

Quality of dried green coffee fruits at different dry bulb temperatures and dew point temperatures¹

Danilo Barbosa Cardoso², Ednilton Tavares de Andrade², Flávio Meira Borém², Nelson Gutierrez Guzman³, Bárbara Lemes Outeiro Araújo², Paula de Almeida Rios², Filipe da Silva de Oliveira²

ABSTRACT - A significant portion of the coffee harvested in Brazil consists of immature (green) fruits, which are more susceptible to damage during the drying process. This study aimed to evaluate the effects of drying at different dry bulb temperatures (DBTs) and dew point temperatures (DPTs) on the quality of green coffee fruits. Unripe fruits were harvested manually and dried continuously to an average water content of 0.139 dry basis (db). Drying was performed in a fixed-layer dryer coupled to a composite air conditioning system in which the drying air had an air flow of 20 m³ min⁻¹ m⁻², and 3 DBTs (30 °C, 35 °C and 40 °C) were used in combination with 4 DPTs (7.5 °C, 11.2 °C, 16.2 °C and 20.4 °C). To evaluate the effects of drying on the grains, the percentage of black-green defects, changes in color, the electrical conductivity of the grain exudates and the contents of trigonelline, chlorogenic acids and caffeine were analyzed. The increase in dry-bulb temperature (DBT) from 30 °C to 40 °C increased the incidence of black-green defects, whereas the highest percentages of defects were observed at dew point temperatures (DPTs) of 11.2 °C and 16.2 °C. Electrical conductivity and chlorogenic acid contents also increased with increasing DBT, with the highest chlorogenic acid contents observed at DPTs of 16.2 °C and 20.4 °C. Trigonelline and caffeine contents were not affected by the drying conditions. The results indicated that drying at 30 °C combined with dew point temperatures of 7.5 °C and 20.4 °C provided the greatest preservation of the quality of immature coffee fruits.

Keywords: *Coffea arabica* L. Drying. Immature fruits. Black-green. Bioactive.

INTRODUCTION

Coffee production has a large impact on the economy of Brazil, the largest coffee producer and exporter in the world (Companhia Nacional de Abastecimento, 2021).

Large-scale coffee harvesting yields fruit at varying levels of maturity, as it is not possible to select only the ripe beans when using mechanized harvesting; thus, different management approaches are required to minimize undesirable defects from black-green beans. Attention to the postharvest stages, such as processing, drying, and storage, is essential to maintain the quality of the final product and, consequently, its economic value (Borém; Andrade; Isquierdo, 2014; Dong *et al.*, 2017). Among these stages, drying is one of the main because it influences the final quality of the coffee beverage; drying also demands high energy expenditure, is associated with high costs, and can be in terraces with solar energy or in mechanical dryers (Silva *et al.*, 2020, 2022).

According to the classification established by Normative Instruction n°. 8 from 11/06/2003, which enacted the “Technical Regulation of Identity and Quality for the Classification of Raw Coffee” (Brasil, 2003), the spermoderm is adhered to the endosperm in both green beans and black-green beans, with the difference between them being their grain color, where the grains of black-green beans are black. Changes in grain color are strong indicators of oxidative processes and enzymatic biochemical transformations that alter the composition of the precursors responsible for the flavor and aroma of beverages, resulting in decreased quality (Bastian *et al.*, 2021; Borém *et al.*, 2013; Chen; Ma; Kitts, 2018).

DOI: 10.5935/1806-6690.v57e202595984

Section Editor: Profa. Elisabeth Mary Cunha da Silva - elisabeth@ufc.br

Author for correspondence

Received for publication in 21/08/2025; approved in 12/07/2026

¹Part of the first author's doctoral dissertation, submitted to the Graduate Program in Agricultural Engineering, Universidade Federal de Lavras, Lavras-MG, Brazil

²Department of Agricultural Engineering, Universidade Federal de Lavras, Lavras-MG, Brazil, cardosodb@gmail.com (ORCID ID 0000-0003-1678-2222), ednilton@ufla.br (ORCID ID 0000-0002-8448-8781), flavioiborem@ufla.br (ORCID ID 0000-0002-6560-8792), barbara.oleo@gmail.com (ORCID ID 0000-0001-5350-5174), paulariosagricola@gmail.com (ORCID ID 0000-0002-2836-918X), filipe.oliveira2@ufla.br (ORCID ID 0000-0003-3463-9630)

³Department of Agricultural Engineering, Universidad Surcolombiana, Neiva-Huila, Colombia, ngutierrezg@usco.edu.co (ORCID ID 0000-0003-2499-8066)

The electrical conductivity test is based on the fact that membranes with some type of deterioration have a lower rate of cell membrane repair when the seeds are exposed to an aqueous medium, causing the loss of compounds to the medium (Araújo, 2020). Thus, the deterioration of the membranes of beans, such as coffee beans, can characterize the onset of degradation of product quality (Błaszkiwicz *et al.*, 2023).

The drying method must be well established, especially for immature coffees, as the temperatures and water reduction rates used can cause physical and chemical transformations.

The drying process can significantly influence the preservation of the physical, chemical, and sensory quality of coffee, particularly when applied to fruits harvested before physiological maturity, which are more susceptible to structural and metabolic changes during water removal. The conditions under which drying is performed, especially the dry-bulb temperature (DBT) and the dew point temperature (DPT) of the drying air, are key factors in preserving the final quality of the product. Previous studies have shown that drying air temperatures above 40 °C may cause thermal damage, compromising bean quality. Therefore, drying temperatures around 35 °C have been recommended, depending on the proportion of immature fruits present (Borém, Andrade, 2019; Isquierdo *et al.*, 2013; Oliveira *et al.*, 2018).

