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Coffee bean quality evaluation under three drying conditions: static, concrete terrace, and suspended terrace drying

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Abstract

The aim of this study was to analyze the influence of different drying structures on the moisture, chemical, and sensory quality of coffee beans. The experiment was carried out with a static dryer, concrete drying, and suspended drying terrace in the years of 2021 and 2022. The research consisted of six treatments and four replicates. The drying of coffee beans was completed when the total moisture reached 11.5%. The moisture, electrical conductivity, and sensory analysis were evaluated. The data were analyzed non-parametrically and through principal component analysis. It was found that the highest moisture was present in the upper layer of the static dryer. The homogenization of the moisture of the coffee bean samples is due to the phenomena of water adsorption and desorption. The longer storage time contributes to the hygroscopic balance of the coffee samples. The conclusion is that different drying structures and distinct layers of the static dryer influenced the moisture of the coffee beans and the longer storage time of the coffee beans in the storage contributed to the uniformity of moisture in the static dryer samples. The treatments with lower moisture were more associated with the best sensory analysis.

Keywords: sensory analysis; electrical conductivity; desorption; principal component analysis.

Practical application: These results can increase the availability of good-quality beans and cup quality of Brazilian coffees.

1 INTRODUCTION

There is currently a greater demand for better-quality coffees, and this increased consumption is attributed to the desirable effects of coffee (Dong et al., 2017). Therefore, producers are looking for alternatives to add value to the product and the coffee drying process is crucial to provide a product with desirable sensory characteristics.

Coffee bean drying aims to maintain and preserve the integrity of the beans during storage and must be carried out under appropriate conditions (Yang et al., 2022). Attention to this process allows this food to be microbiologically safe with uniform physical, chemical, and sensory characteristics. This is a complex process and is considered a critical operation that can lead to deterioration and loss of value of the product when performed incorrectly (Lacerda Filho & Silva, 2006).

Given the importance of this process, continuous studies of the different drying methods are essential. Therefore, it requires periodic evaluation of drying equipment and methods to optimize water loss from the beans while maintaining the properties of the beans (Coelho et al., 2024).

There are currently several technologies available for drying coffee beans, and the choice depends on the processing methods used, economic factors, labor availability, and environmental factors, which influence the physical and chemical properties of the coffee beans and in turn its quality. In the southern region of Minas Gerais, the most widely used method for drying coffee beans is in full sun on a concrete terrace; however, there are other modalities such as mechanical dryers (De Melo Pereira et al., 2019).

In this context, one of the alternatives that arouse interest and curiosity among producers is the use of static dryers that dry coffee beans in an environment protected from rain and dew, with the fruits distributed along the vertical and horizontal profile of a drying chamber. This drying model has been attracting interest from producers, mainly due to the occurrence of rain during the harvest period, which has been causing difficulties in the system of drying coffee beans on terraces in full sun. Another difficulty encountered in this system is related to the scarcity and high cost of labor, leading to the search for drying methods that do not require the use of terraces.

Among the advantages of the static drying system, we can mention the lower initial investment in the acquisition and installation of the equipment when compared to the construction of paved terraces, less need for labor in relation to the use of terraces, and less exposure of the fruits to adverse weather conditions.

The static dryer is not a new technology; however, it has gained ground in recent years among coffee farmers. However, rural producers have found that the drying system in the static

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dryer is uneven since the drying at the bottom is more pronounced than at the top, given that the air flow of this type of dryer moves from the bottom layer to the surface of the bean mass (Brooker et al., 1992).

Oliveira et al. (2020) stated that during the drying process in the chamber, the fruits are in different temperature and moisture conditions along the horizontal and vertical layers of the dryer, which may interfere with the moisture at the end of the drying process at different points in the drying chamber. Souza et al. (2015) analyzed the heat transfer in the drying of soybeans in a fixed-layer dryer and found that there was a lack of uniformity in the moisture of the product along the profile of the drying layer. Grandi et al. (2000), studying a fixed-layer dryer, found that there is a difference in moisture in relation to the position of the coffee samples, in which it was possible to verify a lack of uniformity in the temperature distribution in the plenum chamber. The static dryer is not a new technology, but it has gained ground in recent years among coffee growers. However, rural producers have found that the drying system in the static dryer is uneven since drying in the lower part is more pronounced than in the upper part, given that the air flow in this type of dryer moves from the lower layer to the surface of the bean mass (Brooker et al., 1992).

