time (TpT) and the drying time to the mid-dry stage (TpMD) with correlations of 0.894 and 0.891, respectively. The canonical variable V_1 was therefore designated as TpT/TpMD.

Table 6. Correlations of kinetics variables with canonical variables.

Variables	V_1	V_2	V_3
	Pairs of canonical variables		
TpT	0.894	-0.232	-0.268
TpMD	0.891	-0.293	-0.185
TxT	-0.493	0.847	0.122
TxMD	0.116	0.841	0.164

TpT = total drying time, TpMD = drying time to mid-dry, TxT = mean drying rate at the end of drying, TxMD = mean drying rate at mid-dry.

Figures 3 and 4 show the results as a function of processing type, temperature, and drying airflow.

Figure 3 shows that it was possible to discriminate two groups (I and II) as a function of the processing type. Group I comprises the natural coffees and group II comprises the pulped coffees. These groupings reinforce the results presented in Tables 2 and 3, in which natural coffees showed longer drying times, higher electrical conductivity, and greater potassium leaching. Based on these results, it may be concluded that natural coffees are more physiologically sensitive to the effects of drying. One possible explanation for this phenomenon is that coffees that are processed via a dry method (natural) are exposed to drying air for longer periods, which exposes the endosperm and the embryo to more severe thermal damage, contributing to a greater loss of integrity of cell membranes (Saath et al., 2012; Taveira, Rosa, Borém, Giomo, & Saath, 2012).

With regard to the effect of different drying airflows (24 and 96 m^3 min.$^{-1}$ m^{-2}) on the same processing type, similar values were observed (Figure 3) for the physiological analysis (EC and KL) and for the drying times (TpT and TpMD). These results did not allow the discrimination of groups as a function of drying airflow, although numerically lower drying times were observed under the highest airflow (Table 2).

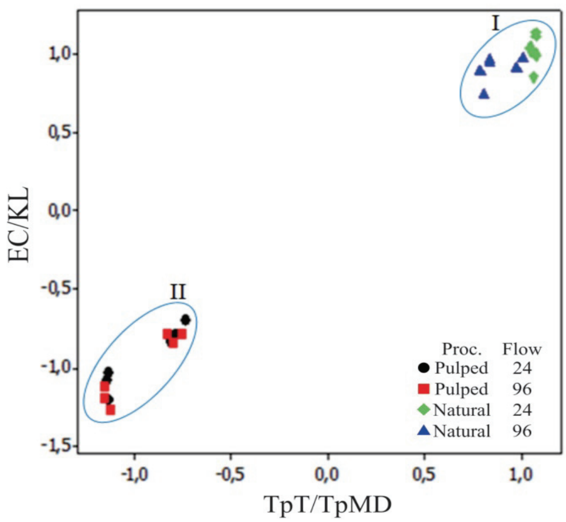

Figure 3. Scores of canonical variables identified by processing type and drying airflow.

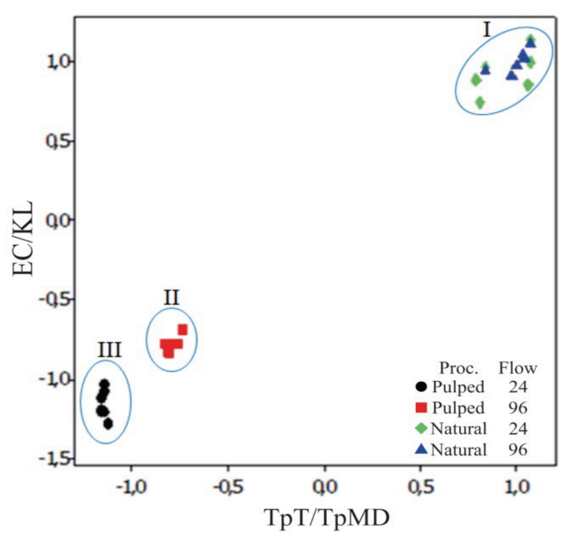

Figure 4. Scores of canonical variables identified by processing type and drying air temperature.