However, studies evaluating the effects of drying conditions on the quality of coffee fruits harvested before physiological maturity remain scarce. In this context, the present study aimed to evaluate the effects of different combinations of dry-bulb temperature and dew point temperature during drying on the quality of immature coffee fruits, contributing to a better understanding of the influence of these variables on the drying process and to the identification of drying conditions that promote the preservation of product quality.

MATERIAL AND METHODS

Green coffee fruits (*Coffea arabica* L. cv. Catuaí 62) were harvested manually from experimental fields on the campus of the Federal University of Lavras (UFLA).

The coffee was harvested manually and selectively, prioritizing beans in the green maturation stage. After harvesting, the green coffees fruits were taken to the Laboratory of Processing of Agricultural Products of the UFLA, where hydraulic separation was applied to remove pits, roasted grains, and floating and shriveled beans from the harvested fruits; the fruits were subsequently sorted again to isolate the green coffee beans, ensuring that only

these beans were sent to the drying stage. The fruits were dried in their complete form, and the dry processing that produces natural coffees was performed. At the time of harvest, the fruits had a water content of $2.50 \pm 0.08 \text{ kg kg}^{-1}$ (db), and after mechanical drying, they reached a water content of $0.139 \pm 0.01 \text{ kg kg}^{-1}$ (db). To determine the initial water content of the coffee fruits, the standard greenhouse method, in which the beans were stored at 105 °C for 24 hours according to the Rules for Seed Analysis (Brasil, 2009), was used. To determine the final water content of the coffee beans, the standard oven method, in which the beans were dried at 105 °C for 16 hours according to international standard method ISO 6673 (International Organization for Standardization, 2003), was used.

The system for drying the samples consisted of an air conditioning unit coupled to a fixed-layer dryer (Figure 1).

The laboratory air conditioning system (LACS) was used to control the characteristics of the drying air according to the model proposed by Fortes *et al.* (2006). This equipment allows the control of the air flow, the drying temperature and the temperature of the water that saturates the air inside the LACS.

The areas where the coffees are placed for drying are composed of four removable trays with a perforated bottom, a square section, four equal sides of 0.3 m and a depth of 0.1 m. The trays are on the same level and are located on a plenum to standardize the air flow. The temperature of the drying air in the plenum was monitored, and the water temperature inside the LACS was monitored by thermocouples (type k) connected to universal controllers (Novus, Model N1100). A frequency inverter (Weg, model CFW-10), was used to control the speed of the centrifugal fan that inflated the heated air in the plenum, thus regulating the air flow.

To monitor the drying process and ensure that the desired water content was achieved, the gravimetric method of mass loss was used to determine when the desired water content was reached. The mass loss was monitored using an analytical balance with a resolution of 0.001 g. The samples were weighed more frequently at the beginning of the drying process (hourly for the first 6 hours) and less frequently throughout the remainder of the process.

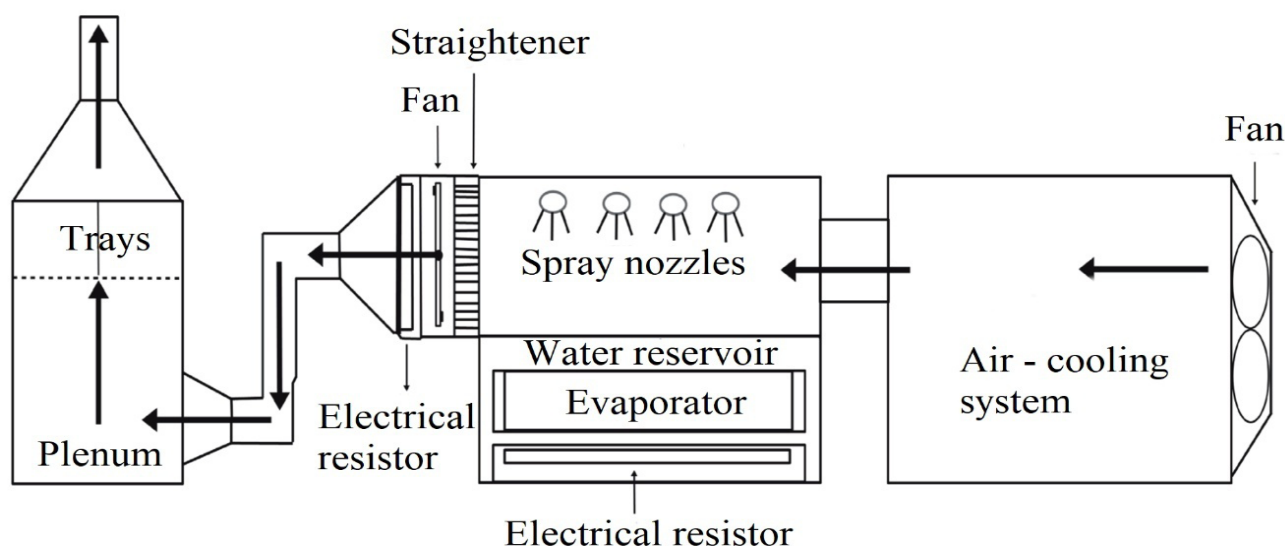
The trays were rotated 90° to minimize possible differences in temperature and air flow between them.