To reduce this nonuniformity, it is possible that during the storage process of the beans in the granary, the moisture of the coffees collected at different points in the drying chamber of the static dryer will become uniform. Therefore, research into different ways of drying coffee always aims to analyze possible changes that occur in the coffee beans (Coelho et al., 2024).

Therefore, the objective is to analyze the influence of the different drying structures on the moisture, chemical, and sensory quality of the coffee after storage in the granary.

2 MATERIALS AND METHODS

The experiment was carried out at the Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais (IFSULDEMINAS – Campus Inconfidentes), specifically at the Educational Production Unit (EPU) Coffee Farm, with its geographic coordinates: latitude 22°19'01" S, longitude 46°19'40" W, with an altitude of 896 m.

The research was conducted over the years of 2021 and 2022, with two distinct trials with the same treatments. The coffee cultivar used was "Topázio 1190" subjected to the dry way process without hydraulic separation of the fruits. For bean drying, three treatments with different structures were applied, namely a static dryer, a concrete terrace, and a suspended bed.

The drying chamber of the static dryer was designed for a volume of 6 cubic meters of coffee beans with the following dimensions: 3 m length (L) × 1 m height (H) (distance between the plenum chamber and the upper end of the dryer) × 2 m width (W). The plenum chamber, which is located below the drying chamber, had the following dimensions: 3 m × 0.3 m × 2 m (L, H, and W). The plenum chamber is an empty space, which receives heated air from the furnace, with the aim of distributing the flow of hot air in the drying chamber. The drying structure had a 3-horsepower fan with 1,720 rotations per minute (rpm), located above the indirect fire furnace (Figure 1).

The experimental design consisted of six treatments – T1: drying in a static dryer with samples 90 cm above the base of the drying chamber, T2: drying in a static dryer with samples 50 cm above the base of the drying chamber, T3: drying in a static dryer with samples 10 cm above the base of the drying chamber, T4: 12 samples were taken at different points of the static dryer to form a composite sample, T5: drying on a concrete terrace, and T6: drying on a suspended terrace. The samples, from treatments 1, 2, and 3, were arranged diagonally across the static dryer, distributed 1.05 m apart from each other. All treatments were divided into four replications.

Each experimental plot contained 10 liters of coffee beans, and inside the drying chamber for treatments T1, T2, and T3, the samples were inside a perforated high-density polyethylene bag, a Raschel bag model. The dryer took 3 days to reach its maximum coffee bean volume. Thus, on the first day, the portions of each treatment were separated and placed in the Raschel bag and distributed at the respective heights as the coffee beans were placed in the drying chamber.

The coffee beans were deposited in the dryer, and when the drying chamber reached its full capacity, the drying process was started. The air ventilation of the static dryer was turned on at room temperature until the drying chamber was fully loaded. Drying began with bean mass at a temperature of 30°C until the point of half-dry (20% water in the coffee bean), followed by a temperature of 40°C until reaching 11 ± 0.5% of water in the beans.

Drying in the chamber was conducted between 7 am and 5 pm. During the night, until the half-dry point, the room temperature ventilation remained on and when the beans reached the point of half-dry, the room temperature ventilation remained off.

The coffee samples for drying on the concrete and suspended drying rack came from the same coffee that was deposited in the static dryer. Drying was completed when the moisture content in the coffee fruits was 11.5 ± 0.5%. The plots with coffee on the concrete and suspended drying terrace at the beginning of drying had 1 square meter and were dried according to the recommendations of Borém et al. (2008). After drying, the coffees were stored in a wooden-lined granary and kept in the dark at room temperature and moisture.

In 2021, the moisture of the samples was measured only after storage in the granary for 21 days. In 2022, the samples were measured at two moments: after drying and after storage in the granary for 70 days. For all plots, storage conditions in the

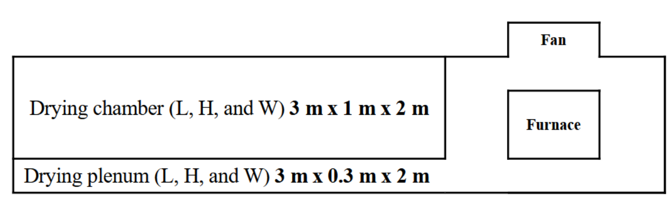

Figure 1. Static dryer, with the representation of the drying chamber, plenum chamber, furnace, and fan.

granary were the same. All plots had their moisture measured using a bean moisture meter, model Gehaka G600i. After this procedure, the samples were sent for physical, chemical, and sensory analyses.