Figure 4 shows the separation of pulped coffees into two new groups, II and III. This discrimination is due to differential responses of the physiological variables (EC and KL) and the drying times (TpT and TpMD) of pulped coffee when subjected to drying at 40 and 45°C. The clustering with these two groups demonstrates that regardless of the airflow used, pulped coffees that are dried at 45°C show higher electrical conductivity and potassium leaching combined with a lower drying time compared with pulped coffee that is dried at 40°C (Table 2 and 3).

Therefore, regardless of the airflow, the temperature increase (from 40 to 45°C) reduces the drying time of pulped coffee but has a negative effect on the physiological quality. For natural coffees, it was not possible to identify differences in either the physiological quality (electrical conductivity and potassium leaching) or the drying times (to the mid-dry or completely dry stages) for the temperatures and drying airflows used.

The relation between drying kinetics variables and coffee sensorial quality for the two flows studied (24 and 96 m^3 $min.^{-1}$ m^{-2}) was analyzed via the estimation of correlation matrix coefficients as a function of processing type (natural and pulped) and drying air temperature (40 and 45°C). The results are shown in Table 7.

Table 7 shows the correlation coefficients that measure the degree of correlation between two variables. These might assume values between -1 and 1. If the coefficient is close to 1, there is a high positive correlation between the two variables; i.e., if one increases the other also increases. If the value is close to zero, it indicates a weak correlation. Nevertheless, if the value is close to -1 it means that the variables have a high negative correlation; i.e., one increases and the other one decreases.

Therefore, no correlations were found between drying kinetics variables and sensorial quality (Table 7) within each air temperature used for drying natural coffee (40 and 45°C); i.e., differences in drying time and drying rate as a function of drying airflow (24 or 96 m^3 $min.^{-1}$ m^{-2}) do not interfere with the sensorial quality of natural coffee when this coffee is dried at 40 or 45°C. These results are consistent with the results of Isquierdo et al. (2013) in a study on the effect of drying rate as a function of drying air with different relative humidities; that study found that for natural coffees that are dried at 40 and 45°C, the increase in drying rate caused by a reduction in the relative humidity of drying air did not influence the sensorial quality. However, these researchers did not study the effect of drying rate for coffees processed via the wet method.

Table 7. Correlation coefficients between the sensorial analysis and drying kinetics variables (drying times and drying rates at mid-dry and at the end of drying) for 24 and 96 $m^3 min.^{-1} m^{-2}$ flows as a function of processing type (natural and pulped) and drying air temperature.

	Processing	Temperature (°C)	Drying time		Drying rate	
			Final	Mid-dry	Final	Mid-dry
Sensorial Analysis	Natural	40	0.278	0.453	-0.412	-0.448
		45	0.274	0.263	-0.146	-0.330
	Pulped	40	0.834	0.815	-0.835	-0.795
		45	0.335	0.231	-0.247	0.028

In the present study, the drying rate influenced the sensorial quality of pulped coffees; however, this effect depends on the drying air temperature.

The results for pulped coffees that were dried at 45°C were similar to those observed for natural coffees; i.e., there was no effect of drying rate on the coffee's sensorial quality. At this temperature, the decrease in quality occurs as a function of thermal damage, which makes the effect of drying rate less evident.

For pulped coffees that were dried at 40°C, a highly positive correlation was found between the drying time and the sensorial score, and a highly negative correlation was found between the drying rate and the sensorial score. Therefore, the increase in the drying airflow from 24 to 96 m^3 $min.^{-1}$ m^{-2} negatively impacted the sensorial quality of pulped coffees that were dried at 40°C.

Conclusion

Under the conditions that this study was conducted, the following conclusions were drawn:

coffee processed via a dry method is more sensitive to mechanical drying with heated air than coffee processed via a wet method, resulting in poorer physiological performance;

airflow does not interfere with the physiological quality of natural and pulped coffees;

a temperature increase from 40 to 45°C results in a decrease in physiological quality for pulped coffee;

at 40°C, the increase in the drying rate resultin from an increase in the drying airflow has a negative correlation with the sensorial quality of pulped coffee.

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