Knowing the mass and initial water content of coffee fruits, it was possible to determine the water content at time *t* from Equation 1:

$$U_t = \frac{M_{at} - (M_{it} - M_{it})}{M_{ms}} \quad (1)$$

Where

U_t is the water content at time *t* (kg of water per kg of dry

Figure 1 - System used for mechanical dryingSource: Isquierdo *et al.* (2013)matter⁻¹ (db)); M_{ai} is the initial water mass (kg); M_{ti} is the initial total mass (kg); M_t is the total mass at time t (kg); and M_{ms} is the dry matter mass (kg).

The air flow was monitored by a blade anemometer and maintained at a constant speed during drying of 0.33 m s^{-1} , which corresponds to a flow of $20 \text{ m}^3 \text{ min}^{-1} \text{ m}^{-2}$. The temperature of the drying air in the plenum and that of the water that saturated the air inside the LACS were recorded every 10 minutes by a Testo 175T3 datalogger with two type t thermocouples.

In total, 12 treatments were performed in a 3×4 factorial scheme in a completely randomized design (CRD) with three dry bulb temperatures (30 °C, 35 °C and 40 °C) and 4 dew point temperatures (7.5 °C, 11.2 °C, 16.2 °C and 20.4 °C). For each treatment, 4 replicates were performed. These combinations of dry bulb temperatures (DBTs) and dew point temperatures (DPTs) resulted in different relative humidities (RHs) of the drying air (Table 1).

The dry bulb temperatures used in this experiment, including a higher temperature (40 °C) and a lower temperature (30 °C), are normally used for unripe coffee fruits (35 °C). Regarding the dew point temperature, normally, in the coffee harvest period, between the months of May and August, in the southern region of Minas Gerais, the dry bulb temperatures and mean relative humidity are in the ranges of 16.5 °C and 71%, respectively, which represents

Table 1 - Drying air conditions of the 12 drying treatments resulting from combinations of dewpoint temperatures and dry bulb temperatures and the respective relative humidities

DBT (°C)	DPT (°C)	Relative humidity (%)
30.0	7.5	24.4
	11.2	31.3
	16.2	43.4
	20.4	56.5
35.0	7.5	18.4
	11.2	23.6
	16.2	32.7
	20.4	42.6
40.0	7.5	14.1
	11.2	18.0
	16.2	24.9
	20.4	32.5

a temperature and dew point of approximately 11.2 °C. At the same time of the year, in more humid regions such as Matas de Minas, the corresponding dew point temperature would be equivalent to 16.2 °C. In addition to these two dew point temperatures, a lower (7.5 °C) and an upper (20.4 °C) temperature were included.

The classification established by Normative Instruction n°. 8 from 06/11/2003, which enacted the

“Technical Regulation of Identity and Quality for the Classification of Coffee Processed from Raw Beans” (Brasil, 2003), was used to identify defects in the coffee. To verify the percentage of black–green and green defects, the amount of each was counted in a 50-gram portion of each drying repetition.

The processed coffee, without removal of defective beans or separation through a sieve, was analyzed for color using a Delta Color 450 G spectrophotometer, with an optical geometry of $d/0^\circ$, a standard illumination of D65 and a standard observation angle of 10° . The analysis was performed by filling grains with an accessory suitable for this type of material. Three fillings were performed for each of the 4 replicates of the 12 treatments. The color was expressed in according to the scale developed by the Commission Internationale de l’Eclairage (CIE) in terms of L^* , a^* , b^* . The L^* coordinate expresses the degree of luminosity of the measured color ($L^* = 0$, black; 100, white). The value of a^* express the degree of variation between red and green (a^* negative = green; a^* positive = red), and the value of b^* indicates the degree of variation between blue and yellow (negative b^* = blue; b^* positive = yellow).

The electrical conductivity of the coffee beans was determined according to an adaptation of the methodology proposed by Malta, Pereira and Chagas (2005).

The flat grains that were retained between circular sieves 13 and 19 sieves and that were classified as green, excluding black–green defects, were analyzed.

Two 50-grain samples from each repetition of the drying treatments were weighed on a 0.001 g precision scale. The samples were immersed in 75 mL of distilled water (inside 200 mL plastic cups) and maintained at 25°C . After imbibition for 3.5 hours, the solutions were agitated immediately before performing the electrical conductivity reading in a BEL conductivity meter (model W12D). The results were expressed in $\mu\text{S cm}^{-1} \text{ g}^{-1}$ of sample.

The nonvolatile compounds caffeine, trigonelline and chlorogenic acids were determined by high-performance liquid chromatography (HPLC) in two replicates of each treatment without changing the sample according to a

methodology that was adapted from Vitorino *et al.* (2001) by Malta and Chagas (2009). Samples of 0.5 g of ground coffee were extracted in 50 mL of boiling distilled water and placed in a water bath with boiling water for 3 min. The extract was filtered through standard filter paper and then filtered through a $0.45 \mu\text{m}$ membrane. The determination of these compounds was performed in a Shimadzu chromatograph with a diode array detection system (model SPD-M10A), Discovery C18 chromatographic column ($250 \times 4.6 \text{ mm}$, $5 \mu\text{m}$), and 272 nm wavelength. The mobile phase consisted of methanol:water:acetic acid (20:80:1), with a flow rate of $1 \text{ mL} \cdot \text{min}^{-1}$. For the identification and quantitative analysis, a standard curve was prepared using standards of caffeine, trigonelline and 5-caffeoylquinic acid (5-QCA).

The experiment consisted of a 3×4 factorial scheme in a completely randomized design with four replicates (4 fixed-layer drying trays).

The data were subjected to analysis of variance, and the means were compared using the Scott–Knott test at a significance level of 5%. The statistical analyses were performed using R software (R Core Team, 2013) with the Easyanova package (Arnhold, 2013).