Data on environment temperature were recorded daily with a digital thermo-hygrometer (MTH 1300), and precipitation was quantified at a weather station (Vantage Pro2 - Davis®). In 2021, maximum ambient temperatures ranged from 14 to 30 °C and minimum temperatures ranged from -2 to 15°C. In 2022, maximum ambient temperatures ranged from 18 to 30°C and minimum ambient temperatures ranged from 3 to 15°C. Precipitation was 45 mm in 2021 and 10 mm in 2022 during the coffee bean drying period.

The physicochemical analysis was conducted in the Soil and Bromatology Laboratory, at IFSULDEMINAS – Campus Inconfidentes, with electrical conductivity (EC) being evaluated in micro-Siemens per centimeter per gram of sample ($\mu S.\ cm^{-1}.\ g^{-1}$), following the methodology of the Specialty Coffee Association of America (AOAC, 1990; SCAA, 2016).

Sensory analyses were conducted by three graded tasters for evaluating specialty coffees (Q-Graders), using the methodology proposed by the Specialty Coffee Association of America (SCAA, 2016), at the Coffee Production Laboratory of IFSULDEMINAS – Campus Machado.

The data were analyzed through a non-parametric Kruskal–Wallis test ($p \leq 0.05$) using the Genes software (Cruz, 2013). Only significant results in the non-parametric analysis were presented given the considerable number of combinations. Multivariate analyses were used to interpret the results for moisture, EC, and sensory analyses, using the Genes software (Cruz, 2013). A dendrogram was performed based on the hierarchical clustering (average connection between groups (UPGMA)) using the generalized Mahalanobis distance. For all analyses, the average data of all variables studied were considered.

3 RESULTS AND DISCUSSION

Analysis conducted after storage in the granary for 21 days in 2021 indicated that the sample's moisture inside the static dryer showed that treatment T1 presented the highest levels, differing from treatments T2, T3, and T4. Treatments T2, T3, and T4 exhibited the lowest sample moisture (Table 1), resulting in a significant difference between treatments T3 and T4.

The coffee beans were dried to a moisture of 11.5 ± 0.5%; therefore, treatments T2, T3, and T4 during the homogenization process lost water due to the desorption phenomenon that is intrinsically linked to the different environmental conditions in which the coffee beans are stored (Corrêa et al., 2014). It is worth noting that the initial levels of samples T2, T3, and T4 were already lower than treatment T1. This inference is supported by the fact that samples from treatments T2, T3, and T4 after storage had the lowest levels of moisture (Table 2).

Treatment T4 represented a sample composed of 12 collection sites from different points of the dryer, where treatments T1, T2, and T3 were located, which characterized the average moisture of the drying chamber (Table 1). Even though differences in moisture were observed for treatments T1, T2, and T3, it appears that treatment T4, with 10.77% water, adequately represented the moisture of the other treatments, given that the values varied between 10.65 and 11.15% for treatments T3 and T1, respectively. Treatment T4 is of practical importance to the coffee bean farmer, given that this treatment is a representation of the moisture that farmers would use to complete the coffee bean drying.

The difference in moisture of treatments T2, T3, and T4 when compared to T5 and T6 was expected, considering that they are different drying structures.

When evaluating the moisture of the samples dried in the static dryer, before storage in the year 2022, treatments T1, T2, T3, and T4 differed from each other, with treatments T1 and T3 being the most contrasting. This is due to their location in the drying chamber, given that the compartment of treatment T1 is the last to receive drying air and treatment T3 is the first (Table 2).

Treatments T1, T5, and T6 have moisture above those of the other treatments; however, during the storage phase, the aim is to exchange water from the coffee beans with the external environment, which may result in water losses. This is due to the hygroscopic nature of coffee, which can cause changes in

Table 1. Moisture analysis (RH) in percentage of dry coffee beans dried through the static dryer, suspended terrace, and concrete terrace after storage in the granary through the year of 2021. Only significant results are shown.