RESULTS AND DISCUSSION

Table 2 shows the breakdown of the effect of the interaction between dry bulb temperature (DBT) and dew point temperature (DPT) on the mean values of the percentage of black–green defects.

The data in Table 2 show that for the same DPT, with an increase in drying temperature, there is also an increase in the average percentage of black–green defects, indicating that temperature affects the emergence of defects during the drying of a large amount of coffee from unripe fruits. Immature grains ferment easily when exposed to temperatures of approximately 40°C (Andrade *et al.*, 2019; Rios *et al.*, 2021).

Table 2 - Percentage of black-green defects as a function of the interaction between dry-bulb temperature and dew point temperature

DBT ($^\circ\text{C}$)	DPT ($^\circ\text{C}$)			
	7.5	11.2	16.2	20.4
30	$25.29 \pm 1.56 \text{ cB}$	$31.81 \pm 2.08 \text{ cA}$	$33.60 \pm 2.07 \text{ cA}$	$23.96 \pm 1.47 \text{ cB}$
35	$31.60 \pm 1.94 \text{ bB}$	$36.91 \pm 2.27 \text{ bA}$	$38.41 \pm 2.36 \text{ bA}$	$39.44 \pm 2.43 \text{ bA}$
40	$53.69 \pm 3.30 \text{ aB}$	$57.60 \pm 3.54 \text{ aA}$	$59.56 \pm 3.66 \text{ aA}$	$52.62 \pm 3.24 \text{ aB}$

Means followed by the same lowercase letter within a column and uppercase letters within a row do not differ ($P > 0.05$) according to the Scott–Knott test

Phenolic compounds that are close to the cell wall tend to react with enzymes present in the grains to form brown polymers. This browning effect can also be produced with the denaturation or oxidation of phenolic compounds, sugars and proteins (Nath *et al.*, 2022).

Considering that, at the same dry-bulb temperature, an increase in dew point temperature results in higher relative humidity of the drying air, it was observed that the incidence of black-green defects did not show a linear behavior as a function of relative humidity. The highest defect percentages were observed under intermediate relative humidity conditions (corresponding to DPTs of 11.2 and 16.2 °C), whereas the lowest percentages occurred at the lowest and highest relative humidity levels (DPTs of 7.5 and 20.4 °C). These results indicate that not only the drying intensity, but also the balance between air temperature and humidity, influences the occurrence of defects in immature coffee fruits.

At a dry bulb temperature of 30 °C, the lowest mean percentage of black-green defects occurred at DPTs of 20.4 °C and at 7.5 °C, for which the values did not differ significantly, and the highest values were found at the two intermediate DPT values of 16.2 and 11.2 °C.

At a DBT of 40 °C, the percentage of green-black defects was lower at DPTs of 20.4 and 7.5 °C and higher at DPTs of 16.2 and 11.2 °C, a results that is similar to that found at a DBT of 30 °C. These results are similar to those found by Andrade *et al.* (2019), who dried green coffee

fruits at 40 °C and showed higher percentages of green-black defects when the relative humidity was intermediate (17.5%) and lower percentages when the relative humidity was highest (32.5%) and lowest (10%).

Table 3 shows the effect of the interaction between the dry bulb temperature (DBT) and the dew point temperature (DPT) on the mean values of the colorimetric parameter L*.

The parameter L* indicates the luminosity, where samples with higher values are lighter while those with lower values are darker.

Within each DPT, there was always a decrease in L* with increasing DBT, indicating darker grains on average. Within the same DPT, there was always an increase in the amount of black-green defects, causing the samples to have lower L* values on average.

Within each DBT, the lowest values of the parameter L* were found at DPTs of 11.2 and 16.2 °C, and we can also relate this to the greater amount of black-green defects present at these intermediate DPTs.

França *et al.* (2005) reported that the L* parameter alone can be used to separate defective and nondefective grains before roasting.

The analysis of variance did not indicate a significant effect of the interaction between dry bulb temperature and dew point temperature on the mean values of the colorimetric parameter a*. The isolated effects of DBT and DPT are shown in Tables 4 and 5.

Table 3 - Mean L* (lightness) values of processed coffee as a function of the interaction between dry-bulb temperature and dew point temperature

DBT (°C)	DPT (°C)			
	7.5	11.2	16.2	20.4
30	44.08 ± 0.87 aB	43.83 ± 0.87 aB	43.20 ± 0.86 aB	45.46 ± 0.90 aA
35	44.23 ± 0.88 aA	41.80 ± 0.83 bB	42.98 ± 0.85 aB	42.16 ± 0.83 bB
40	42.84 ± 0.85 bA	40.81 ± 0.81 bB	40.16 ± 0.80 bB	41.80 ± 0.83 bA

Means followed by the same lowercase letter within a column and uppercase letters within a row do not differ ($P > 0.05$) according to the Scott-Knott test

Table 4 - Mean a* values of processed coffee as a function of dry-bulb temperature

DBT (°C)	a*
30	- 0.22 c
35	0.11 b
40	0.62 a

Means followed by the same lowercase letter within the column do not differ from each other ($P > 0.05$) according to the Scott-Knott test

Table 5 - Mean a* values of processed coffee as a function of dew point temperature

DPT (°C)	a*
7.5	0.20 a
11.2	0.07 a
16.2	0.16 a
20.4	0.26 a

Means followed by the same lowercase letter within the column do not differ from each other ($P > 0.05$) according to the Scott-Knott test

The chromatic coordinate a^* indicates positive values for red and negative values for green.

Tables 4 and 5 show that there was only a significant difference when the different DBTs were compared. There was an increase in the value of the a^* coordinate with the increase in temperature. The DBT of 30 °C resulted in the smallest amount of black–green defects, on average, and therefore had a greater amount of green grains, which is indicated by the lowest value of a^* .