Treatments*	RH (%)	Treatments	RH (%)
T1: static dryer at 90 cm	11.15 a	T2: static dryer at 50 cm	10.80 b
T1: static dryer at 90 cm	11.15 a	T3: static dryer at 10 cm	10.65 b
T1: static dryer at 90 cm	11.15 a	T4: composite sample	10.77 b
T1: static dryer at 90 cm	11.15 b	T6: suspended terrace	11.45 a
T2: static dryer at 50 cm	10.80 b	T5: concrete terrace	11.10 a
T2: static dryer at 50 cm	10.80 b	T6: suspended terrace	11.45 a
T3: static dryer at 10 cm	10.65 b	T4: composite sample	10.77 a
T3: static dryer at 10 cm	10.65 b	T5: concrete terrace	11.10 a
T3: static dryer at 10 cm	10.65 b	T6: suspended terrace	11.45 a
T4: composite sample	10.77 b	T5: concrete terrace	11.10 a
T4: composite sample	10.77 b	T6: suspended terrace	11.45 a

*Means followed by the same letter do not differ by the Kruskal–Wallis test at 5% probability.

moisture during storage, a phenomenon known as hygroscopic balance (Borém et al., 2013b).

To keep the coffee bean quality and cellular integrity, it is important that drying is carried out with a mass temperature of up to 40 °C and the moisture of the samples at around 11% (Saath et al., 2010), a condition analogous to that of the experiment in treatments T2, T3, and T4.

After storage in the granary for 70 days, only significant difference between treatments was found for coffee beans dried in the static dryer for treatments T1 and T2 (Table 3). For the other treatments in the drying chamber, there was no significant difference; therefore, this longer storage period contributes to the homogenization in moistures for treatments T2, T3, and T4. This homogenization is due to the phenomena of water adsorption and desorption. These phenomena can occur with the environment supplying or removing water from coffee beans (Corrêa et al., 2014).

For treatments T5 and T6 (Table 3), there was a significant difference between treatments T2 and T3, considering that this difference already occurred before storage (Table 2).

It can be observed that over the 2 years of the study, the results were different regarding water desorption and adsorption in the period after storage in the granary (Tables 1 and 3). This result suggests that longer storage times are necessary to achieve hygroscopic balance in coffee bean samples from the static dryer.

These differences are associated with storage time, the characteristics of the coffee beans, and the environment, corroborating the statements of Rosentrater and Verbeek (2017) who reported that hygroscopic balance is associated with each sample material, and this process occurs under different conditions of temperature, moisture, and speed. Simón et al. (2016) further reinforced that sorption isotherms are associated with the material's balance in moisture.

In the years 2021 and 2022, the coffee bean samples did not differ in terms of sensory analysis using the Kruskal–Wallis test (Table 4), indicating that under adequate management conditions, any drying structure is likely to obtain similar quality. Carmo et al. (2020) concluded that the process of drying coffee beans on a suspended and concrete terrace did not influence the sensory characteristics of the coffee beans. The authors describe that in the suspended drying rack, the fruits receive greater aeration on both sides, reducing the attack of microorganisms, drying is more uniform and of better quality. The initial hypothesis was that coffees from suspended drying terraces would produce coffees with different quality than those from static dryers and cement drying terraces.

These results are supported by research from Santos et al. (2017) who described that cement and suspended drying terraces produced beverages with similar qualities across different post-harvest processing methods of coffee.

Studies have shown that drying coffee beans in mechanical dryers is faster, but it brings significant losses in coffee bean quality since the temperature of the mass under the conditions in which the experiments were conducted varied between 40 and 60°C (Dong et al., 2017; Kulapichitr et al., 2019). However, this was not observed in the study when evaluating the sensory analysis and EC since the coffees were dried at a maximum

Table 2. Moisture analysis (RH) in percentage before granary storage, in dry coffee beans dried in the static dryer, suspended terrace, and concrete terrace through the year of 2022. Only significant results are shown. IFSULDEMINAS – Campus Inconfidentes. Inconfidentes/MG, 2023.