Coradi, Borém and Oliveira (2008) observed higher a^* coordinate values at a drying temperature of 60 °C, with the coffees being classified lower quality than those dried at 40 °C in a mechanical dryer.

Table 6 shows the breakdown of the effect of the interaction between the dry bulb temperature and dew point temperature on the mean values of the colorimetric parameter b^* .

Positive values of the b^* parameter indicate yellow and negative values indicate blue. In the treatments with the highest amounts of black–green defects, the lowest values of the b^* coordinate were found; the inverse was also observed, with lower amounts of black–green defects and higher values of b^* . This pattern was also reported by Andrade *et al.* (2019); the drying treatment with the lowest percentage of black–green defects had the highest L^* and b^* values. Rios *et al.* (2020) observed a trend of lower L^* values for a DBT of 40 °C and lower values of the a^* parameter in the treatment with the lowest DBT (35 °C) and DPT (2.6 °C).

Table 7 shows the effect of the interaction between the dry bulb temperature and the dew

point temperature on the mean values of electrical conductivity.

Among the DPTs, the lowest mean electrical conductivity values were found at 7.5 °C and 20.4 °C when the DBT was 30 °C, which is similar to the pattern observed for the percentages of black–green defects.

At a DPT of 11.2 °C, there was an increase in electrical conductivity with the increase in DBT, which is the same pattern shown for the increase in the amount of black–green defects with the increase in the DBT.

At a DPT of 16.2 °C, the lowest DBT (30 °C) had the lowest electrical conductivity value. When evaluating the average percentage of green–black defects at this DPT, the lowest values were also found for a DBT of 30 °C. At a DPT of 20.4 °C, there was an increase in the electrical conductivity values with the increase in DBT. This same growth behavior was observed for the amount of black–green defects with increasing drying temperature. At a DBT of 30 °C, the highest values of electrical conductivity were observed at DPTs of 16.2 and 11.2 °C, and the lowest values were observed at DPTs of 20.4 and 7.5 °C. The patterns at this DBT are the same as those found for the percentage of black–green defects. At a DBT of 35 °C, we found the highest values of electrical conductivity at DPTs of 16.2 and 11.2 °C and the lowest values at DPTs of 20.4 and 7.5 °C. The lowest percentage of black–green defects at a DBT of 35 °C was also observed at the lowest DPT (7.5 °C). At a DBT of 40 °C, the lowest electrical conductivity value was observed at the lowest DPT of 7.5 °C, the same temperature at which the lowest percentage of black–green defects was observed.

Table 6 - Mean b^* values of processed coffee as a function of the interaction between dry-bulb temperature and dew point temperature

DBT (°C)	DPT (°C)			
	7.5	11.2	16.2	20.4
30	7.82 ± 0.80 bB	8.09 ± 0.83 aB	7.58 ± 0.78 aB	9.30 ± 0.96 aA
35	9.32 ± 0.96 aA	6.88 ± 0.71 bB	7.75 ± 0.80 aB	7.17 ± 0.73 bB
40	8.08 ± 0.83 bA	6.15 ± 0.63 bB	5.27 ± 0.54 bB	7.24 ± 0.74 bA

Means followed by the same lowercase letter within a column and uppercase letters within a row do not differ ($P > 0.05$) according to the Scott–Knott test

Table 7 - Electrical conductivity ($\mu\text{S} \cdot \text{cm}^{-1} \text{G}^{-1}$ of sample) of immature coffee beans as a function of the interaction between dry-bulb temperature and dew point temperature

DBT (°C)	DPT (°C)			
	7.5	11.2	16.2	20.4
30	18.36 ± 1.24 bB	19.67 ± 1.33 cA	20.46 ± 1.38 bA	17.70 ± 1.19 cB
35	21.36 ± 1.44 aB	23.01 ± 1.55 bA	23.22 ± 1.57 aA	20.74 ± 1.40 bB
40	22.07 ± 1.49 aB	25.19 ± 1.70 aA	24.48 ± 1.65 aA	25.37 ± 1.71 aA

Means followed by the same lowercase letter within a column and uppercase letters within a row do not differ ($P > 0.05$) according to the Scott–Knott test

The loss of selectivity of the cell membrane is associated with several factors, including the damage suffered by coffee beans during the processing and drying stages. Therefore, the greater the deterioration that occurs in the drying process, the more intense the increase in the values of these analyses will be (Reinato *et al.*, 2012).

Malta *et al.* (2013) found lower values of electrical conductivity, potassium leaching, and total titratable acidity and higher enzymatic activity of polyphenol oxidase in coffees subjected to slow drying in the shade, regardless of the processing method used. These results indicate less damage to cell membrane systems during slower drying, with lower rates of Water Removal.

Several authors have reported that drying time is affected by different drying air temperatures and that electrical conductivity, potassium leaching, total titratable acidity and grease acidity increase with increasing drying temperature regardless of the type of processing (Coradi *et al.*, 2019; Oliveira *et al.*, 2018).

Electrical conductivity and potassium leaching are indicators of cell membrane integrity, and sugars are involved in membrane protection mechanisms. Slow drying may contribute to the development of protective mechanisms for cell membranes, preserving their integrity and, therefore, maintaining the quality of the coffee (Coradi *et al.*, 2021), as observed in the results obtained in this study.

As the grains from harvested green fruits are immature, their cell walls and membranes are not fully formed, and there has not yet been a maximum accumulation of dry matter. These characteristics of immature grains make them more susceptible to damage caused by drying at high temperatures and fast drying rates.

Table 8 shows the breakdown of the effect of the interaction between the DBT and DPT on the mean trigonelline values.

According to the results, there was no correlation between the treatments and the amount of trigonelline in coffee beans from unripe fruits. Trigonelline contents vary according to the species of the bean, Arabica coffee, in beans classified as both green and normal, has approximately 1.0% trigonelline (Caporaso *et al.*, 2018), corroborating the results shown in Table 8. This compound is sensitive to temperature and may lead to the degradation and generation of volatile and nonvolatile compounds (Shi *et al.*, 2024). Jeszka-Skowron *et al.* (2022) verified that thermal processing, such as roasting and steaming, results in a substantial reduction of this compound in Arabica coffees. However, there was not a significant decrease in the percentage of trigonelline among the dry samples at DBTs of 30 °C to 40 °C, representing this degradation.

The analysis of variance did not indicate a significant effect of the interaction between DBT and DPT on the mean contents of chlorogenic acids. The isolated effects of the DBT and DPT are shown in Tables 9 and 10.

Table 8 - Trigonelline content (% dry matter) as a function of the interaction between dry-bulb temperature and dew point temperature

DBT (°C)	DPT (°C)			
	7.5	11.2	16.2	20.4
30	1.535 ± 0.037 aB	1.560 ± 0.038 bB	1.700 ± 0.041 aA	1.585 ± 0.038 aB
35	1.510 ± 0.036 aB	1.680 ± 0.041 aA	1.645 ± 0.039 aA	1.620 ± 0.039 aA
40	1.535 ± 0.037 aA	1.570 ± 0.038 bA	1.570 ± 0.038 bA	1.615 ± 0.039 aA

Means followed by the same lowercase letter within a column and uppercase letters within a row do not differ ($P > 0.05$) according to the Scott–Knott test

Table 9 - Chlorogenic acid content (% dry matter) as a function of different dry-bulb temperatures

DBT (°C)	Chlorogenic Ac. (% dry matter)
30	3.830 ± 0.195 c
35	4.132 ± 0.211 b
40	4.950 ± 0.250 a

Means followed by the same lowercase letter within the column do not differ from each other ($P > 0.05$) according to the Scott–Knott test

Table 10 - Chlorogenic acid content (% dry matter) as a function of different dew point temperatures

DPT (°C)	Chlorogenic Ac. (% dry matter)
7.5	4.061 ± 0.207 b
11.2	4.168 ± 0.212 b
16.2	4.433 ± 0.226 a
20.4	4.493 ± 0.229 a

Means followed by the same lowercase letter within the column do not differ from each other ($P > 0.05$) according to the Scott–Knott test

Chlorogenic acid is bioactive compound with antioxidant, antimutagenic, anticancer and anti-inflammatory properties (Huang *et al.*, 2023). As presented in Tables 9 and 10, the chlorogenic acid content increased significantly with increasing dry-bulb temperature, reaching 4.95% of dry matter at 40 °C, and was also higher at dew point temperatures of 16.2 and 20.4 °C. This behavior was consistent with the increase in the incidence of black-green defects observed with the elevation of dry-bulb temperature. Farah, Monteiro and Trugo (2005) also reported higher concentrations of chlorogenic acids in beans with black-green defects.

Chlorogenic acids are important phenolic compounds in coffee and tend to occur at higher concentrations in immature beans, decreasing throughout the maturation process. Therefore, the association observed in this study suggests that drying conditions that promoted a higher incidence of black-green defects were also related to higher chlorogenic acid contents.

The analysis of variance did not indicate significant effects of the interaction between the DBT and DPT on the mean values of caffeine. The isolated effects of the DBT and DPT are shown in Tables 11 and 12.

The content of caffeine, an alkaloid that is relatively stable when exposed to thermal processes (Grzelczyk *et al.*, 2022), did not change significantly

according to the values presented in Tables 11 and 12. The percentage of caffeine ranged from 1.57% to 1.65%, above the values found by other authors for Brazilian Arabica cultivars and hybrids, which range from 1.05 to 1.54% (Bobková *et al.*, 2022; Duarte; Pereira; Farah, 2010). Some studies reported results for ripe fruits. The observed difference in the percentage of caffeine between ripe and unripe fruits can be explained because França *et al.* (2005), studying the amount of this compound in Arabica coffee, found a significant difference when analyzing beans classified as black, green and burnt compared with nondefective beans and a mixture of these different types of beans.

CONCLUSIONS

1. The increase in dry-bulb temperature (DBT) during the drying of immature coffee fruits increased the incidence of black-green defects. Among the drying conditions evaluated, a DBT of 30 °C combined with dew point temperatures (DPTs) of 7.5 °C and 20.4 °C resulted in the lowest percentages of this defect;
2. Treatments with a higher incidence of black-green defects exhibited lower L* and b* values, higher a* values, and higher electrical conductivity, indicating greater impairment of the cellular integrity of the coffee beans;
3. The chlorogenic acid content increased with increasing dry-bulb temperature and was associated with the higher incidence of black-green defects observed under the highest drying temperatures.

ACKNOWLEDGMENTS

The authors would like to thank CNPq and Capes for financial support.

DATA AVAILABILITY STATEMENT

The research data is available only upon request to the corresponding author.