Treatments*	RH (%)	Treatments	RH (%)
T1: static dryer at 90 cm	11.80 a	T2: static dryer at 50 cm	11.00 b
T1: static dryer at 90 cm	11.80 a	T3: static dryer at 10 cm	10,90 b
T1: static dryer at 90 cm	11.80 a	T4: composite sample	11.40 b
T2: static dryer at 50 cm	11.00 a	T3: static dryer at 10 cm	10.90 b
T2: static dryer at 50 cm	11.00 a	T4: composite sample	11.40 b
T2: static dryer at 50 cm	11.00 b	T5: concrete terrace	11.72 a
T2: static dryer at 50 cm	11.00 b	T6: suspended terrace	11.75 a
T3: static dryer at 10 cm	10.90 b	T4: composite sample	11.40 a
T3: static dryer at 10 cm	10.90 b	T5: concrete terrace	11.72 a
T3: static dryer at 10 cm	10.90 b	T6: suspended terrace	11.75 a
T4: composite sample	11.40 b	T6: suspended terrace	11.75 a
T1: static dryer at 90 cm	11.80 a	T2: static dryer at 50 cm	11.00 b

*Means followed by the same letter do not differ by the Kruskal–Wallis test at 5% probability.

Table 3. Moisture percentage comparative after granary storage in coffee beans dried in the static dryer, suspended terrace, and concrete terrace in the year of 2022. Only significant results are shown. IFSULDEMINAS – Campus Inconfidentes. Inconfidentes/MG, 2023.

Treatments*	RH (%)	Treatments	RH (%)
T1: static dryer at 90 cm	11.95 a	T2: static dryer at 50 cm	11.72 b
T2: static dryer at 50 cm	11.72 b	T5: concrete terrace	12.10 a
T2: static dryer at 50 cm	11.72 b	T6: suspended terrace	12.20 a
T3: static dryer at 10 cm	11.72 b	T5: concrete terrace	12.10 a
T3: static dryer at 10 cm	11.72 b	T6: suspended terrace	12.20 a

*Means followed by the same letter do not differ by the Kruskal–Wallis test at 5% probability.

Table 4. Comparison between sensory analysis and electric conductivity (EC) for coffee beans dried in a static dryer, suspended terrace, and concrete terrace in the years of 2021 and 2022. IFSULDEMINAS – Campus Inconfidentes. Inconfidentes/MG, 2023.

Treatments	Sensory 2021	Sensory 2022	EC 2021 (μS. cm^{-1}. g^{-1})	EC 2022 (μS. cm^{-1}. g^{-1})
T1: static dryer at 90 cm	76.88 a	81.37 a	6.65 a	12.97 a
T2: static dryer at 50 cm	75.62 a	82.18 a	6.50 a	14.00 a
T3: static dryer at 10 cm	80.37 a	82.00 a	6.49 a	15.14 a
T4: composite sample	78.81 a	82.13 a	5.68 a	15.52 a
T5: concrete terrace	74.68 a	81.25 a	6.77 a	16.78 a
T6: suspended terrace	77.81 a	82.06 a	6.80 a	13.20 a

*Means followed by the same letter do not differ by the Kruskal–Wallis test at 5% probability.

temperature of 40°C in the mass. There is already a consensus in the literature that drying temperatures in the coffee mass above 40°C cause significant damage and losses in coffee bean quality (Borém et al., 2013a; Isquierdo et al., 2013; Oliveira et al., 2013).

In 2022, the sensory score was higher than that in 2021, with an average increase of 4.47 points; this is due to the lower rainfall during the harvest period and the more appropriate maturation stage, considering that coffee beans with 2.33% green, 31.01% raisin, 39.66% ripe, and 13.50% green and buoy.

Coelho et al. (2024) also worked with different coffee bean drying methods, including suspended drying terraces and fixed layers with the movement of coffee beans by drying palettes, and found no difference in the sensory analysis. Borém et al. (2008) highlighted that temperature monitoring, constant movement of coffee beans on the drying terrace, and optimization of air flow in the static dryer are associated with good coffee quality, allowing the available technologies, when used appropriately, to ensure the coffee quality.

Electrical conductivity was not influenced in the years 2021 and 2022 by the drying methods (Table 4); however, based on the principal component analysis, the variable was more associated with treatment T1 in 2021 and in 2022 with treatment T5 (Figure 2). This result for treatment T5 is more related to the drying method in the concrete terrace. This structure is more subject to adverse environmental conditions, and beans are subject to a longer period in these conditions. Saath et al. (2010) found that due to the long drying period in a concrete terrace, the coffee beans are subject to external interference, which can compromise quality. Santos et al. (2017) found that drying coffee beans on a cement mud terrace was the structure that contributed most to increasing EC, with suspended and concrete terraces obtaining lower values without significant differences between them.