REFERENCES

ANDRADE, E. T. *et al.* Mathematical modelling and immediate and latent quality of natural immature coffee under different drying conditions. **Engenharia Agrícola**, v. 39, n. 5, p. 630-638, 2019. <https://doi.org/10.1590/1809-4430-Eng.Agric.v39n5p630-638/2019>

Table 11 - Caffeine content (% dry matter) as a function of different dry-bulb temperatures

DBT(°C)	Caffeine (% dry matter)
30	1.654 ± 0.054 a
35	1.584 ± 0.052 a
40	1.621 ± 0.053 a

Means followed by the same lowercase letter within the column do not differ from each other (P > 0.05) according to the Scott-Knott test

Table 12 - Caffeine content (% dry matter) as a function of different dew point temperatures

DPT (°C)	Caffeine (% dry matter)
7.5	1.570 ± 0.051 a
11.2	1.637 ± 0.054 a
16.2	1.645 ± 0.054 a
20.4	1.627 ± 0.053 a

Means followed by the same lowercase letter within the column do not differ from each other (P > 0.05) according to the Scott-Knott test

- ARAÚJO, C. da S. *et al.* Predição da condutividade elétrica e lixiviação de potássio do café pela técnica de espectroscopia NIR. **Food Analytical Methods**, v. 13, n. 12, p. 2312-2320, 2020. <https://link.springer.com/article/10.1007/s12161-020-01843-y>
- ARNHOLD, E. Package in the R environment for analysis of variance and complementary analyses. **Brazilian Journal of Veterinary Research and Animal Science**, v. 50, n. 6, p. 488-492, 2013. <https://pesquisa.bvsalud.org/portal/resource/pt/vti-334230>
- BASTIAN, F. *et al.* From plantation to cup: changes in bioactive compounds during coffee processing. **Foods**, v. 10, n. 11, p. 2827, 2021. <https://doi.org/10.3390/foods10112827>
- BLASZKIEWICZ, J. *et al.* Effect of green and roasted coffee storage conditions on selected characteristic quality parameters. **Scientific Reports**, v. 13, n. 1, p. 6447, 2023. <https://doi.org/10.1038/s41598-023-33609-x>
- BOBKOVÁ, A. *et al.* Variability of caffeine content in green and roasted *Coffea arabica* regarding the origin, post-harvest processing, and altitude, and overview of recommended daily allowance. **Journal of Environmental Science and Health**, v. 57, n. 12, p. 989-998, 2022. <https://doi.org/10.1080/03601234.2022.2159739>
- BORÉM, F. M. *et al.* Evaluation of the sensory and color quality of coffee beans stored in hermetic packaging. **Journal of Stored Products Research**, v. 52, p. 1-6, 2013. <https://doi.org/10.1016/j.jspr.2012.08.004>
- BORÉM, F. M.; ANDRADE, E. T. de. Processing and drying of coffee. In: HUI, C. L.; BORÉM, F. M. (ed.). **Drying and roasting of cocoa and coffee**. [S. l.]: CRC Press, 2019. p. 141-170.
- BORÉM, F. M.; ANDRADE, E. T.; ISQUIERDO, E. P. Coffee drying. In: BORÉM, F. M. (ed.). **Handbook of coffee post-harvest technology**. Georgia: Norcross, 2014. p. 97-118.
- BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. **Instrução Normativa nº 8, de 11 de junho de 2003**. Aprova o Regulamento Técnico de Identidade e de Qualidade para a Classificação do Café Beneficiado Grão Cru. Brasília, DF: MAPA, 2003. 15 p.
- BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. **Regras para análise de sementes**. Brasília, DF: MAPA, 2009. 399 p.
- CAPORASO, N. *et al.* Non-destructive analysis of sucrose, caffeine and trigonelline on single green coffee beans by hyperspectral imaging. **Food Research International**, v. 106, p. 193-203, 2018. <https://doi.org/10.1016/j.foodres.2017.12.031>
- CHEN, X.-M.; MA, Z.; KITTS, D. D. Effects of processing method and age of leaves on phytochemical profiles and bioactivity of coffee leaves. **Food Chemistry**, v. 249, p. 143-153, 2018. <https://doi.org/10.1016/j.foodchem.2017.12.073>
- COMPANHIA NACIONAL DE ABASTECIMENTO (BRASIL). **Acompanhamento da safra brasileira de café: safra 2021, n. 2: segundo levantamento**. Brasília, Conab, 2021. v. 8, p. 1-63.
- CORADI, P. C. *et al.* Adjustment of mathematical models and the quality of drying the pulped coffee at different air conditions. **Journal of Agricultural Science and Technology**, p. 38-48, 2019. <https://doi.org/10.17265/2161-6264/2019.01.004>
- CORADI, P. C. *et al.* Development and validation of a heated air diffusion system for drying, aiming to optimize rotary dryers and the final quality of the coffee. **PLOS ONE**, v. 16, n. 6, e0251312, 2021. <https://doi.org/10.1371/journal.pone.0251312>
- CORADI, P. C. *et al.* Development and validation of a heated drying air diffusion system to optimize rotary dryers and final coffee quality. **PLOS ONE**, v. 16, n. 6, 2021. <https://doi.org/10.1371/journal.pone.0251312>
- CORADI, P. C.; BORÉM, F. M.; OLIVEIRA, J. A. Qualidade do café natural e despulpado após diferentes tipos de secagem e armazenamento. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 12, n. 2, p. 181-188, 2008. <https://doi.org/10.1590/S1415-43662008000200011>
- DONG, W. *et al.* Effect of different drying techniques on bioactive components, fatty acid composition, and volatile profile of robusta coffee beans. **Food Chemistry**, v. 234, p. 121-130, 2017. <https://doi.org/10.1016/j.foodchem.2017.04.156>
- DUARTE, G. S.; PEREIRA, A. A.; FARAH, A. Chlorogenic acids and other relevant compounds in Brazilian coffees processed by semi-dry and wet post-harvesting methods. **Food Chemistry**, v. 118, n. 3, p. 851-855, 2010. <https://doi.org/10.1016/j.foodchem.2009.05.042>
- FARAH, A.; MONTEIRO, M. C.; TRUGO, L. C. Distribuição de ácidos clorogênicos nos principais defeitos do café. In: SIMPÓSIO DE PESQUISA DOS CAFÉS DO BRASIL, 4., 2005, Londrina. **Anais [...]**. Brasília: Embrapa Café, 2005.
- FORTES, M. *et al.* Modeling of a high-precision air conditioner for use in agricultural processing. **Engenharia Agrícola**, v. 26, p. 578-589, 2006. <https://doi.org/10.1590/S0100-69162006000200028>
- FRANÇA, A. S. *et al.* Physical and chemical attributes of defective crude and roasted coffee beans. **Food Chemistry**, v. 90, n. 1, p. 89-94, 2005. <https://doi.org/10.1016/j.foodchem.2004.03.028>
- GRZELCZYK, J. *et al.* Evaluation of the thermal stability of bioactive compounds in coffee beans and their fractions modified in the roasting process. **Food Chemistry**, v. 387, p. 132888, 2022. <https://doi.org/10.1016/j.foodchem.2022.132888>
- HUANG, J. *et al.* Chlorogenic acid: a review on its mechanisms of anti-inflammation, disease treatment, and related delivery systems. **Frontiers in Pharmacology**, v. 14, p. 1218015, 2023. <https://doi.org/10.3389/fphar.2023.1218015>
- INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. **Green coffee: determination of loss in mass at 105 °C: ISO 6673**. Geneva, 2003. 17 p.
- ISQUIERDO, E. P. *et al.* Drying kinetics and quality of natural coffee. **Transactions of the ASABE**, v. 56, n. 3, p. 995, 2013. <https://doi.org/10.13031/trans.56.9794>
- JESZKA-SKOWRON, M. *et al.* Comprehensive analysis of metabolites in brews prepared from naturally and technologically treated coffee beans. **Antioxidants**, v. 12, n. 1, p. 95, 2022. <https://doi.org/10.3390/antiox12010095>
- MALTA, M. R. *et al.* Alterações na qualidade do café submetido a diferentes formas de processamento e secagem. **Revista**

Engenharia na Agricultura – Reveng, v. 21, n. 5, p. 431-440, 2013. <https://doi.org/10.13083/reveng.v21i5.450>

MALTA, M. R.; CHAGAS, S. J. D. R. Avaliação de compostos não-voláteis em diferentes cultivares de cafeeiro produzidas na região sul de Minas Gerais. **Acta Scientiarum. Agronomy**, v. 31, n. 1, p. 57-61, 2009. <https://doi.org/10.4025/actasciagron.v31i1.6629>

MALTA, M. R.; PEREIRA, R. G. F. A.; CHAGAS, S. J. D. R. Condutividade elétrica e lixiviação de potássio do exsudato de grãos de café: alguns fatores que podem influenciar essas avaliações. **Ciência e Agrotecnologia**, v. 29, n. 5, p. 1015-1020, 2005. <https://doi.org/10.1590/S1413-70542005000500015>

NATH, P. *et al.* Browning reactions in foods. In: CHAUHAN, O. P. (ed.). **Advances in food chemistry**: food components, processing and preservation. Singapore: Springer Nature Singapore, 2022. p. 117-159. https://doi.org/10.1007/978-981-19-4796-4_4

OLIVEIRA, P. D. de *et al.* Quality of natural and pulped coffee as a function of temperature changes during mechanical drying. **Coffee Science**, v. 13, n. 4, p. 415-425, 2018.

R CORE TEAM. **R**: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2013.

REINATO, C. H. *et al.* Quality of the coffee dried on grounds with different surfaces and thickness layers. **Coffee Science**, v. 7, n. 3, p. 223-237, 2012.

RIOS, P. D. A. *et al.* Colour variation in immature coffee dried under different dry bulb and dew point temperature conditions. **Research, Society and Development**, v. 9, n. 7, e539974419, 2020. <https://doi.org/10.33448/rsd-v9i7.4419>

RIOS, P. D. A.; CARDOSO, D. B.; ANDRADE, E. T. Origin of black-green defect in the artificial drying of immature coffees. **Coffee Science**, v. 16, e161884, 2021. <https://doi.org/10.25186/v16i.1884>

SHI, Q. *et al.* Comparison between ultra-high pressure coffee and conventional cold-brewed coffee at different roasting degrees: physicochemical characteristics and volatile and non-volatile components. **Foods**, v. 13, n. 19, p. 3119, 2024. <https://doi.org/10.3390/foods13193119>

SILVA, C. S. *et al.* Post-harvest of coffee: factors that influence the final quality of the beverage. **Revista Engenharia na Agricultura – REVENG**, v. 30, p. 49-62, 2022. <https://doi.org/10.13083/reveng.v30i1.12639>

SILVA, J. de S. *et al.* Harvesting, drying and storage of coffee. In: PEREIRA, L. L.; MOREIRA, T. R. **Quality determinants in coffee production**. Cham: Springer International Publishing, 2020. p. 1-64. https://link.springer.com/chapter/10.1007/978-3-030-54437-9_1

VITORINO, M. D. *et al.* Metodologias de obtenção de extrato de café visando a dosagem de compostos não-voláteis. **Revista Brasileira de Armazenamento**, n. 3, p. 17-24, 2001.



This is an open-access article distributed under the terms of the Creative Commons Attribution License