Fernandes et al. (2014), working with coffee bean drying using different methods, found that coffee fruits from conventional harvests obtained lower EC values on suspended drying terraces compared to those on concrete drying terraces. The authors attribute this lower EC to better aeration during drying. The same authors did not find any significant difference in the sensory analysis for coffee beans from conventional harvests dried on concrete and suspended drying terraces.

The principal component analysis captured 72.39% of all data variance. It is possible to verify that there was a grouping in the results of the sensory analysis for treatments T2, T3, and T4 (Figure 2). For moisture content after storage in the granary in 2021 and before and after storage in the granary in 2022 and electric conductivity in 2021, the results were more grouped with treatment T1, which resulted in higher moisture. Therefore, the higher moisture in treatment T1 was more associated with the lower sensory quality of the coffee beans. To interpret the associations, the angle between the two vectors was analyzed, with a positive association when the angle is less than 90° and a negative association when the angle is higher than 90° (Yan & Tinker, 2006).

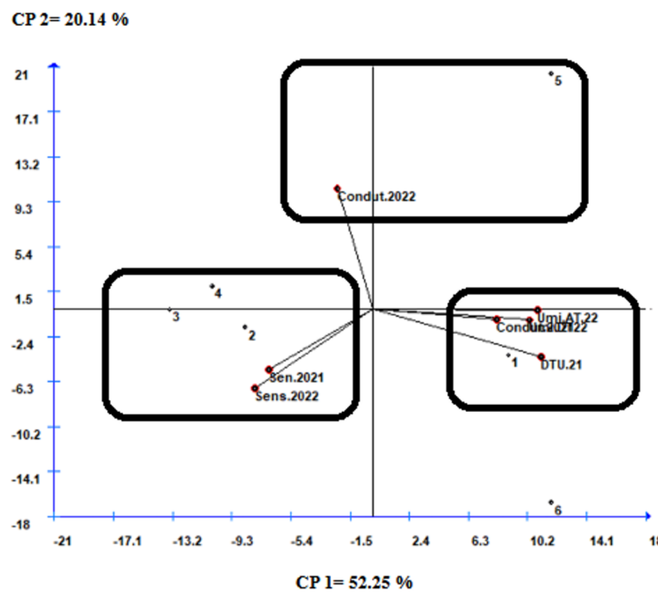

Figure 2. Graphic representation of the principal component analysis (PCA) for the variables of electric conductivity in 2022 (Condut. 2022), electric conductivity in 2021 (Condut. 2021), sensory analysis in 2022 (Sen. 2022) and sensory analysis in 2021 (Sens. 2021), moisture before storage in the granary 2022 (Umid. AT 2022), and moisture after storage in the granary in the year 2022 (DTU. 22), and after storage in the granary in the year of 2021 (DTU. 21), for coffee beans dried in static dryers, suspended terraces, and concrete terraces in the years of 2021 and 2022. IFSULDEMINAS – Campus Inconfidentes. Inconfidentes/MG, 2023.

In the dendrogram (Figure 3) according to the cut line, it is possible to detect the composition of two large groups formed by treatments T1, T5, T6 and T2, T3, T4, the latter being the same training in the principal component analysis (Figure 2), in which the groups were structured based on the best sensory score and lowest moisture of the treatments.

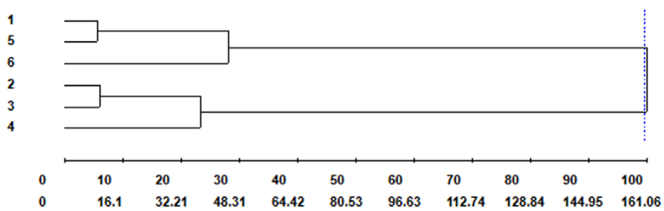

Figure 3. Dendrogram showing the relationship between the six treatments through the UPGMA grouping for the variables in dry coffee beans submitted to static dryers, suspended terraces, and concrete terraces over the years of 2021 and 2022. IFSULDEMINAS – Campus Inconfidentes. Inconfidentes/MG, 2023.

4 CONCLUSIONS

Different drying structures and different layers of the static dryer influenced the moisture of the coffee beans. It was found that the longer storage time of the coffee beans in the granary contributed to the uniformity of the moisture in the static dryer samples. The treatments with lower moisture were more associated with better sensory analysis. Samples with higher moisture were correlated with higher EC.

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